knowable MAGAZINE

FROM ANNUAL REVIEWS

VOLUME 2

ANNUAL REVIEWS

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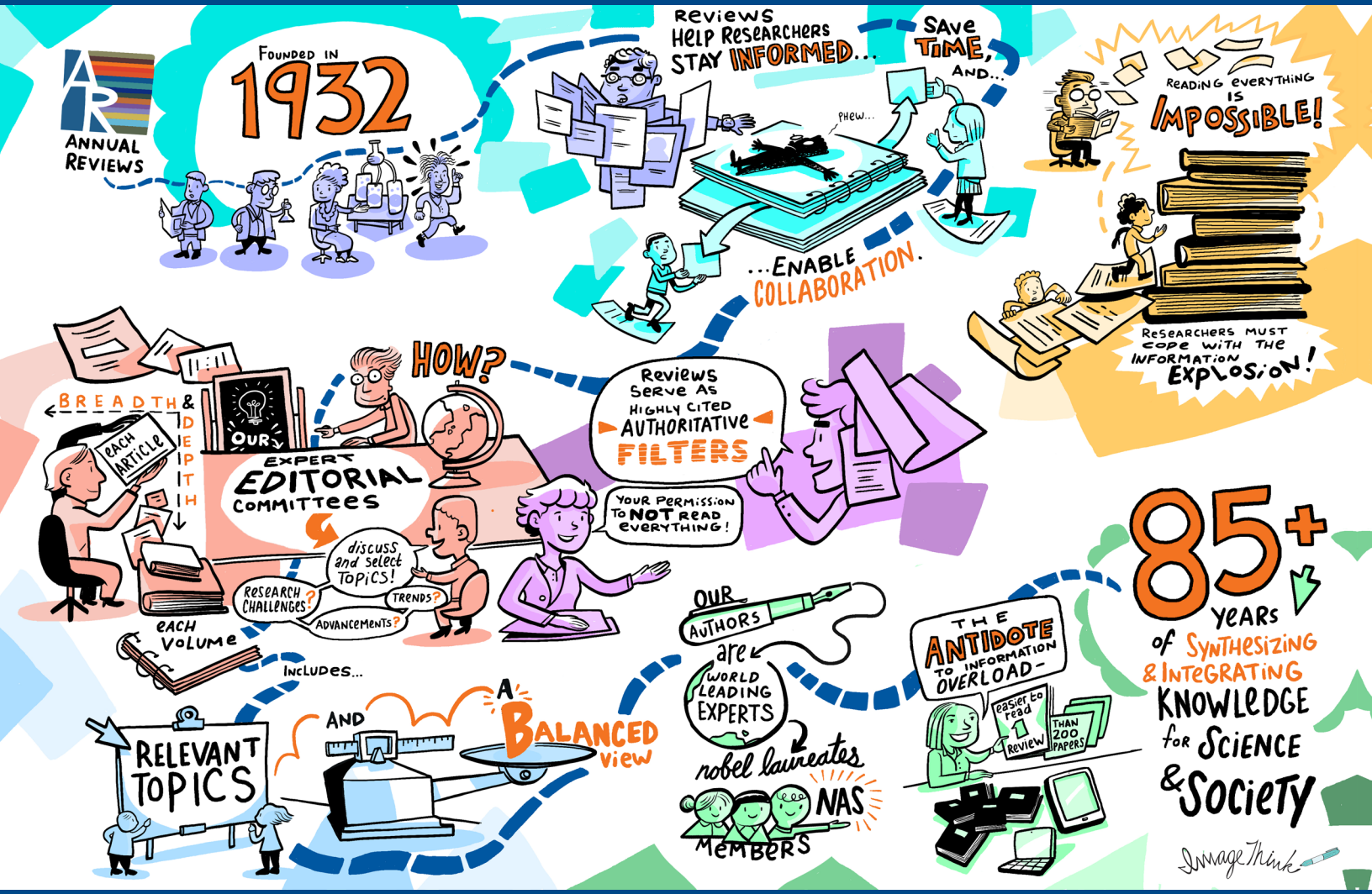

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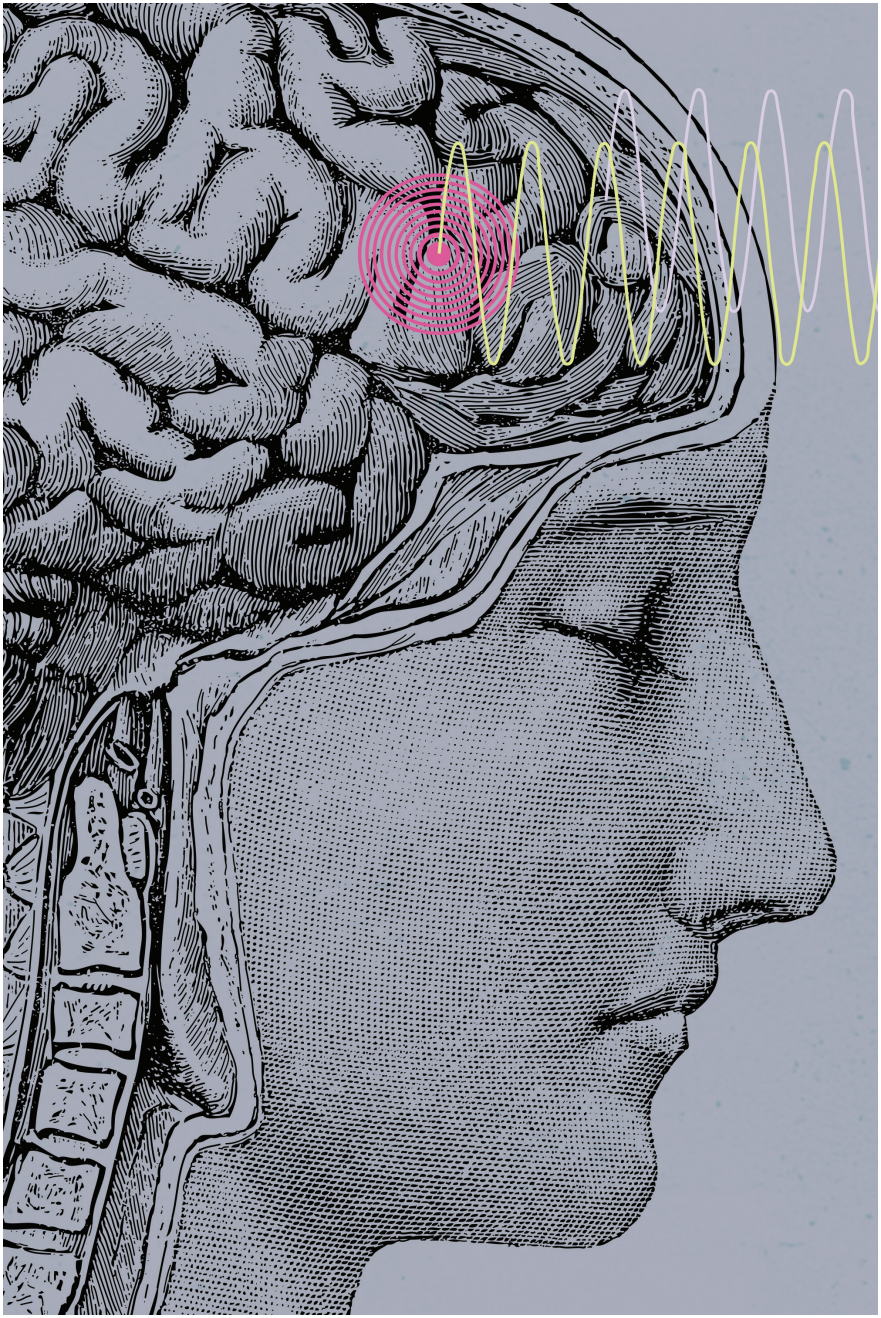
CONTENTS

ON THE COVER: ILLUSTRATION BY MARINA MUUN



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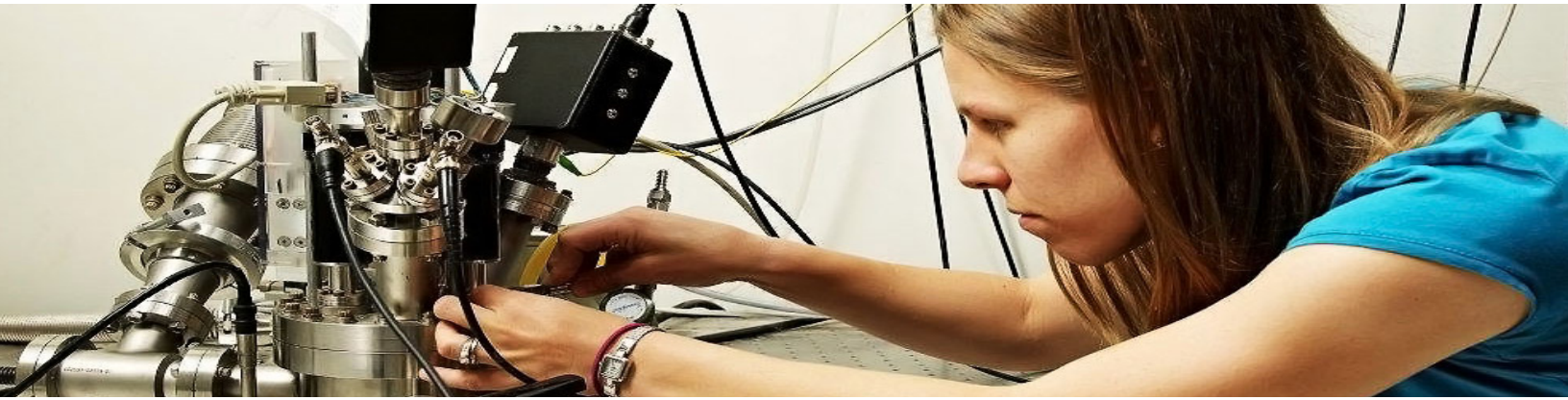

Accelerating scientific discovery.

Expanding knowledge.

Advancing the understanding of emerging scientific fields is a cornerstone of our work. Through developing new technologies, supporting imaginative research scientists and creating new collaborations at the frontiers of traditional scientific disciplines, we are expanding knowledge, which is intellectually satisfying and yields practical benefits for society.

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Image: Julie Bert adjusts magnetic force microscope,
Courtesy of Kathryn Moler, Stanford

CREDIT: MAKI NARO

With *Knowable*, science is accessible for everybody

Society needs reliable guides to scientific facts

Too often, learning is left for the children. That's especially true for science. Many organizations and individuals recognize the importance of funding and advocating for STEM (science, technology, engineering and math) education in schools. But it's not just kids that need to know about science. (As I write, I know many in the 50-plus crowd suddenly very interested in viruses, for example, as we adjust to life with the coronavirus pandemic.) And, children aren't the only ones fascinated by discoveries that shed new light on the natural world or insights into everyday life.

As citizens, adults have an urgent need for clear information on many topics informed by science. If you believe that truth is knowable — that we live in a world where facts are facts, and they matter — you are among the many who appreciate an accessible and authoritative guide for sorting out those facts. At *Knowable*, our mission is to be one of those guides.

We launched *Knowable* in late 2017 as an online-only publication, posting several articles each week. Rather than providing instant reports on the latest hot studies, *Knowable*'s articles sought depth and perspective, drawing on the rich archives of the journals from Annual Reviews, *Knowable*'s publisher. While Annual Reviews covers dozens of scientific fields with thorough, scholarly, reference-rich technical reviews for an academic audience, *Knowable* applies similar rigor for a more wide-ranging group of readers. Emphasizing a commitment to sound science journalism, *Knowable* provides evidence-based analyses of issues across a broad spectrum of disciplines where science meets society, and where scientific research meets the unknown.

Last year we produced our first print collection, featuring a sampling of *Knowable*'s content. You now hold the second print volume, once again compiling a set of *Knowable* stories that address issues of vital interest to daily life and public policy while also exploring the frontiers of scientific exploration. From revealing the secrets of the whirling firestorms known as firenadoes to the use of soda taxes to fight obesity, *Knowable* confronts major issues of the day with the most reliable scientific knowledge and insight available.

In the pages that follow we probe the pluses and minuses of organic farming, explore the meaning of "sustainable" labels on various products, analyze the effectiveness (or lack thereof) of workplace performance reviews and examine the psychology behind the impulse for revenge. We reveal the science of the (many) microbes in your mouth and the reasons why forgetting may not be a deficiency of the brain, but a strategy for improving mental efficiency.

Last, and perhaps especially interesting for the adults in the room, we excerpt stories from our special report, "The Working Life", in which we apply scientific evidence to the world of everyday work, examining the trend of using research to guide management decisions, the need for work/life balance, and the prospect of artificial intelligence automation depleting the number of available jobs (or not).

Not all realms are completely knowable, it's true. But those that are invite our exploration, using the tools of science and the fuel of curiosity to chart its features. I hope you enjoy what you read here. Online, you will find many more articles, as well as data-rich graphics and videos, and the supporting technical articles, all free to read.

Knowable has so far relied on generous funding from the Gordon and Betty Moore Foundation and the Alfred P. Sloan Foundation. This year, we are also launching a program that will help us to continue to produce high-quality science journalism online that children and adults alike will be able to access for free. (Supporters will also receive future print collections!) Please consider joining us. Knowledge is for everyone. ●

Eva Emerson, Editor-in-Chief
Knowable Magazine
from *Annual Reviews*

Exercise as medicine

Researchers digging into the mechanisms that underlie the benefits of exercise are finding that physical activity affects not just muscles and the cardiovascular system, but almost every part of the body, from the immune system to the brain to the energy systems within individual cells. As the science accumulates, clinicians are on the verge of considering exercise as type of medicine — a therapy that they can prescribe in specific doses for specific needs.

knowmag.org/Exercise

Accounting for CO_2

Atmospheric carbon dioxide levels have increased by almost a third since the first measurements were taken in the 1950s. The world's average temperature has already warmed by around 1 degree Celsius (1.8 degrees Fahrenheit) since preindustrial times, raising sea levels and increasing the frequency of extreme weather events. To limit global warming by reducing carbon dioxide emissions, scientists need to figure out where that carbon dioxide is coming from in the first place. But accurately tracking those emissions is fraught with difficulties that researchers must cope with in order to assess progress and validate international agreements.

knowmag.org/CountingCarbon

Seeking the heat

The solar corona, the sun's upper atmosphere, is composed mostly of electrons and the bare nuclei of hydrogen and helium atoms. Streams of charged particles — the solar wind — escape the corona and wash over the Earth with occasionally disastrous results: The largest coronal flares can wreak havoc with power grids, wireless communication and satellites. Yet after eight decades of study, much about the corona remains a mystery. Perhaps most baffling is its temperature — a blistering 1 million or so degrees Celsius, compared with the balmy 5,500 degrees at the sun's surface. Now NASA's Parker Solar Probe and other space missions are attempting to discover the corona's secrets, possibly enabling scientists to predict dangerous solar eruptions with enough warning to protect vital equipment.

knowmag.org/SolarCorona

Video games go to school

Scientists who study the use of video games in classrooms say data are lacking on whether the games can actually improve learning. In all but a few circumstances, most agree, teachers still outperform games. But growing evidence suggests that some types of video games may improve brain performance on a narrow set of tasks. Rigorous experiments indicate that games can be effective in teaching a second language, math and science. Such studies may help educators figure out how to harness any game-related brain-boosting potential for better classroom results.

knowmag.org/VideoGames

Meet graphene's cousins

Graphene — an array of interlinked carbon atoms arranged in a sheet just one atom thick — is stronger than steel but extremely flexible, and electrons zip through it at high speeds. After its discovery in 2003, graphene promised a world of applications, including superfast electronics, ultrasensitive sensors and incredibly durable materials. Today such promises are coming close to realization.

CREDIT: CHIARA VERCESI

But graphene is no longer alone in its category — other single-atom layer substances, built from elements such as phosphorus and boron, are offering scientists new choices for novel materials and electronics.
knowmag.org/Graphene

Bloodstream cruisers

Extracellular vesicles — little envelopes made of membranes — cruise the bloodstream, delivering freight such as genetic material and proteins to recipient cells, altering their biology. A few decades ago scientists thought that these tiny bubbles, known as EVs for short, were mundane cellular trash bags. But researchers have since discovered that tumors send EVs to distant tissues, helping cancer spread. Now scientists are finding that the messages EVs deliver are important in multiple sites around the human body, both in health and sickness, potentially influencing everything from how we learn to the timing of childbirth.
knowmag.org/EVs

Questioning Einstein's gravity

Albert Einstein became world-famous in 1919, after an eclipse expedition validated his explanation for gravity — the general theory of relativity — thereby rendering Newton's law of gravity no longer in force. Since then Einstein's theory has passed numerous tests, but experts wonder whether his explanation for gravity might someday suffer the same fate as Newton's. There is no guarantee that general relativity reigns over the entire expanse of the cosmos, and several rival theories have been proposed just in case it doesn't.
knowmag.org/Gravity

Banking on medical data

Inside the walls of the UK Biobank, scientists hold the bodily fluids of half a million Britons in state-of-the-art, robot-managed freezers. Blood biochemistry, genetic analysis, images of brains, hearts and other organs — all the internal secrets of volunteers — are combined with intimate personal confessions about lifestyle and packaged with confidential medical histories. The UK Biobank showcases how Big Data can answer fundamental questions about human health, with results touching on everything from aging to susceptibility to asthma.
knowmag.org/Biobank

INFOGRAPHIC

HISTORY OF UK BIOBANK

2003 UK Biobank established
2006 Recruitment begins
2010 500,000 recruited
2012 Open for research
2013 Physical activity data collection starts
Death and cancer registries made available for study
2014 Hospital outpatient data made available
2015 First study using genetic data is published
2016 Biochemistry studies begin
Mental health questionnaire conducted
Imaging of 100,000 begins
2017 Exome sequencing begins
Genetic data of full cohort released for research
2018 Whole genome sequencing begins (on 50,000 participants)
2019 10,000th registered researcher taps bank for study
Clinical, prescription data for ~45% of participants made available

SOURCE: UK BIOBANK

The global soda tax experiment

AN INCREASING NUMBER OF CITIES AND COUNTRIES HAVE BEGUN TAXING SUGARY BEVERAGES. BUT CAN RAISING THE PRICE OF THESE DRINKS REALLY MAKE A DENT IN OBESITY, DIABETES AND OTHER AILMENTS?

BY GREG MILLER

THEY'RE CLOYINGLY SWEET, nutritionally empty — and, increasingly, subject to taxation. More than 35 countries and seven cities in the US — starting with Berkeley, California, in 2015 — now impose a tax on soda and other sugar-sweetened beverages. And several more places are considering it.

Public health researchers and organizations such as the American Heart Association and the American Academy of Pediatrics see these taxes as low-hanging fruit in the battle against obesity and the health problems such as diabetes that often come with it. In the United States, nearly 40 percent of adults are obese, which adds $147 billion to the nation's annual health care spending, according to the Centers for Disease Control and Prevention. The problem is complex. But the widespread consumption of foods packed with added sugars — which add calories but no essential nutrients — plays a major role. Beverages account for nearly half the added sugar in the American diet.

"It's really hard to shift these behaviors, and taxes are, if not the single most, one of the most impactful and important policies to move the needle on unhealthy eating habits," says Christina Roberto, a behavioral scientist at the University of Pennsylvania in Philadelphia. Taxes have helped to reduce the public health impact of alcohol and tobacco, and many public health researchers say there's good reason to think they can mitigate the harms of sugary beverages, too.

At the same time, there are also reasons why soda taxes might *not* have the impact on public health that advocates hope for. The current taxes may be too low to affect purchasing behavior. People could switch to other unhealthy foods. Or, in some cases, people could simply buy their sodas in a neighboring city that doesn't tax them.

Definitive answers won't come fast: Chronic conditions like obesity and diabetes take years to develop, and so, too, will any health benefits resulting from a new tax. But an emerging body of research suggests that beverage taxes have already reduced consumption of sugary drinks in some communities — an encouraging and essential step.

> "What we've learned in the last 20 years is that what you drink doesn't affect what you eat."
>
> —BARRY POPKIN

Taxing bad habits

The use of taxes to compel people to make healthier choices has a long history with tobacco and alcohol, which are taxed by nearly every country in the world. "There's decades of work now on tobacco, hundreds of studies from around the world, showing that if you raise prices you induce adults to quit smoking and prevent kids from taking it up," says Frank Chaloupka, an economist at the University of Illinois at Chicago. Research has linked higher cigarette taxes to reduced mortality from throat and lung cancer and other respiratory diseases, Chaloupka and two coauthors wrote last year in the *Annual Review of Public Health*. Other studies have linked higher taxes to lower rates of hospitalization for heart failure and lessened severity of childhood asthma.

With alcohol, it's more like dozens of studies, but the conclusions are similar, Chaloupka says. Alcohol taxes have been linked to lower frequency and intensity of drinking and reductions in unhealthy consequences of alcohol abuse, from cirrhosis of the liver to motor vehicle injuries to alcohol-related violence. The higher the tax, as a rule, the greater the impact.

Sugary beverages may seem more innocuous than cigarettes and alcohol, but there's strong evidence tying them to a host of chronic health problems, says Barry Popkin, an economist and nutrition researcher at the University of North Carolina, Chapel Hill. Sugary drinks cause sharper spikes in blood sugar than most types of food, studies find. Over time, they may be more apt to disrupt the body's insulin regulation. And sugar dissolved in a drink doesn't trigger the brain's satiety mechanisms the same way that sugar in solid food does. As a result, "what we've learned in the last 20 years is that what you drink doesn't affect what you eat," Popkin says.

Those extra liquid calories (roughly 250 in a 20-ounce bottle of many popular sodas, or 10 percent of the recommended daily total for an adult male), add up. Studies by Popkin and others have linked habitual consumption of sweetened beverages to an elevated risk of weight gain, obesity, type 2 diabetes, cardiovascular disease and other health problems. A 2010 meta-analysis

OPPOSITE PAGE CREDIT: MICHAEL MORGANSTERN

of previous studies that tracked a total of 310,819 participants, for example, found that people who drink one or more sugary drinks a day have a 26 percent higher risk of developing type 2 diabetes than those who drink no more than one sugary drink per month.

This research has focused on beverages containing calorie-adding sweeteners such as sucrose (table sugar) and high fructose corn syrup — not just sodas but also sports and energy drinks, fruit juices with added sugar, and sweetened coffee and teas.

There's less research, and more expert disagreement, on the health effects of pure fruit juice (which can contain as much sugar per serving as soda, but has vitamins and other nutrients also) as well as beverages with artificial sweeteners that don't add calories.

Sugary beverages certainly aren't the only culprits. Sugary foods are, too. But they're more difficult to define and regulate, says Kristine Madsen, a pediatrician and research scientist at the University of California, Berkeley School of Public Health.

"If you start getting into foods that could be classified as junk food you get into huge debates," she says. Take granola bars. Some are loaded with fat and sugar — essentially cookies masquerading as health foods. Others might be packed with nuts and dried fruit and contain little added sugar, making them legitimate sources of protein and dietary fiber. But a typical beverage with added sugar has no nutritional value, Madsen says. "There's nothing it adds to someone's diet that benefits them."

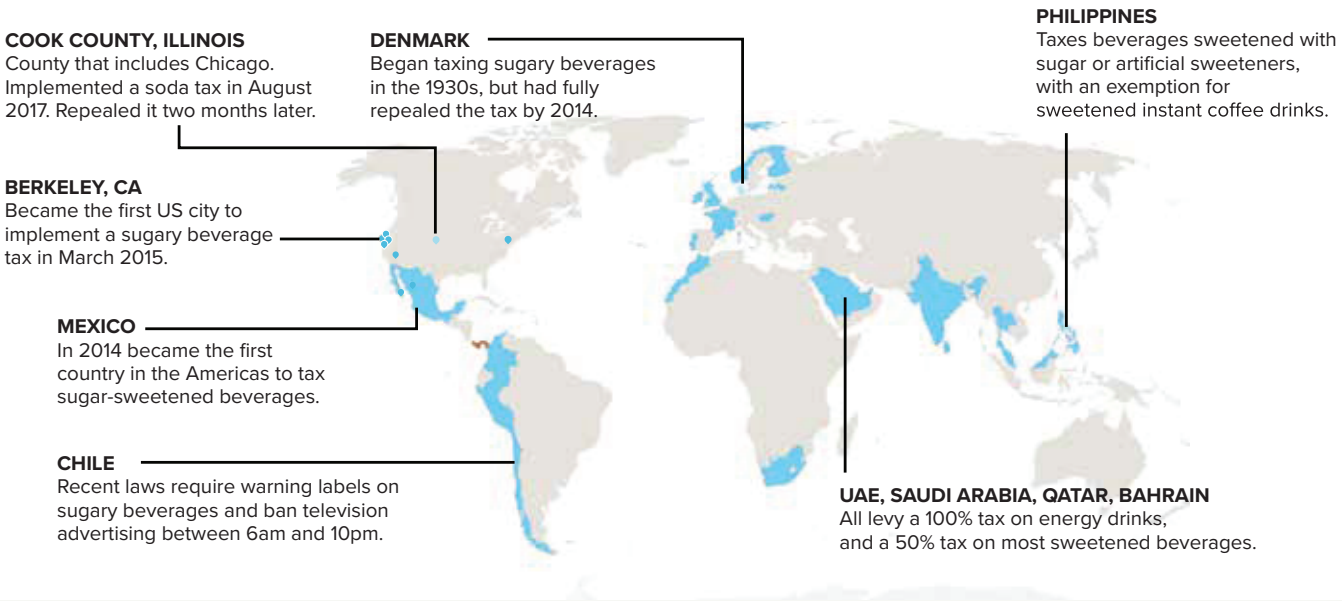
The idea behind sugary-beverage taxes is rooted in basic economics: Raising the price on a product tends to discourage people from buying it, especially if it's not something they deem essential in the first place. One encouraging sign for soda taxes, Chaloupka says, is that economists find that the price elasticity for sugary beverages — that is, the degree to which people respond to price increases by reducing their purchases — is at least as great as it is for alcohol and tobacco.

In wealthier countries, that sugary-beverage price elasticity averages about −0.8, meaning that for every 10 percent increase in the price of soda, purchases decline by 8 percent. (Price elasticity averages about −0.4 for tobacco and ranges from −0.5 to −0.8 for alcohol.) Not surprisingly, people with less money tend to be more sensitive to price increases, and research in lower-income countries and communities reports even higher price

Teas, sodas, sports drinks, more: A broad variety of beverages contain caloric sweeteners, but beverage taxes don't treat them equally. For example, 100% fruit juice generally gets a pass for nutritional reasons, even though it contains plenty of sugar that's chemically no different than sugar added artificially. In a similar vein, among public health researchers and policy makers there's disagreement on whether to tax sweetened milk, because the added sugar may make it more likely that children will drink milk.

CREDIT: KNOWABLE MAGAZINE

SUGARY BEVERAGE TAXES AROUND THE WORLD



List of countries as of May 2019 ● Implemented ● Passed

Americas:
USA (8 local) • Bermuda • Mexico • Dominica • Barbados • Panama • Colombia • Peru • Chile

Europe:
Norway • Finland • Estonia • Latvia • United Kingdom • Ireland • Belgium • France • Hungary • Spain (Catalonia) • Portugal • St Helena

Africa, Eastern Mediterranean and Southeast Asia:
Morocco • Saudi Arabia • Bahrain • Qatar • United Arab Emirates • India • Sri Lanka • Thailand • Malaysia • Maldives • Mauritius • South Africa

Western Pacific:
Philippines • Brunei • Cook Islands • Fiji • Palau • French Polynesia • Kiribati • Nauru • Samoa • Tonga • Vanuatu

SOURCES: GLOBAL FOOD RESEARCH PROGRAM UNC, F.J. CHALOUPKA *ET AL* / *AR PUBLIC HEALTH* 2019, REPORTING BY G. MILLER

elasticity, so that a 10 percent price increase results in more than a 10 percent reduction in purchases.

Public health researchers and economists bored into these data and more at a meeting convened in 2015 by the World Health Organization to review soda tax research and make recommendations. Along with price elasticity, the experts considered actual purchase data — what little were available at the time — from countries where taxes had been implemented, along with a small number of computer modeling studies estimating how calories saved from reduced soda consumption might translate to reduced risk of obesity and diabetes. The WHO's resulting report acknowledges the need for more research, but it concludes that taxes of 20 to 50 percent are most likely to be effective, based on the currently available evidence.

That's in the same ballpark as existing taxes on alcohol and tobacco, note Chaloupka and colleagues. Alcohol taxes range from 0.3 percent in Kyrgyzstan to 44.9 percent in Norway, with an average

of 17 percent worldwide. Tobacco taxes average 48 percent in high-income countries and 32 percent in low- and middle-income countries.

Only a few countries have levied beverage taxes at the higher end of the WHO's recommended range: Saudi Arabia and the United Arab Emirates. They levy a 50 percent tax on sweetened beverages, for example, and a 100 percent tax on energy drinks. (The goal in Saudi Arabia was raising revenue, not improving public health.) In other places it's more complicated.

A few countries, including the United Kingdom and South Africa, have implemented tiered or graded beverage taxes that increase with sugar content. In the UK, where the nationwide tax went into effect in April 2018, several beverage manufacturers responded by reformulating their drinks to contain less sugar (adding artificial sweeteners, at least in some cases), thereby avoiding the highest tax rate. (Coca-Cola refused, deciding instead to reduce serving size and pass some of the tax to consumers.) The impact on sales, not to mention public health, remains to be seen.

In the United States, beverage taxes range from 1 to 2 cents an ounce. Structuring a tax this way makes it easy to implement, but it also means that the percentage of the price increase varies for different products.

Researchers who support the taxes acknowledge that such small price increases are unlikely to dissuade occasional soda drinkers. But those aren't the people at greatest risk. The hope is that taxes will make a dent in consumption by people with more serious habits — such as the 5 percent of Americans who report drinking roughly 600 calories worth of sugary beverages (more than four 12-oz cans) on any given day.

Soda studies

One of the best-studied taxes is in Mexico, which in January 2014 became the first country in the Americas to implement a significant sugary-beverage tax. Like many middle-income countries, Mexico has seen the health risks associated with overconsumption surpass the health risks of undernutrition. Roughly two-thirds of Mexicans are overweight or obese, and diabetes has become the country's leading cause of death and disability.

The Mexican tax adds one peso per liter to the price of all beverages with added sugar. That typically works out to about 10 percent, says Arantxa Colchero, a health economist at the National Institute of Public Health in Cuernavaca who has studied the tax. Drinks with artificial sweeteners are excluded, as are pure milk and fruit juices. But unlike many places, Mexico taxes milk and yogurt drinks with added sugar. (Elsewhere, policy makers have decided

HOW A SODA TAX OF 1.5 CENTS PER FL OZ AFFECTS PRICES

Because prices of the same beverage often differ by container size, policies that levy taxes per fluid ounce can result in different percent tax increases depending on the specific purchase. Here are how a 1.5 cents-per-ounce tax would affect prices of three common soda-container sizes.

12 fl oz

Priced at 89 cents (before state taxes) at a California mini-mart, it would cost $1.07 — a 20% increase.

20 fl oz

A price of $2.19 at the same store would rise to $2.49 — a 14% increase.

2 Liter

A price of $2.49 would rise to $3.50, a 41% increase.

SOURCE: STAFF RESEARCH

CREDIT: NYC HEALTH

A video by the New York City's Department of Health and Mental Hygiene (NYC Health) warns people to avoid sugary drinks. The video ad is part of NYC Health's "The Sour Side of Sweet" campaign, launched in 2017.

that the benefits of getting children to drink milk outweigh the downsides of added sugar in beverages like chocolate milk — a point of debate among public health researchers.)

To assess sugary-beverage purchases before and after the tax, Colchero and colleagues used a nationwide survey of more than 75,000 Mexican households. According to their analyses, purchases dropped 6 percent in the tax's first year, more in households that were low-income, had children or were heavy consumers to begin with. Bottled water purchases, on the other hand, increased 16 percent — an encouraging sign, Colchero says, that people were switching to a healthier alternative. A follow-up study using additional data found similar effects, and suggested that the drop in sugary-beverage sales grew to nearly 10 percent in the second year of the tax.

Can such modest decreases translate to better health? Computer modeling studies based on the Mexican purchase data suggest that they could. In one study, researchers used a simulation to predict the prevalence of cardiovascular disease and related conditions. The model was developed using the Framingham Heart Study in the US — which uses public health data on age, sex, smoking, body mass index and more to predict cardiovascular health trends — but the scientists plugged in Mexican public health data wherever available.

That study predicted 189,300 fewer new cases of type 2 diabetes and 20,400 fewer heart attacks and strokes over a 10-year period, assuming a sustained 10 percent decrease in sugary-beverage consumption in Mexico (and estimating that people would make up 39 percent of those lost calories elsewhere in their diets). "The impacts would be much higher if the tax was 20 percent," says Colchero, who was not part of that study but collaborated on another study that also predicted substantial reductions in diabetes resulting from the tax.

The second modeling study also estimated the impact of the sugary-beverage tax on Mexico's obesity rate by converting numbers on reduced soda purchasing to calories saved, and using a computer model to predict changes in body mass index. After 10 years with the current tax, the scientists predicted, Mexico's obesity rate would drop by 2.5 percent, potentially corresponding to several million fewer obese people.

Both modeling studies suggested that doubling the tax would roughly double the public health benefits. The Mexican legislature is considering legislation that would do that.

In Berkeley, which implemented a penny-per-ounce tax on sweetened beverages in 2015 — the first such tax in the US — researchers have also seen reduced beverage purchases. One study examined millions of checkout scanner transactions for two supermarket chains in the area and found a 10 percent drop in sales of the taxed beverages. Sales of bottled water, which isn't taxed, rose 16 percent during the same time period; sales of untaxed vegetable, fruit and tea drinks rose 4 percent.

A recent study from Philadelphia found an even greater reduction in sugary-beverage sales. That city's beverage tax went into effect in January 2017. To

evaluate it, behavioral scientist Roberto and colleagues used a dataset of sales at supermarkets, pharmacies and big-box stores like Walmart. Sales of sweetened beverages dropped 51 percent the year after the tax was implemented, the team reported in May 2019 in the *Journal of the American Medical Association*. Sales in Baltimore, a nearby city with similar demographics and no beverage tax, remained flat during the same period, suggesting that the tax was responsible for the drop, as opposed to some regional trend or societal shift.

