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SCIENCE NEWS MAGAZINE
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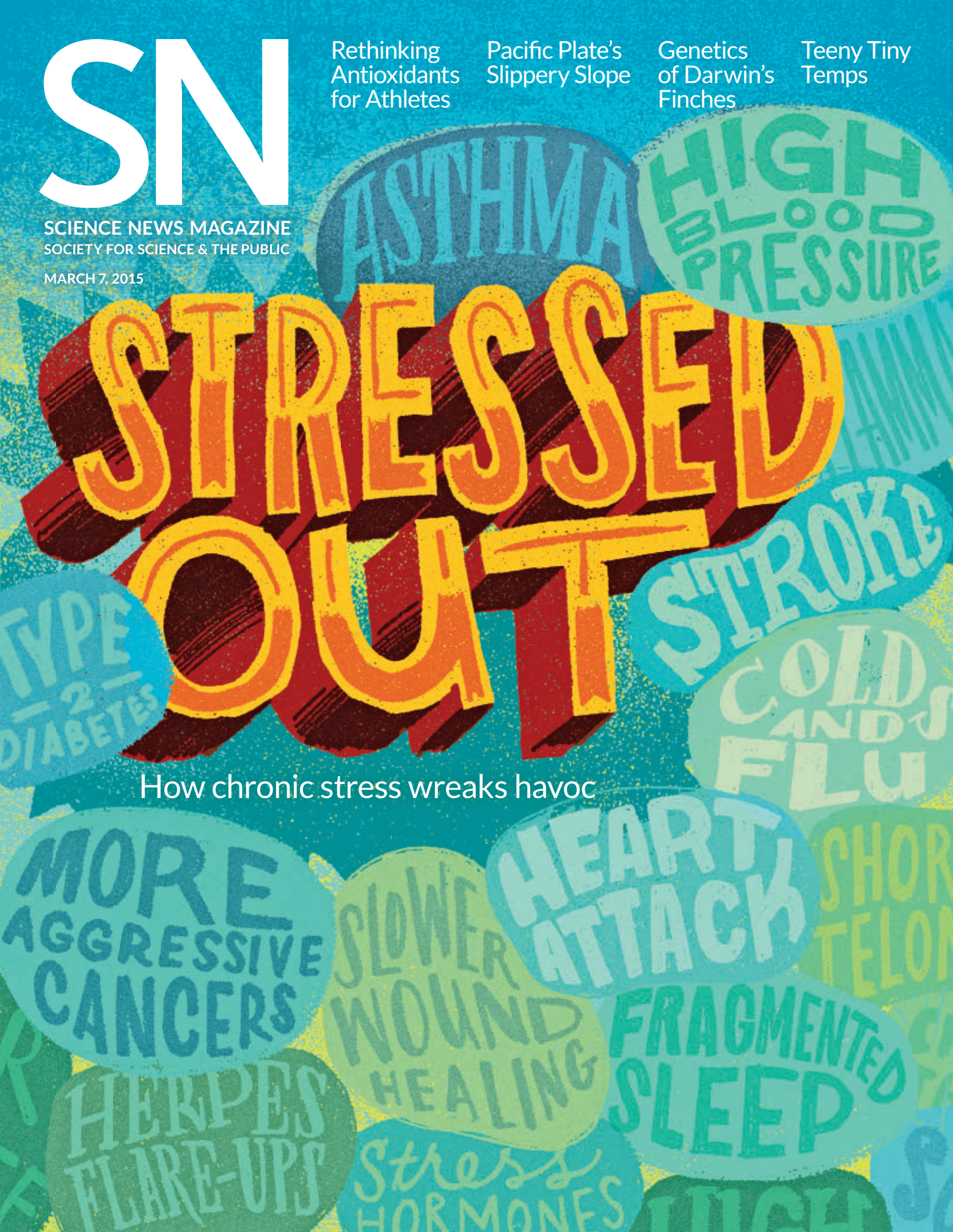
MARCH 7, 2015

Rethinking Antioxidants for Athletes

Pacific Plate's Slippery Slope

Genetics of Darwin's Finches

Teeny Tiny Temps



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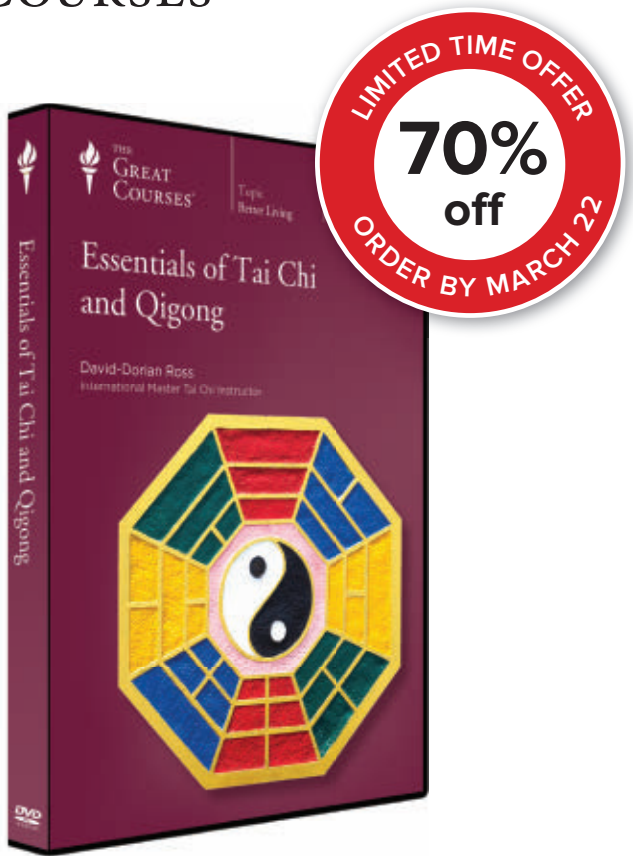