About a quarter of that decline was offset by an increase in sales in three surrounding zip codes, suggesting that some people were willing to drive across the city line to get their soda, or at least pick some up when they were passing through. But even factoring in that cross-border shopping, Philadelphia has seen a 38 percent decline in the purchase of sweetened beverages, the researchers conclude. That's equivalent to an annual reduction of 78 million 12-ounce cans of sugary drinks, or 49 cans per person in a city of 1.6 million.

Several factors could account for the larger drop in sales in Philadelphia compared with Berkeley, Madsen says. Philadelphia's tax is greater (1.5 cents per ounce, versus 1 cent per ounce in Berkeley) and its population is poorer, on average, and so might have felt more of a pinch from the price increase. In addition, Berkeley residents drank relatively little soda to begin with. "It is harder to see a large drop in sales if you start with low baseline sales," Madsen says.

Other researchers also have found evidence that Philadelphia's beverage tax is changing consumer behavior. "All these studies use different datasets, but the nice thing is we're getting some confirmation," says John Cawley, an economist at Cornell University. Cawley and colleagues surveyed hundreds of Philadelphians before and after the tax was implemented, initially approaching people as they exited stores to ask about their purchases, then following up by phone with more detailed questions.

> "The tax revenue is being invested where it will do the most good in relation to the harms being caused by the sugary drinks."
>
> —JIM KRIEGER

Adults who participated in the study reported drinking about 10 fewer sodas a month after the tax, amounting to a reduction of about 31 percent, according to a study recently published by Cawley and colleagues in the *Journal of Health Economics*. The study also provides the first data on how beverage taxes affect children, Cawley says. The Philadelphia tax did not reduce soda consumption by children as a whole, the researchers found, but it did reduce consumption among those who were frequent soda drinkers to begin with.

Healthy outlook?

Despite the growing evidence that taxes reduce sugary-beverage sales, there is so far no direct evidence that the taxes have the intended health effects. Gathering such evidence won't be easy. Ideally, researchers would like to monitor the health of a representative group of people before and after the tax, says Lisa Powell, a health economist at the University of Illinois at Chicago. "You need to plan those studies and recruit people well in advance of the tax and track them over time, which is extremely expensive to do," she says. So far this has not been done, although Roberto has applied for funding for a study that would use electronic health records for thousands of patients in the University of Pennsylvania hospital system to look for changes in body mass index, and possibly indicators of diabetes, before and after the enactment of the Philadelphia soda tax.

The alternative, looking for changes in the overall population — say, in the prevalence of obesity or diabetes — requires more data and more sophisticated statistics. Powell and other researchers suggest that 10 years would be a reasonable time frame to expect to see a payoff in reduced rates of diabetes and cardiovascular disease. That's about how long it took for lung cancer rates to drop after states started implementing tobacco taxes, Popkin says. "We didn't have the hard biological health outcomes for a long time," he says.

In the meantime, the taxes are raising significant revenue. The seven US cities with beverage taxes currently raise a total of $133 million per year. Although not all of those taxes were passed as public health

SUGARY BEVERAGE TAXES IN THE US

LOCATION	TAX	INCLUDES	EXEMPT	IMPLEMENTED
Albany, CA	1 cent per ounce	Drinks with added caloric sweetener	• Milk-based drinks • 100% fruit juice • Beverages distributed from retailers with revenue <$US 100,000 per annum	April 2017
Berkeley, CA	1 cent per ounce	Sweetened drinks	• Meal replacement and dairy drinks • Diet sodas • Fruit juice • Alcohol	March 2015
Boulder, CO	2 cents per ounce	"Excise tax" on beverages with ≥5g added caloric sweeteners/12 ounces	• Milk-based drinks • 100% juice	July 2017
Cook County, IL	1 cent per ounce	Sugar- and artificially-sweetened drinks	N/A	August 2017, repealed October 2017
Navajo Nation	2% junk food tax	"Minimal to no nutritional value food items," including sugar-sweetened beverages	N/A	April 2015
Oakland, CA	1 cent per ounce	Distribution tax on drinks with added caloric sweeteners	• Milk-based drinks • 100% juice • Beverages distributed from retailers with revenue <$US 100,000 per annum	July 2017
Philadelphia, PA	1.5 cents per ounce	"Excise" tax on sugar- and artificially-sweetened drinks, including diet soda	• Milk-based drinks • 100% juice	January 2017
San Francisco, CA	1 cent per ounce	Drinks with added sugar and >25 kcal per 12 ounces; applies to syrup and powder concentrates	• 100% juice • Artificially sweetened beverages • Infant formula • Milk products • Medical drinks • Alcoholic beverages	January 2018
Seattle, WA	1.75 cents per ounce	Distribution tax on sugary drinks	• Diet sodas • Milk-based drinks • 100% fruit juice	January 2018

SOURCE: GLOBAL FOOD AND RESEARCH PROGRAM UNC

measures, most of the revenue goes to improve community welfare in some way.

Exactly where the money goes depends on local politics and perceived needs in the community. In Philadelphia, for example, the tax was passed as a means to raise money to expand early childhood education. In Berkeley, the money has gone to local organizations that promote nutritional education and exercise, including the Edible Schoolyard project initiated by restaurateur Alice Waters to build kitchen gardens at middle schools to teach children about food and nutrition.

In Seattle, which implemented a 1.75-cent-per-ounce soda tax in 2018, the revenue has been used for a variety of programs aimed at improving health equality, such as subsidizing fruit and vegetable purchases for low-income people, says Jim Krieger, a former chief of chronic disease prevention for the city and executive director of Healthy Food America, a research and education nonprofit. Partly as a result of targeted marketing by beverage companies, Krieger says, low-income communities have higher rates of sugary-beverage consumption and higher rates of disease associated with those drinks. "The tax revenue is being invested where it will do the most good in relation to the harms being caused by the sugary drinks."

Culture shift

The beverage industry is strongly opposed to these taxes. In 2016, it spent $30 million in California alone to oppose new ballot measures to impose beverage taxes in Oakland and San Francisco (both

passed). Industry-funded ads present the taxes as attacks on consumer freedom, unfairly burdensome to low-income people, and bad for employment and the overall economy. Studies by independent researchers in Philadelphia and Mexico have found little or no evidence for negative economic impacts.

The industry has lobbied effectively for state laws banning new local beverage taxes. Michigan passed the country's first such law in 2017; Arizona, California and Washington followed suit in 2018.

The California law leaves in place the existing beverage taxes in Berkeley, Oakland, Albany and San Francisco, but it upended plans to put soda taxes on the ballot in at least two other cities, Santa Cruz and Richmond. In the face of industry opposition, the California legislature in April 2019 shelved discussions of a bill that would have imposed a statewide beverage tax.

If the goal is improving public health, taxes that cover a larger geographic area would be advantageous, Cawley and colleagues wrote in a paper last year in the *Annual Review of Nutrition*. "Optimally, this would be something that's happening not at the city level but at the state or national level, so that there's less incentive to just drive a mile or two to evade the tax," Cawley says.

Public health researchers who advocate for the taxes see them as just one part of a larger strategy to tackle obesity and diabetes. Several countries are trying a more comprehensive policy approach. In Chile, which has the highest obesity rate in Latin America and has led the world in sugary-beverage sales per capita in recent years, lawmakers have passed a suite of policies since 2012 that include a small sugar-sweetened-beverage tax, warning labels on foods with high levels of added sugar (similar to the labels on cigarette cartons warning of the health risks of smoking), bans on sugary beverages in schools, and limits on marketing foods and beverages with added sugar to children. "The more comprehensive you can make the laws, the bigger health effect you're going to have," says Popkin, who has advised the Chilean government on these policies.

> "The more comprehensive you can make the laws, the bigger health effect you're going to have."
>
> —BARRY POPKIN

But in addition to new policies, what has to happen is a cultural shift, says Laura Schmidt, a public health researcher at the University of California, San Francisco. "With tobacco, the number one thing that made the difference was norms," she says. "The policies and the debate and the education campaigns made smoking unpopular."

Countermarketing — media campaigns that undermined tobacco company advertising by pointing to negative health effects or industry manipulation of consumers — may have played a role as well.

It's a strategy already being tried with sugary beverages, for example with the "Berkeley vs. Big Soda" campaign launched in 2014 to counter industry-funded ads trying to prevent voters from approving the tax there, and New York City's "Pouring on the Pounds" campaign, which emphasized the connection between sugary beverages and weight gain. (One ad, for example, showed a man opening a soda can and pouring out chunky, gelatinous fat.)

Cultural changes may be underway in the US, where consumption of added-sugar beverages has been declining steadily since the early 2000s. One study, based on nationally representative data from the CDC, found that the proportion of American adults who reported drinking at least one sugary beverage a day dropped from 62 percent to 50 percent from 2003 to 2014 (and from 80 percent to 61 percent for children).

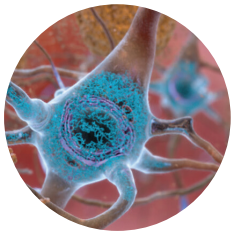
With additional nudges from soda taxes and other policies, advocates say, that decline could develop into significant health benefits in the years ahead. And as public perception shifts, lawmakers will feel emboldened to pass more aggressive policies, Schmidt says. "It's a virtuous cycle." ●

ASSOCIATED ANNUAL REVIEWS CONTENT

The Economics of Taxes on Sugar-Sweetened Beverages: A Review of the Effects on Prices, Sales, Cross-Border Shopping, and Consumption

J. Cawley *et al* /
Annual Review of Nutrition

Q&A



Neuroscientist Marc Aurel Busche

Watching Alzheimer's in action

A look inside the brains of engineered mice suggests therapies might need to target two key proteins — tau and amyloid-beta — at the same time

By Tim Vernimmen

SLOWLY AND INSIDIOUSLY, they pile up in the brains of people with Alzheimer's disease.

Abnormal bits of protein known as amyloid-β glom onto each other to form the infamous plaques that reminded German psychiatrist Alois Alzheimer of millet seeds when he first spotted them in the brain of a deceased patient in 1906. And then there are the tau proteins, which normally help to stabilize the cellular skeleton of brain cells, but may start to form tangles as people age, or when tau is defective.

The consequences are also familiar: Short-term memory loss usually comes first. Then mood swings, language impairment, disorientation and confusion inevitably ensue. But how these symptoms result from the two faulty proteins and the tangles and plaques they create has long been unclear.

To study Alzheimer's brain tissue, for decades neuroscientists had to make do with slices of brain they could manipulate in the lab. But how comparable was this to what goes on in living, intact brains affected by Alzheimer's? About 15 years ago, technology developed in the lab of neuroscientist Arthur Konnerth at the Technical University of Munich offered a way to get at this question by allowing scientists to watch the brains of mice in action.

Marc Aurel Busche, a neuroscientist and psychiatrist at the UK Dementia Research Institute in London who conducts research and counsels patients with memory issues, was the first to apply this new technique to mouse models of Alzheimer's. It has led to some surprising results, as outlined in an article by Konnerth, Busche and colleagues in the *Annual Review of Neuroscience*. This interview has been edited for length and clarity.

Can you explain in basic terms how this technique allows us to see the brain in action?

What we really see is calcium flowing into the cells, which happens every time a nerve cell fires.

To make this visible, we add molecules to the brain cells that can bind calcium and will change their fluorescence when they do so — a change we can see or record using a microscope. For the studies we have done, we have removed a very small part of the cortex, the outer layer of the brain, so we could also see other regions such as the hippocampus, which is important in memory.

Newer developments now allow us to make images of the hippocampus without removing the cortex. But in any case, we have been able to show that the removal did not affect mouse behavior or activity levels.

Mice have rather different brains from ours, and they don't live anywhere near as long. How do you create a mouse model with a condition akin to Alzheimer's?

The development of mouse models is inspired by genetics. There are two forms of Alzheimer's: a sporadic form that occurs only in the elderly, and a familial form that sets in much earlier. In the second case, we often know exactly which genetic mutation is causing it. We insert human genes with these mutations into the mouse DNA so that the mice overproduce, in particular, the protein from which amyloid-β originates.

The engineered mice form amyloid plaques similar to human patients, and they also have memory impairments. Yet it is important to mention that these

COURTESY OF THE NATIONAL INSTITUTE ON AGING / NIH; JAMES PROVOST

mice don't model all aspects of the disease. Many of them don't have tangles of tau, for example.

So they mimic the early-onset form of Alzheimer's rather than the one that relates to aging?

Yes, but in terms of the clinical symptoms and the way the brain tissue is affected by the disease, the two are not very different. So we believe that the mice are also useful to understand the aging-related form.

When you first applied this new imaging technique to look at the brain activity of a mouse overproducing human amyloid-β, did you find what you expected?

No. Our hypothesis was that the brain cells surrounding amyloid plaques would be silent. But we found the opposite — many of these neurons were hyperactive. In the hippocampus, a crucial area for consolidating memories, this hyperactivity appeared even before the formation of amyloid plaques.

This suggests that the hyperactivity is not due to the plaques themselves, but to amyloid proteins in solution: Amyloid plaques tend to be surrounded by a halo of soluble amyloid-β. Reassuringly, the hippocampus was subsequently also found to be hyperactive in people with very early Alzheimer's.

Could this hyperactivity be an attempt by healthy cells in the hippocampus to compensate for other cells that may have been damaged by the disease already?

That was the first hypothesis that many people had, that the hippocampus had to work a little harder to maintain its memory function. There is increasing evidence, however, that this might not be true. In human studies, the cognitive decline is faster in people who have the highest levels of hyperactivity. This is the opposite of what you would expect if a more active hippocampus helps them to compensate for the damage. And in mice, it has been shown repeatedly that hyperactive neurons are in fact detrimental to normal function.

Might we say that rather than working harder, they are just making more noise?

Yes. If certain cells are active the whole time, they can drown out the meaningful signals of others.

Could this hyperactivity explain some of the symptoms seen at early stages of Alzheimer's?

A certain degree of coherent activation of the hippocampus and the cortex is important for the succesful storage and retrieval of memory. Hyperactivity impairs this communication, and mice with a hyperactive hippocampus are impaired in cognitive and behavioral tests. When we treat them to reduce the hyperactivity, however, the communication is normalized, and their behavior improves.

Hyperactivity might also disturb the activity and coordination of brain regions in the so-called "default mode network" — a number of interconnected brain areas that are active when we are not performing a task, when our mind is left to wander. This network plays an important role, for example, in the formation of memories about oneself, such as when and where one had lunch yesterday — known as self-referential memories.

I think it is important to mention that apart from memory impairments, many people with Alzheimer's also experience depression, attention deficits or sleeping problems early on — symptoms that we didn't use to pay much attention to. It is not clear whether these are all manifestations of the disease or early risk factors for developing it, but it could be that some of these also relate to changes in the default mode network. Depression, for example, is affected by the same circuit; it has many self-referential aspects.

The link with sleeping problems is interesting and worrying. What is known about it?

I started looking at sleep in mice after noticing that my patients in the memory clinic often complain about sleep impairments. If we look at the electrical activity of the human or mouse brain using EEG [electroencephalography, a recording of electrical activity in the brain], we can see distinct slow waves traveling across the brain during the deeper stages of sleep. It turns out that these waves are less coherent, and therefore quite probably impaired, in Alzheimer's.

Sleep could be a major driver of Alzheimer's progression, as we now know it is affected very early on. Many studies show that the proteins we believe are driving the disease are released in larger quantities when we are awake, and that sleep may assist in their removal. In that sense, sleep hygiene — minimizing the impact of factors such as activities or drinks that may

interfere with your sleep — is important. But again, we don't yet know for sure that sleep deprivation contributes directly to the development of Alzheimer's. It could also be that sleep disturbances are just an early symptom of the disorder.

Can sleeping pills be part of the solution?

The problem with sleeping pills is that they often suppress the normal rhythm of sleep. Most of the drugs we typically use change normal sleep physiology — some of them are more like anesthesia.

It's not the normal kind of sleep that is healthy for you. They can provide huge relief, for a short period of time, if someone really does not sleep, but it's not a permanent solution.

Have the hyperactivity findings inspired any new pharmacological approaches to Alzheimer's?

We believe hyperactivity might also contribute to the epilepsy-like — or epileptiform — activity first described in mice that overproduce human amyloid-β by the lab of Lennart Mucke at UC San Francisco. Many clinicians were initially skeptical, but it turns out that such activity occurs in 15 percent to 25 percent of Alzheimer's patients. Now there are experiments with the epilepsy drug levetiracetam, which has been shown to reduce epileptiform activity in the amyloid-β mouse model while also improving their cognition. It is being tested in a large-scale phase III clinical trial to see if it can help in early Alzheimer's.

Quite a few other medical trials for Alzheimer's that were trying to prevent the formation or reduce the concentration of amyloid-β have ended early. What might they have missed?

First of all, there are still amyloid-targeting treatments in phase III trials, and I do really hope that some of them might turn out positive. But I think the recent setbacks point to the fact that the mice we use are incomplete models, and that the other protein, tau, might make the difference.

Many groups have shown we can basically cure these amyloid-producing mice. But it's not effective in patients, because they also have the tau protein. The current thinking in the field, which is reflected in the design of the clinical trials, is that there is no particular interaction between amyloid-β and tau. But research over the last few years, including our own, shows that there is a synergy between the two proteins, and that amyloid-β might make the effects of tau worse.

> "Research over the last few years, including our own, shows that there is a synergy between the two proteins, and that amyloid-ß might make the effects of tau worse."
>
> —MARC AUREL BUSCHE

In your most recent study, you have tried to cast light on the way the two proteins interact. It shows that when neurons in the brain of mice are engineered to overproduce human tau as well as amyloid-β, they are not hyperactive, as they are in the amyloid-only mice, but silenced. That seems quite contradictory — how might these results be reconciled?

I think it is really important to look at how the disease progresses in space and time. It is indisputable that about a fifth of patients have epileptiform activity early on — that the hippocampus is hyperactive in many patients with early Alzheimer's — and that when they are interacting with the outside world, their default mode network often does not turn off in the way it normally would. So there is plenty of evidence of increased activity.

At the same time, we have known for a while that the brain is silent later on in the course of the disease — studies show a decrease in metabolism and blood flow.

We have a simple model right now that is based on what we see in patients' brains. Amyloid plaques appear first, and as long as we mostly have amyloid-β, we expect to see more hyperactivity. Then when tau starts to spread, it will gradually become dominant, and more and more nerve cells will be silenced. This silencing may be reversible — in the mice, at least, these cells are not dead, but in a resting state. Yet to prevent or even repair this situation, I think we will very likely need to target both proteins at the same time. ●

To date a dinosaur

STEGOSAUR EXPERT SUSIE MAIDMENT IS LAYING CRUCIAL GROUNDWORK FOR ASSIGNING AGES TO FOSSILS FROM NORTH AMERICA'S MOST DINOSAUR-RICH ROCKS. MORE PRECISE TIMINGS PROMISE TO REVEAL PLENTY ABOUT HOW THE BEASTS LIVED AND EVOLVED THROUGH TIME.

BY LAURA POPPICK

AT THE BASE OF A PALE HILL IN THE badlands of northeastern Wyoming, Susie Maidment hits her hammer against stone. She breaks off a fist-sized chunk, grabs a loose piece between her fingers and places it on her tongue. “Silty,” she announces as the sediment brushes the roof of her mouth.

Maidment’s graduate student, Joe Bonsor, takes note on his clipboard then brings a piece of rock close to his face and squints at it through a hand lens. The layer below this one has slightly larger sand particles, Maidment says — suggesting that the two formed under different conditions. It’s one of many bits of data needed for the job the two paleontologists have come over from the UK to do: piece together, layer by layer, the history of the Late Jurassic, from details in the rocks that formed at that time.

The hills around us on this June day sprawl with dusty prickly pear cactus, juniper and sagebrush. Scorpions and rattlesnakes pose the most immediate threats. But during the Late Jurassic, streams and ponds would have flushed through the landscape, and dinosaurs — the creatures that make this spot so compelling to Maidment and Bonsor — would have sent prey scurrying into shadows.

Along our path, we stop to huddle over a two-inch fossil fragment that Bonsor picked up from the dry rubble — tangible remains of these long-departed animals. Maidment notes that every creature larger than a meter in size that lived on land during the Late Jurassic would have been a dinosaur — and anything with a bone as thick as this one would have come from one. “If it’s big and it’s from the Jurassic,” she says, “it’s a dinosaur bone.”

Dinosaur research has been steadily expanding in recent years, with new fossil discoveries and ever-improving fossil-scanning technology reshaping the way scientists understand these animals that dominated terrestrial ecosystems for more than 130 million years. But fossils on their own can reveal only so much about bigger-picture questions. Do differences in the head crests of hadrosaurs, say, or the skeletons of stegosaurs, represent evolutions through time, or the difference between males and females from the same time? If changes through time, how long did that evolution take, and what caused the shift? Where on the planet were dinosaurs most prevalent and diverse? Who fell prey to whom, and what type of terrain did these creatures carve their lives through? Unearthing additional fossils won’t tell you all these things. The answers, more often, rest in the rocks that surround the bones. And those rocks are, in many cases, not well studied.

> “We think of dinosaurs as really, really well known, but they are actually not that well known at all.”
>
> —SUSIE MAIDMENT

Maidment, a paleontologist at the Natural History Museum in London, is leading the push to change that, at least for North America’s Late Jurassic. This summer, she and Bonsor teamed up with an international group of paleontologists in a dinosaur dig dubbed Mission Jurassic, which aims to excavate new museum specimens and to explore the surrounding sediments for deeper details. They’re working in the Morrison Formation, a suite of rocks that has produced more Jurassic dinosaur bones than any other collection of rocks on the continent. Maidment’s ultimate goal: to develop the first-ever comprehensive chronology of the entire Morrison that maps out how the landscape changed through time and how different fossils fit into it.

Only once this framework has been established can researchers really begin to tease apart who’s related to whom and how these Late Jurassic dinosaurs evolved. “We think of dinosaurs as really, really well known,” Maidment says, “but they are actually not that well known at all.”

Your favorite stegosaurs and more

Mapping the chronology of the Morrison isn’t trivial. The formation stretches across roughly 1.2 million square kilometers from New Mexico and Arizona in the south all the way to Montana in the north. But it’s a challenge worth tackling, given what the formation holds. “These rocks have all of your favorite dinosaurs,” Maidment says, rattling off well-known names including stegosaurus, diplodocus and brontosaurus. “All the ones you knew when you were 7.”

At 38, she’s focused on stegosaurs, and has distinguished herself as one of the world’s leading experts on this group of dinosaurs. In 2015, she led a team that

OPPOSITE PAGE CREDIT: EMILY OSTERLOFF / NATURAL HISTORY MUSEUM

Susie Maidment and Joe Bonsor examine properties of rock through hand lenses.

CREDIT: LAURA POPPICK

described the most complete stegosaur skeleton ever discovered — a specimen that came from the Morrison (though she was not involved in excavating it).

She first visited this fruitful formation as a graduate student at the University of Cambridge in 2006 and has since returned five times to study fossil beds and sleuth out the Morrison's ancient environmental history. "That's going to be amazing information she can bring," says Victoria Egerton, a paleontologist with positions at the Children's Museum of Indianapolis and the University of Manchester, and one of the lead organizers of the Mission Jurassic dig.

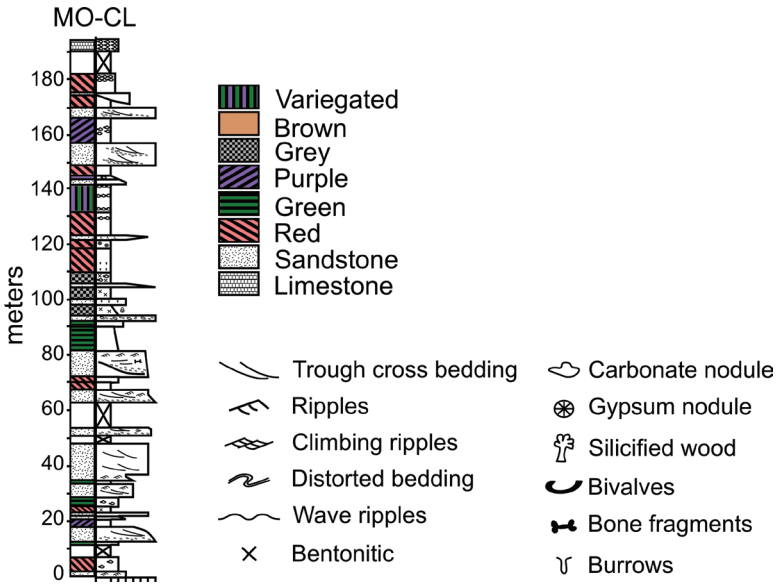
Maidment also brings a somewhat uncommon mix to the research, of prestige for her paleontological lab work plus a strong knowledge of field geology — experience she gained as an undergraduate geology student at Imperial College London and by working as a geologist for an oil company before landing at London's Natural History Museum in 2009.

The geologic work she and colleagues have conducted within the Morrison suggests that it formed over the course of 9 million years, give or take a few million, between about 156 million and 147 million years ago. But beyond that, researchers still have a poor sense of the ages of individual layers within the rocks where many fossils have come from. So paleontologists have resorted to grouping these fossils into a single unit of time — a practice that can lead to seriously flawed interpretations, Maidment says.

For example, studies of Morrison fossils have begun to reveal differences in skeletons found in the southern portion of the formation compared with similar ones found in the north — including stegosaurs that Maidment has studied. But without ages assigned to these fossils, researchers can't know if their differences represent changes through time, or place-based differences from the same time. That's an important distinction to make as researchers build family trees and try to understand the broader story of dinosaur evolution.

"If you're dividing time into 10 million years, you are smushing together a whole load of different ecosystems and different animals that never would have lived together," Maidment says. By way of

DEPICTING SEDIMENTARY LAYERS



A stratigraphic log from a site called Cisco Landing, near Moab in Utah.

CREDIT: SUSIE MAIDMENT

context: Just 12 million years of evolution produced humans, gorillas and chimps from a single common ancestor.

Paleobiologist Anjali Goswami, a colleague of Maidment's at the Natural History Museum who studies vertebrate fossils from other parts of the world, says that establishing a robust timeline is key to untangling the Morrison, and that Maidment's efforts here are vital. "The error in what we are trying to estimate is really huge. She's doing a lot of really time-consuming fieldwork to try to remedy those errors."

That fieldwork includes the painstaking task of collecting what geologists call stratigraphic logs: inch-by-inch observations of sediment layers (or strata) from the base of a rock face to the top (from the oldest sediments to the youngest) — sometimes spanning hundreds of feet of stone. It's why Maidment stuck the silt in her mouth (a common geologic test of sediment size) and what has consumed her time in the Morrison over the past seven years.

The activity is slow but rhythmic: Extend the tape measure; note where you are in the rock face and how far you've come from the previous layer; knock off a piece of the layer with your rock hammer; get the sample as close to your face as possible while still able to focus on it beneath your hand lens; note the size of the sediment and the quality of its layers; and, if you're inclined, put a bit in your mouth.

Jot down notes, confer with your field partner to confirm your interpretation of your observations, and then move on to the next layer directly above. If a plant or other obstruction appears in the way, skirt to the right or left in a straight line to find the next well-exposed area and proceed upward, forward in geological time.

The end product in the field notebook looks like a vertical bar code decorated with symbols that indicate size of sediments, thickness of layers, and the ancient environments these layers might represent. Wavy layers often form in watery places where sand ripples might develop, so they may represent a stream bed or coastline. Flat layers may represent a calmer environment like a lake bottom. Sand and silt fall faster through water than clay, which settles in places where tides and currents slacken.

On their own, these individual bar codes aren't very helpful. A single ripple layer can form in a number of different environments, including a small stream. But with many bar codes collected across a region, scientists can start to find patterns across corresponding layers, build connections, and sculpt a three-dimensional illustration of how the landscape might have unfurled and morphed through time — shifts from wet to dry to coastal to riverine, each iteration layered one on top of the next.

Since 2012, Maidment has collected more than 20 of these stratigraphic logs across the Morrison and has worked to correlate them with 245 additional ones that others have collected over the years. While collecting them has been a massive, multidecade effort accomplished by many scientists, Maidment is the first to pull them all together into a cohesive framework, work that's been accepted for publication in the *Journal of Sedimentary Research.*

Vertebrae of a sauropod encased in sandstone near Torrey, Utah.

CREDIT: CHRISTOPHER DEAN / UNIVERSITY OF BIRMINGHAM

"She's really someone who is pushing ahead with that in a way that I don't think other people have been," says Roger Benson, a paleobiologist at the University of Oxford who wrote an article in the 2018 *Annual Review of Ecology, Evolution, and Systematics* last year on the lingering unknowns in dinosaur biology and evolution. He sees the well-studied rocks of the Morrison as somewhat of a Rosetta Stone for other less-studied rocks of the same age, and what Maidment finds could help unravel the story of Late Jurassic dinosaurs not just in North America, but elsewhere. "The work she is doing is really important and fundamental," he says.

Fascinated from the start

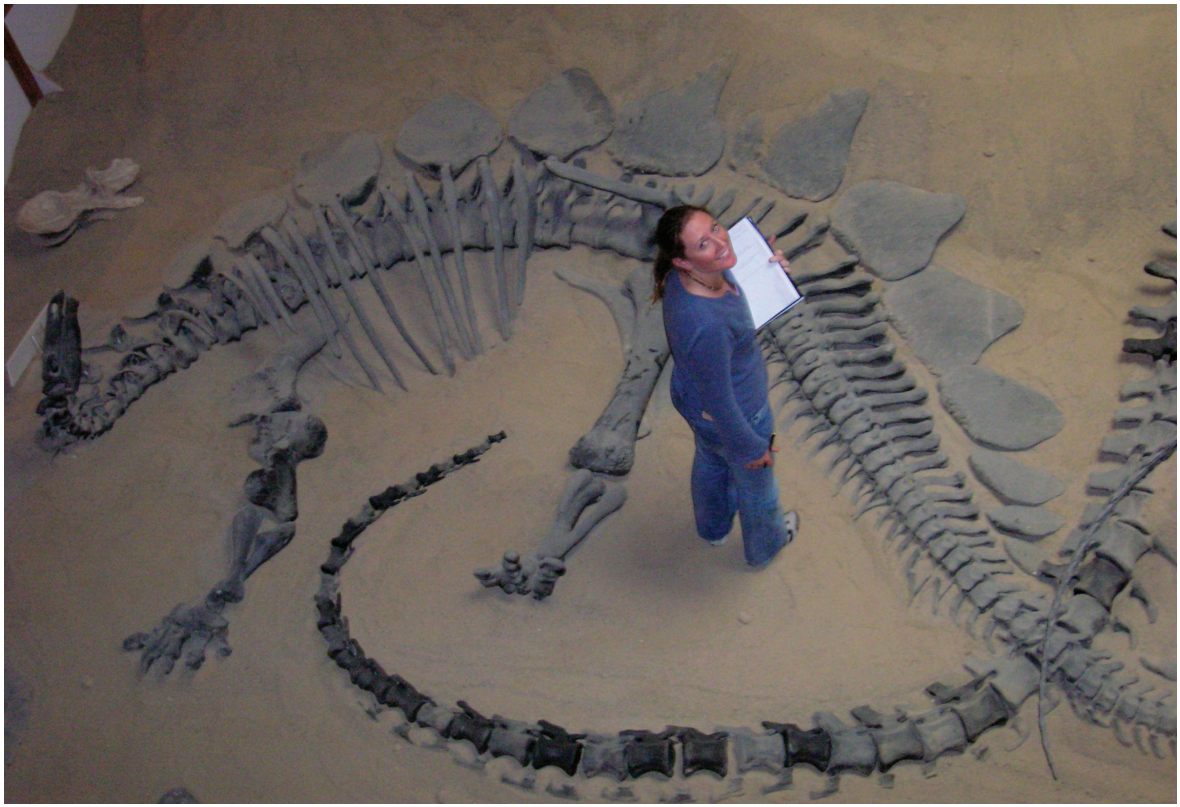
As we drive down a dirt road to the Mission Jurassic dig site, over cattle guards and through several barbed wire ranching gates, Maidment describes her decades-long commitment to unraveling the story of dinosaurs.

She spent her childhood collecting fossil ammonites along the cliffs of the Jurassic Coast in southern England, but traces her specific fixation on dinosaurs back to a conversation she had with her grandfather when she was 6, when he asked what she wanted to be when she grew up. "At the time I was wavering viciously between scientist and princess," she deadpans. Her grandfather, an electrical engineer, gently pushed for scientist. She wasn't sure what options existed in science, but knew she liked dinosaurs, so he suggested she study them. Since then, that's been her pursuit. "It's always what I wanted to do," she says.

We arrive at the dig site, and I join Bonsor as he crouches with a group of other students. They kneel on pads and methodically brush away dusty layers to excavate the remains of a sauropod — a long-necked, long-tailed plant eater from a group of the most massive animals ever to live on land.

Using a metal trowel to discard clumps of dirt and a razor blade to carve finer details, Bonsor comes across an object with the distinct reddish hue of bone. "This has always been my goal," he says as he gazes at his first-ever dinosaur find. "Pretty much this second has been my life goal."

The allure of discovering new fossils certainly motivates Maidment as well. But she says that she often finds the sediments even more enticing than the dinosaurs — especially if they contain datable material.



CREDIT: REESE BARRICK / COLLEGE OF EASTERN UTAH

Maidment during her PhD years. This stegosaur, a mix of real and cast bones, is on display at Utah State University Eastern's Prehistoric Museum in Price, Utah.

But locating rocks with that material isn't easy, says David Eberth, an emeritus geologist at the Royal Tyrrell Museum in Alberta who has conducted extensive fieldwork studying younger dinosaur-rich rocks in Canada. "You have to go where the rocks will talk to you," he says.

Eberth is referring to rocks that contain the mineral zircon, the preferred material scientists use to date Earth's oldest remains. Tiny zircon crystals are especially helpful for two reasons: They're strong and can stay intact across millions of years, and they contain the radioactive element uranium. Uranium decays to the element lead at a known rate, so researchers can measure the ratio of uranium to lead in a zircon to calculate its age.

Zircons form in volcanoes, so researchers look for them in ancient volcanic ash layers where they would have been buried relatively soon after they formed. But ash doesn't always fall neatly alongside fossil beds, and trying to process zircons from sediments broken down from ash can be challenging. The cost and difficulty of doing zircon work means many spots in the Morrison lack zircon dates. This is where stratigraphic logs become helpful in assigning ages to fossils: Though zircons may be absent from some fossil sites, they are present in others, and geologists can extrapolate the age of one sediment layer by correlating it with a corresponding layer of known age elsewhere in the rock formation. Work like this, Eberth says, "is absolutely key to making any sense of patterns we see coming out of the Morrison."

But you need more than zircon dates and stratigraphic logs, he adds. Sometimes seemingly corresponding layers look alike but do not actually match up; the resemblance could be coincidental. "You can't tell," he says. "You need a huge multidisciplinary tool kit to tell you" — including other lines of evidence from the sediment layers.

Researchers also correlate the chemistry of the strata — chemostratigraphy — by looking at the ratios of different elements in the rocks. And they carefully note the orientation of magnetic

CREDIT: LAURA POPPICK

Maidment's graduate student Joe Bonsor (left) works on excavating a dinosaur bone. "Pretty much this second has been my life goal," he says.

mineral grains within the strata — magnetostratigraphy. Only when these multiple lines of evidence match up can scientists solidify the timing of layers. "Then," Eberth says, "you start putting the animals in it."

> "If you're dividing time into 10 million years, you are smushing together a whole load of different ecosystems and different animals that never would have lived together."
>
> —SUSIE MAIDMENT

During past field seasons, Maidment has collected cores of Morrison rock for magnetostratigraphy and samples of ash for zircon analysis. This time, she is keeping an eye out for more volcanic ash layers. Otherwise — tape measure in one hand and hand lens in the other — she's fully focused on collecting observations for a new stratigraphic log that she'll transfer to a computer and add to her mounting collection from across the formation.

Maidment's efforts to compile all existing Morrison logs into a single comprehensive framework will help make the most of the relatively few reliable zircon dates that she and colleagues have collected over the years. "That would be a big contribution," says Kenneth Galli, a geologist at Boston College whose team has collected and analyzed zircons from the Morrison.

And by bridging this gap between geology and paleontology, she's filling a niche that others aren't necessarily equipped for, says Amanda Owen, a sedimentologist at the University of Glasgow in Scotland who has studied the Morrison extensively and whose stratigraphic logs helped inform Maidment's chronology.

The smell of ancient eons

As Maidment, Bonsor and I continue our way up the silty hill to complete their log for the day, Maidment knocks off a gray stone and hands a piece to me. I bring it to my face and notice a strikingly familiar but out-of-place odor — the dank, musky smell of a lake.

Maidment confirms that rocks can, incredibly, retain the smell of their origins millions of years after they form. I could actually be holding a piece of lake bottom.

Soon after, ominous storm clouds descend and we hustle back to the central dig site to take cover. But our minds are still stuck in the Jurassic. "It's very relaxing," Maidment says of the sensory experience of collecting logs: the smell of rock, the taste of sediment. "I love doing it."

Before the incoming rain kicks us off the dig site, a hubbub forms around one of the fossil quarries. Paul Kenrick, a paleobiologist from the London museum, has found a fragment the length of a thumbnail.

Maidment examines the find between her fingers and tentatively identifies it as a piece of a femur. Based on its curvature, she thinks it might have come from a small therapod — a meat-eating dinosaur that would have been magnitudes smaller than the sauropods the team has been digging up. "The small stuff is less well known, it's rarer," she says as people huddle close to get a look. "It shows that there are other things in here."

The rain starts to fall as we pile into trucks and head down the dirt road before it becomes slippery and impassable. As we leave, we rattle over beds of undiscovered bone. Those bones will bring the team back the next day — but it's the surrounding layers that will bring the bones to life. ●

ASSOCIATED ANNUAL REVIEWS CONTENT

Dinosaur Macroevolution and Macroecology

R.B.J. Benson / ***Annual Review of Ecology, Evolution, and Systematics***

Q&A

Biologists Jessica Mark Welch and Gary Borisy & dental researcher Floyd Dewhirst

Getting the microbe story, straight from the mouth

A trio of researchers has mapped the living things that make the tongue, gums and palate home

By Eryn Brown

IF YOU'VE EVER BRUSHED your teeth or swished some mouthwash, they've been in your sight: the hundreds of billions of microorganisms — mostly bacteria — that live in the average human mouth. Dangling from the hard palate, burrowed in the nooks and crannies of the tongue and intertwined in the plaque on teeth are the many hundreds of species that make up the human oral microbiome.

For most, the bacteria in your mouth seem largely an inconvenience — critters all mixed together in a smelly goo, that must be flossed, brushed or rinsed away to keep your breath pleasant and gums healthily pink. But for Jessica Mark Welch of the Marine Biological Laboratory in Woods Hole, Massachusetts, and Gary Borisy and Floyd Dewhirst of the Forsyth Institute in Cambridge, Massachusetts, the oral microbiome is a wonder. Far from a jumbled mess of cells, it's a varied, ordered ecosystem that can reveal larger truths about the ways microbes interact with one another — and how their interactions impact the environments they inhabit.

Charting the way microbes array themselves in the mouth could shed light on the ways communities of organisms organize themselves in a variety of ecosystems, the scientists say, from the pores of kitchen sponges to the surfaces within kelp forests. Understanding more about the microbial rules of engagement could help leverage microbiomes to improve health, or, more far afield, help solve technological challenges like making biofuel from switchgrass.

And of course, exploring the oral microbiome specifically can sharpen understanding of how some bacteria in the mouth keep us healthy — as key actors in normal metabolism — while others may be implicated in illnesses like gum disease, heart disease and cancer.

Mark Welch, Borisy and Dewhirst, who recently reviewed what's known about the geographic distribution of species inhabiting the mouth in the *Annual Review of Microbiology*, have used genetic analysis and fluorescent imaging to map the microbes — from the chain-linked *Streptococcus* species that thrive on the tongue to the rod-shaped *Corynebacteria* that hang out in dental plaque to all the other bacteria that live among them.

Their work suggests that bacteria live in communities that are far more structured than previously believed. "I think we expected more big wads of bacteria," says Mark Welch. "What was really a surprise was to see how organized they were. It tells us a lot about how they are working together."

This interview has been edited for length and clarity.

Jessica, you are a geneticist. Gary, you're a cell biologist. How did you end up studying bacteria in the mouth?

GB: We wanted to study microbiomes — communities of bacteria — the ways they organize themselves, and why that matters.

The mouth was not the first place we began. We started by looking in the natural environment, at microbes in a pond and in a marsh in Woods Hole. We also sampled the man-made environment: dollar bills, and the scum around the toilet bowl.

JMW: And what you find on the sponge in your kitchen sink! There are microbiomes everywhere, and they play an important role in ecosystems.

GB: But we realized rather early on that there was a big problem. When we collected our samples, we could see many individual organisms, but we weren't really sure what we were looking at. The genomics

CREDIT: JAMES PROVOST

database for most environments was sparse. No one had systematically sequenced the microbes we were seeing, so it was hard to identify them when we sampled them, much less understand the ways they worked together to make ecosystems.

And studying the mouth solved that problem?

GB: Yes. One reason for going to the mouth was the existence of this superb database that our coauthor Floyd Dewhirst and his colleagues at Forsyth had developed — the Human Oral Microbiome Database, which catalogs the genomes of hundreds of bacterial species found in the mouth. A lot of the organisms we would see if we started collecting bacteria from the mouth for our research were already identified and cultured, and the genomic information was being curated — all of this provided the foundation for the imaging work we wanted to do.

Also, from a craven perspective, it seemed it would be easier to get money to support this work if we did something related to humans.

JMW: Another thing that makes the mouth a fantastic environment to study is that the different microbial communities — the bacteria that grow on the different surfaces in the mouth — are so different from one another.

And yet they're all in the same mouth, experiencing the same saliva, the same immune system, the same daily eating and sleeping schedule. You're controlling for many of the factors that might influence the community. You can really compare the influence of the surfaces they're living on, and their location in the mouth.

So what is this landscape of the mouth? Who lives where?

FD: The Human Microbiome Project defines nine sites in the mouth — the tongue, palate, tonsils, sub- and supra-gingival plaque on teeth, the keratinized gingiva, the buccal mucosa, the throat, and saliva.

And surprisingly, even though your tongue touches the roof of your mouth, if you rub a Q-tip on either spot I can tell you with 100 percent certainty which surface you just sampled. The organisms living on your tongue are a very different community from what's on the roof of your mouth.

Why are they so different?

JMW: From the point of view of a bacterium, it matters what kind of surface you're living on. The teeth are solid, they're always there. If you can root yourself onto them, you're not going to get dislodged unless someone pushes you off with a toothbrush or something. Bacteria such as *Corynebacteria* precipitate calcium from saliva. It's thought that they turn into that calculus that your dentist scrapes off your teeth. They grow very slowly, but they thrive by gluing themselves to their surface.

> "The organisms living on your tongue are a very different community from what's on the roof of your mouth."
>
> —FLOYD DEWHIRST

But if you're on the cheek cells, which shed pretty frequently, you have to bind quickly and grow rapidly. The fundamental limit on the length of time you can be bound to your surface and remain in the mouth is likely to be one of the factors that really structure the bacterial community. *Streptococcus* do well on the cheeks. They're the first to show up, they grow quickly and then they move on.

How many microbes are in the mouth?

FD: We don't really know the number of bacteria in an average mouth. But there are something like 10^{11} [100 billion] organisms per gram of plaque — so we're looking at a large number.

What people usually talk about is how many species are in there. The Human Oral Microbiome Project identified a little over 700 different species of bacteria. (There are also fungi and viruses.)

About 400 of the 700 bacterial species are much more common in people than the others. And were you to take a swab of the cheek and sequence, sequence, sequence until you saw everything you could, there'd probably be somewhere between 200 and 300 organisms. They would be distributed almost on a logarithmic scale, with the most common organism making up 10 percent of the population, the second organism 5 percent, the third just 2 percent and very rapidly, by the time you get to the 50th, you're down to 0.1 percent of the population. There's this long tail.

Since we eat and drink, we take in all of the other microorganisms from the planet. A splash of sea water, some dirt

on your spinach. Eventually, if you sampled enough people, enough times, every microorganism on the planet could show up in somebody's mouth.

GB: You could say the mouth is almost like an open sewer but that may take it too far. Only some of the organisms really take up residence and live there on a regular basis.

JMW: Dental plaque and the surface of the tongue are among the densest microbial habitats on Earth. Bacteria are pretty much wall to wall in there.

I thought bacteria was what plaque was. There's other stuff in there?

JMW: The bacteria secrete stuff.

GB: It's called the "extracellular matrix," or "extra-polymeric substance" ...

JMW: Or slime! Plaque is a biofilm — bacteria adhered to a surface, embedded in a matrix of their own making. And biofilms are cool. Bacteria behave differently in a biofilm. There are parts of their metabolism they only turn on in a biofilm, and they tend to be more resistant to antibiotics and changes in the environment. A lot of the material in dental plaque biofilm is DNA, which is interesting. Do the bacteria die and spread their DNA all over the place?

What led you to start making fluorescent images of the colonies formed by the bacteria?

GB: We had a gap in our understanding of microbiome organization. DNA sequencing gave us a catalog of bacterial genomes, but it had a big limitation: You have to grind up your sample to get the DNA, and in the process you lose all the spatial information — who is next to whom.

This had been a missing piece of the jigsaw puzzle of understanding microbiomes. We realized we could develop imaging tools to see the members, in their habitat, in as close to their normal arrangement as possible.

Why is that so important?

JMW: If you can see who a bacterium is next to, then you're more likely to understand whom they're interacting with. That's important because if we want to recognize what an unhealthy microbiome is — and maybe figure out how to shift it into a healthier state — we need to understand how the bacteria work together. If there's a particular microbe you want to get rid of, you need to know what else is there next to it, helping it grow or ready to take its place.

GB: Consider a watch (before they became digital). You have so many springs; you have so many wheels; you have a glass surface; you have a metal back; you have a couple jewels. But how does the watch work? Having the parts list is not sufficient. You have to know how the parts fit together, and how one affects another. With DNA sequencing we're given the parts list, but we're not told how they work together. If you want to understand the function you have to know the structure.

What do your images show?

JMW: Vast differences between the structures and make-ups of different parts of this oral ecosystem. For instance, if you look at images of dental plaque and of a microbial community on the tongue, they're just completely different.

The plaque is characterized by a shape of bacterial community we call a hedgehog, organized around *Corynebacteria* (in the image, these are the magenta-purple filaments that radiate out from the center). We think the *Corynebacteria* are the foundation of community, acting like the coral in the reef or the oak tree in the forest — creating the habitat that other organisms then inhabit at characteristic positions. The ring of bacteria we've colored green that you see around the outside of the structure are *Streptococcus*, and they stay in the aerobic zone, exposed to oxygen. They appear to be creating a low-oxygen zone in the interior that's been occupied by different bacteria.

But if you look at a microbial community scraped from the surface of the tongue, you see a gray core — dead human epithelial cells — with other bacteria forming these very dense communities growing outwards and expanding together.

FD: With the bacteria in the plaque, it's almost like you take your fingers and intertwine them — almost every neighboring cell is a different species. But on the tongue, you have these big chunks of blue or red or another color, with cells favoring proximity to cells of the same species.

And this overarching structure has a function in the mouth, presumably?

JMW: Right. Looking at the spatial organization of bacteria in the mouth tells you which microbes are directly attached to the host, and which have the most opportunity to interact with it and its metabolism.

We know that some bacteria in the mouth participate in our nitrate metabolism — how we take in nutrients from food, which can actually modulate blood pressure. If you consume a diet that is rich in nitrate, rich in green leafy vegetables, it will lower your blood pressure a little bit, but not if you use antiseptic mouthwash. In my opinion that might be one reason — and this may be going out on a limb — why we, as the host, allow the bacteria to grow to such density. We have a reason to let them do that.

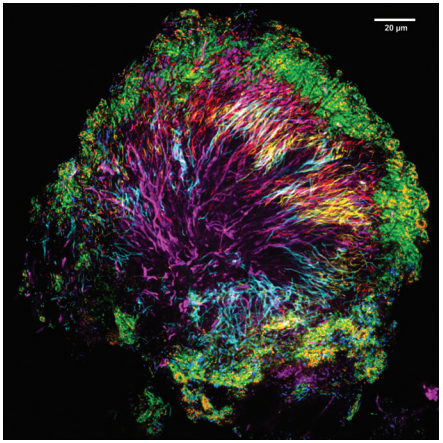
Researchers are trying to learn more about the ways microbes are implicated in periodontitis (gum disease) and caries (cavities). A common mouth bacterium known as *Fusobacterium nucleatum* seems to be involved in colon cancer. It's famous among oral microbiology people because it binds to everything. If it's attached to harmless *Streptococcus*, it can evade the immune system and enter the body through the cheek cells, and it probably gets into the colon just by being swallowed.

GB: Some bacteria provide a service to the host, but some turn against us. If we drink a lot of sugary beverages, bacteria that like the sugar thrive, and produce acid that creates cavities. If these get into our bloodstream, they can cause serious disease, such as heart-valve infections. It's like a garden. When plants aren't growing where they should, we call them weeds, even though in other places they'd be just fine.

JMW: When we ask volunteers to give us their dental plaque, we ask them to please not brush their teeth for 24 or 48 hours before we take our samples — and we have to ask them whether they have valvular heart disease. It can be especially hazardous for people with valvular heart disease to let these bacteria build up in their mouths.

So yes. These bacteria can provide a benefit to us, but they can hurt us too … and if we want to fight these pathogens we have to understand structure. A microbe's behavior depends on where it is. A lot of times research is conducted on a single bacterium, in culture. But that bacterium is going to act differently if it's next to another bacterium. We need to study both together if we really want to understand what they're doing in the wild. If we figure out which are next to each other in the various locations of the mouth, we know which ones to put in the petri dish.

Scientists have suggested that different parts of the mouth have different bacterial communities for some time. But people still like to sample saliva to measure bacteria in dental plaque. It's easy. But saliva is a mixture of bacteria from different sites in the mouth and, it turns out that they are mostly tongue bacteria, not plaque. The notion that there is location-specific structure hasn't sunk in, which is one reason we wanted to write the article.



CREDIT: IMAGE BY J. MARK WELCH AND G. BORISY

A sample of dental plaque hides a surprisingly organized set of bacterial communities, made visible using fluorescent imaging methods that highlight distinct species. Here, purple-colored *Corynebacteria* form the foundation of a specialized, intertwined structure called a hedgehog.

Where else can scientists look to better understand microbe communities in the human body?

GB: Most people are already looking at the gut. But probably every part of the body will have a distinctive microbiome — the ear, the nose, the belly button, the vaginal tract — and interesting structures.

JMW: I've been trying to flip this around the other way, looking at where else in the world — beyond the human body — you can find interesting spatial structures like those in the human mouth.

It's taken me full circle back to marine organisms. Kelp and other macroalgae are similar to the mouth, in a way. There's a fixed surface that's nutrient-rich, and immersed in flowing water, and that promotes structure in the community.

Kelp is an ecosystem engineer. It is important as habitat for fish and other organisms and for regulating the transfer of nitrogen and carbon. We're interested in the degree to which the bacteria might be needed for this. How much does the kelp act by itself, and how much does it require microbes to do its work? Analyzing what's going on in the human mouth might get us closer to an answer. ●

Why forgetting may make your mind more efficient

EVIDENCE BUILDS FOR WAYS THAT THE BRAIN ACTIVELY ERASES MEMORIES

BY TOM SIEGFRIED

IN THE QUEST TO fend off forgetfulness, some people build a palace of memory.

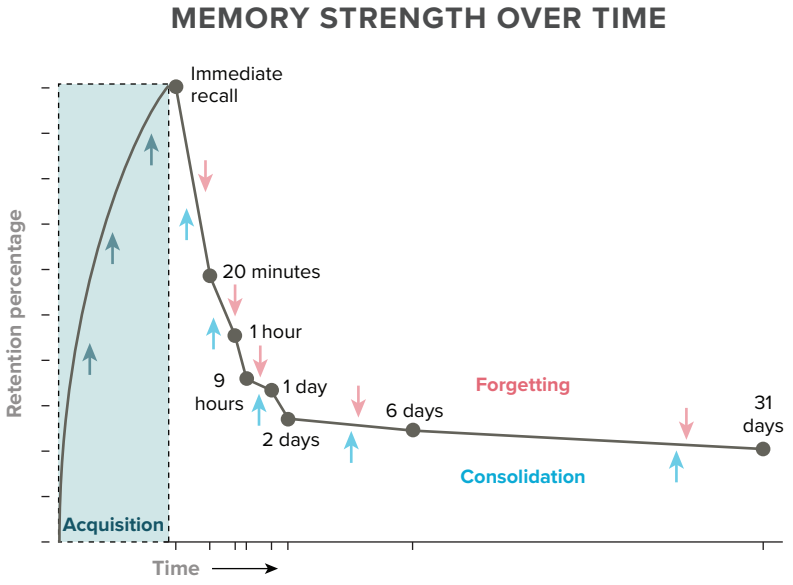
It's a method for memorizing invented in ancient times by (legend has it) the Greek poet Simonides of Ceos, more recently made popular by multiple best-selling books (and the "mind palace" of Benedict Cumberbatch's Sherlock Holmes).

Memory palaces provide imaginary architectural repositories for storing and retrieving anything you would like to remember. Sixteen centuries ago, Saint Augustine spoke of "treasures of innumerable images" stored in his "spacious palaces of memory." But twenty-first century scientists who study memory have identified an important point to remember: Even the most luxurious palace of memory needs trash cans.

"There are memories that we don't want and we don't need," says neuroscientist Maria Wimber. "Forgetting is good and an adaptive thing."

Traditionally, forgetting has been regarded as a passive decay over time of the information recorded in the brain. But while some memories may simply fade away like ink on paper exposed to sunlight, recent research suggests that forgetting is often more intentional, with erasure orchestrated by elaborate cellular and molecular mechanisms. And forgetfulness is not necessarily a sign of a faulty memory. "In fact," Wimber says, "it's been shown over and over in computational models and also in animal work that an intelligent memory system needs forgetting."

Far from signifying failure, forgetting may be the brain's frontline strategy in processing incoming information. Forgetting is essential, some researchers now argue, because the biological goal of the brain's memory apparatus is not preserving information, but rather helping the brain make sound decisions. Understanding how the brain forgets may offer clues to enhancing mental performance in healthy brains while also providing insights into the mechanisms underlying a variety of mental disorders.



A graph conceived by the 19th century German psychologist Hermann Ebbinghaus quantified the decay of memory over time. In this example, recall is strong (a peak percentage is retained) after acquiring a memory. Afterwards the memory rapidly decays for about two days and then begins to stabilize as consolidation balances forgetting.

Biology of remembering

Memory itself is still something of a mystery, but it basically consists of physical changes in the brain that encode past experiences. Those memory traces — known as engrams — can be accessed to reconstruct the past, albeit imperfectly. Many experts believe that engrams are built by strengthening synapses — the sites where signals are transmitted between nerve cells, or neurons. Recalling a memory reactivates a pattern of nerve cell signaling that mimics the original experience.

"The prevailing view is that the formation of an engram involves strengthening of synaptic connections between populations of neurons … that are active during an event," Sheena Josselyn and Paul Frankland write in the 2018 *Annual Review of Neuroscience*. "This increases the likelihood that the same (or similar) activity pattern within this cell assembly can be recreated at a later time."

OPPOSITE PAGE CREDIT: BENEDETTO CRISTOFANI / THEISPOT; THIS PAGE SOURCE: R.L. DAVIS & Y. ZHONG / *NEURON* 2017

Engrams obviously do not save every detail of every experience. Some records of activity patterns do not persist. And that's a good thing, says Wimber, of the University of Birmingham in England.

"An overly precise memory is maybe not really what we want in the long term, because it prevents us from using our memories to generalize them to new situations," she said in San Diego at the 2018 meeting of the Society for Neuroscience. "If our memories are too precise and overfitted, then we can't actually use them to … make predictions about future situations."

If your memory stores every exact detail of getting bitten by a dog in the park, for instance, then you wouldn't necessarily know to beware of a different dog in a different park. "In fact," Wimber says, "what we might want is a more flexible and more generalized memory and that would involve a bit of forgetting of the details and more the development of a gist of a memory."

Such "streamlined" memories are not side effects of flaws or constraints on memory power, Frankland and Blake Richards pointed out in a paper in *Neuron* in 2017. Such simplification "is an essential component of adaptive memory," they wrote. "Simple memories that store the gist of our experiences and avoid complicated details will be better for generalizing to future events."

Getting the gist, and just the gist, is therefore valuable as an aid to making smart decisions, say Frankland, of the Hospital for Sick Children in Toronto, and Richards, of the University of Toronto. In fact, they believe it is wrong to think of memory "simply as a means for high-fidelity transmission of information through time." Rather, they propose that "the goal of memory is to guide intelligent decision making."

Getting just the gist is especially helpful in changing environments, where loss of some memories improves future decision making. For one thing, forgetting can eliminate outdated information that would hamper sound judgment. And memories that reproduce the past too faithfully can impair the ability to imagine differing futures, making behavior too inflexible to cope with change. Failure to forget can result in the persistence of debilitating memories, as with post-traumatic stress disorder.

> "Forgetting might be the default system of the brain."
>
> —RONALD DAVIS

Active forgetting

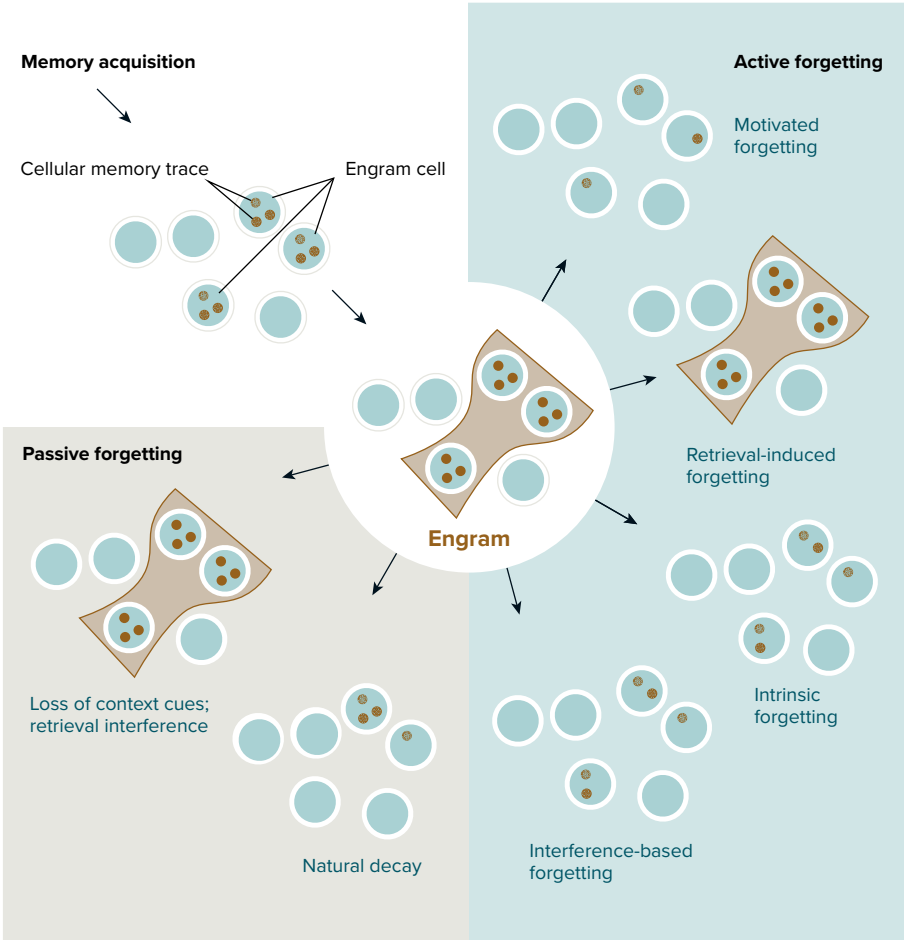
Forgetting's great value implies that it doesn't happen accidentally. In some cases, forgetting may simply reflect an inability to recall a memory trace even if the engram encoding it remains intact. But a growing number of researchers believe that can't be the whole story. As Ronald Davis and Yi Zhong point out, the brain's remarkable storage ability suggests that it possesses an efficient information management system, equipped with data disposal methods. "Because of the extraordinary large number of memory engrams that can accumulate in the brain across time, it seems logical that the brain must have … mechanisms to remove memories that become unused," they wrote in 2017 in *Neuron*.

While psychologists have considered the possibility of active forgetting for more than half a century, the neurobiological study of forgetting is still in its infancy. But scientists have begun to discern some of the brain's tactics for information erasure. In their paper in *Neuron*, Davis, of Scripps Research Institute Florida, and Zhong, of Tsinghua University in Beijing, described various studies in the last few years on mechanisms that may implement the forgetting process.

Some forgetting does appear to be "passive" — a result of either natural decay of the biological material forming engrams or the loss of ability to retrieve them. But many forms of forgetting are more like running a program that wipes data off your hard drive. New stimuli can actively interfere with old memories, for instance. Recalling parts of a memory can induce loss of other parts of it. And "forgetting cells" might actually signal the brain to sweep memory traces away, Davis and Zhong suggested. "We posit that … the brain also has the inherent biological capacity to erode memory traces using signaling systems" similar to those used in acquiring memories and storing them. In fact, forgetting could be the brain's main strategy in managing information.

"I would speculate that forgetting might be the default system of the brain," Davis said. "We might have a slow chronic forgetting signal in our brains that basically says let's erase everything unless a judge … comes to intervene and says this memory is worth saving."

ERASING MEMORIES



SOURCE: ADAPTED FROM R.L. DAVIS & Y. ZHONG / *NEURON* 2017

When memories are acquired (upper left), traces of the memory are stored by molecular changes in networks of cells, forming an engram. Memories stored in engrams can be forgotten "passively" by different processes (lower left), such as loss of contextual cues permitting retrieval of the memory, interference with retrieval by other similar memories, or simply the decay of unstable biological materials in the engram cells. Some researchers believe "active" forgetting may be more potent at erasing memory than the passive mechanisms. Several forms of active forgetting have been proposed, including intentional attempts to suppress unpleasant memories (motivated forgetting); forgetting of some parts of a memory by retrieval of other parts; decay of memory induced by interference from other information processing; and "intrinsic" forgetting — erasure of information by cells and biochemical processes as an essential part of the brain's memory apparatus for managing information efficiently.

In various experimental studies, Davis and others have amassed ample evidence for the role of biochemical processes that actively erase memory. Studies in fruit flies, for instance, implicate the well-known chemical messenger molecule dopamine.

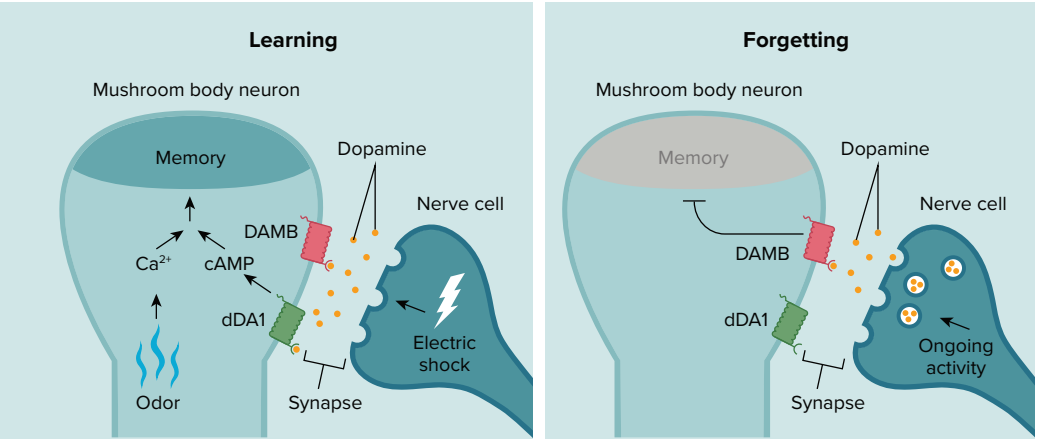
Flies can remember to avoid an odor associated with an electric shock, a memory managed by cells known as mushroom body neurons. Shocks activate other neurons that transmit dopamine to the mushroom body cells, initiating biochemical reactions that store a memory linking the shock to the odor. But that memory is soon forgotten (typically by the next day). Something erases it, and the evidence suggests dopamine is responsible for the forgetting, too.

Dopamine's dual role is not fully understood. But mushroom body neurons possess two distinct molecular antennas that respond to dopamine; one of those antennas (or receptor molecules) initiates memory formation, the other promotes erasure. Whether dopamine promotes or erases memory may depend on the context, including prevailing biochemical conditions and how active the mushroom body neuron is at the time.

In any case, the erasing process involves a protein known as Rac1, which plays a part in structuring synapses. Restructuring synapses in response to Rac1 may be responsible for weakening engrams, some studies indicate. Blocking Rac1 activity, for example, helps to extend how long memories persist.

Rac1 may also be involved in a second forgetting mechanism, driven by the birth of new nerve cells (the process known as neurogenesis). Studies in rats have found that new neurons integrated into existing

DOPAMINE'S ROLE IN MEMORY BUILDING AND DECAY



Fruit flies remember to fear an odor if its presence is accompanied by an electric shock. That memory forms because the shock stimulates the release of the molecule dopamine from nerve cells linked to mushroom body neurons at the same time that the odor triggers a cellular signal (via calcium). When stimulated by dopamine, a "molecular antenna" or receptor molecule (dDA1) on the mushroom body neuron initiates chemical reactions (via the cAMP signaling molecule) that restructure the mushroom body neuron, strengthening the memory. Recall fades over time as, in the absence of the odor, lower levels of dopamine stimulate another dopamine receptor molecule (DAMB), leading to a weakening of the memory.

neural circuits can restructure the circuitry. Such changes in connections might make memories harder to access, Frankland said. Animal studies have shown that disrupting neurogenesis preserves memories, while high levels of neurogenesis drive forgetting. Whether that form of forgetting is important in humans remains unknown, as the amount of neurogenesis in adult humans is still an unsettled question.

In any case, many types of "forgetting cells" are probably involved in erasing engrams. "Dozens of molecular and cellular pathways likely exist to erode memories," Davis and Zhong wrote in *Neuron*.

How and when those processes operate can depend on various factors, such as physical activity, stress and sleep. Sleep is known to enhance memory in humans and other animals, presumably by providing a time when memories can be stored (or "consolidated") in the brain. But sleep may also aid memory by suppressing the processes that drive forgetting, Davis and Zhong point out. A 2015 study published in *Cell* found evidence that sleep inhibits release of the dopamine forgetting signal to mushroom body neurons.

If forgetting is the key to how the brain successfully processes its massive daily data input — as research suggests — then flaws in the forgetting process could plausibly contribute to brain disorders, Davis and Zhong note. Deficits in the ability to forget may be involved in autism spectrum disorders, for instance. Certainly post-traumatic stress disorder reflects an inability to forget disturbing experiences. Unwanted, repetitive invasive memories are a feature of some psychiatric disorders, such as schizophrenia. And the inability to forget cues associated with addictive drug use impairs recovery from substance abuse.

On the plus side, better insight into the biology of forgetting could help identify drugs capable of enhancing needed memories while disposing of undesirable ones. But such benefits may appear only after much more research, Davis said at the neuroscience meeting — speaking at a rather sparsely attended session.

"We're at the very, very beginning of trying to understand the neurobiology of active forgetting," he said. But he expects that the field will rapidly attract more attention. "I guarantee you five years from now this room will be filled," he said. "Hordes of neuroscientists will start invading this field." If he's right, future meetings on forgetting might best be convened at a spacious palace — with plenty of trash bins and perhaps even a dumpster. ●

SOURCE: J.A. BERRY *ET AL* / *NEURON* 2012

ASSOCIATED ANNUAL REVIEWS CONTENT

Memory Allocation: Mechanisms and Function

S.A. Josselyn & P.W. Frankland / *Annual Review of Neuroscience*

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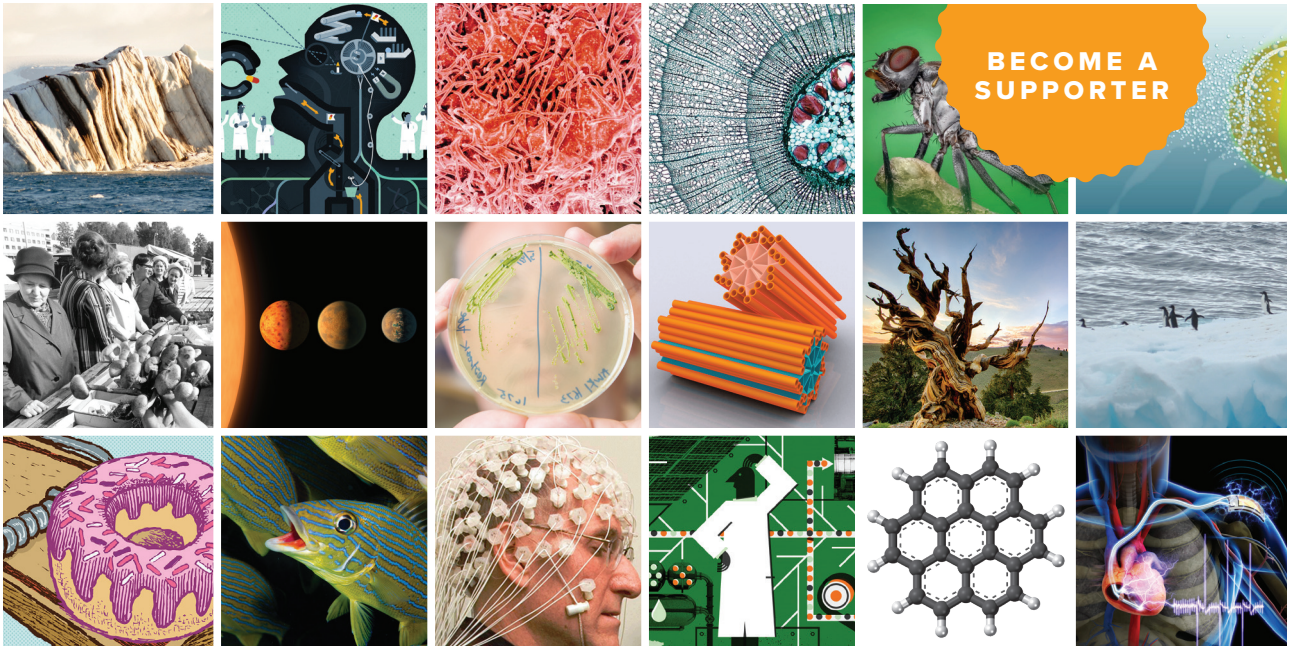

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Q&A

Psychologist Michele Gelfand

Revenge is bittersweet at best

Research is starting to reveal how the urge for vengeance may have evolved, when it can be useful and what could prevent the violence it can provoke

By Tim Vernimmen

PSYCHOLOGIST MICHELE Gelfand has long been curious about conflicts and how we might negotiate our way out of them. She's especially intrigued by the psychological desire to retaliate — and the fact that this urge is so often contagious.

People not involved in the original conflict may sometimes feel like taking revenge for the harm done to others in their group. They might even take it out on relatives of the perpetrator or others perceived as belonging to the same group, even if those people hold no responsibility whatsoever.

Gelfand, now at the University of Maryland, tackles the topic with a range of research tools, from brain imaging in the lab to fieldwork in the Middle East. In an article in the 2019 *Annual Review of Psychology*, she and her colleagues explain what revenge research has taught us so far. This conversation has been edited for length and clarity.

This is a fascinating subject, yet it seems difficult to study. How do you go about it?

As a social scientist, I've always been a proponent of having multiple methods to study anything, as every method has its strengths and limitations. You can manipulate contexts where people in the laboratory feel like they have been intentionally harmed. You can also conduct surveys to ask people about times they've felt they've been harmed in the past, and study their reactions and their emotions in those contexts.

And in some recent work that we've published on honor cultures — where there is a willingness to retaliate against people to defend one's reputation even if doing so is very risky or costly — we have even used computational models, to try and simulate the circumstances under which revenge might turn out to be beneficial. These simulations suggest that unreliable institutions and a generally tough environment may be crucial conditions for the evolution of honor cultures.

Why do you think this subject has been largely ignored for so long?

It's interesting, because revenge — which we define as motivated retaliation after one perceives harm to one's well-being — is a universal phenomenon. It is very common, and it takes a serious toll. In the US, for example, desire for revenge has been implicated in over 60 percent of school shootings and over a quarter of bombings.

It may be that early philosophers were more focused on virtue, considering revenge to be a very negative phenomenon. Only recently have researchers started to theorize that the urge to retaliate might reflect something really fundamental about human psychology, with both positive and negative aspects.

You and your coauthors stress that "vengeance can be functional and even necessary." Really?

Yes, and there are a number of different reasons for that. From an individual perspective, revenge has long been thought to be a deterrent, a way to signal to others that one is strong and not to be messed with.

More recently, the focus has shifted to cultural processes, suggesting that revenge also reflects how groups operate, and helps people work together at times when cooperation is essential for group survival.

Would you go as far as recommending revenge in certain situations?

I'm not sure I would recommend it, but we can understand why it exists, and why it may

CREDIT: PHOTO 12 / ALAMY STOCK PHOTO; JAMES PROVOST

be needed. When institutions upholding the rule of law are absent or weak, offering very little protection, revenge can serve an important function. In such a context, people who are expected to seek revenge if they are harmed will often manage to ward off aggression. So it really serves a function there.

You mention that the Bible pivoted on revenge from the Old to New Testaments, moving from "an eye for an eye, a tooth for a tooth" to "turning the other cheek." How might this be explained?
Arguably, the New Testament was written during a period when we had larger states, more stability and social organization, and where revenge would therefore have been less valuable compared to the days of the Old Testament. But we would need to test this more directly.

We are still struggling to suppress people's urge to take revenge. Does your research point to new ways of doing so?
Strengthening institutions certainly helps — for example, by improving people's trust in the police or the legal system. When you can outsource these kinds of punishments and believe that they will be fair and just, revenge becomes less attractive.

On an individual level, empathy and perspective-taking are important. If we understand our own biases and our own contribution to a conflict, forgiveness is more likely.

Last but not least, I think we should help people understand how to manage conflicts, in the same way that we teach mathematics and physics and biology in schools today. Negotiation and conflict management should be a required course.

Should "revenge is a dish best served cold" be taught in school? Is it advisable to let things cool down before you do something you might regret?
I think that's right. People often seek revenge when they are angry, which may reduce their self-control. Revenge often involves risk, which people have a natural aversion to, and anger is one of the strongest factors that can overcome this aversion. Later, when people get more psychological distance from what happened, that might reduce the anger and the revenge instinct.

Has there been a time when revenge felt very satisfying to you personally?
Luckily, I can't say I have any particular stories.

Perhaps even if you had, you might have been apprehensive to discuss it. Though revenge is the driver behind many famous stories and movies, it is not something we tend to be proud of.
I think that is largely true in the US and some other Western countries, but I wonder whether it is universal. In contexts where revenge serves a function in managing one's reputation, people might be more willing to talk about these stories, and they might be a source of pride instead of embarrassment.

This would be an interesting hypothesis to test. There is certainly some universality to revenge, but there is also a tremendous amount of cultural variation. In some cultures, seeking revenge is seen as absolutely necessary to restore one's reputation. The importance of honor is instantiated in many ancient proverbs, such as the Arabic "dignity before bread." Given its importance, people are often willing to fight to restore their honor.

This might even extend to taking revenge on people who were not involved before.
Yes. Probably the most interesting thing we have learned is how contagious revenge can become, across people and time. One of the things we consider to be really fundamental to this is what we call entitativity, which is really just how interchangeable people are believed to be. For example, if you and I are entitative, and someone harms you, that feels as if it was harm to myself, and motivates me for revenge.

Outgroup members can be perceived as interchangeable as well. If someone who harmed you is related to another person, I could seek revenge on this person I have never had any contact with. This way, conflicts can escalate from the individual to the group level, even across generations, all because of this perception of entitativity.

How might this insight help us to break the cycles of violence between groups?
One of the ways in which people try to reduce these issues is by broadening the group identity, promoting a national identity instead of a tribal one. A key issue, however, is that we shouldn't just operate on the idea of identity. A shift in perspective should be accompanied by measures to end discrimination and promote a fair allocation of power and resources between groups as well. ●

Firenadoes and drifting embers: The secrets of extreme wildfires

RESEARCHERS PROBE THE WEATHER-LIKE PHYSICS OF DEADLY INFERNOS

BY ALEXANDRA WITZE

FLAMES BEGIN TO RISE. MIKE HECK jumps back. The tendrils lick upward, wavering in the wind, then coalesce into a vortex of flame, an incandescent tornado writhing in orange and red. “There it goes!” says one onlooker. Another whistles in astonishment.

But nobody is concerned. Heck set the fire deliberately, igniting a pan of liquid on the floor of a room lined with concrete blocks to contain the flames. A suction hood overhead prevents smoke from billowing into nearby classrooms at the University of Maryland in College Park.

Heck’s supervisor, fire scientist Michael Gollner, now at U.C. Berkeley, regularly conjures up such blazing pillars, known as fire whirls, in his lab. (Gollner and colleagues explore the science of these phenomena in the 2018 *Annual Review of Fluid Mechanics*.) From them, and from other fiery experiments, he aims to learn how flames intensify and spread as cities and landscapes burn. Gollner’s goal is to better understand what drives fire to leap its way from house to house and from tree to tree.

Gathering new insights into fire behavior has become increasingly urgent as wildfires have become more extreme, particularly in western North America. Starting in the mid-1980s, big wildfires suddenly became much more common in western US forests, especially in the northern Rocky Mountains. More recently, forests in the Pacific Northwest have seen the biggest increase in wildfire sizes, with a nearly 5,000 percent increase in burn area from 2003 to 2012 compared with the 1973–1982 average. Nationwide, the average acreage burned in the years since 2000 is nearly double the annual average for the 1990s.

And just in the last few years, several deadly infernos have incinerated parts of California. More than 5,600 buildings burned to the ground in and around Santa Rosa in October 2017. In July 2018 in Redding, a towering plume of hot air and ash spawned a spinning “firenado” like the one in Gollner’s lab — but much bigger, and ferocious enough to kill a firefighter. The same month, fires burned vast acreage in Mendocino and three other counties. Four months later, 85 people died in the Camp Fire in Paradise, many of them incinerated while trying to escape the blaze in their cars.

> “Nature has given an astonishing sequence of events, each one outdoing the one before.”
>
> —JANICE COEN

Record-breaking ravages

All told, the state’s recent fires set records for California’s biggest, deadliest and most destructive wildfires. “Nature has given an astonishing sequence of events, each one outdoing the one before,” says Janice Coen, an atmospheric scientist who studies wildland fires at the National Center for Atmospheric Research in Boulder, Colorado. She and others find themselves asking: “Is this different from the past? What’s going on here?”

Many factors have driven this unprecedented expansion of wildfire devastation. Decades of reflexively snuffing out fires as soon as they ignited have allowed fire-fueling shrubs and trees to accumulate in unburned areas. Climate change brings warmer temperatures, less rain and snowpack, and more chances for fuels to dry out and burn. (Human-caused climate change has been blamed for nearly doubling the forest area burned in the western United States since 1984.) Meanwhile, more people are moving into wildland areas, increasing the chance that someone will ignite a fire or be in harm’s way when one begins to grow.

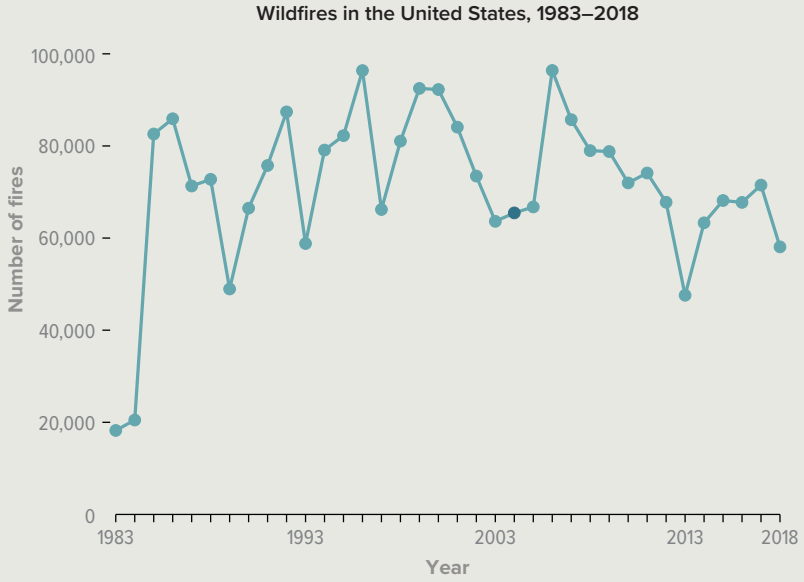
Coen and other scientists are tapping physics to help reveal what causes an ordinary blaze to escalate into an epic megafire. To do this, some researchers drive to the edges of wildfires, probing their secrets with laser and radar equipment that can see through the billowing smoke clouds. Others have developed cutting-edge models that describe how flames race across the landscape, driven not only by fuels and terrain but also by how the fire and atmosphere feed back on one another. And still others, like Gollner, are devising laboratory experiments to figure out why one house may ignite while its neighbor remains unscathed.

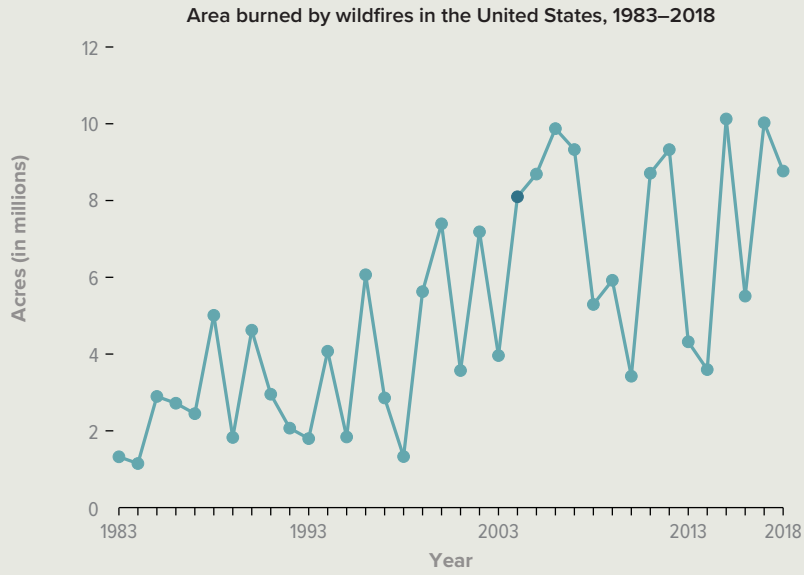
Such findings may show how people can better prepare for a future with more intense wildfires, and perhaps how firefighters can more effectively combat them.

OPPOSITE PAGE CREDIT: PETER BUSCHMANN / FOREST SERVICE, USDA

WILDLAND FIRES, BY NUMBER AND ACRES BURNED

The total number of all US wildfires shows an overall increase over the last few decades, although there's a lot of year-over-year variability. Total acres burned in those wildfires shows a similar, if slightly more dramatic, upward trend. Studies that have focused on western US wildfires have shown a clear increase in recent years in the number of large fires.





2004 fires and acres do not include state lands for North Carolina

SOURCE: NATIONAL INTERAGENCY COORDINATION CENTER

Fire weather

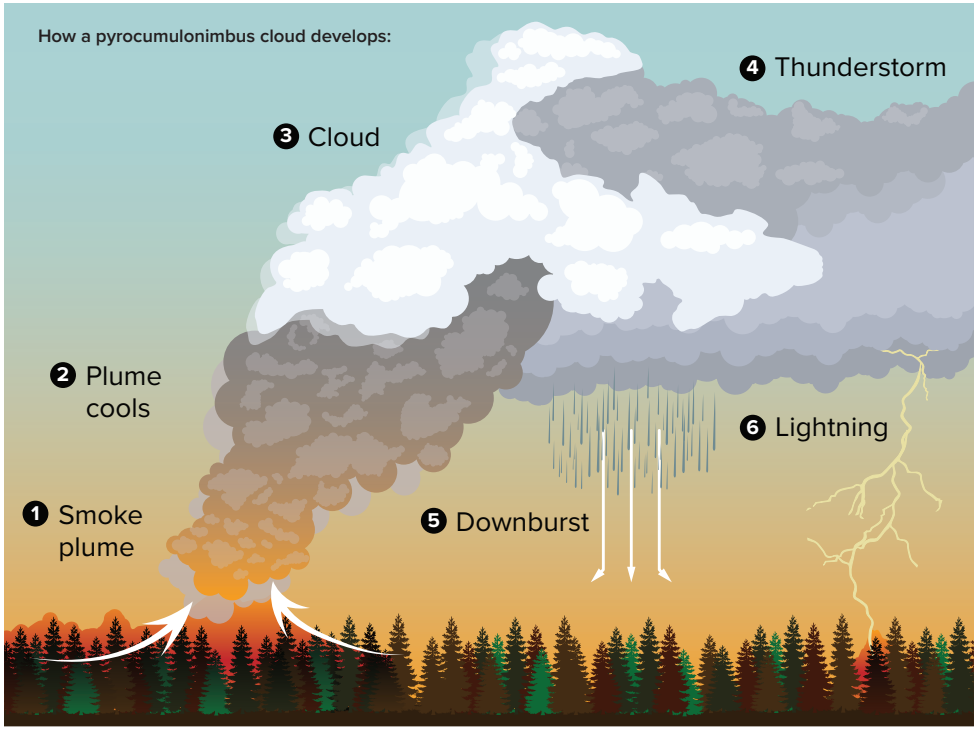
When it comes to battling blazes, "there's a lot of reliance on what people have seen fires do in the past," says Neil Lareau, a meteorologist at the University of Nevada, Reno. "That personal deep experience is really valuable, but it breaks down when the atmosphere goes into what I would call outlier mode — when you're going to be witnessing something you've never seen before."

So Lareau works to gather information about fires as they unfold, hoping to one day be able to deliver specific warnings for firefighters as they battle the flames. He understands the danger more than many academic researchers do: He spent three summers trying to get as close to wildfires as he could, as part of the renowned fire-meteorology research team led by Craig Clements of San Jose State University in California.

Like the storm chasers who stalk tornadoes on the Midwest plains, fire chasers have to be prepared for anything. They go through firefighter training, learning how to anticipate where the fire line might move and how to deploy a fire shelter in an emergency. They register with the federal emergency management system so they can be officially invited into areas where the public can't go. And they travel with a sophisticated laser-scanning machine in the back of one of their trucks for penetrating the ash and smoke plumes rising off an active fire.

"Just by virtue of pointing our laser at things, we started seeing things people had not documented in the past," Lareau says. Early discoveries include why a fire's plume spreads out as it rises while smoky air is pushed outward and clear air is folded

THE RISE OF A FIRE-FUELED STORM CLOUD



1. Fire creates a plume of hot, turbulent air and smoke.
2. Cooler air mixes with the smoke plume as it rises. The plume cools and expands.
3. Higher up, the air in the plume cools more, forming a cloud.
4. Instability in the atmosphere can transform the cloud into a thunderstorm, forming a pyrocumulonimbus cloud.
5. When rain meets dry air, the rain evaporates and sends a burst of high-speed winds toward the ground in what's called a downburst.
6. The storm can also produce lightning, which may start new fires.

Pyrocumulonimbus clouds form and feed off the heat rising from a wildfire or volcanic eruption. As a smoke plume rises, it cools and expands, allowing the moisture in the atmosphere to condense into a cloud that can create lightning or even firenadoes — essentially a thunderstorm born from the fire.

SOURCE: BUREAU OF METEOROLOGY, AUSTRALIA

inward, and how rotating columns of air can form within the plume. "There's this fascinating environment where fire and atmospheric processes interact with one another," he says.

One of the most dramatic examples of "fire weather" is the thunderstorm-like clouds that can appear high above a fire. Called pyrocumulonimbus clouds, they form when there is relatively high humidity in the atmosphere. A plume of ash and hot air rises rapidly from the fire, expanding and cooling as it gets higher. At some point, typically about 15,000 feet high, it cools off enough that water vapor within the air condenses into a cloud. The condensation releases more heat into the plume, reinvigorating it and generating a bright white cloud that can tower up to 40,000 feet high.

Beneath the cloud base, air can rush upward at speeds approaching 130 miles an hour, driven by convection within the plume, the San Jose State team has discovered. The more the fire grows, the more air gets pulled into the updraft, intensifying the entire conflagration. And in rare cases it can even spawn a flaming tornado below.

Birth of a fiery tornado

Lareau watched a firenado form almost in real time during the Carr fire, near Redding, in July 2018. In this case he wasn't nearby with a laser in his truck, but

This pyrocumulonimbus cloud roared into existence over the Willow fire near Payson, Arizona, in 2004. Below is the dark smoke plume; above is the startlingly white cloud of condensed water droplets.

CREDIT: ERIC NEITZEL / WIKIMEDIA COMMONS

sitting at a computer looking at radar data. Weather radars, like those used for your local forecast, can track the speed of small particles such as ash moving in the air. As the Carr fire developed, Lareau pulled up radar data from a military base nearly 90 miles from the growing fire. By watching how the ash moved in opposite directions at different levels in the atmosphere, he could see how atmospheric rotation within the plume was shrinking and intensifying. Like figure skaters pulling their arms in during a spin, the rotation contracted and sped up to form a coherent vortex — a tornado embedded in the larger ash plume.

It is only the second known example, after a 2003 firestorm in Australia, of a tornado forming because of a pyrocumulonimbus cloud, Lareau and colleagues wrote in December 2018 in *Geophysical Research Letters.* The fire provides the initial heat that generates the cloud, which then generates the tornado. "The dynamics that lead to the rotation collapse aren't just driven by fire, they are also driven by the cloud itself," Lareau says. "That's really what's different about this case, compared to your more garden-variety fire whirl."

Imagine a twister in the midst of a conflagration, and it's easy to see why the Carr fire was so devastating. With wind speeds topping 140 miles an hour, the fire tornado knocked down electrical towers, wrapped a steel pipe around a power pole and killed four people.

Predicting flames' next move

That sort of devastation is what drives Coen to model wildfires. She grew up just outside of Pittsburgh, the daughter of a firefighter, and later became entranced by how winds, eddies and other atmospheric circulation help drive the spread of flames. Depending on how the air flows across the landscape, a fire can shift where it is moving — perhaps splitting into two parts and then merging again, or popping off little eddies or whirls along the fire line. "Foresters think about fires as fuel and terrain," Coen says. "To us, as meteorologists, we see a lot of phenomena we recognize."

In the 1980s and 1990s, meteorologists began to link weather models, which describe how air flows over complex terrain, with those that predict fire behavior. One such system, a computer model developed at the US Forest Service's Missoula Fire Sciences Laboratory in Montana, is now regularly used by federal agencies to forecast where fires will grow.

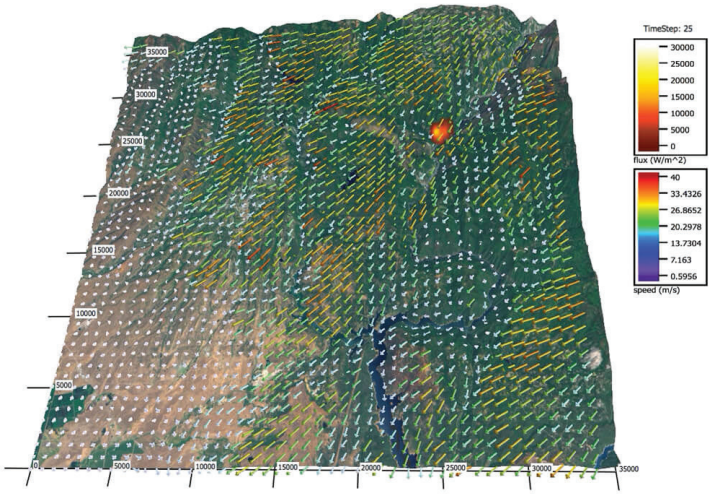
Coen went a step further and developed a joint atmosphere-and-fire model that incorporates airflow. It can, for instance, better simulate how winds eddy and break around peaks in steep terrain.

Her model became shockingly real on November 8, 2018, when she was scheduled to give a talk titled “Understanding and Predicting Wildfires” at Stanford University. The night before, while working on her presentation, she saw reports that the Pacific Gas and Electric Company was considering shutting down equipment in parts of the Sierra Nevada foothills because strong winds were forecast.

The next morning she went to the symposium but sat in the back searching the Internet and listening to emergency radio feeds. As colleagues spoke, she followed scanner traffic, hearing that a fire had ignited in Northern California and spread quickly toward the town of Paradise. “That’s when I had to launch into my presentation,” she says. “I could tell by the winds, by how badly the evacuation was going, that it was going to be a horrible event. But at that point we didn’t know it would be the most deadly one in California history.”

Those strong winds she had heard about turned out to be crucial to how the fire spread and engulfed Paradise. Strong downslope winds pushed the flames into the heavily forested town. It was entirely predictable according to the physics in her models, Coen says: “A lot of weird things make sense after you look at these fine-scale circulations.”

Another example is the Tubbs fire that devastated Santa Rosa in October 2017, roaring across 12 miles in just over three hours. Coen’s models explore how airflows known as the Diablo winds move across the landscape. It turns out that a layer of stable air slid quickly over the complex topography above Santa Rosa. Where it hit mountain ridges, it generated bursts of high-speed winds. Surprisingly, the wind bursts didn’t come off the highest peaks, but rather a smaller set of peaks that were downwind. The location of some of those wind bursts, which reached up to 90 miles an hour according to her model, corresponds to where the fire ignited — perhaps because of electrical equipment failures. Coen described the work in December 2018 in Washington, DC, at a meeting of the American Geophysical Union.



CREDIT: UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH (UCAR)

This simulation of the first eight hours of the Camp fire, which devastated the town of Paradise, California, in November 2018, demonstrates how wind (white arrows) drove the rapid spread of the fire (orange and yellow) once it ignited. Janice Coen, a researcher at the National Center for Atmospheric Research, developed the computer simulation, which links small-scale motions in the atmosphere with the movement of fire on the surface, to better understand fire threats.

Coen's models also help explain the Redwood Valley fire, which started in the same windstorm as the Tubbs fire. (Fourteen separate fires broke out in Northern California in the span of 48 hours, as a high-pressure weather system inland sent Diablo winds rushing offshore.) But in this case there was a seven-mile-wide gap in the mountains that winds were able to rush through, compressing and speeding up. It was like a single narrow river of winds — which would be hard to spot with traditional weather or fire forecasts, Coen says. "If you were looking at the weather data and saw this one situation was unusual compared to the rest, your mind would tend to dismiss it," she says.

But forecasters need to pay attention to those blips of high-speed wind readings. They could be signaling that something very localized — and very dangerous — is going on.

From spark to combustion

Researchers like Coen track the spread of a fire's perimeter to predict where the active fire line might move. But physics can also help scientists better understand another type of fire spread: what happens when the winds catch embers and loft them miles ahead of the fire front. When they land, those embers can sometimes smolder in place for hours before igniting a pile of leaves, a deck or something else flammable. That's a big problem for firefighters trying to figure out where to deploy their resources — whether to stay on the main fire line or to chase where they think spot fires might ignite.

To get at this question, Gollner has been working out the small-scale physics of what it takes for an ember to ignite. His Maryland lab is in the Department of Fire Protection Engineering and looks the part. Butane lighters fill drawers. A box of pine straw rests on a shelf. Thick fire-protective gloves lie atop a stool. The air smells mildly acrid, like the whiff of a fire just extinguished.

> "You're never going to make anything fireproof. But as you make it better you make a big difference."
>
> —MICHAEL GOLLNER

Along one wall of the lab, beneath a large ventilation hood, Gollner shows off a metal contraption a little flatter and wider than a shoebox. This is where he creates an ember by igniting a cork-shaped piece of wood and putting it inside the box.

A fan blows a constant breeze over the smoldering firebrand, while instruments beneath the box measure the temperature and heat flow of the surface it is sitting on. With this device Gollner can study what it takes for embers to generate enough heat to start a building fire. "A lot of studies have been done on beds of grasses and fine stuff," he says. "We wanted to understand, how does it ignite your deck, your roof or your structure?"

It turns out that a single ember, or a handful of embers, can't build up that much heat if it lands on a material such as a deck or a roof. But put one or two dozen embers into Gollner's device and the heat flux goes up dramatically, he and his colleagues reported in the March 2019 *Fire Safety Journal*. "You start to have re-radiation between them," he says. "It glows, under the wind — it's just beautiful."

Just a small pile of embers can generate about 40 times the heat you'd feel from the sun on a hot day. That's as much heating, and sometimes more, as comes from the fire itself. It's also enough to ignite most materials, such as the wood of a deck.

So if there are a lot of embers flying ahead of a fire, but those embers land relatively far from one another, they may not build up the radiative heat needed to generate a spot fire. But if the embers pile up, perhaps blown by the wind into a crevice of a deck, they can smolder together and then trigger an ignition, Gollner says. Most homes that burn in the wildland-urban interface ignite from these embers, often hours after the fire front itself has passed.

Understanding the heat flux at these small scales can illuminate why some houses burn while others don't. During the Tubbs fire, homes on one side of some streets were destroyed while those on the other side had hardly any damage. That may be because the first house that ignited radiated energy to its neighbor, which then burned neighboring homes like dominoes because of the radiative heat. When houses are closely packed together, there's only so

CREDIT: ALEXANDRA WITZE

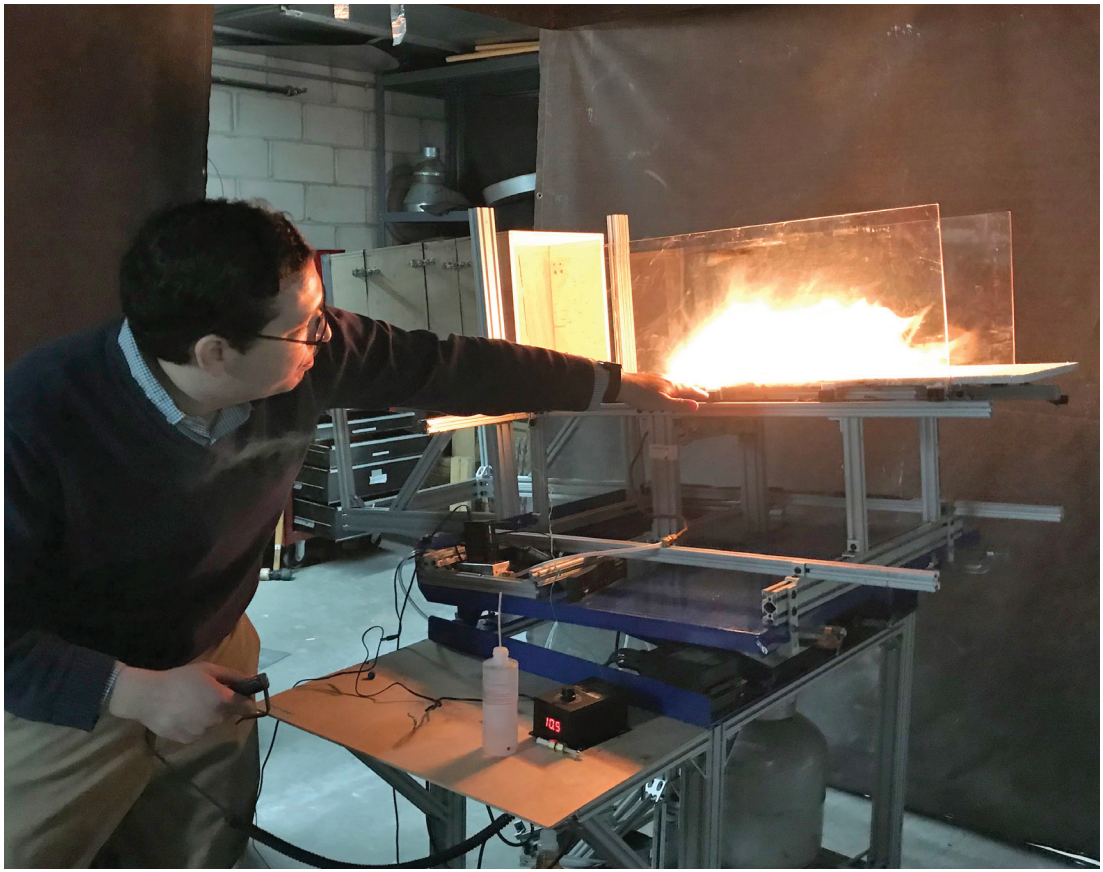
A large fire whirl, taller than a human, springs into existence in the laboratory of fire scientist Michael Gollner.

much homeowners can do to mitigate the danger by clearing brush and flammable material around the house.

Controlling the beast

Gollner — a California native who grew up evacuating from wildfires — is now working on other aspects of fire spread, like what it takes for a flaming piece of vegetation to break off in high winds and ignite other shrubs downwind. He is studying fire whirls to see if they can be used to burn off oil slicks in the ocean, since whirls burn the oil faster and more cleanly than a nonrotating fire. And he is beginning a project on the health effects of inhaling wildfire smoke.

For now, he hopes his research can help save homes and lives during an active fire. “You’re never going to make anything fireproof,” he says. “But as you make it better you make a big difference.” Homes built with shields against embers coming in through attic openings, or using ignition-resistant materials like asphalt instead of wood shingles, may be less likely to ignite than homes not built to those standards. If only 10 homes and not 1,000 ignite during



Fire scientist Michael Gollner demonstrates a device that tests how fire spreads at different angles. When he raises the ignition surface from horizontal to tilted, the flames react differently — information that firefighters can use when battling growing fires.

CREDIT: ALEXANDRA WITZE

a firestorm, firefighters might be able to better manage the next big conflagration, Gollner says.

As climate warms and fires grow more extreme, fire scientists know their work is more relevant than ever. They are pushing to make their research matter where it counts — on the front lines with emergency management officials. Coen, for instance, is working to run her wildfire models faster than real time, so that when the next big fire breaks out she can quickly predict where it might go given the wind and other atmospheric conditions. And Lareau is developing ways to track a fire's spread in near real time.

He uses weather information like the ground-based radar he used to track the Carr firenado, as well as satellites that can map the fire perimeter by studying heat flowing off the ground. Eventually, he wants to see a real-time prediction system for wildfires like those that currently exist for thunderstorms, tornadoes, hurricanes and other weather events.

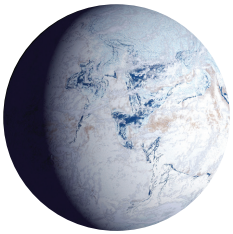
"The warnings aren't going to stop the fire," says Lareau. "But maybe it will help us decide where to make those decisions. These are environments where minutes matter." ●

ASSOCIATED ANNUAL REVIEWS CONTENT

Fire Whirls

A. Tohidi *et al* /
Annual Review of Fluid Mechanics

Q&A



Geologist Paul Hoffman

The story of Snowball Earth

Ancient rocks suggest that ice entirely covered our planet on at least two occasions. This theory may help explain the rise of complex life that followed.

By Laura Poppick

THE EARTH HAS ENDURED many changes in its 4.5-billion-year history, with some tumultuous twists and turns along the way. One especially dramatic episode appears to have come between 700 million and 600 million years ago, when scientists think ice smothered the entire planet, from the poles to the equator — twice in quick succession.

Drawing on evidence across multiple continents, scientists say these Snowball Earth events may have paved the way for the Cambrian explosion of life that followed — the period when complex, multicellular organisms began to diversify and spread across the planet.

When Caltech geologist Joe Kirschvink coined the term Snowball Earth in 1989 — merging ideas that some geologists, climate physicists and planetary chemists had been thinking about for decades — many earth scientists were skeptical that these cataclysmic events could really have occurred. But with mounting evidence in support of the theory and new data that help pin down the timing of events, more scientists have warmed up to the idea.

Paul Hoffman, a geologist at the University of Victoria in British Columbia, has helped pioneer Snowball Earth research over the last 25 years. Among other things, he amassed 50 months' worth of fieldwork in Namibia, where he gathered evidence of ancient glacial activity in rocks that are interspersed with limestone. Since limestone tends to form in the warmest parts of the ocean, this sandwich-like pattern supports the idea that glaciers covered all of the Earth, cold as well as warm spots, during Snowball Earth episodes. *Knowable* spoke with Hoffman, who recounts his life work in the *Annual Review of Earth and Planetary Sciences*, about the evolution of the Snowball Earth theory and what questions remain. This conversation has been edited for length and clarity.

What did the planet look like during Snowball Earth?

The name describes its appearance from outer space — a glistening white ball. The ice surface is mostly coated with frost and tiny ice crystals that settled out of the cold dry air, which is far below freezing everywhere. Gale-force winds howl in low latitudes. Beneath the floating ice shelf, a dark and briny ocean is continually stirred by tides and turbulent eddies generated by geothermal heat slowly entering from the ocean floor.

What first tipped off geologists that this could have happened?

Geologists were struggling to understand what they saw in the geologic record — that not too long before the first appearance of complex life, there was unmistakable evidence of glaciation even in the warmest areas of the Earth. Geologists had a very difficult time understanding how this was possible.

The deposits that glaciers leave behind are very distinctive. They look like cement that has been dumped out of a cement truck. These Snowball ice sheets would have flowed from the continents out onto the ocean, so we have a lot of deposits that formed in the marine environment where you get what are known as dropstones: pebbles or boulders that are out of place. Very often, you see structures related to the impact, as if the stone was somehow dropped and then plunked into the underlying sediment. It's difficult to imagine what, other than floating ice, could have possibly transported this debris; trees, which can carry soil and stones out to sea in their roots, had not yet evolved.

CREDIT: NASA; JAMES PROVOST

How did you get involved in studying this hypothesis?

I had known about the hypothesis since even before I was interested in working on the problem myself. Joe Kirschvink at Caltech told me about it a few months after he had the idea in 1989, but he never did anything more with it at that time. I liked it because I like ideas, but there was a credibility gap, so before our work, the hypothesis was dormant.

The biggest problem was that because the conditions were so different from any other time in Earth's history, we didn't understand the implications of the hypothesis well enough to know whether any given bit of geologic evidence was either for or against it. We had to have climate models to see what actually happens under Snowball conditions, and that modeling, developed later, has been extremely important.

My main contribution was making the case that it was a credible scientific hypothesis by arguing, from different disciplines within geoscience, that there was a lot of geological evidence consistent with the predictions. As I often like to say, new ideas or hypotheses are like small children: It's best not to judge them too early because you don't know what they are going to be like as adults. Very often, the problem with new ideas is not that they are wrong, but that they are incomplete.

> "On Snowball Earth, ecosystems may have been more isolated from one another and this might be a situation that would be helpful for evolving new forms of life."
>
> —PAUL HOFFMAN

What triggered these events?

That's the "why" question and that's maybe the most difficult one. I don't think there is a consensus on this. There are a number of factors that contributed, and I think it is useful to look at this in two ways. First of all, what was the general condition that made for a colder climate and therefore made the Earth more susceptible to this runaway ice growth phenomenon? And then what was the immediate trigger that tipped it over the edge?

When the Snowball events occurred, the supercontinent Rodinia was in the process of breaking up. A supercontinent is a state in which all of the continents are clustered together in one group. The reason why people think there is a connection there is that the breakup of a supercontinent would increase rainfall in the continental areas, and that would increase the weathering of crustal rocks. The weathering of rocks actually consumes carbon dioxide, so that would lead to less carbon dioxide in the atmosphere and therefore a colder climate.

As for what actually caused the immediate trigger, attention has focused in recent years on a sequence of very large volcanic eruptions that occurred in what is now the high arctic of Canada. These eruptions occurred around 717 million and 719 million years ago. When you get fire fountains — lava that comes out of one place over a period of weeks or months — you get a strong thermal upwelling in the atmosphere from the heating effect of that lava. These upwellings can loft sulfur aerosols into the stratosphere where they hang around for a significant amount of time. These sulfur gas particles reflect incoming solar radiation and have a strong cooling effect. Because of the coincidence in timing between these eruptions and the onset of the first and longer of the two Snowball Earths, it's been postulated that that may have been the immediate trigger.

What did life on Earth look like at the time, and how did it change as a consequence of these events?

There were certainly bacteria and there were also algae and unicellular primitive animals, or protists.

There is also evidence that the first multicellular animals originated at this time, probably something like sponges. Why is a matter of speculation. There are a number of ideas on this, but they are difficult to test. One idea is that on Snowball Earth, ecosystems may have been more isolated from one another and this might be a situation that would be helpful for evolving new forms of life, and particularly forms of life that are altruistic — ones with cells that find that there is an advantage in working together rather than working individually. So more isolation of different ecosystems

might have allowed certain ecosystems that had a higher proportion of these multicellular altruists to establish a foothold.

How was the Snowball theory received by other geologists?

I think I underestimated how emotional people would get about it and how wedded people were to the idea that the Earth has never really been greatly different than it is today. In the 19th century, people had a difficult time believing that most of northern Europe and North America were covered by an ice sheet only 20,000 years ago. That was as hard for a 19th-century geologist to accept as Snowball Earth has been for 20th-century geologists.

For a long time we had a lot of evidence for glaciation at low latitude and in the warmest parts of the Earth, but we didn't really have a good idea of the dates of these events. It was sort of embarrassing. But between 2010 and 2014 that situation dramatically changed. We now have pretty precise estimates from two very different dating techniques, and it's impressive that they are giving highly consistent results. I think working out the timescale has caused a majority of geologists working on the problem to now accept the Snowball hypothesis.

Alternative theories have arisen over the years, including what is called the Slushball theory — a less extreme version of Snowball Earth. How does pinning down the dates help sort out these alternative theories?

In the Slushball scenario, carbon dioxide would start building up very quickly, so the glaciation would be short-lived and the ice would retreat gradually. This is not what we see in the geologic record. We now know that the first Snowball lasted for 58 million years and that is completely inconsistent with the Slushball idea. Also, we see the Snowball glaciations terminate extremely abruptly and they are followed by clear evidence of a complete and abrupt climate reversal, a very hot period. That is not explained by the Slushball model.

I don't think there are any other alternatives that satisfy the evidence.

What other questions remain?

The dating has created a new set of problems. One thing the dating revealed was that the two Snowball Earths occurred in rapid succession and were very unequal in duration. The first one lasted 58 million years and the second one lasted only 5 million to 15 million years. So we don't know why there is this great disparity in how long the glaciations lasted. And why was it that there was just this short interval between the two? There's only about 10 million years when there was no ice at all and then suddenly the planet went back into Snowball Earth. So why two in rapid succession? And why wasn't there a third one or a fourth one? These are new questions that have arisen as a result of our understanding of the timing.

> "I think it is very important to understand that the Earth has not always been the way it is today. Snowball Earth is an example of the kinds of amazing things that the Earth has been through that we would never have suspected if we didn't investigate the geologic record."
>
> —PAUL HOFFMAN

Could it happen again in the future?

I don't think we are in a very good position to say whether or not it's likely to happen in the future. The future is a long time. I think we can say it is not going to happen in the next several tens of thousands of years.

Why study Earth history?

The history of our planet is one of the greatest stories. Because we live here and we are dependent on this place, I think it is very important to understand that the Earth has not always been the way it is today. Snowball Earth is an example of the kinds of amazing things that the Earth has been through that we would never have suspected if we didn't investigate the geologic record.

Dealing with Snowball Earth has been fantastic — it's been the most intense learning experience of my life, and I never anticipated that it would be accepted in my lifetime.

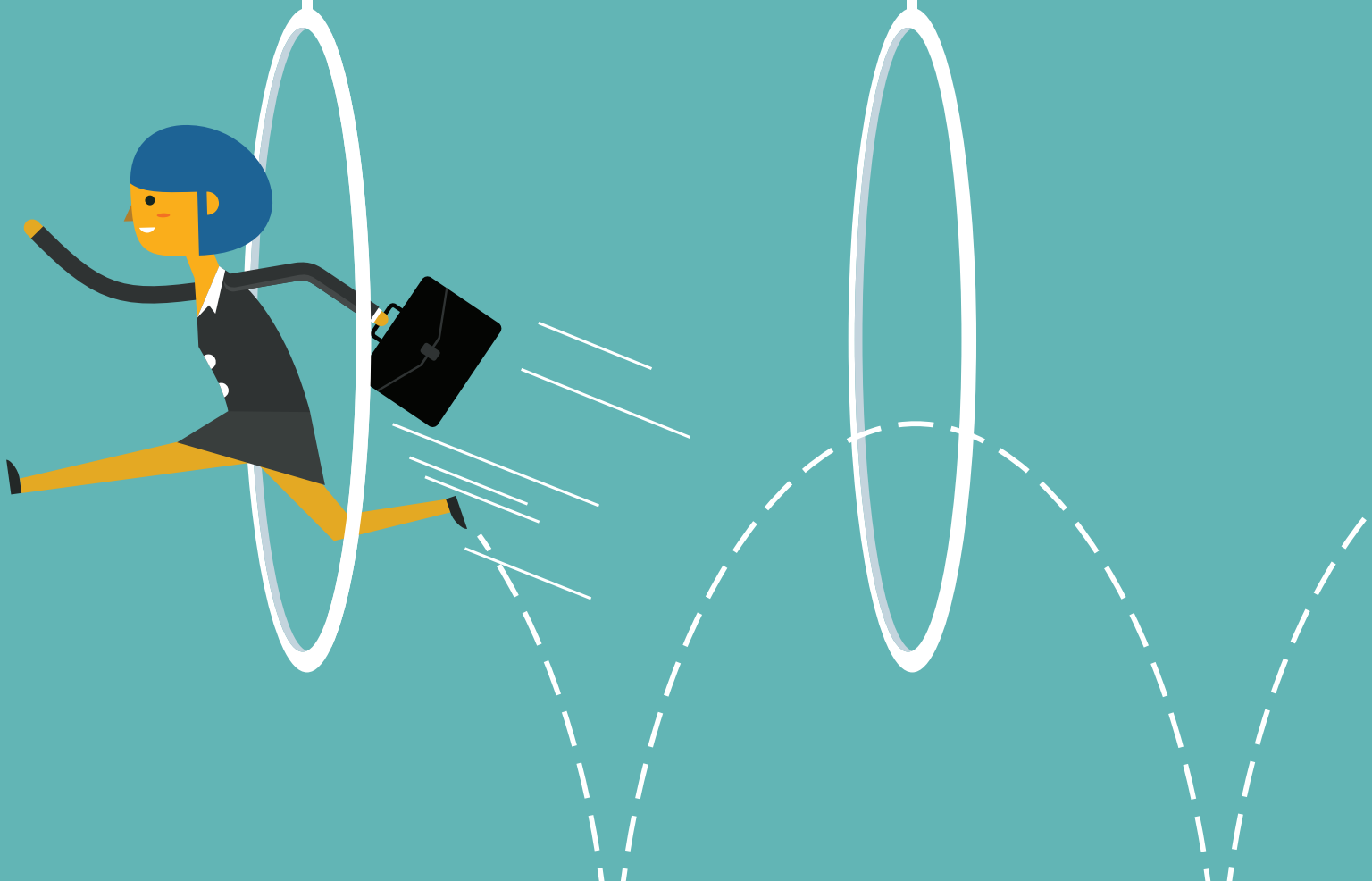
And you're still at it, after 25 years?

I'm still doing fieldwork in Namibia, as a 77-year-old. It's just a large and fascinating problem. It's hard to pull myself away. ●

Low marks for performance reviews

ANNUAL ASSESSMENTS CAN BE WILDLY INACCURATE — NOT TO MENTION SOUL-CRUSHING. HERE'S WHY THE RITUAL, DREADED BY MANAGERS AND THE MANAGED ALIKE, FALLS SHORT, AND WHAT MIGHT WORK BETTER.

BY CHRIS WOOLSTON



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WHETHER A BUSINESS MODEL IS BUILT on gigabytes, interest rates or the latest innovations in aluminum siding, every company ultimately depends on its people — some more than others. Businesses of any size have stars that drive productivity and get results. But look beyond those high achievers — the break room might be one place to check — and you'll find others who drag the company down with shoddy performance.

The ultimate success or failure of a company often comes down to the quality of employees. As Jack Welch, former chairman of General Electric, once said, "the team with the best players wins." But as CEOs and managers try to set up winning companies, they face a surprisingly difficult task: sorting the good employees from the bad ones. Baseball pitchers have earned run averages and quarterbacks have touchdown passes, but the value of a given coder or salesperson can be much harder to define. Companies spend millions of dollars and burn countless hours conducting performance reviews and devising checklists to assess their employees, and business scholars have studied the issue with great urgency and intensity.

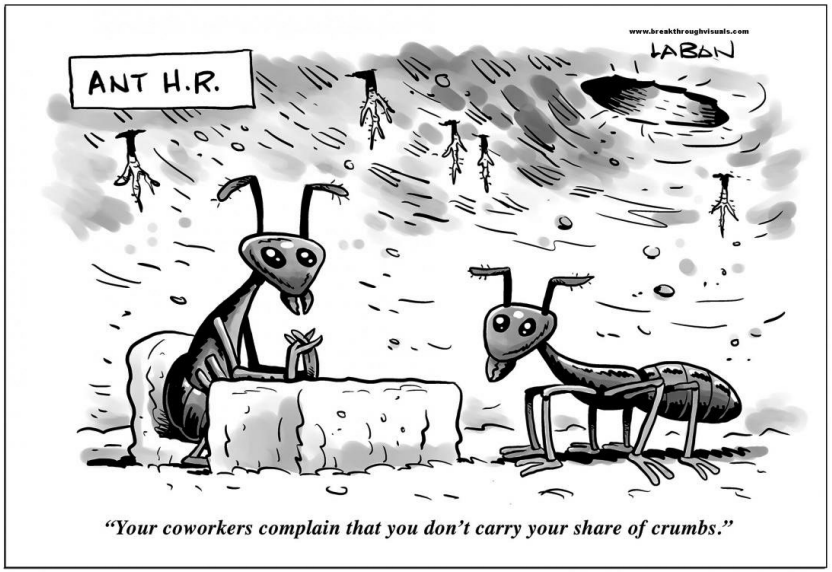
The results so far? By all available evidence, formal attempts to rate employees don't seem to meaningfully improve employee performance or give companies any sort of competitive advantage, says Elaine Pulakos, a management expert and CEO of PDRI, a management consulting company based in Arlington, Virginia. "They end up being extremely costly and have no impact on productivity," she says. Pulakos discussed the science of employee evaluation in the 2018 *Annual Review of Organizational Psychology and Organizational Behavior*.

Despite many efforts, no one has been able to come up with a rating system that can reliably discern which companies are blessed with a deep bench of high performers and which brim with mediocrity. You certainly can't tell simply by looking at the bottom line. Pulakos cites a 2012 report that gathered more than 23,000 employee ratings from 40 companies and found no sign that ratings had any effect on profits or losses. "Performance ratings have no relation to organizational performance whatsoever," she says.

Out of all of the methods used to rate and grade employees, the dreaded annual or semiannual performance reviews are especially unhelpful and potentially harmful, Pulakos says. "They're really toxic and people hate them," she says. "You're creating artificial steps just to check a box." Pulakos points to brain imaging research positing that even high-performing employees automatically go into a defense mode during performance reviews, turning a supposedly productive meeting into a fight-or-flight scenario.

Formal annual performance reviews can be extremely damaging to a company's culture, says Herman Aguinis, the Avram Tucker Distinguished Scholar and professor of management at George Washington University in Washington, DC. "It's a soul-crushing enterprise," he says. "The employee doesn't know what they're supposed to do, and the manager doesn't see any value in it. They're only doing it because human resources told them to."

All too often, Aguinis says, formal performance reviews



"Your coworkers complain that you don't carry your share of crumbs."

become a self-serving exercise in politics, not a realistic examination of an employee's strengths and weaknesses. "Some managers will give biased ratings on purpose," he says. "I have personally seen a supervisor giving a bad employee a good rating just so that employee could get promoted out of his unit."

Still, some HR experts continue to see some value in annual performance reviews. In a post on her popular Evil HR Lady blog, Suzanne Lucas says "annual performance reviews aren't all bad. Formal ratings provide a macro-view of performance and engagement levels across the company. If the results of any group (department, experience level, etc.) stick out — it can indicate a bright spot or potential problem worth looking into."

"I think the Little Engine was probably worried about his performance reviews."

CREDIT: MARTHA GRADISHER / CARTOONSTOCK.COM

The growing body of research questioning the value of performance reviews has encouraged many companies to rethink their approach. Dell, Microsoft, IBM and other big business names such as the Gap, Accenture and General Electric have ditched the process, a move at times fanfared in press releases and headlines. But a 2018 survey by the research firm WorldatWork found that 80 percent of companies still used formal performance reviews. "Behavior change in organizations is really hard," Pulakos says.

Businesses that abandon formal performance reviews still have to keep tabs on employees, Aguinis says: "Companies that say they are getting rid of ratings are still using ratings. They just have different labels." For one thing, managers must have some rationale for assigning promotions and raises. If there's no data on performance, the process of handing out promotions and raises can turn chaotic. In some cases, companies could be vulnerable to lawsuits if they don't have a way to justify decisions.

Everyday management

To really understand the value of their employees, Aguinis says, managers should double down on the practice of everyday management. That means checking in on employees every day and giving them real-

time feedback on things they're doing well and areas where they can improve. "When performance is a conversation, when it's not something that happens just once a year, the measurement becomes very easy and straightforward with no surprises," he says. He adds that it's important to gather input from many different people within the system — peers as well as supervisors. "The best source of data is often not the manager," he says.

When rating employees, it's best to keep things simple, says Seymour Adler, a talent and rewards partner at Aon, a management and HR consulting firm headquartered in London. He ruefully remembers a mistake early in his career, when he was part of a team that came up with a 40-point scale to rate employees. "That's an over-engineered solution in my view," he says.

Rating employees solely on objective measures such as sales numbers, absentee days or customer calls may seem like a winning strategy, but those data points can be wildly misleading, Adler says. A salesperson with the most sales may have a better territory or better luck than others, not more talent or drive. "Objective measures may seem straightforward, but you have to think about all the factors that are beyond an employee's control," he says.

Daily evaluation and feedback may sound like an onerous task, but Adler says there's an important loophole: Most employees do just fine without constant scrutiny. "When I work with companies, I encourage them to get away from ratings and start managing by exception," he says, meaning that the exceptional employees need the most attention. Out of 100 employees, there might be three or four who are struggling so mightily that they need an intervention or a career change.

> "Performance ratings have no relation to organizational performance whatsoever."
>
> —ELAINE PULAKOS

At the other end, there might be five or so excellent employees who should get special treatment because they drive the company's success. A 2012 study by Aguinis and coauthor Ernest O'Boyle Jr. found that the top 1 percent of workers account for 10 percent of a company's productivity. The hardworking, competent but unexceptional workers in between the extremes — Adler calls them "the Mighty Middle" — are going to make about the same contribution to a company's bottom line regardless of how much time they spend in performance reviews.

Some companies have taken appreciation of superstar employees to extremes. In his 2015 book *Work Rules!* former Google executive Laszlo Bock reveals that the company routinely pays high-performing employees five or six times as much as other employees at the same level, maybe even more. He also cites such instances as one worker receiving a $1 million stock bonus while another received just $10,000.

Of course, Google is an industry outlier in many ways. Pulakos notes that the company lives on data, and it has methods for rating and ranking employees that just wouldn't work anywhere else. That's one of the big lessons of modern business scholarship: Every company has to figure out its own approach to getting the most out of its employees.

"You have to evaluate your own strategic goals," Pulakos says. "What works for Google is not going to work the same way for anyone that is not Google."

In the world of business, there aren't many universal truths. Just one, really: Annual performance reviews are the worst. ●

ASSOCIATED ANNUAL REVIEWS CONENT

The Evolution of Performance Management: Searching for Value

E.D. Pulakos *et al* / *Annual Review of Organizational Psychology and Organizational Behavior*

Q&A

Environmental historian Ellen Stroud

She sees dead bodies

An environmental historian looks at how Americans treat corpses and what it means

By Chris Woolston

DEATH HAS ALWAYS BEEN A fact of life. But somehow, even after endless repetitions of the cycle, we still haven't figured out how we feel about dead bodies. Are they vessels of loved ones that should be preserved for as long as possible? Bundles of organic material that should be reunited with the earth? Harsh reminders of our own mortality that should be disposed of quickly and thoroughly?

Ellen Stroud, an environmental historian at Penn State University, explored the macabre history and legal ambiguities of American bodies in the *Annual Review of Law and Social Science*. *Knowable* spoke with Stroud about her fascination with corpses, modern examples of the legal limbo surrounding dead people and her plans for her own body when she's done with it. This conversation has been edited for length and clarity.

Why are you so interested in dead bodies?

I think everybody finds bodies fascinating. But I'm coming at this mainly from my preoccupation with ecological systems; I've also studied the history of forests in the Northeast. I like thinking about how our bodies interact with natural environments — when we're living and when we're dead. It's a fun puzzle as long as it remains somewhat abstract. But there are so many ideas and emotions that our bodies symbolize. It becomes very messy, and I'm trying to understand the messiness.

How do people react to your research topic?

It's unpredictable. If I'm chatting with someone on an airplane, I'm more likely to mention my work on forests than dead bodies, just to be safe. When people find out about my research topic, they tend to share weird family stories. One was from a college friend of mine, whose grandfather had passed away in a hospital in the Boston area. The family wanted to bring the body home to prepare it for burial, but the hospital said no. But there were no laws or even rules against it. Eventually, the hospital relented and the family took the body home. The grandfather spent the night in the back of a pickup covered with a tarp.

You write that the legal system has had trouble grappling with the meanings of dead bodies. What are some recent examples?

People are frequently flabbergasted to learn what is lawful when it comes to bodies. In September 2018, a woman in North Carolina was arrested after she kept her 93-year-old mother's body in her home, reportedly because she wanted to watch her mother decompose. She was charged with "concealing a death," not with keeping a body. If she had reported the death, she might have been able to legally hold on to her mother for a while. As a practical matter, she probably wouldn't have been able to live with the body for very long, but it's not clear that she would have been violating any specific law.

When you read something upsetting like that, it's easy to assume that it must be against the law. But when it comes to dead bodies, laws often don't exist until someone transgresses a norm. People might not even realize that there is a norm until someone crosses what they see as a line.

In 2009, a man in Stevenson, Alabama, buried his wife in his front yard, with a headstone and everything. He said it was her dying wish to stay home. The neighbors complained and the city sued, but there were no state or local laws against burying a body in his front yard. In fact, only a few states have explicit laws against burials on private property. The state Supreme Court ruled

CREDIT: CHERYL FLEISHMAN / ALAMY STOCK PHOTO; JAMES PROVOST

against him in 2013, and a work crew used heavy equipment to remove the casket, which was encased in a concrete vault. The remains were cremated, and the headstone was left in place. The site looked the same as it did before, but it was important to his neighbors to know that the body was gone.

Bodies are far more likely to be cremated today than they were in past generations. How does cremation change the environmental impact?

Many people assume that cremation is "greener" than burial, but the question is more complicated than it may seem at first. People imagine that once you're cremated, you're not a pollutant at all, that the heat has somehow purified everything. But bodies today may have mercury fillings in teeth, silicone in breasts or titanium rods in legs. And many people are cremated in a coffin, so their ashes contain remains of upholstery and everything else. In presentations, I often show slides of the Mount Auburn cemetery near Boston and a large crematorium in Manhattan. I ask people: Which one would you rather live next to? The answer is pretty clear. When you look down at a big city from a plane, you see that cemeteries are some the largest stretches of open space. In a way, people are using their bodies to keep land open, and one could argue that's a good use.

Is there any more legal clarity around ashes than bodies?

There are some laws against dispersal of ashes, but nobody pays the slightest bit of attention. People spread them wherever they want to.

What is the "greenest" way to dispose of a body?

It really depends on what part of the process one is thinking about. Ed Abbey famously said he wanted to be eaten by vultures, but I doubt my body would be very healthy vulture food given what I've put into it over the years. Burial at sea is appealing in many respects, but it's important to weight a body down so that it stays underwater, and then I have questions about how one would or would not decompose and the environmental implications of that.

There are outfits that will use your body as part of an artificial coral reef or compress your ashes into an artificial gem, or artist Jae Rhim Lee can sell you a mushroom suit to turn you into compost. But if you're looking for a more mainstream green option, the green burial movement is likely the way to go. Many cemeteries these days have sections set aside for burials without embalming, without concrete vaults, where biodegradable caskets or even just shrouds are used. There are even a number of places now (for example, Prairie Creek Conservation Cemetery in Florida) where land conservation is an explicit part of their mission.

You've written that, historically, the treatment of bodies often depends on social status. Is that still the case?

Absolutely. Consider *Bodies: The Exhibition*, a traveling exhibit of corpses preserved in resin. The exhibit uses unclaimed bodies from China, and critics say that some may have been unjustly executed prisoners. Whether that's true or not, there's nothing illegal in the US about selling tickets for a show featuring the bodies of victims of atrocities.

I've written about an area of southeast Arkansas. Within a few miles, there's a Native American burial mound, a white family's private graveyard, a town cemetery and the cemetery from a Japanese internment camp, and each site is subject to different rules. The burial mound is deteriorating from neglect, but the family graveyard and town cemetery are well-kept. The internment camp grave markers have only recently become part of a larger commemorative site. And on the same property as the white family's private burial ground, there are African-American burials that are not marked. As Americans, we have a brutal history of treating some groups of people as things. That has happened with living people, and it happens with dead bodies, too.

What do you want to happen with your body?

On an ecological level, how I dispose of my body isn't going to be as important as how I dispose of my Volkswagen. But I've put way more thought into what I'm going to do with my body than with my car. I keep trying to get to the place where I can think of myself as a thing. I like to joke — but I don't think I'm joking, really — that I could always donate my body to a forensic anthropology research center that tests how bodies decompose. They might throw you into a puddle or put you out in the desert for a few weeks. If you live close enough, they'll even pick you up for free. It's very economical.

It's odd. I wouldn't mind that for myself, but I didn't want to do anything like that with my father's body. And I don't entirely understand why. ●

A middle path to sustainable farming

AGRICULTURAL ECONOMISTS ARE HOMING IN ON HYBRID, LOW-INPUT METHODS THAT WILL BOTH SAFEGUARD THE ENVIRONMENT AND FEED THE FUTURE BILLIONS

BY NATASHA GILBERT

ALFALFA, OATS AND RED CLOVER ARE soaking up the sunlight in long narrow plots, breaking up the sea of maize and soybeans that dominates this landscape in the heart of the US farm belt. The 18-by-85-meter sections are part of an experimental farm in Boone County, Iowa, where agronomists are testing an alternative approach to agriculture that just may be part of a greener, more bountiful farming revolution.

Organic agriculture is often thought of as green and good for nature. Conventional agriculture, in contrast, is cast as big and bad. And, yes, conventional agriculture may appear more environmentally harmful at first glance, with its appetite for synthetic pesticides and fertilizers, its systems devoted to one or two massive crops and not a tree or hedge in sight to nurture wildlife. As typically defined, organic agriculture is free of synthetic inputs, using only organic material such as manure to feed the soil. The organic creed calls for caring for that soil and protecting the organisms within it through methods like planting cover crops such as red clover that add nitrogen and fight erosion.

But scientists bent on finding ways to produce more food globally with as little environmental impact as possible are finding that organic farming is not as green as it seems. In a simple contest of *local* environmental benefits, organic wins hands down. That doesn't hold true on a global scale, though, because organic farming can't match the high-yield muscle of big agriculture. A widespread shift to organic would leave billions hungry, researchers predict, unless farmers put more land to work by turning now-unfarmed habitats into food-producing fields — doing more harm than good to natural ecosystems.

"Organic farming is often seen as synonymous with sustainable farming, but it is not the Holy Grail of sustainable agriculture," says Verena Seufert, an environmental geographer at VU Amsterdam who studies sustainable food systems. But the strategies being tested in those fields in Iowa, and similar methods finding their way onto hundreds of millions of acres of farmland globally, might just be. In experiments in Europe and across North America, agronomists are testing hybrid approaches that weave together the green touch of organic farming with a dash of chemical fertilizer and pesticide applied only when needed — an approach known as low-input agriculture. They hope that this cocktail of farming techniques will steer future farming to a truly sustainable footing.

This shift toward fusion farming comes at a time of increasing political interest in greener, more productive agriculture. Heads of state and governments met in September 2019 at the United Nations in New York for a summit to discuss progress toward 17 global sustainability targets to be met by 2030. Producing more food with fewer impacts is key to reaching many of these goals, which include ending hunger and slashing water pollution. That's also in line with meeting a separate set of targets that countries party to the Convention on Biological Diversity are working toward.

Many experts worry that little progress has been made, particularly on saving biodiversity. But others are confident that a greener agricultural revolution is not far off. "It's optimistic, but it's not a pipe dream," says Jules Pretty, an agroecologist at the University of Essex in the UK, who studies sustainable agriculture. "Agriculture could be at a turning point."

> "Agriculture could be at a turning point."
>
> —JULES PRETTY

And turn it must, says Andrew Balmford, a conservation scientist who studies farming's impacts on biodiversity at the University of Cambridge in the UK. "Agriculture is by far the biggest threat to biodiversity, and that will only get worse as we try to feed 10 billion people in the future."

Organic aims

Over the next 30 years, agricultural economists estimate, food production will need to at least double to feed billions of extra bellies as the global population grows. But the current farming system cannot carry on as it is without wreaking great damage,

Red clover (foreground) grows alongside corn (background) in a crop rotation experiment at Iowa State University's experimental farm in Boone County.

OPPOSITE PAGE CREDIT: PAULA R. WESTERMAN

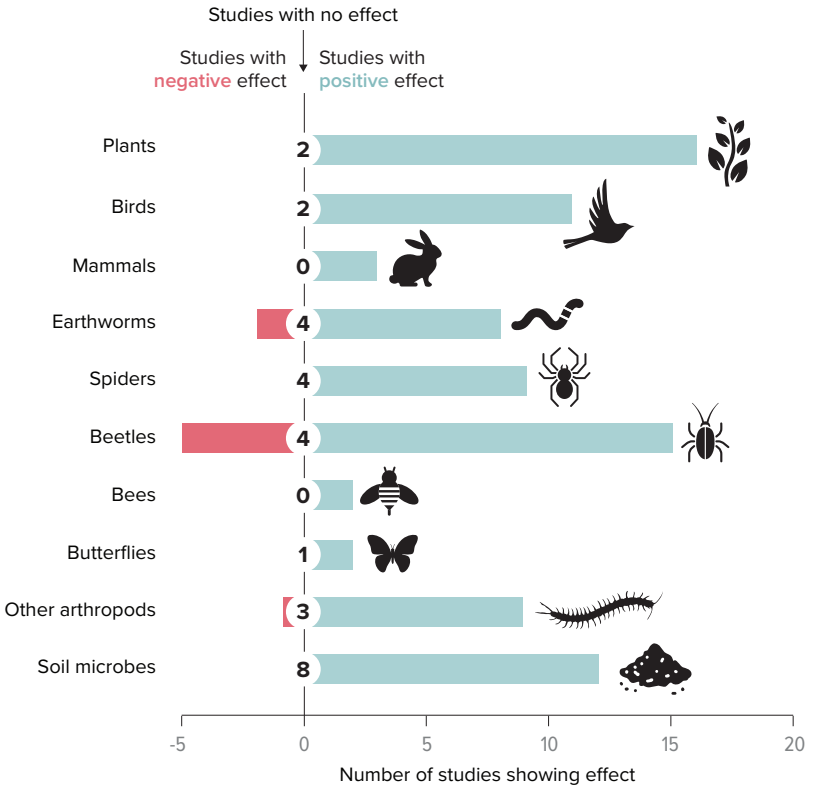
experts conclude. The International Union for Conservation of Nature, a science-based conservation organization, says that of the 8,500 threatened species it has studied, agriculture alone imperils 62 percent, ranging from the elegant African cheetah to California's lovable Fresno kangaroo rat. Fertilizers running off farmland and into rivers and lakes are fueling toxic algal blooms across the world, suffocating fish and damaging ecosystems. And agriculture has its hand in around 80 percent of global deforestation.

The organic movement was sparked, in part, from similar environmental concerns in the early twentieth century. With its roots in Europe and the US, organic farming grew from the idea that soils nurtured with compost rather than synthetic fertilizers could safeguard the soil and biodiversity while producing more nutritious food. Today, organic produce is a must-have stock on the shelves of many major Western supermarkets, and organic farming is practiced in more than 180 countries, on more than 172 million acres of farmland. Although this is still just 1.4 percent of global agricultural land, land farmed organically has increased more than sixfold since 1999 and is rising.

Organic farming could easily spread further and help put more food on the global dinner table, says John Reganold, an agroecologist at Washington State University. "In many ways, organic farming is leading the way towards food security and sustainability because it is a well-recognized farming system that is economically successful — and so more farmers want to try it. I think we owe credit to organic for that," he says. But he and many others who have studied the issue say that without a massive change in diet, organic could never grow enough food globally on existing farmland despite its demonstrated pluses.

Many studies have shown that organic farming has benefits for biodiversity on farms. For example, in an assessment comparing organic and conventional

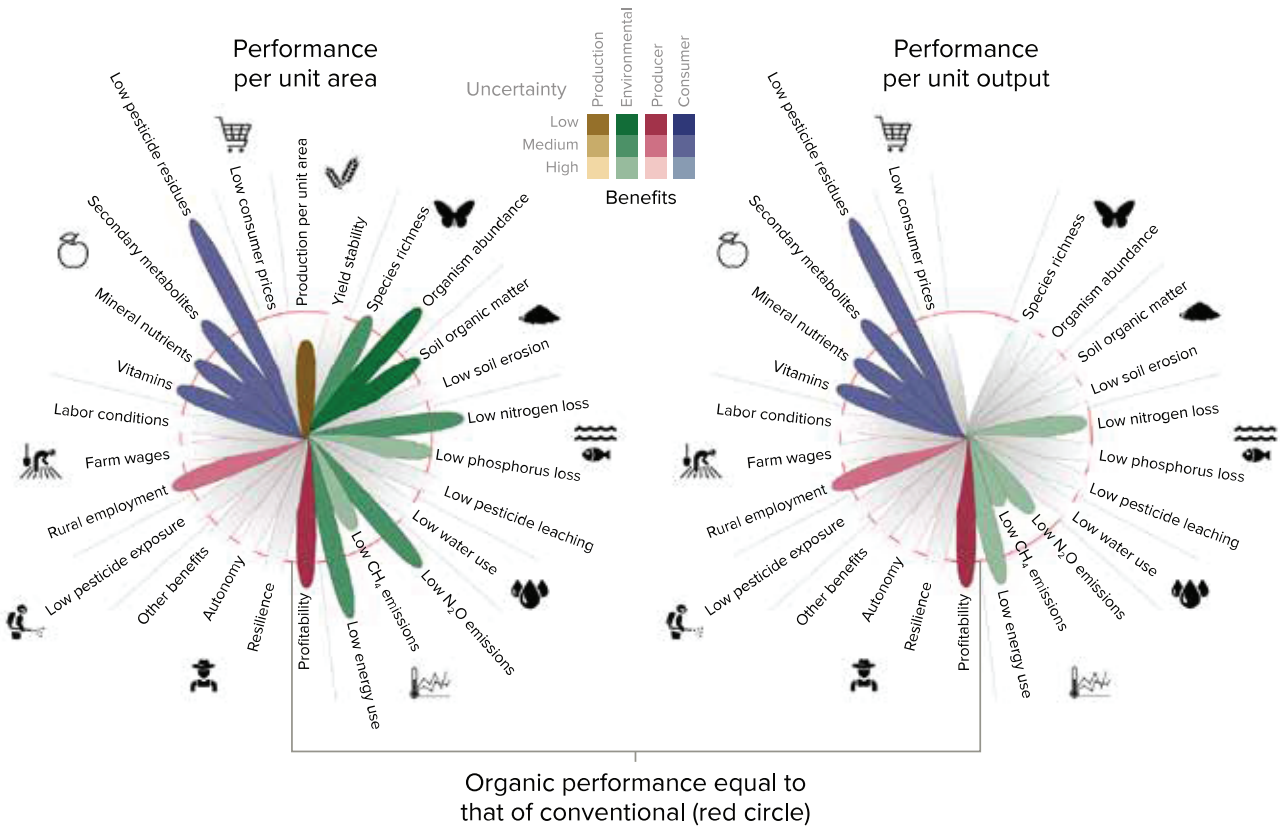
IMPACT OF ORGANIC FARMING ON BIODIVERSITY



Many studies show that organic farming is beneficial to biodiversity, especially for creatures like birds, spiders and some soil-dwelling insects. The effect is less pronounced for animals like butterflies. Outcomes for other critters, such as beetles, are more uncertain, with individual studies showing a breadth of effects.

SOURCE: FIBL 2011

ORGANIC AND CONVENTIONAL OUTCOMES ON TWO DIFFERENT MEASURES



The benefits of organic farming depend a lot on what is being measured. For a variable like low pesticide residues, organic farming has clear benefits over conventional farming, as indicated by the petal extending beyond the red circle, which demarks where organic performance equals that of conventional farming. But for a variable like low nitrogen loss, organic farming's benefit diminishes when output is assessed (right) rather than area (left).

SOURCE: ADAPTED FROM V. SEUFERT *ET AL* / *SCIENCE ADVANCES* 2017

farming published in *Science Advances* in 2017, Seufert reported that organic farms host up to 50 percent more organisms such as bees and birds than conventional farms. Organic farms nurture greater biodiversity largely because they don't use synthetic herbicides and pesticides, allowing plants, insects and other animals to thrive. Farmworkers also benefit from lower pesticide exposure, Seufert says.

Organic farms also take better care of soil than average conventional farms, studies show. Enriched with compost from rotted animal manure or plant matter, organic soils can contain up to 7 percent more organic matter than their chemically enhanced counterparts, according to Matin Qaim, an agricultural economist at the University of Goettingen in Germany, and colleague Eva-Marie Meemken, writing in the 2018 *Annual Review of Resource Economics*. Organic matter, rich in diverse microbes, is key to the health and structure of soil, helping it hold on to water and reducing erosion.

Qaim and Meemken report that, acre for acre, organic farming consumes less energy largely because it doesn't use synthetic fertilizers. It also releases lower levels of some greenhouse gases such as carbon dioxide and methane, and leaches fewer polluting nutrients such as nitrates from fertilizers into rivers and groundwater. Organic fields are also an experimental ground for greener farming techniques, such as planting cover crops including the leguminous hay crop red clover (*Trifolium pratense*). Cover crops help suppress weeds and guard against erosion.

Yield is the one crucial feature where organic farming falls short, Qaim concludes. Organic yields are on average up to 25 percent lower than conventional farming yields. Some crops grow better than others under organic conditions: Legumes, which fix nitrogen from the air and thus can meet some of their own nitrogen needs, tend to produce deficits of just 10 to 15 percent. But yields of nitrogen-thirsty cereals are 21 percent to 26 percent lower on organic soils, due to limited nutrient supply as well as greater susceptibility to pest outbreaks and encroachment by weeds.

"The facts are not in favor of organic — the observation that organic yields are lower than in conventional practices cannot be denied," Qaim says.

Small yields add up to a big problem. Switching all the world to organic would mean turning 24 percent more natural habitats into agricultural land to meet future demands, researchers calculate. Small yields also drive up greenhouse gas emissions produced by organic farming because land must stay working rather than being allowed to regularly go fallow. Organic's land-use costs would undo much of the ecological good that organic brings locally, Qaim says.

Organic advocates, however, question the size of yield gaps reported in much of the scientific work. The Rodale Institute, an organic advocacy and research center in Kutztown, Pennsylvania, says its own work shows that under certain conditions organic farming can match or exceed conventional yields. Andrew Smith, the institute's chief scientist, acknowledges that organic yields are overall lower. But he says they have plenty of scope to grow if greater investment is made in developing crop and animal breeds better suited to organic's challenges, and in doing more research on best practices. Global funding for research on organic farming is less than 1 percent of that spent on conventional farming and food, according to a 2017 report from the International Federation of Organic Agriculture Movements.

Conventional farming's failures

The researchers who conclude that organic could not feed the globe's growing population also recognize that conventional agriculture can't carry on as it is, either. So agronomists are doubling down on the middle road, testing a fusion of techniques where farmers use green practices topped with synthetic inputs when necessary. Many of these green techniques, such as planting cover crops and growing different crops in the same field one year to the next, were once routinely used in agriculture to manage weeds and soil health but fell out of favor after World War II when the cost of synthetic fertilizers and herbicides dropped. These methods are now making a supercharged comeback in the low-input agriculture movement.

Studies are starting to show that low-input fusion farming comes up trumps for both yields and the environment. After an eight-year experiment ending in 2016, agronomists at the universities of Minnesota and Iowa State reported promising results from three-crop rotation systems on a 22-acre experimental farm at Iowa State. The crops were switched over periods of two, three or four years and assessed for yield, profit and environmental effects such as soil erosion and nitrogen leaching into rivers and groundwater.

CREDIT: MICHEL CAVIGELLI / USDA-ARS

Different crops grown in the same field at the same time can boost yields and help control weeds and pests. Here, strips of corn grow alongside alfalfa and soybeans in test plots at the US Department of Agriculture's Agricultural Research Service Farming System project, in Beltsville, Maryland.

> "The observation that organic yields are lower than in conventional practices cannot be denied."
>
> —MATIN QAIM

In the two-year crop rotation, researchers planted maize and soybeans in alternating years, but added a mixed crop in the three-year rotation, planting oats and red clover together for year three. They planted oats along with a different legume, alfalfa, in year three of the four-year rotation field, then let the alfalfa keep growing into the fourth year, after the oats were harvested.

The team was able to slash the input of synthetic chemicals. Researchers added fertilizers in the two-year rotation plots at rates typical of conventional farms, but used substantially less in the three- and four-year rotation plots: on average 85 percent and 91 percent less synthetic nitrogen (13 and 8 kilograms per hectare per year, respectively). The researchers added manure to boost nitrogen but it contained about half the amount of nitrogen that a full application of synthetic fertilizer supplies. They also added substantially less herbicide active ingredient to the low-input maize and soybean crops: 94.8 percent (0.06 kg/ha) and 92.5 percent (0.12 kg/ha), respectively. Herbicide application did not differ across the longer and shorter rotations.

Yields rose as the number of rotations increased and were unaffected by the lower herbicide use in the longer rotations. On average, maize yields were 4.5 percent higher and soybean yields 25 percent higher in the three- and four-year rotations compared with the two-year rotations. The alfalfa and clover steps are key for this effect, says Matt Liebman, an agronomist at Iowa State and one of the study's authors. "You begin to see big changes in nutrient dynamics because the hay crops like alfalfa and clover take atmospheric nitrogen and put it into the soil" for the crops that follow, he says. "So you don't have to have anywhere near as much fertilizer."

Problems with weeds and disease also looked somewhat better. Despite a lower use of herbicide in the three- and four-year rotations, weeds intruded equally in the two- and four-year rotation plots. And soybeans grown in the longer rotations succumbed less often to soybean sudden death syndrome, a fungal infection

common to the Midwestern farm belt. "The crop rotations typically result in much more effective management of insect disease and weed pests with much lower investment in chemical pesticides because you disrupt the life cycles of many of the pests that are specialized for particular crops," Liebman says.

Finally, the low-input, longer rotation strategies also had environmental benefits. The potential harm to freshwater ecosystems caused by the herbicide (known as toxicity load) was 99.9 percent lower in the low-input maize plots than in the conventional maize plots. And though the longer rotations required more labor, profits for all three rotation systems were similar overall.

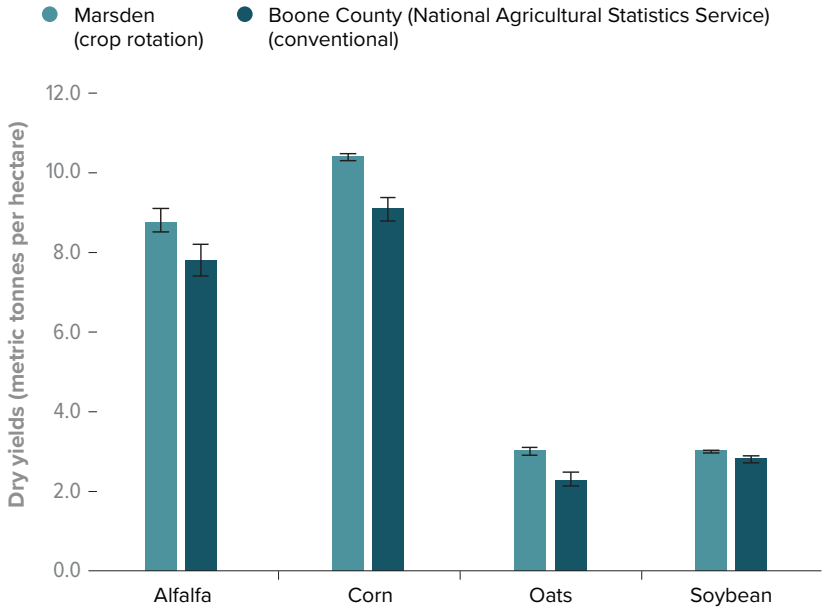
Balancing yields and pollution

Other studies in Europe and across the US are reporting similar results. A meta-analysis of 15 studies done in the US, Canada, France, Sweden, Switzerland and Norway concluded that yields of maize grown under low-input conditions were equal to those produced under conventional conditions, and 24 percent higher than organic crops. Wheat yields were 12 percent lower than conventional, but 43 percent higher than organic, according to the analysis, published in 2016 in *Agronomy Journal*. On average, crops grown under low-input conditions received less than half the synthetic pesticide applied to conventionally grown crops and were often cultivated as part of a crop rotation that included more plant species than in conventional systems.

Agronomist Laure Hossard of the Montpellier campus of the French National Institute for Agricultural Research, a coauthor of the meta-analysis, says it's unclear why wheat yields dropped but maize yields didn't under low-input conditions. Perhaps wheat succumbed more to uncontrolled disease or needed more fertilizer. Still, the low-input wheat yield losses were small, and the study's overall conclusion is that low-input farming can dramatically cut back on pesticide use without drastically harming yields.

There are some potential downsides to low-input farming, Hossard says. Money spent on pesticides and fertilizers may not always compensate for lost income from

CROP ROTATION OUTPERFORMS CONVENTIONAL PLANTING



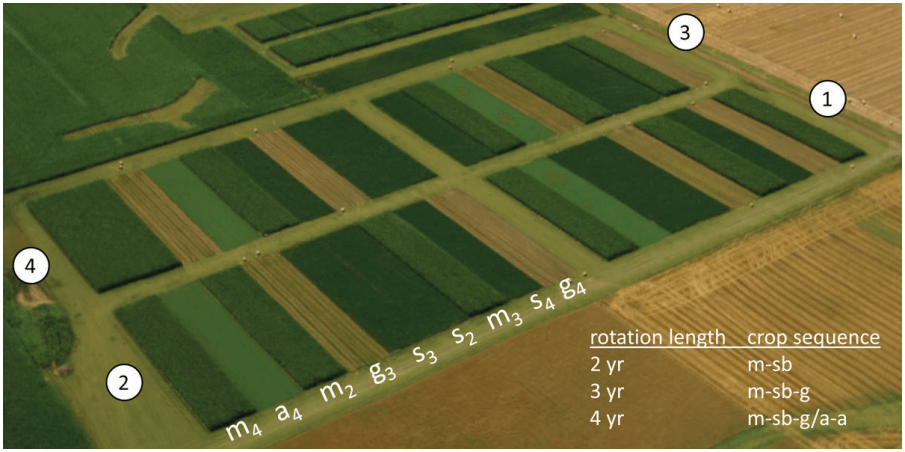
Average yields in the Marsden Farm crop rotation experiments are higher than that of conventional commercial farms in Boone County.

SOURCE: N.D. HUNT *ET AL* / *ENVIRONMENTAL SCIENCE AND TECHNOLOGY* 2019

ASSOCIATED ANNUAL REVIEWS CONTENT

Organic Agriculture, Food Security, and the Environment

E. Meemken & M. Qaim / Annual Review of Resource Economics



Narrow plots of corn (m), soybeans (sb/s), oats (g), and alfalfa (a) grow at Iowa State University's Marsden Farm where agronomists tested how crop rotations and low levels of synthetic inputs, like herbicides and fertilizers, affect yields. All three crop rotations (two-year, three-year and four-year) were tested in four replicate blocks (1, 2, 3, 4). The more diverse crop rotations had yields that were equal to or better than the conventional system, despite receiving fewer synthetic inputs.

CREDIT: A. DAVIS *ET AL* / *PLOS ONE* 2012

slightly lower yields. Although studies have shown that it is possible to cut pesticide use by around 30 percent without reducing farmers' income, these calculations may vary from year to year as prices for crops and synthetic inputs fluctuate. Also, low-input crops don't command higher prices like organic products do, so they may be less profitable than conventional products, she says.

Even as researchers fine-tune low-input strategies in experimental plots, farmers are beginning to apply these tactics in their own fields. It's unclear how many farmers are taking on a fusion farming approach, but a survey of 2,012 farmers across the US found they are increasingly using green techniques, such as planting cover crops, and that acreage planted in cover crops nearly doubled from 2012 to 2016.

And in an analysis of 400 global sustainable farming programs published last year, Pretty and colleagues found that 47 of the initiatives are running on a large scale, meaning they are practiced on more than 10,000 farms or the same number of hectares (almost 24,700 acres) of farmland globally. Some 163 million farms — 29 percent of global farmland — are now solidly on sustainable ground, Pretty says, meaning that outcomes such as yields are at least maintained while doing at least no further harm to the environment. Many of the programs achieved this feat not by pure organic practices but through a plethora of low-input fusion farming practices such as agroforestry, where trees are planted in crop fields to help fertilize soil without the need for synthetic nitrogen, or by integrated pest management, where natural predators are used instead of synthetic pesticides to control pests.

Sustainable systems are "popping up at scale all over the place," Pretty says — momentum is building as farmers see sustainable practices working. "We are at a turning point. We can produce more with less impact. We are moving towards greater sustainability," he says.

Eco-friendly future

None of this means that eco-minded eaters should stop buying organic produce, Seufert says. On local scales, organic farming is an important part of the movement toward producing more food with fewer impacts. But the global larder won't ever be stocked with just organic produce — doubling or even tripling organic farmland is a more realistic and environmentally desirable target, she suggests. The challenge is to ensure that the remaining global farmland gets onto a more sustainable footing, and she and others see low-input fusion farming as a promising path.

But this future won't hinge just on farmers adopting greener techniques, analyses conclude. Researchers who study food security and sustainable agriculture say that our diets must change, too (cutting back on red meat is key). A broader move to greener pastures would also require new government policies that ban toxic pesticides and remove unhelpful subsidies.

For now, research is making strides by enabling a deeper understanding of what eco-friendly farming actually is. Says Balmford, "We can't afford to be ideological about what sustainable systems look like." ●

Q&A

Environmental scientist Eric Lambin

A blizzard of ‘sustainability’ labels

Earth-friendly certifications and standards abound for products like coffee, chocolate and palm oil. But do the programs work?

By Jyoti Madhusoodanan

CONSIDER COFFEE FARMS. The Rainforest Alliance standard (that little green frog) requires coffee farmers to increase tree cover on their plantations and ensure fair treatment of workers, among other things. Fair-trade certifications — there are a variety, with logos of leafy yin-yangs, dancing figures and more — require farmers to use water efficiently, prohibit bonded labor and offer safe working conditions. The Smithsonian Migratory Bird Center’s Bird Friendly certification checklist requires a coffee farm to have at least 10 different tree species and at least 40 percent of the plantation covered in shade. Farmers who comply can then sell their certified products at a higher price.

These efforts have led to a deluge of more than 400 ways to certify various goods and services — and much confusion for those consumers who want to choose responsibly. (At my local grocery store, I couldn’t find a single package of coffee without one of these many symbols, or at least the word “sustainable,” printed on it.) What’s more, the data are still unclear on which certifications truly make a product better for the planet or for farmers, says environmental scientist Eric Lambin of Stanford University and the Catholic University of Louvain, who coauthored an article on the topic in the 2018 *Annual Review of Environment and Resources*.

Lambin says that one thing is clear: Certifications are most likely to work when, in addition to consumers following through on their green intentions by buying certified products, nonprofits put significant muscle into the effort and governments offer their support. This conversation has been edited for length and clarity.

Why are there so many different ways for a product to get certified as sustainable?

In the 1980s, it was largely thought that sustainability objectives would be achieved via government policies that would mandate certain basic sustainability practices. Over the years it became clear that most states — especially developing countries — were not able to do this effectively because they had other priorities and limited capacity. This whole realm of voluntary sustainability standards emerged when private actors, such as non-governmental organizations, various societies and private companies, stepped in. The goal at that stage — was to achieve “governance without government,” a slogan at the time.

This history explains why each certification emerged independently, rather than in an organized fashion. The traders or a local non-governmental organization might start an initiative to make timber or coffee production more sustainable. Someone else might look at golf courses, or water consumption. A lot of these certifications are specific to one commodity, or to a place, such as the tropical rainforest. It’s an uncoordinated, sort of free-market approach.

Is it useful to have so many standards?

Yes and no. Some level of competition forces standards to demonstrate effectiveness. But too much duplication leads to wasted resources in terms of transaction costs, manpower, verification work, fundraising and advertising.

The other problem is that when you have many organizations that do exactly the same thing, one of them might create a very easy sustainability certification that anyone can get because it doesn’t require much change. And that leads to a race to the bottom. But some do try to be more effective and demonstrate real impact.

CREDIT: MAURITIUS IMAGES GMBH / ALAMY STOCK PHOTO; JAMES PROVOST

Are some standards emerging as clear winners?

We are only starting to have reliable evidence on this. Until four or five years ago, most studies trying to evaluate the impact of the standards were not sufficiently rigorous. Even now, the evidence is still very mixed.

For example, we found that in one province of Colombia, coffee farmers who were Rainforest Alliance–certified planted more trees on their farms compared to neighbors who were not certified. We also noticed that these farmers' children had studied more years at school than the kids of their neighbors who were not certified.

It turned out that because a farm must meet 90 criteria to receive the certification, many of these farmers, who were not literate, were quite happy to keep the kids at school for a few more years so they could help with the administrative work of reading forms and filing reports to get certified. In this way, the certification provided more than just environmental benefits — it provided social and potentially economic benefits, too. When kids get a few additional years of schooling, it has a positive impact — not just on farming, but also on job opportunities and innovation.

But when another research group studied coffee certification in Honduras, they came up with slightly different results: While few Rainforest Alliance–certified farmers were expanding their fields into forests, farmers certified by Fairtrade, UTZ and 4C were still causing deforestation.

Why the difference?

Mostly because the social and policy context in Honduras is different. Also, these studies are done by different teams, and we use slightly different methods and definitions, making it tough to compare results. In Honduras, they surveyed farmers to ask about forest clearing but not about tree planting, whereas in Colombia, we used satellite data to find out. The field is only starting to adopt a systematic approach to compare and evaluate the effectiveness of eco-certification.

But these nuanced findings led me to look beyond evaluating the effectiveness of a single standard. In more recent work, we have found that these sustainability certification standards become clearly successful and transformative when they are supported by, or get integrated into, public policy.

How does a voluntary certification become public policy?

Here's an example: Bolivia was reforming its forestry code a few years ago. A few forest concessions [public lands that timber companies lease from the state for wood extraction] were eco-certified under the label of the Forest Stewardship Council (FSC), and they were more productive and profitable. So the government decided that rather than write a forestry code from scratch, they would reuse entire segments of the FSC guidelines as the new code.

Suddenly this certification system that was purely voluntary was now public policy.

Large multinational companies also contribute to such upscaling. For example, a company such as Unilever might say that by 2020 or 2030, they commit to completely eliminating tropical deforestation from their supply chain. That means the property of every producer from whom they buy palm oil has to be deforestation-free. With a large company, that's a significant proportion of the global palm oil production.

But then how does the multinational meet that goal? They might try to implement a change by mandating a certification by the nonprofit Roundtable on Sustainable Palm Oil (RSPO) for all their palm oil suppliers. So now suddenly every producer who wants to sell to Unilever has to be RSPO-certified. Again, you have this powerful upscaling mechanism of a voluntary certification system. And that's when you start to have a big impact.

It's almost as if the idea of governance without government doesn't really work.

Exactly — and for another reason that's even more fundamental. One of the reasons the Rainforest Alliance coffee certification was successful in Colombia, or RSPO for palm oil is more likely to work in the Sabah state in Malaysia, is because these governments made sustainability a goal with a range of supportive policies.

In Colombia, the Colombian Coffee Growers Federation supported cooperatives of producers to help smallholders meet sustainability standards. These cooperatives then promoted new varieties of plants, introduced technology and explained the benefits of certification to farmers. The government also worked to develop an export market, boosting the reputation of, and

demand for, Colombian coffee as this high-quality, eco-certified coffee.

These supportive policies are necessary for a certification system to succeed. It's not just that you need the government to upscale a voluntary certification, it's that government intervention is necessary to make efforts successful in the first place, beyond the most progressive producers.

Do consumers also contribute to the success of sustainability efforts?

Commodities that have a consumer-facing aspect tend to be certified more often than ones that are processed and integrated into other products.

For example, you or I make an individual decision to buy this pack of coffee or chocolate over another one, perhaps based on packaging marked with a "certified sustainable" label. For these products, there's a very short supply chain linking the producer to you, the consumer. So the pressure from the consumers on retailers — and therefore on the whole supply chain — is much more direct, and there's a greater incentive for producers to make this claim of sustainability.

But that's not the case for other types of products. Take palm oil, for example — about half the goods that you find in a supermarket have some palm oil in them. It's in your shampoo, your biscuits, your soap, etc. But you never go and buy a bottle of palm oil. Because it's just one of many ingredients in a product, it's difficult to check whether the palm oil has been certified. So there's also less direct consumer pressure on companies to improve their standards.

Can consumers play a part in improving the standards?

Yes, it's a combination of consumers and non-governmental organizations. Consumers often have a very poor understanding of the nitty-gritty of a certification. But large companies conduct marketing campaigns, and the companies clearly sense that, at least in Europe and North America, there is a new wave of consumer demand for sustainably produced items.

In the past, companies would decide that external certification standards were too stringent, and come up with a much weaker, internal standard to call themselves sustainable. But now a number of studies have shown that this kind of "greenwashing" is penalized by consumers. If a company makes a big sustainability claim, and then a nongovernmental organization, scientist or investigative journalist demonstrates the claim was bogus, the company's reputation is damaged much more severely than if it made no claim whatsoever.

Pressure is especially effective when the supply chain is very concentrated, meaning a few companies hold a large market share. For example, five large companies control about 90 percent of the global trade in palm oil. When it's that concentrated, consumers and nonprofits can campaign hard, name and shame the companies into taking action on sustainability, like Greenpeace has been doing with Nestlé, Unilever and more. Companies tend to quickly adopt sustainability standards just to protect their reputation among consumers.

What are some choices or actions consumers can take to support sustainability efforts?

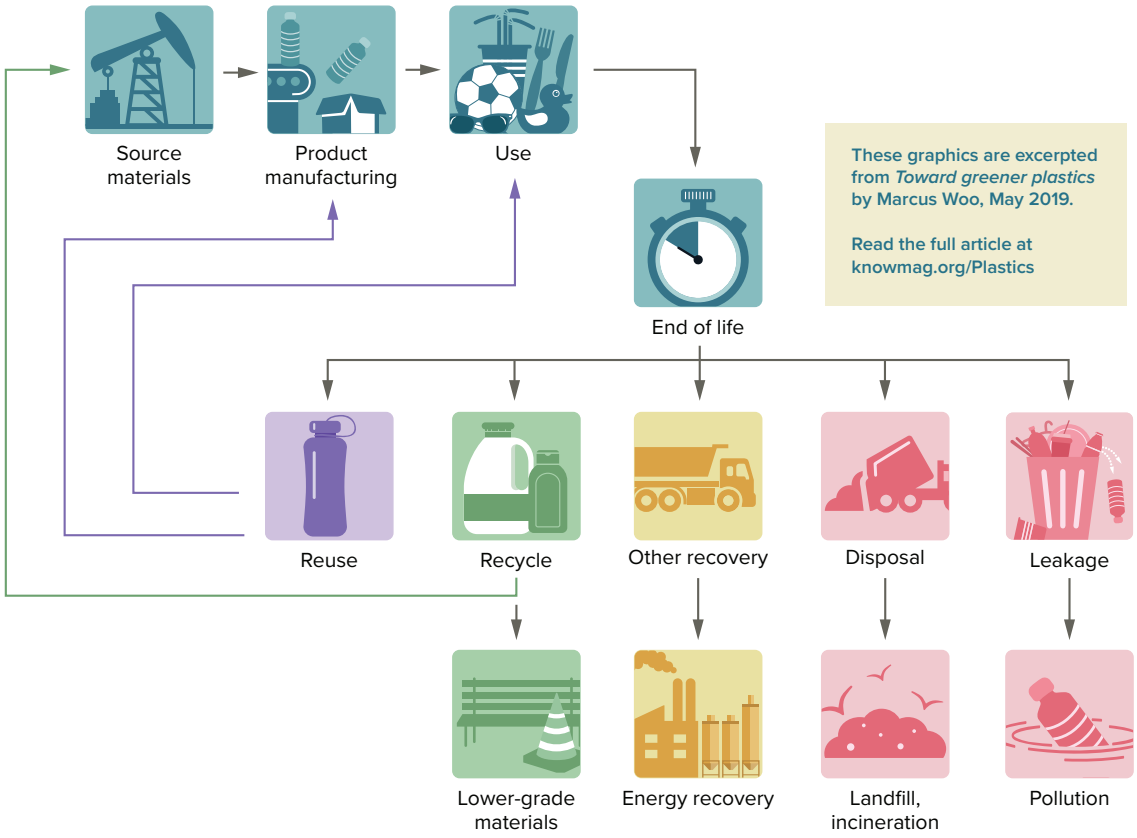
Just buying certified products and pushing for more stringent standards helps. Consider coffee: Only 25 percent of the coffee that's produced under some certification label is sold with a certified label. The rest is just sold as conventional coffee with no price premium, which suggests that consumer demand still doesn't match production. In surveys, consumers say sustainability is very important to them, but studies of actual market behavior show that their purchasing of certified products is still very low. They don't translate the preferences they express into actual buying decisions.

It's really a paradox. Think about it, these smallholder coffee farmers in remote areas are quite poor. They make all the effort to comply with 90 different criteria and get audited every year. It's a lot of work. And if there's little consumer demand for certified coffee, the price premium for producers decreases over time. In our Colombia study, for example, the price premium decreased from 20 percent to 2 percent above the price of conventional coffee, and some farmers were abandoning the certification because it was too much work for 2 percent more income.

And most coffee or chocolate consumers are wealthy people in rich countries. All that's needed is for them to take a second, check on the package whether the product is certified, and pay a few extra cents for it. And too few of them do it. ●

TOWARD GREENER PLASTICS

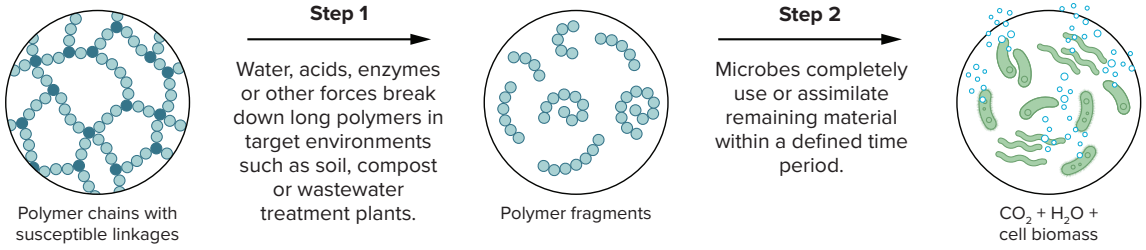
The life cycle of plastic products



These graphics are excerpted from *Toward greener plastics* by Marcus Woo, May 2019.

Read the full article at knowmag.org/Plastics

How biodegradable plastics break down



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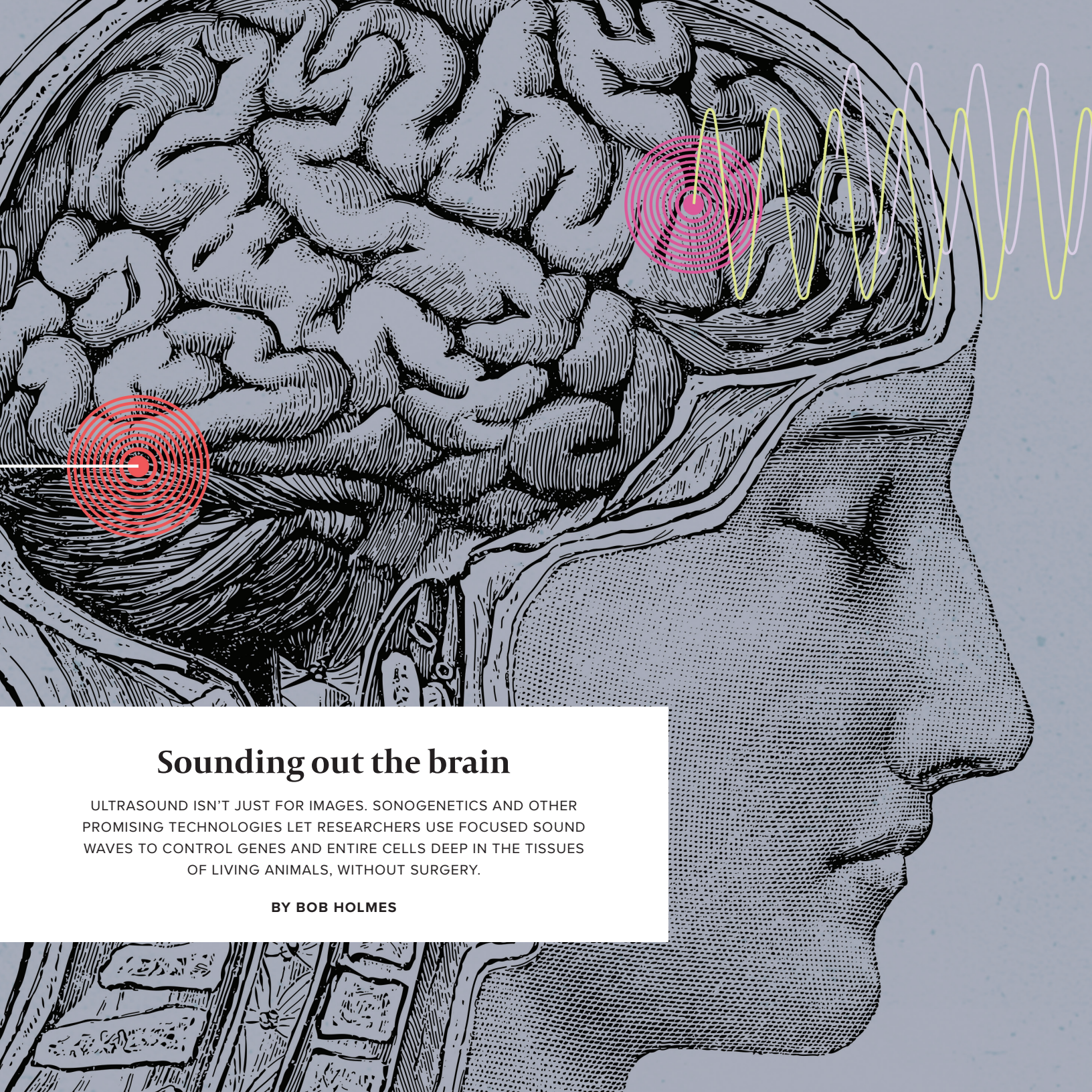


Sounding out the brain

ULTRASOUND ISN'T JUST FOR IMAGES. SONOGENETICS AND OTHER PROMISING TECHNOLOGIES LET RESEARCHERS USE FOCUSED SOUND WAVES TO CONTROL GENES AND ENTIRE CELLS DEEP IN THE TISSUES OF LIVING ANIMALS, WITHOUT SURGERY.

BY BOB HOLMES

MOST PARENTS' first glimpse of their children comes in ultrasound images taken months before birth. But ultrasound could soon offer much more than prenatal portraits. In the last few years, researchers have opened a new door for ultrasound, developing techniques that harness the familiar, safe and noninvasive sound waves to control genes, alter brain function and deliver drugs to targets with millimeter precision.

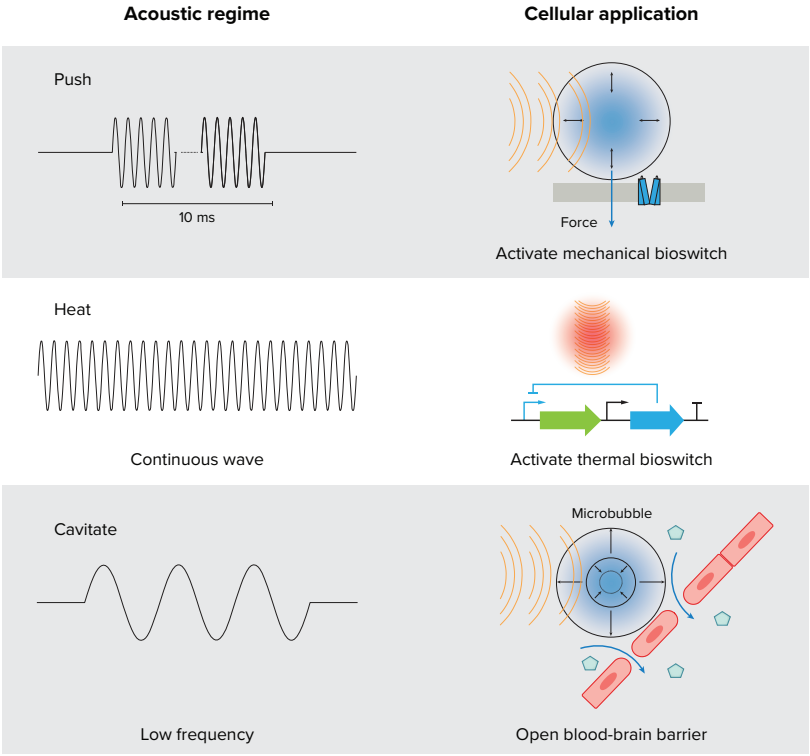
The advance of what's being termed sonogenetics offers a new twist on one of biology's biggest recent successes. For about a decade, biologists have been able to control genes and nerve cells by activating light-sensitive proteins with laser light. The technique, known as optogenetics, has transformed the field of neuroscience, and its use is spreading to many other branches of biology. With light, researchers can now control the firing patterns of individual nerve cells, turn on specific regulatory genes in particular cells to see how this affects development, and do many other things. But optogenetics faces a critical shortcoming: Light doesn't penetrate very far into living tissue, so its applications are mostly limited to tiny, transparent animals, cell cultures in petri dishes and where optical fibers can be surgically implanted into deeper tissue.

Ultrasound waves, in contrast, penetrate deep into tissues — hence their use for fetal imaging. They also can be focused almost as precisely as laser beams. At that millimeter-sized focus, ultrasound pulses can gently warm or physically jiggle cells. (More intense pulses can heat cells enough to kill them, an effect long used to destroy rogue regions of the brain to treat disorders such as essential tremor, a Parkinson's-like disease.)

As researchers develop cellular switches that are sensitive to temperature or vibration, they are gaining control over cellular processes beyond the reach of optogenetics. "This has the potential to provide the core capability of optogenetics, but now you can do it noninvasively in deep tissues," says Mikhail Shapiro, a chemical engineer at the California Institute of Technology in Pasadena.

For example, Shapiro is developing temperature-sensitive switches to control gene function. Most cells naturally have switches of this sort, but those typically aren't powerful enough for research use: gentle warming turns up gene activity only about tenfold, which can be difficult to detect amid all the processes going on in a

HOW ULTRASOUND CAN BE PUT TO WORK IN CELLS



Researchers can use focused ultrasound waves to control cells by pushing motion-sensitive molecular switches (top), by heating temperature-sensitive ones (middle), or by causing microbubbles in blood to swell and collapse (bottom), stretching the walls of surrounding blood vessels and allowing small molecules to pass through.

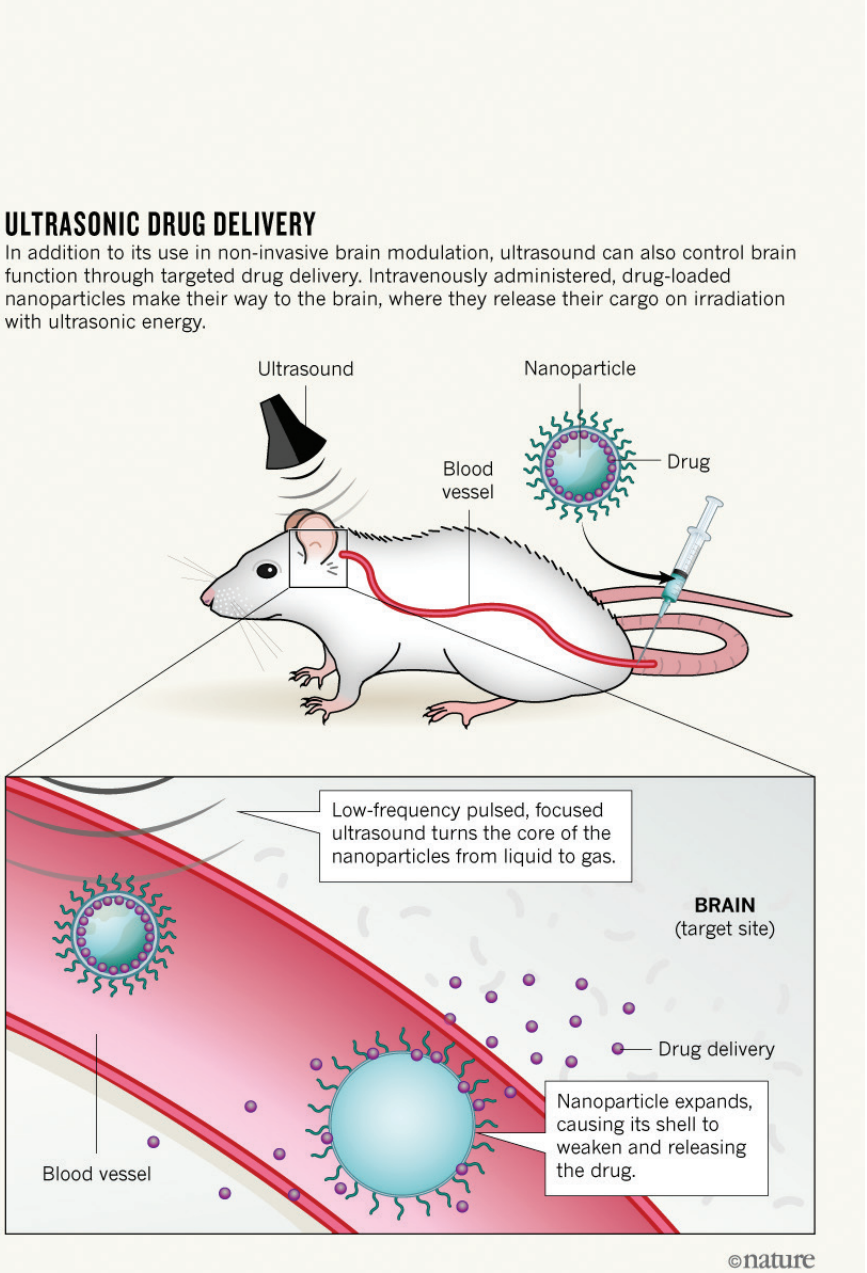
One example of how ultrasound can be used deliver drugs to a precise target in a rat brain.

living organism. But Shapiro's team found two proteins — one from a bacterium, the other from a virus — that had a 300-fold effect on gene activity over a 3-degree shift in temperature. After some genetic tweaking, he tuned these proteins to respond at different temperatures ranging from 32°C to 46°C. "As a result, now we have a whole library of thermal bioswitches, so you can pick the temperature you want them to operate at," he says.

So far, his team has used genetic engineering to insert the temperature switches into bacteria. Other researchers are beginning to put them in mammalian cells, too.

Still others are developing genetic switches that are activated by ultrasound-induced vibrations, rather than heating, with a report in 2018 on the technique's use in cancer immunotherapies. Eventually, it could also be used to explore the function of genes by selectively turning them on or off in particular cells to see what happens.

Researchers have also found that the right sort of focused ultrasound pulses can somehow excite or inhibit nerve cells directly, even without specially engineered switches. The effect is not as precise as the switches, but can be sufficient for some studies.



CREDIT: *NATURE*

Squeezing past the blood-brain barrier

Ultrasound may also find use as a tool to insert genes into specific brain cells called neurons. Ordinarily, cells in intact, living brains are difficult to genetically engineer, because the cells lining blood vessels in the brain seal tightly against one another to keep pathogens and large molecules from entering the brain. This blood-brain barrier keeps out the viruses typically used by genetic engineers to introduce new genes.

Nearly two decades ago, Kullervo Hynynen, a medical biophysicist now at the Sunnybrook Research Institute in Toronto, showed that focused ultrasound could gently stretch those tight junctions and open the blood-brain barrier. It did so by agitating tiny microbubbles that are often injected in the bloodstream to improve visibility on ultrasound scans. His team and others have used the method to deliver chemotherapy drugs to specific parts of the brain while sparing the rest.

Now Shapiro and his colleagues have used the same technique to slip gene-toting viruses into targeted brain regions. Once through the blood-brain barrier, these viruses can permanently add new genetic switches to those brain cells. The switches can be activated by molecules small enough to cross the barrier on their own.

"We do this brief ultrasound treatment, get the genes into that part of the brain, and then whenever we want to control the neurons at that location in the brain, we just give a pill that turns these neurons on and off," says Shapiro. His team has used the technique to block the formation of fear memories in mice by selectively inactivating neurons in the hippocampus, a key region for memory that is implicated in anxiety disorders and Alzheimer's disease.

"We do this brief ultrasound treatment, get the genes into that part of the brain, and then whenever we want to control the neurons at that location in the brain, we just give a pill that turns these neurons on and off."

—MIKHAIL SHAPIRO

Sound drug delivery

A third approach uses ultrasound to control brain activity by triggering the release of drugs in specific regions. One particularly promising example involves the anesthetic propofol. Raag Airan, a radiologist at Stanford University, and his colleagues bind propofol to oily droplets in the blood, which sends the drug around the body. A pulse of focused ultrasound releases the propofol in a specific area. Detached from the droplets, the drug is now in a form small enough to cross the blood-brain barrier on its own and temporarily knock out the function of brain cells at that site.

Besides its use as a research tool, the technique should prove useful for neurosurgeons planning to destroy a particular brain region — to treat seizures, for example — but who want to make sure that the ablation will not have severe side effects. The focused release of propofol should let surgeons preview the effect of their proposed surgery. "The plan is to release this drug only in that specific region and use that to see whether this is the site we want to remove," says Charles Caskey, a biomedical engineer at Vanderbilt University Medical School in Nashville, Tennessee, who collaborates with Airan's team.

So far, most of these uses of sonogenetics are still in the proof-of-concept stage, where researchers are verifying that they work and building an arsenal of trusted techniques. Only then will actual clinical and research applications become possible. However, if the techniques pan out, both researchers and medical workers could soon have powerful, new, noninvasive tools at their disposal. If the recent burgeoning of optogenetics is any guide, that's likely to be a very good thing. ●

ASSOCIATED ANNUAL REVIEWS CONTENT

Memory Allocation: Mechanisms and Function

D. Maresca *et al* / *Annual Review of Chemical and Biomolecular Engineering*

Q&A

Neuroscientist John Donoghue

Bypassing paralysis

By decoding brain activity with electrical implants, computers can help disabled people move a robotic arm — or their own

By Tim Vernimmen

WHAT IF A BRAIN STILL worked, but the limbs refused to listen? Could there be a way to artificially translate the intentions of people with paralysis into movements? Over a four-decade career, neuroscientist John Donoghue, founding director of the Wyss Center for Bio and Neuroengineering in Geneva, convinced himself that he could do it.

In 2002, Donoghue showed that monkeys could move a cursor with the help of a decoder that interpreted their brain activities. In the decade that followed, he and his colleagues showed that the system worked in people as well. Individuals with quadriplegia could use their brain activity to move a cursor. That line of research recently culminated in the demonstration that people with paralysis could control a tablet computer this way. Donoghue himself went on to further develop the system to allow people to open and close a robotic hand, and to reach, grasp and drink from a bottle by using a multijointed robotic arm.

In 2017, he was a coauthor on a study demonstrating how a similar system could help people do all those things with their own arms. Now more than a dozen patients have used the technology in experimental settings. Donoghue's ultimate goal is to develop technology that they — and many others like them — can take home and use day-to-day to restore the abilities they have lost.

This conversation has been edited for length and clarity.

How do you find out which movements someone with paralysis would like to make?

We implant a small 4-by-4-millimeter microelectrode array into the brain's motor cortex, in a region that we know directs the movements of the arm. This array consists of 100 hair-thin silicon needles, each of which picks up the electrical activity of one or two neurons. Those signals are then transmitted through a wire to a computer that we can use to convert the brain activity into instructions to control a machine, or even the person's own arm. We are assuming that the relevant variable here — the language we should try to interpret — is the rate at which neurons discharge, or "fire."

Let me explain this using the example of moving a cursor on the screen.

We first generate a movie of a cursor moving: say, left and right. We show this to the person and ask them to imagine they are moving a mouse that controls that cursor, and we record the activity of the neurons in their motor cortex while they do so. For example, it might be that every time you think "left," a certain neuron will fire five times — pop pop pop pop pop — and that if you think "right," it will fire 10 times. We can use such information to map activity to intention, telling the computer to move the cursor left when the neuron fires five times, and right when it fires 10 times.

Of course, there are other decisions to be made: What if a neuron fires just three times? So you need a computer model to decide which numbers are close enough to five. And since neuronal activity is naturally noisy, the more neurons we can measure, the better our prediction will be — with the array we implant, we usually get measurements from 50 to 200.

For the arm prosthesis, we similarly ask people to imagine making the same movement with their own arm. There were people who thought you would have to build separate models for "flex and extend your elbow," "move your wrist up and down," and so on. But it turns out this isn't necessary. The brain doesn't think in terms of muscles or joint angles — the translation of intentions into movement happens later.

CREDIT: ADAPTED FROM N.G. HATSOPOLOUS *ET AL/ AR NEUROSCIENCE* 2009; JAMES PROVOST

How do you find the exact spot in the motor cortex at which to implant the array?
In fact, I don't think the exact location matters that much. There is also no need for us to know exactly what each individual neuron is trying to do, as long as we can dependably predict the intended action from their combined activity. That goes against the standard old theory that there is a separate location for controlling each finger, for example. If that were the case, it would mean that if you put the array in a particular place you'd get great thumb control, but nothing else. I've spent my entire scientific career saying it is not true that doing something only engages a small and specific part of the brain. All our neurons form parts of large, interconnected networks.

Do people get better with experience in using the device?
Not really. The neurons often change their activity, which can corrupt the map, so we have to recalibrate the model at the beginning of every session. This means people have to work with a different model every day, so they don't get better at it.

And if something goes wrong and we give them control that isn't very good, they don't get over it on that day, which can be very frustrating for them. It appears the brain isn't plastic enough to change the activity of specific neurons quickly enough to overcome such problems the same day.

How can a computer give directions to a real arm?
In the case of the patient that we've published about, it's electrical stimulation of the muscles themselves, which seemed the most practical. The energy cost is very high, however. It would be more energy efficient to stimulate the nerves that control the muscles, as they are excellent amplifiers of energy. Yet stimulating the right nerves in the right way is pretty complicated — you can't simply shock them into action.

Having a person move their own arm is an important achievement, although it is slow and definitely not as dexterous as we'd like it to be.

Do you think that all of us might one day consider it practical to put an array into our brain so we can communicate with a computer or other devices more directly?
I don't. Evolution has given us such fabulous natural interfaces that I think the barrier of brain surgery will remain too high. There's always a risk of something going wrong, so I don't think we should use implants for pure augmentation like that. Some people will do dangerous things, of course, but fortunately, you can't easily stick an electrode in the right place in your own brain.

Have you heard of neurologist Phil Kennedy? He was the first person to implant an electrode in a human permanently, and he later had himself implanted in Belize, as no one in the United States would do anything like that. I find that disturbing — he's a perfectly healthy, very bright man.

I think the aim of the field should be to create the opportunity for people with paralysis to restore or achieve typical abilities. For people who want to be superenabled, I think we need some serious regulations, as that could be extraordinarily disruptive. It also raises other issues — if I am rich and you are not, and only my child gets a brain booster implant, this creates a very unfair situation.

How do you apply such ethical considerations to your work?
I think we should always strive to make the technologies we create available to as many people as possible. That doesn't mean we should stop developing or producing them because they currently cost too much and we can't give them to everybody who needs them. But eventually, that should be the goal.

What is the biggest obstacle to getting this technology out there to people who need it?
One issue is that the arrays tend to degrade over time in the rather harsh environment of the brain. But as some have lasted for over five years, I don't think this is the main obstacle, as you'll probably want to get a new one anyway after that much time has passed.

If you ask me, the biggest problem is that people have a plug on their head with wires everywhere connecting them to a computer. For this to become a product people can use at home, it will have to be largely technician-free and located entirely inside the skull.

At the Wyss Center, we are trying to do exactly that: develop an implantable system that can radio out the signals. That is very hard, because we need to make the entire device small, and it will need a very good battery. If you can use this only 45 minutes a day to save power, it's not worth it. So that's what we are working on right now. ●

The future of work: Will robots take my job?

AUTOMATION THREATENS TO REPLACE SOME WORKERS BUT CAN GROW OVERALL EMPLOYMENT. THE ONE SURE THING IS THAT TECHNOLOGY WILL CHANGE HOW WE LABOR.

BY M. MITCHELL WALDROP

BACK IN THE 1990S, WHEN US BANKS started installing automated teller machines in a big way, human tellers seemed to be facing rapid obsolescence. If machines could hand out cash and accept deposits on their own, around the clock, who needed people?

The banks did, actually. True, ATMs made it possible to operate branch banks with fewer employees: 13 on average, down from 20. But the cost savings encouraged banks to open many new branches, so total employment of tellers actually went up.

You can find similar stories in fields like finance, health care, education and law, says Boston University economist James Bessen, who alerted his colleagues to the ATM story in 2015. "The argument isn't that automation always increases jobs," he says, "but that it can and often does."

That's a lesson worth remembering when listening to predictions about the future of work in the age of robots and artificial intelligence. Think driverless cars, or convincingly human speech synthesis, or creepily lifelike robots that can run, jump and open doors on their own: Given the breakneck pace of progress in such applications, how long will there be anything left for people to do?

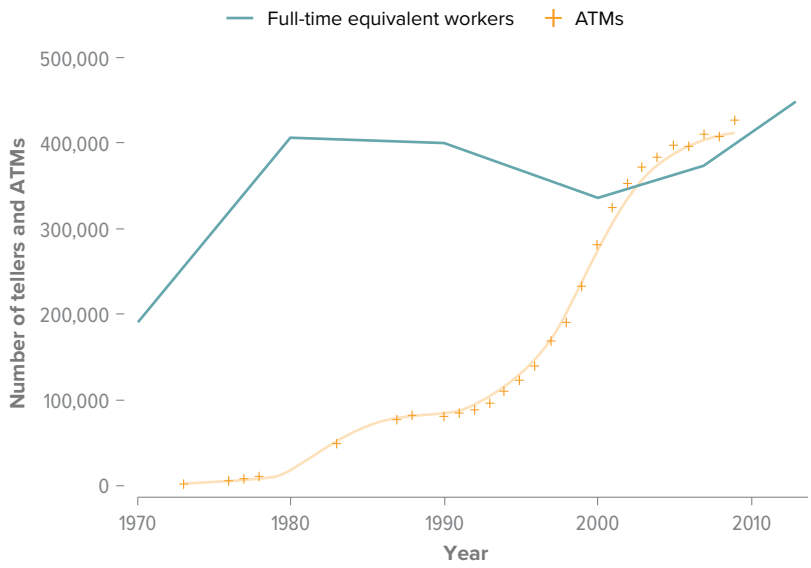
That question has been given its most apocalyptic formulation by figures such as Tesla founder Elon Musk and the late physicist Stephen Hawking. Both warned that machines will eventually exceed human capabilities, move beyond our control and perhaps even trigger the collapse of human civilization. But even less dramatic observers are worried. In 2014, when the Pew Research Center surveyed nearly 1,900 technology experts on the future of work, almost half were convinced that artificially intelligent machines would soon lead to accelerating job losses — nearly 50 percent by the early 2030s, according to one widely quoted analysis. The inevitable result, they feared, would be mass unemployment and a sharp upswing in today's already worrisome levels of income inequality. And that could indeed lead to a breakdown in the social order.

Or maybe not. "It's always easier to imagine the jobs that exist today and might be destroyed than it is to imagine the jobs that don't exist today and might be created," says Jed Kolko, chief economist at the online job-posting site Indeed. Many, if not most, experts are cautiously optimistic about employment — if only because the ATM example and many others like it show how counterintuitive the impact of automation can be. Machine intelligence is still a long way from matching human abilities, says Bessen. Even when you factor in developments now in the pipeline, he says, "we have little reason in the next 10 or 20 years to worry about mass unemployment."

So — which way will things go? There's no way to know for sure, says Kolko. But maybe, he adds, that's not the right question: "The debate over the aggregate effect on job losses versus job gains blinds us to other issues that will matter regardless" — such as how jobs might change in the face of AI and robotics, and how society will manage that change.

RISE OF THE ATMS—AND THE TELLERS

In the early 1980s, automated teller machines began populating banks and stoking fears that the machines would make human bank tellers obsolete. But after an initial dip, the number of full-time bank workers actually began to rise.



OPPOSITE PAGE CREDIT: MARINA MUUN; THIS PAGE SOURCE: BESSEN / BOSTON UNIVERSITY SCHOOL OF LAW 2015

"There are many different possible ways we could configure the state of the world," says Derik Pridmore, CEO of Osaro, a San Francisco-based firm that makes AI software for industrial robots, "and there are a lot of choices we have to make."

Automation lessons from the past

In the United States, at least, today's debate over artificially intelligent machines and jobs can't help but be colored by memories of the last four decades, when total employment by US automakers, steel mills and other manufacturers began a long, slow decline. From a high of 19.5 million workers in 1979, total jobs dropped to about 17.3 million in 2000 — followed by a precipitous fall to 11.5 million after the Great Recession of 2007–2009. (The total has since recovered slightly, to about 12.7 million.) Similar changes were seen in other heavily automated countries such as Germany and Japan.

Automation can't possibly be the whole reason for the decline, says Bessen. "If you go back to the previous hundred years," he says, "industry was automating at as fast or faster rates, and employment was growing robustly." That's how we got to millions of factory workers in the first place. Instead, economists blame the employment drop on a confluence of factors, among them globalization, the decline of labor unions, and a 1980s-era corporate culture in the United States that emphasized downsizing, cost-cutting and quarterly profits above all else.

But automation was certainly one factor. "In the push to reduce costs, we collectively took the path of least resistance," says Prasad Akella, a roboticist who is CEO of Drishti, a start-up firm in Palo Alto, California, which uses AI to help workers improve their performance on the assembly line. "And that was, 'Let's offshore it to the cheapest center, so labor costs are low. And if we can't offshore it, let's automate it.' "

> "We have little reason in the next 10 or 20 years to worry about mass unemployment."
>
> —JAMES BESSEN

AI and robots in the workplace

Automation has taken many forms, including computer-controlled steel mills that can be operated by just a handful of employees and industrial robots: mechanical arms that can be programmed to move a tool such as a paint sprayer or a welding torch through a sequence of motions. Such robots have been employed in steadily increasing numbers since the 1970s. There are now about 2 million industrial robots in use globally, each taking the place of one or more human workers.

The distinctions between automation, robotics and AI are admittedly rather fuzzy — and getting fuzzier, now that driverless cars and other advanced robots are using artificially intelligent software in their digital brains. But a rough rule of thumb is that robots carry out physical tasks that once required human intelligence, while AI software tries to carry out human-level cognitive tasks such as understanding language and recognizing images. Automation not only encompasses both, but also includes ordinary computers and non-intelligent machines.

AI's job is toughest. Before about 2010, applications were limited by a paradox famously pointed out by the philosopher Michael Polanyi in 1966: "We can know more than we can tell" — meaning that most of the skills that get us through the day are practiced, unconscious and almost impossible to articulate. Polanyi called these skills tacit knowledge, as opposed to the explicit knowledge found in textbooks.

Imagine trying to explain how you know that a pattern of pixels is a photo of a puppy, or how you can safely negotiate a left-hand turn against oncoming traffic. It sounds easy enough to say "wait for an opening in traffic" — until you try to define an "opening" well enough for a computer to recognize it, or to define precisely how big the gap must be to be safe. Tacit knowledge contained so many subtleties that there seemed no way for programmers to extract it, much less encode it in a precisely defined algorithm.

Today, of course, even a smartphone app can recognize puppy photos (usually), and autonomous vehicles are making those left-hand turns routinely (if not always perfectly). What's changed just within the last decade is that AI developers can now throw massive computer power at huge datasets — a process known as "deep learning." It amounts to showing the machine a zillion photographs of puppies and a zillion photographs of not-puppies, then having the AI software adjust a zillion variables until it can identify the photos.

Although this deep learning process isn't particularly efficient — a human child only has to see one or two puppies — it's had a transformative effect on AI applications

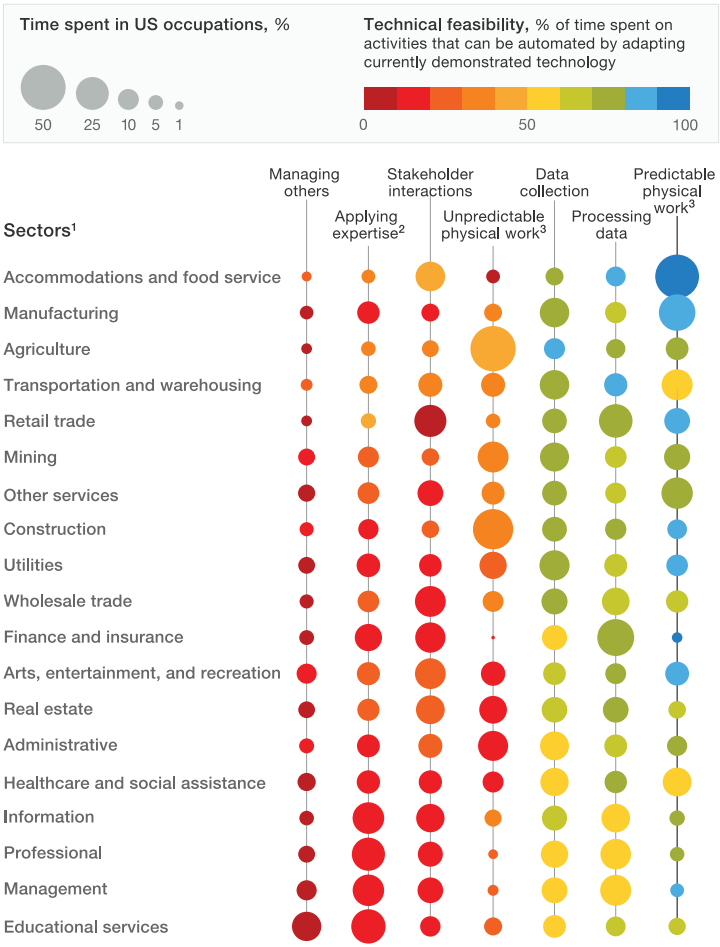
such as autonomous vehicles, machine translation and voice or image recognition. And that's what's freaking people out, says Jim Guszcza, US chief data scientist at Deloitte Consulting in Los Angeles: "Wow — things that before required tacit knowledge can now be done by computers!" Hence the new anxiety about job losses in fields like law and journalism that never worried about automation before. And the predictions of rapid obsolescence for store clerks, security guards and fast-food workers, as well as for truck, taxi and delivery van drivers.

Meet my colleague, the robot

But then, bank tellers were supposed to become obsolete, too. What happened instead, says Bessen, was that automation via ATMs not only expanded the market for tellers, but also changed the nature of the job. As tellers spent less time simply handling cash, they spent more time talking with customers about loans and other banking services. "And as the interpersonal skills have become more important," says Bessen, "there has been a modest rise in the salaries of bank tellers" and an increase in the number of full-time rather than part-

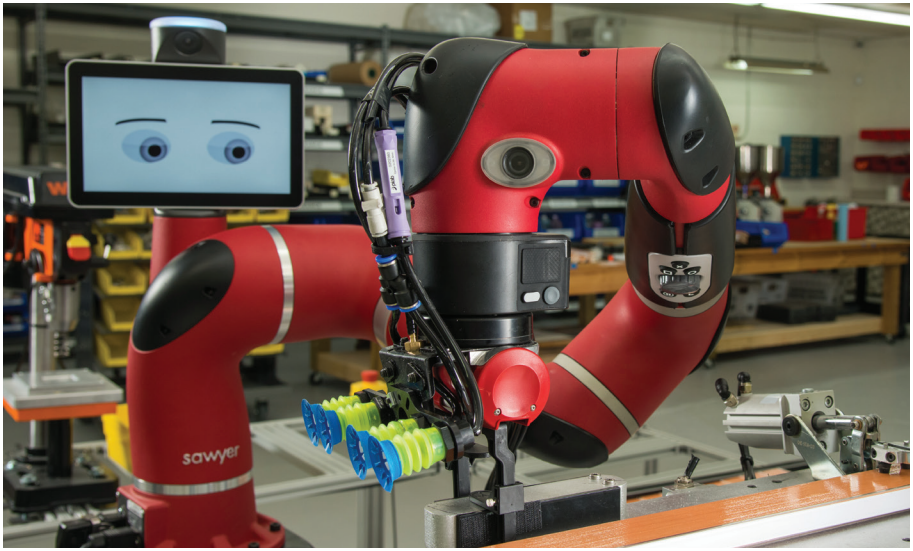
A job is greater than its tasks: Every job, from janitor to CEO, is a mix of individual tasks that fall somewhere between hard to automate with today's technology (red), and easy to automate (blue). At the same time, each type of task makes up a certain percentage (circle size) of the work in any given industry sector. Taken together, these measures suggest that a sector such as manufacturing (second row from top) may be ripe for additional automation because it still involves quite a lot of predictable physical work (large blue circle, right). In contrast, the healthcare and social assistance industry (fifth row from bottom) requires managing others and using expertise (red circles, left), tasks that aren't very feasible for automated systems.

Automation is technically feasible for many types of activities in industry sectors, but some activities can be more affected than others.



In practice, automation will depend on more than just technical feasibility. Five factors are involved: technical feasibility; costs to automate; the relative scarcity, skills, and cost of workers who might otherwise do the activity; benefits (eg, superior performance) of automation beyond labor-cost substitution; and regulatory and social-acceptance considerations.

[1]**Agriculture** includes forestry, fishing, and hunting; **other services** excludes federal-, state-, and local-government services; **real estate** includes rental and leasing; **administrative** includes administrative support and government administration; **healthcare and social assistance** includes private, state-government, and local-government hospitals; **professional** includes scientific and technical services; **educational services** includes private, state-government, and local-government schools.
[2]Applying expertise to decision making, planning, and creative tasks.
[3]Unpredictable physical work (physical activities and the operation of machinery) is performed in unpredictable environments, while in predictable physical work, the environments are predictable.



Sawyer, a collaborative robot made by Rethink Robotics, is one of many such "cobots" designed to work safely alongside humans on the shop floor. Sawyer guides its movements with a computer vision system, uses force feedback to know how hard it is gripping (and to keep from crushing things), and can be trained to do a new task simply by guiding its seven-jointed arm through the required motion. The expression of the eyes on the display screen change to indicate Sawyer's status, from "working well" to "needs attention."

CREDIT: COURTESY OF RETHINK ROBOTICS INC.

time positions. "So it's a much richer picture than people often imagine," he says.

Similar stories can be found in other industries. Even in the era of online shopping and self-checkout, the employment numbers for retail trade are going up smartly. The fact is that, even now, it's very hard to completely replace human workers.

Steel mills are an exception that proves the rule, says Bryan Jones, CEO of JR Automation, a firm in Holland, Michigan, that integrates various forms of hardware and software for industrial customers seeking to automate. "A steel mill is a really nasty, tough environment," he says. But the process itself — smelting, casting, rolling, and so on — is essentially the same no matter what kind of steel you're making. So the mills have been comparatively easy to automate, he says, which is why the steel industry has shed so many jobs.

When people are better

"Where it becomes more difficult to automate is when you have a lot of variability and customization," says Jones. "That's one of the things we're seeing in the auto industry right now: Most people want something that's tailored to them," with a choice of color and accessories. Every vehicle coming down the assembly line might be a bit different.

It's not impossible to automate that sort of flexibility, says Jones. Pick a task, and there's probably a laboratory robot somewhere that has mastered it. But that's not the same as doing it cost-effectively, at scale. In the real world, as Akella points out, most industrial robots are still big, blind machines that go through their motions no matter what is in the way, and have to be caged off for safety's sake. With machines like that, he says, "flexibility requires a ton of retooling and a ton of programming — and that doesn't happen overnight."

Contrast that with human workers, says Akella. Reprogramming is easy: "You just walk onto the factory floor and say, 'Guys, today we're making this instead of that.'" Better still, people come equipped with talents that few robots can match, including hand-eye coordination, fine motor control and ability to deal with the unexpected.

To help those human workers, many manufacturers are investing heavily in collaborative robots or "cobots," such as Rethink Robotocs' Sawyer (see photo). Cobots represent one of the fastest-growing categories of industrial automation today.

AI and its limits

Akella's current firm, Drishti, also offers AI software for assisting workers. Details are proprietary, but the basic idea is to use computer vision technology to function like a GPS for the assembly line, giving workers turn-by-turn instructions and warnings

as they go. Say that a worker is putting together an iPhone, and the overhead camera believes that only three of four screws were secured: "We alert the worker and say, 'Hey, just make sure to tighten that screw as well before it goes down the line.' "

This does have its Big Brother aspects, admits Drishti's marketing director, David Prager. "But we've got a lot of examples of operators on the floor who become very engaged and ultimately very appreciative," he says. "They know very well the specter of automation and robotics bearing down on them, and they see very quickly that this is a tool that helps them be more efficient, more precise and ultimately more valuable to the company."

This theme — using technology to help people do their jobs rather than replacing people — is likely to be a feature of AI applications for a long time to come. Just as with robotics, there are still some important things that AI can't do.

Take medicine. Deep learning has already produced software that can interpret X-rays as well as or better than human radiologists, says Darrell West, a political scientist at the Brookings Institution in Washington, DC. "But we're not going to want the software to tell somebody, 'You just got a possible cancer diagnosis,' " he says. "You're still going to need a radiologist to check on the AI" — and then, if the results are bad, a cancer specialist to break the news to the patient and plan treatment.

Likewise in law, AI can be a huge help in finding precedents relevant to a case — but not in interpreting them, or using them to build a case in court. More generally, says Guszcza, deep learning is good at identifying features and focusing attention. But it falls short on things like dealing with surprises and applying common sense — "all the things that humans are very good at."

Job evolution

AI's limitations are another reason why economists like Bessen don't see it causing mass unemployment anytime soon. "Automation is almost always about automating a task, not the entire job," he says. And while every job has at least a few routine tasks that could benefit from AI, there are very few jobs that are all routine. In fact, says Bessen, of all the jobs listed in the 1950 census, "there was only one occupation that you could say was clearly automated out of existence — elevator operators." There were 50,000 in 1950, and effectively none today.

On the other hand, you don't need mass unemployment to have massive upheaval in the workplace, says Lee Rainie, director of internet and technology research at the Pew Research Center in Washington, DC. "The experts are hardly close to a consensus on whether robotics and artificial intelligence will result in more jobs, or fewer jobs," he says, "but they will certainly change jobs."

Preparing for the future of work

The resulting era of constant job churn could force some radical changes in the wider society. Suggestions from Pew's experts and others include an increased emphasis on continuing education and retraining for adults seeking new skills, and a social safety net that has been revamped to help people move from job to job and place to place. There is even emerging support in the tech sector for some kind of guaranteed annual income, on the theory that advances in AI and robotics will eventually transcend the current limitations and make massive workplace disruptions inevitable, meaning that people will need a cushion.

This is the kind of discussion that gets really political really fast. At the moment, says Rainie, Pew's surveys show that it's not really on the public's radar: "There are a lot of average folks, average workers saying, 'Yeah, everybody else is going to get messed up by this — but I'm not.... I can't imagine how a machine or a piece of software could replace me.' "

But it's a discussion that urgently needs to happen, says West. Just looking at what's already in the pipeline, he says, "the full force of the technology revolution is going to take place between 2020 and 2050. So if we make changes now and gradually phase things in over the next 20 years, it's perfectly manageable. But if we wait until 2040, it will probably be impossible to handle." ●

ASSOCIATED ANNUAL REVIEWS CONTENT

How Technology Is Changing Work and Organizations

W.F. Cascio & R. Montealegre / *Annual Review of Organizational Psychology and Organizational Behavior*

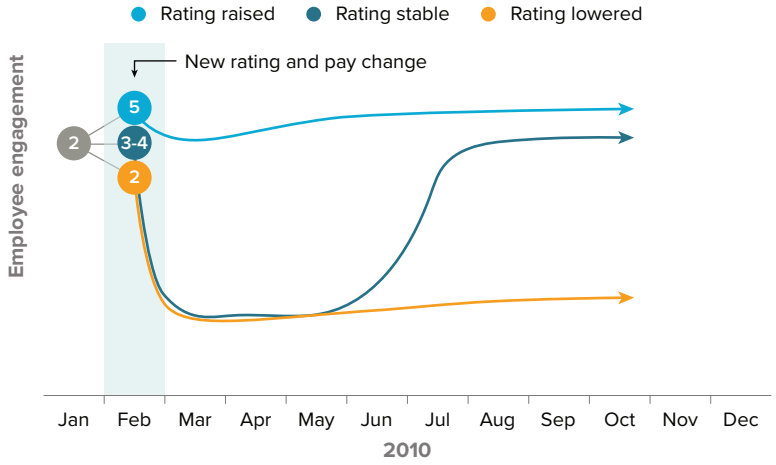
Is it time to bring data to managing?

TRENDY OFFICE LAYOUTS. PERFORMANCE REVIEWS THAT CRUSH MORALE. THERE'S PLENTY OF EVIDENCE ON HOW TO GET THE BEST OUT OF WORKERS, BUT BUSINESSES OFTEN IGNORE IT.

BY ERYN BROWN

A DEMOTIVATING APPRAISAL SYSTEM

Instead of improving performance and morale, changes to the ways employees were assessed wreaked havoc at a large company and demoralized employees, industrial-organizational psychologist Alan Colquitt found. A shift from a three-point to a five-point rating scale moved people who were performing just fine (former twos) to new positions on the scale. Some were elevated to top-performing fives (blue line). Others were kept at middling threes or fours (teal line). Still others were demoted to twos (orange line). After receiving the new ratings — and with them, related changes in pay — employees' feelings toward the company and their job performance plummeted, as measured in surveys of engagement. Even people who were newly rated as fives showed slight dips in engagement. Engagement rose again over time, but more slowly for those with lower ratings.



ALAN COLQUITT is a student of the ways people act in the workplace. In a corporate career that spanned more than 30 years, the industrial-organizational psychologist advised senior managers and human resources departments about how to manage talent — always striving to "fight the good fight," he says, and applying scientific rigor to his job.

Should executives ask employees for hiring referrals? Colquitt would consult the research to see if that would bring in better candidates. How to get more women into senior management? Colquitt would dig into studies that revealed the reasons for the stubborn endurance of the glass ceiling.

And then he hit a ceiling of his own.

A Fortune 500 firm where he worked had put in place a compensation system that was making employees miserable. Colquitt hadn't implemented the system, which gave better raises and bonuses to those who scored high on a five-point performance scale. But people complained to him about it, incessantly. He decided to push upper management for change.

True to his roots, Colquitt reviewed the published literature and combed through internal data to show higher-ups where things were going wrong. The evidence led him to a stark conclusion: The firm's performance assessments and pay structure were completely counterproductive, reducing happiness of individual workers and hurting the enterprise as whole.

Colquitt recommended that his employer scrap the system. The company's CEO backed him, but others in the organization pushed back hard.

Colquitt kept arguing. No dice. After a couple of years, exhausted and ready for a career shift anyway, he gave up. He left corporate life and became an affiliate research scientist at the Center for Effective Organizations at the University of Southern California. He began teaching, speaking and writing, and published a book — *Next Generation Performance Management: The Triumph of Science Over Myth and Superstition* — in 2017.

"I was pretty outraged by it all," he says today. "What we do in organizations has very little relationship to what the science says we should do."

Getting companies to pay attention to science and engage in so-called "evidence-based management" is a challenge that has been driving industrial-organizational psychologists nuts for the better part of 20 years. Whether it's hiring staff or determining salaries or investing in technology, managers making high-stakes decisions have a vast scholarly literature at their disposal — studies conducted over more than a century, in labs and in the field, vetted through peer review, that show whether pay incentives drive internal motivation (often not); whether diversity training works (only under the right conditions); whether companies should get rid of performance ratings (yes, Colquitt

OPPOSITE PAGE CREDIT: MARINA MUUN; THIS PAGE SOURCE: NEUROLEADERSHIP INSTITUTE

would say); how to train effective teams; and more.

Executives love hard numbers, and they desperately want to know how to keep their best employees, how to make more widgets, how to be more creative. So you'd think they'd lap up the research. "It's hard to find students in graduate school who don't hear the idea of evidence-based management and say, 'Yes! Of course!'" says Neil Walshe, an organizational psychologist who teaches the approach at the University of San Francisco School of Management.

Except most companies don't. Occasionally, a firm will make a splash — the poster child these days is Google, which gets kudos for its data-centric, research-based "People Operations" (aka human resources) department. But most executives would rather copy another company's ideas than assess evidence relevant to their own circumstances. Managers falter — victims of inertia ("we've always done things this way!") confusion ("industrial-organizational *what*?"), or even downright hostility to expertise.

Interest in evidence-based practices may get a boost as more and more companies start delving into data analytics the way Google has, observing their own operations and putting the information to use in thoughtful ways. Perhaps, proponents hope, managers who open their minds to analytics will also open their minds to other new ways of thinking, seeing the value in evidence.

Or maybe human nature will keep getting in the way.

"There are really good reasons why people don't use evidence, and changing that is hard," Colquitt says.

The science of business

Science-inspired ideas have been applied to business since at least 1911, when mechanical engineer-turned-management consultant Frederick Winslow Taylor's *Principles of Scientific Management* applied insights from engineering to improve efficiency, arguing that "the best management is a true science, resting upon clearly defined laws [and] rules."

Taylor worked with Bethlehem Steel to optimize the volume of pig iron a worker could load onto railroad cars in a single day. He studied "the tiring effect of heavy labor" and tasked a young assistant to look up "all that had been written on the subject in English, German and French." He conducted experiments to figure out how much iron a man could consistently haul and through a process of analysis determined that a "first-class man," with the right strength and pacing, should be able to manage 47 tons. He urged managers to move workers who couldn't handle such a load into other roles.

In later decades, researchers studied industrial behavior with ever-increasing rigor, and the field of industrial-organizational psychology was born. Academic work increasingly informed business practices. During World War I, the military used assessments to place soldiers in jobs where they'd be most successful. In the 1920s and 1930s, a series of famous studies at Western Electric's Hawthorne plant in Cicero, Illinois, influenced managers to pay attention to social interactions on teams.

Japan's postwar economic boom was also built on research, including the 1950s-era innovations of statistician W. Edwards Deming, who focused on product

RESEARCH-HEAVY RESOURCES

Good evidence can be hard to come by, but these resources may help:

The Center for Evidence-Based Management, or CEMBa, is a nonprofit devoted to helping managers, academics and others learn more about evidence-based management. CEMBa holds annual meetings, releases a newsletter and keeps participants up to date on emerging ideas.

Science for Work is a nonprofit company that combs through the relevant scientific literature and summarizes the findings and implications into five-minute reads.

Google's re: Work shares management insights from the company's lauded, evidence-oriented People Operations department and from other companies.

quality, among other things, as a driver of business success. It didn't take long for American companies to adopt "total quality management," as the trend became known in the United States, when Japanese firms began to threaten American predominance.

With the start of the twenty-first century, another concept was percolating up through the industrial-organizational psychology ranks: an approach called "evidence-based management," championed by Carnegie Mellon professor Denise Rousseau, who spoke on the subject in Honolulu in 2005 at a meeting of the Academy of Management.

Rousseau had assumed that companies paid attention to the research she and her colleagues so carefully produced, but slowly it began to dawn on her that that wasn't the case. It was an epiphany that "blew my mind," she says today. Managers rejected scientifically proven strategies and refused to abandon practices the literature didn't support — things like paying executives outlandishly more than rank-and-file employees. Bosses made decisions based on gut feeling. They copied blue chip companies like General Electric and Coca-Cola, even when what those outfits did had little relevance. They chased trends.

Rousseau and other industrial-organizational psychologists thought this seemed like a colossal waste of time, effort and money. They saw a model for change in a movement called evidence-based medicine, which urges physicians to consider the best available external evidence when deciding how to treat patients. Increasingly, beginning in the 1990s, doctors were expected to lean on research, not just go with their guts.

Shouldn't businesspeople, similarly, take stock of the work that psychologists had so carefully produced?

"It's time to start an evidence-based movement in the ranks of managers," exhorted Stanford Business School scholars Jeffrey Pfeffer and Robert I. Sutton in 2006 in the *Harvard Business Review*. The pair tartly opined that if doctors practiced medicine the way managers practiced management, the morgues would be packed and the courts brimming over with malpractice lawsuits. Managers should "relentlessly seek new knowledge and insight" to hone key practices, the professors said.

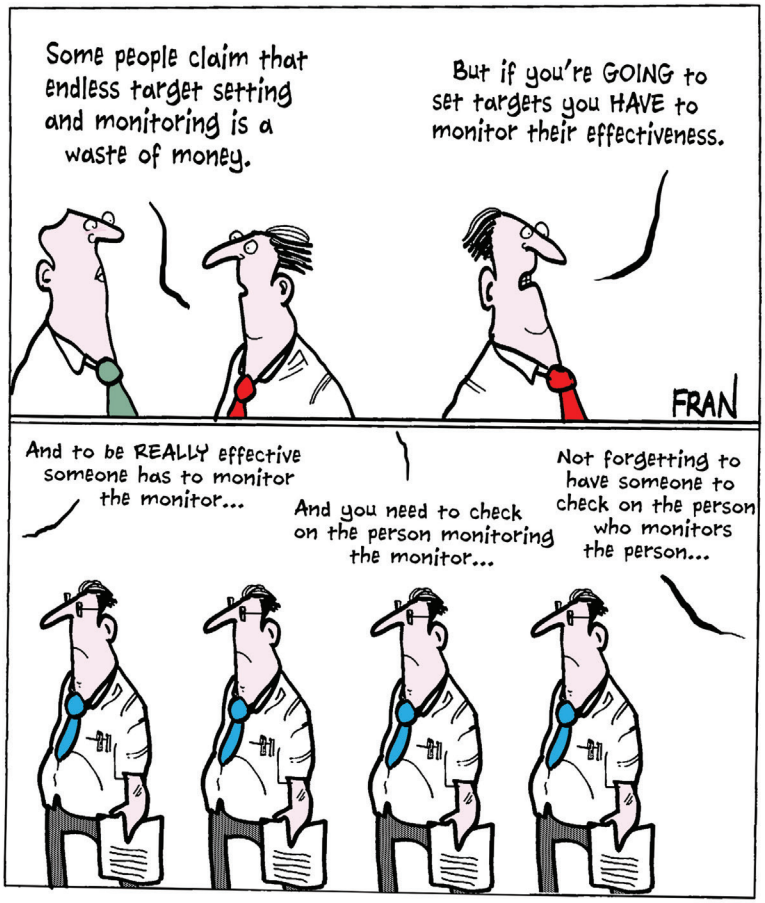
> "What we do in organizations has very little relationship to what the science says we should do."
>
> —ALAN COLQUITT

The idea took root. Researchers like Rousseau wanted companies to read their papers, to be sure — but they also urged critical thinking in a broader sense, in which everything from science to internal surveys to gut feelings is considered in a systematic way, following a six-step process. The concerns of evidence-based managers are "Why are we doing this? What is the problem we're trying to solve? How do we know the solution will solve the problem?" says Eric Barends, managing director of the nonprofit Center for Evidence-Based Management.

Worried about revealing trade secrets, companies are loath to talk openly about their real-world experiences with evidence-based management. Still, the approach can yield results. Take the case of one company that couldn't retain software engineers. It asked Cheryl Paullin, a Minneapolis-based industrial-organizational psychologist with the Human Resources Research Organization, a nonprofit that advises HR departments, if it should raise salaries to keep programmers on board.

Reviewing the academic literature and a variety of metrics within and outside of the company, Paullin and her colleagues determined that programmers were leaving not because of pay but because they weren't getting the training they wanted. "We were able to say: 'Don't try to keep them by focusing on their pay — that's not what's causing the problem,'" Paullin says.

In another case, documented by Barends for a forthcoming evidence-based management textbook, Ctrip, the largest travel agency in China, conducted a randomized trial to help determine if allowing call center employees to work from home would improve their individual performance (several academic studies suggested it would). The company chose 250 employees for the three-month-long experiment, assigning those with even-numbered birthdays to work at home and those with odd-numbered birthdays to work in the office. Remote workers increased their performance by 13.5 percent over their colleagues in the office and used fewer sick days, too. "Stunned" by the result, Ctrip's CEO decided to adopt remote working for all call center employees.



Cartoons about absurd management decisions resonate with many.

CREDIT: FRAN / CARTOONSTOCK

Or there's the far from straightforward problem of assigning salary ranges to different types of workers. To evaluate jobs and set pay, many companies still rely on outdated systems designed in the 1940s that assign higher salaries to people who are managers or in charge of budgets and give short shrift to newer sorts of jobs that are very valuable to twenty-first century firms — roles like project management or functions requiring expert skills and knowledge, says Philipp Schuch, a cofounder of Gradar.com, a Dusseldorf, Germany-based HR tech startup.

So Gradar is using an evidence-based approach to build a web-based job evaluation tool that it hopes will do better. It spent months studying existing systems to understand what criteria they used to grade jobs and derive pay scales, then conducted a comprehensive literature search to come up with updated, requirements-based criteria more sensible for today's workplace: things like responsibility for key functions and projects, and not just people and organizational responsibility.

The company built a pilot system, then tested it over and over to validate its results against established systems. Then they built an online system and tested and retested again (verification is a crucial part of an evidence-based approach). Today, more than five years after Schuch and colleagues began thinking about Gradar, the company is working with 100 medium to large companies around the world.

They range from auto parts manufacturers to theater companies to universities — "and it still works across all the different jobs. We get consistent results," says Gradar cofounder Ralf Kuklik.

Why managers won't commit

Schuch and Kuklik are believers in their tool, but they're also realists. Schuch worked for years at large German companies and has paid attention to what other companies do with evidence-based management.

"It's not much, honestly," he says.

That's a common refrain.

"We'd love to see a commitment from a leader that says, 'I expect our decisions about people and work and the organization to have evidence behind them,'" says John Boudreau, research director at the Center for Effective Organizations, housed in USC's Marshall School of Business. "I don't know that I have seen examples of that. Especially at the high level, the CEO level."

"I'm a little baffled that it's not more widespread," says Jennifer Kurkoski, director of Google's People Innovation Lab

CASTING A WIDE NET

Evidence-based management doesn't just mean considering the conclusions of academic studies. Instead, it's an iterative process that requires managers to seek out multiple streams of information, figure out how to apply them to the problem at hand, and then assess the results. Evidence can come from a range of sources, including:

Scientific studies that use rigorous methods to ask and answer a well-defined question.

Practitioners who are immersed in the field and have amassed qualitative expertise.

Organizations in possession of relevant internal data.

Stakeholders, including employees and managers, who have on-the-ground, practical knowledge.

(PiLab). "Companies spend billions on R&D, almost none of which is devoted to making people work better. It's not something we understand yet. And we should."

But there are many reasons why managers have been slow to embrace evidence-based management.

It's a lot of work. Companies must spend a great deal of time, effort and money to assimilate research findings, or to test and validate new policies or systems. "Most people want to put things in place quickly, and get it done," says Elaine Pulakos, president of PDRI, a Washington, DC–based talent management company. Executives, always with an eye on the bottom line and the next quarter's results, often see this sort of research as overhead they can't afford.

People fear change and risk. Even though an evidence-based management approach may ultimately yield better results, the perceived safer route is hewing to well-known "best practices" championed by other companies, and promoted by consultants who may or may not have done rigorous study. "People get enamored with something they can easily implement that someone else has tried before them," says Pulakos. If Exxon Mobil or Google has scored with some initiative, she adds, "it makes it safe." But maybe irrelevant, too.

Managers put more faith in intuition than they put in science. "We're all experts on human behavior, right?" jokes organizational psychologist Ed Lawler, of USC's Center for Effective Organizations. It's an abiding sense that's often flawed. Sometimes, research reveals that algorithms are better than people at particular tasks, such as initial screenings for new hires. But "people tend not to like findings that don't present humans in a good light," says Sara Rynes, an industrial-organizational psychologist at the University of Iowa.

Parsing the scientific literature can be hard. Managers, unlike doctors, aren't required to have any kind of advanced training, and often can't read a scholarly report or engage in the statistical analysis needed to understand internal employee data. At the same time, academics catch fire for not making their findings more readable, or for publishing their work in prestigious journals that keep studies hidden behind paywalls — pushing managers toward popular business books and articles that don't always present research correctly.

"It's hard to find the research, and it's hard to read, and it's hard to interpret," Colquitt says. "There are so many more channels to get information … it's hard for leaders or HR professionals to sort the wheat from the chaff."

Making matters worse — ironically — the very people who champion the science-based approach haven't yet proved that it works with the kind of rigorous study that they would like. In that sense, "the evidence for evidence-based management is almost nonexistent," admits Rob Briner, an industrial-organizational psychologist at the Center for Evidence-Based Management.

In a paper in the *Annual Review of Organizational Psychology and Organizational Behavior* in 2017, Rynes and coauthor Jean Bartunek of Boston College examined 134 scholarly articles about evidence-based management. Most were essays and other pieces advocating or criticizing the approach, talking about

how to teach it, and the like. Only about a fifth were empirical studies reporting research or reviewing such studies. The authors highlighted just a handful of those as "exemplary" — noting that many focused on small numbers of subjects and relied on self-reporting from managers for data, a method "known to be fraught with numerous biases and opportunities for error."

"People want more evidence that when people use our studies it actually does something," says Rynes.

As Google goes . . .

Advocates for evidence-based management think their approach may start looking more interesting to more people now that companies are embracing big data analytics — slicing and dicing truckloads of behavioral information, much of it collected through internal workplace computer systems, to dig up insights. Some of this information sits in databases, other bits are embedded in operational systems, and can be mined.

Here, Google reigns supreme. It's in the business of collecting and analyzing information, after all. Kurkoski's team, heavy with PhDs, questions all kinds of assumptions about organizations. Then it consults the research, tries to find data within its operations to shed light on the question, and tests new ways to solve problems. Questions like: "Do managers matter?" (yes, because the best ones boost job satisfaction among workers); "Why are women leaving our company?" (industry-standard, 12-week maternity and paternity leaves are too short); even "What shape of lunch table will get coworkers talking?" (a long one).

> "People want more evidence that when people use our studies it actually does something."
>
> —SARA RYNES

Kurkoski is close-lipped about a lot of what Google does — she won't share how many people are on PiLab's staff, for instance — but the company has earned a lot of attention for its work in the business and popular press. A 2016 article in the *New York Times Magazine*, for instance, detailed a 2012 initiative known as "Project Aristotle," designed to figure out what made effective teams work and what made bad ones fizzle. The company ultimately homed in on "psychological safety" — how comfortable workers feel taking risks, a well-studied subject in the organizational psychology canon.

The brilliance of Google's approach was the way it used science to encourage workers to talk about their feelings, one Google manager who went on to apply the findings told *The Times*. "By putting things like empathy and sensitivity into charts and data reports, it makes them easier to talk about," he said.

Colquitt is among those who think the new rage for data analytics might spark renewed interest in evidence-based management — the operative word being "might." He pounds out blog posts, stuffed with research citations, when the NFL decides to fine players who don't stand for the national anthem, or when United Airlines toys with converting its bonus system into a winner-takes-all-lottery. He's digging deeper into the problem of performance management and pay.

And the fodder keeps coming. Studies that find open offices don't, in fact, encourage conversation and collaboration. Studies that find employees resent the corporate fad of hot-desking — jumping from desk to desk instead of having a dedicated workspace, based on a notion that this will spark synergies and blue-sky thinking.

In one recent paper calling on industrial-organizational psychologists to put "an end to bad talent management," Colquitt and his coauthors called out companies who fall for consultants promising to help them understand "the brain science of millennials" and other trendy topics, with little or no evidence for any of it.

"We needed to write about it and put these things to bed," Colquitt says. "But no one reads these papers anyway — so they won't stay in bed long."

Then it's back to the talks and the blogs and the books, and fighting that good fight. ●

ASSOCIATED ANNUAL REVIEWS CONTENT

Evidence-Based Management: Foundations, Development, Controversies and Future

S.L. Rynes and J.M. Bartunek / *Annual Review of Organizational Psychology and Organizational Behavior*

Q&A

Legal scholar Joan Williams

What will it take to fix work-life balance?

It's time to toss out the idea that dedicated professionals must always be on the clock or that retail shops will founder if they standardize employee hours, legal scholar Joan Williams says in a Q&A. The data tell a different tale.

By Jyoti Madhusoodanan

GONE ARE THE DAYS WHEN splitting "breadwinner" and "homemaker" roles was the norm. Today, in seven out of 10 families with children, both parents are employed. Since 1965, women have nearly tripled the time they spend on paid employment, and men have doubled their hours tackling chores or childcare — both, in other words, are doing more.

All that effort exacts a steep price: Many adults find it difficult to keep up with work and family responsibilities. And yet decades worth of data show that a saner work-life balance — whether achieved via more flexible hours, facilities such as lactation rooms, or job-sharing arrangements — can benefit employees and employers alike.

Companies that institute flextime policies, for example, find that employees are more satisfied, less likely to quit and better at raking in profits for the business. Flexible work hours may also attract more talent, reduce absenteeism and help people do their work more effectively overall.

These changes can add up to big business savings. One bank, for example, trained managers at certain branches to be more accommodating of people's personal lives and found that employees stayed with these branches longer — and so did customers. Over two years, that loyalty added up to an extra $106 million in profits.

But workplaces have been slow to embrace these ideas — why so? One big reason is the link between work and social status, says legal scholar Joan Williams of the University of California Hastings College of the Law. Writing in the *Annual Review of Psychology*, she and her colleagues note that for many high-level, highly paid jobs, putting in long hours is considered a show of strength, and constant availability a sign of dedication.

Now director of the university's Center for WorkLife Law, Williams recalls finding the work-life juggle so tough at times that she was tempted to quit her job after having children. *Knowable Magazine* spoke with Williams about why the struggle persists. This conversation has been edited for length and clarity.

What policies are most needed to improve work-life balance?

One is to address extremely long hours, which make it so that the only person who can hold a high-level job is the breadwinner, supported by a flow of family caregivers. The solution there is to make more realistic work hours.

The second concerns the rigidity of when and where you work. Japan, for example, has an unrelenting face-time culture, so that precludes things like flextime to accommodate, for example, a well-baby visit. The solution there is to make the workplace less rigid, so that employees have more control on both when and where they can work.

The truly important policy is to redefine what constitutes full-time work. We need to redefine the ideal worker in a way that's consistent with people's values for their families, including being present for family responsibilities such as childcare and eldercare.

Why is it difficult to implement policies that improve work-life balance?

For a long time we've been talking to employers about the business case for workplace flexibility. But the problem to overcome is not about money, it's about identity.

CREDIT: MARINA MUUN; JAMES PROVOST

The way we've defined the ideal worker means that people who have been successful have sacrificed the other areas of their life in order to achieve workplace success. These people, now managers, have a tremendous amount personally invested in their belief that the only way to be a successful professional is to be an always-on worker who outsources daily childcare and much of the emotional work involved with raising children.

To come in and say to them, "You can organize this work differently" is very threatening. Because then — why did they themselves give up all that? It feels like being told you've been a bad parent. That's a painful thing to admit.

Are there other social or cultural obstacles to change?

People think long hours are about making money. But they're not. Time norms have always been a way of signifying elite status. In the US, it used to be that the less you worked, the more elite you were, encapsulated in the term "bankers' hours" — bankers only worked 9 a.m. to 3 p.m. Now it's the more you work, the more elite you are. "I'm slammed" is a polite way of saying "I'm important."

Are companies starting to realize the importance of work-life balance for professional employees?

I know there has been an arms race over parental leave in Silicon Valley, for example, such that companies are offering better and better parental leave policies. That's commendable and important. On the other hand, it doesn't take three or 10 months to raise a child, it takes 20 years. I haven't heard about Silicon Valley firms embracing flexible work policies like job shares, telecommuting, non-marginalized part-time schedules or flextime. Those are quite different from paid leave.

You started out studying executives, but later you focused your research on the schedules of hourly paid retail employees. What motivated the change?

I've stopped working with companies on work-life issues for professionals because I saw so little progress, unfortunately. But though we didn't see the potential for real improvement for professionals, we did see that potential around issues that commonly arise for hourly paid workers in retail.

In their case, they usually don't have too little flexibility — they have too much. They typically have "just-in-time" schedules: working different times every day and different days every week, usually with three days' notice of their schedule. And given that low-income families in the US often rely on networks of family and friends for childcare, it means they're relying on people who might also have these just-in-time schedules.

This leads to a pattern of serial quitting because they can't plan ahead. In some industries with these schedules, such as hospitality or retail, documented turnover rates have been between 100 and 500 percent a year.

And it's not in employers' interests. A decade of studies has shown that this lean scheduling — keeping stores very short on work hours for employees — decreases sales.

> "People think long hours are about making money. But they're not. Time norms have always been a way of signifying elite status."
>
> —JOAN WILLIAMS

You tested a stable scheduling system at the Gap where, among other things, stores eliminated tentative, on-call shifts and gave workers two weeks' advance notice of work hours. How did these changes help the retailer?

This is the first study to show that a shift to stable scheduling can increase sales by 7 percent, which is a lot in retail. You typically have to launch a major marketing campaign to see that kind of increase. And this was a very high return on investment. Gap spent around $31,200 out of pocket to increase employees' hours, and increased sales by about $2.9 million in these 19 intervention stores.

What were the reasons for that increase?

Because there's such constant turnover of employees in retail, a lot of associates don't know what the product is, or where it is. Many of us have walked out of retail stores because we couldn't find a size, or the line was too long at the cashier.

In the intervention stores, we saw a decrease in turnover among more experienced associates. So customers would walk in and it'd be easier to find somebody to help, the person would be more likely to help with the product and be more skilled at actually helping.

Were you surprised that these apparently small things would matter so much?

I was kind of stunned by the results. It's not intuitive. But once you're in the stores, it makes perfect sense.

Did you find any common ground between the problems faced by hourly paid retail workers and those of high-earning professionals?

In some ways, the commonality is the definition of the ideal worker as someone who's always available to the employer. Both of these — the voracious schedules of professionals and the extraordinarily unstable schedules in retail — are justified on the grounds of business necessity. But that's not really the case.

What do employers need to do to solve these problems?

In the low-wage context, we need to communicate to the key industries affected by just-in-time schedules — namely retail, hospitality and health care — that they're leaving money on the table. What employers using these schedules don't understand is that because they're so focused on controlling labor costs, they're not making as much money as they could. They are artificially reducing sales and labor productivity. A slight increase in labor costs may well pay for itself through increased sales and more sales per hour.

In the elite context, it's a very different proposition. There has to be some way to start a conversation about new ways of working that doesn't trigger this identity-threat reaction of "What do you mean there are new ways of working? Are you saying I was a bad father?"

Are there things that employees can do as well?

It depends on the situation. For example, when the kids get old enough, you might say to them, "What are the three things between now and January that you really need me to be at, and I will move mountains to make sure I'm there." Another thing is to identify when face time is important at their job and when it isn't, so they don't have to always be present, but be there when it matters.

According to a recent Pew survey, fathers now contribute more to household chores and childcare than they did in the past. Has this eased the burden of work-life balance that rests on women?

Women still do about twice as much as men in terms of household work and childcare. What has changed is that an increasing number of younger men (we have no idea what proportion it is) feel that being a good father means being involved in the daily care of children rather than just someone who shows up to the school play. That is really the most important source for change.

We've told employers for 30 years that voracious work schedules in elite jobs were driving talented women away, and they didn't care much. But once those schedules began to drive away talented men as well, we found ourselves in a different conversation.

Have you seen any signs of change as a result of this?

Although mainstream institutions have been notably unresponsive, many entrepreneurs have founded new companies that build work-life balance into the business model.

In the legal profession, I found close to 60 organizations that have reinvented the business model in ways that bake work-life balance into the model. They gave two different flexible schedules: one was a short, 10- to 20-hours-per-week schedule, and the other was 40 to 50 hours a week, but you could work out of the home and dependably take vacations and eat dinner with your family.

The first model was adopted chiefly by women who saw themselves as stay-at-home moms, but the second was evenly distributed between both men and women.

One of the upsides of the romance with entrepreneurship is that people are using it to reinvent business models in ways that prioritize making money rather than simply enacting virtue or manliness or elite status. ●

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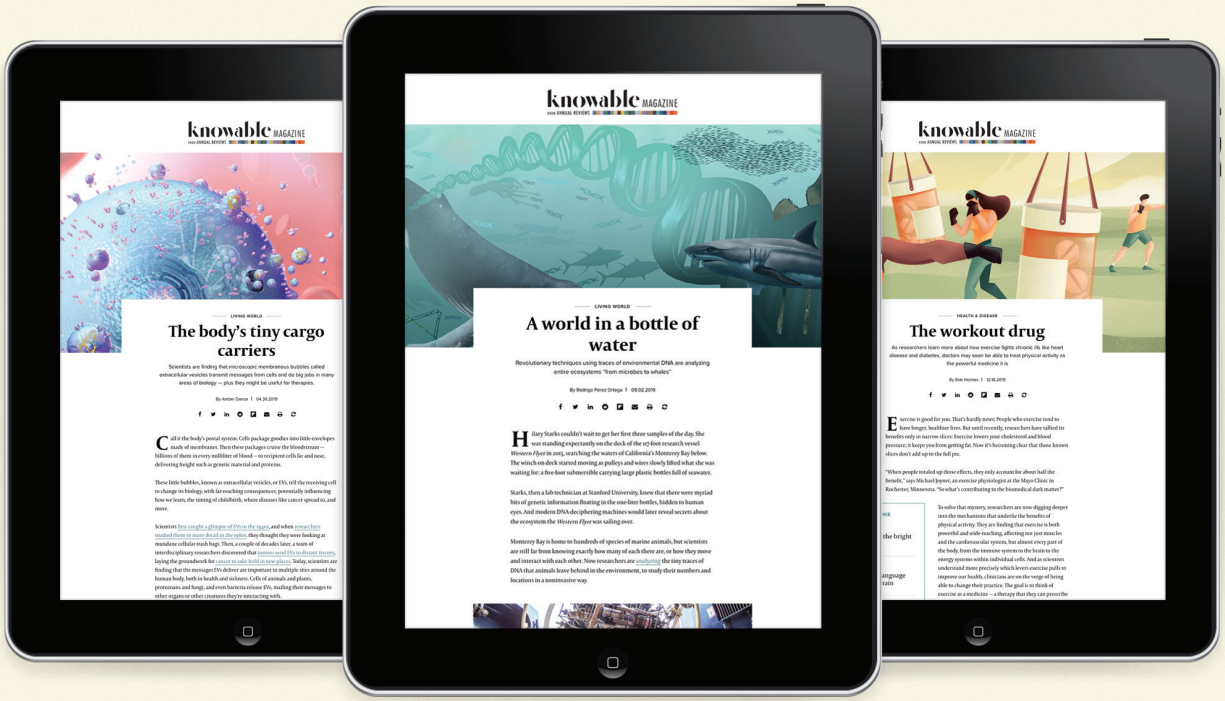
Stay in the know ... or just reach out and say hello.



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