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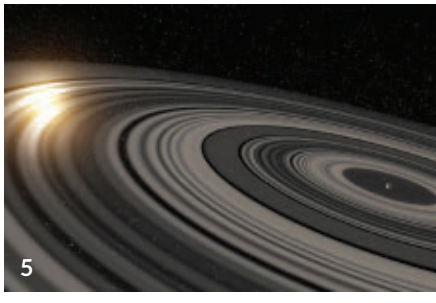

5

Departments

COVER Long-lasting stress can have negative effects that contribute to asthma, slow wound healing and heart disease. *Jeff Rogers*

CLOCKWISE FROM TOP: FISHER PHOTOSTUDIO/SHUTTERSTOCK; RON MILLER; K.T. GRANT

Why stress doesn't just stay in your head

My favorite quote in Nathan Seppa's story about chronic stress and health (Page 18) belongs to Rosalind Wright, a pulmonologist who studies links between psychological stress and diseases like asthma. Stress, she says, is "not just affecting your head."

Of course, the brain is where chronic stress starts. But its influences on the body roam far and wide, working insidiously through the neuroendocrine and immune systems, depositing its hazards on the heart, encouraging tumors and discouraging bodily defenses against colds and flu. It's not surprising that stress chips away at health; as George Bernard Shaw wrote over a century ago, "the sound body is a product of the sound mind." But Seppa reports new details about how long-lasting stress physicalizes what we experience psychologically, to our body's detriment. The latest evidence offers insights into how the psyche can sabotage the body. It also shows how very fuzzy is the line we draw between body and mind. What affects one probably influences the other, even if scientists have yet to reveal all the connections and mechanisms.

There's a bright side, however: The latest bevy of results may point to ways to stop the stress cycle, and they emphasize the importance of doing so. Identifying the molecular actors that transform stress into inflammation may lead to new targets for drugs. And even without pills, there are many effective ways to cope with stress. (Yes, the usual suspects such as tai chi and meditation are both on the list on Page 22, but so are real-time heart-rate monitoring and parenting classes.)

In another context, different kinds of stress can be good for you. As Laura Beil explains (Page 24), oxidative stress may be crucial to building up muscle efficiency. That calls into question the popular practice, based on decades-old research, of taking antioxidant supplements to boost athletic performance. In the last 10 years, more sophisticated studies have suggested otherwise, Beil reports.

Also notable in this issue are reports on slipperiness in plate tectonics (Page 6), a gene that largely controls beak shape in Darwin's finches (Page 7) and a forecast of megadroughts in the U.S. Southwest (Page 10). That last one, I hope, won't make anyone too stressed out. — *Eva Emerson, Editor in Chief*

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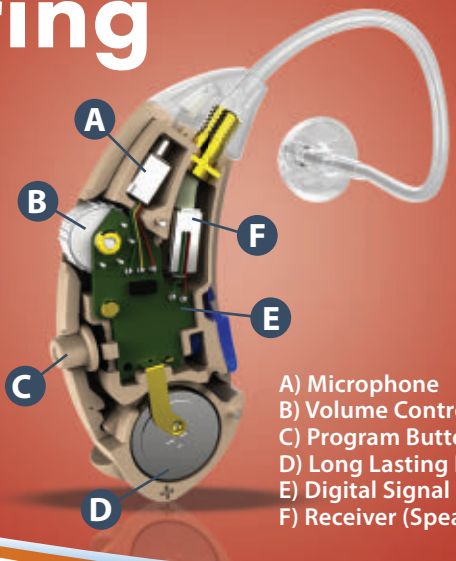

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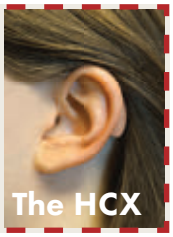

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50 YEARS AGO

Outer space on Earth

In an effort to foresee as many as possible of the problems of space travel, man is building a vast array of strange testing devices, designed to create at least part of the feeling of space.... Experiments have been undertaken in places ranging from the bottom of the ocean (which simulates low gravity) to a rocket-powered vibration machine.... The toughest test for man in space, however, will still be — when he gets there.

UPDATE: Early simulations of life in space focused on survival in temperature and atmospheric extremes. As space programs aim toward longer missions to distant targets such as Mars, quality of life has become increasingly valued. Recent bed rest studies have evaluated the effects of microgravity (*SN: 6/15/02, p. 376*), and hugely long confinement research suggests disruptions may occur in astronauts' sleep (*SN: 2/9/13, p. 8*). Psychology and teamwork — of man *and* woman — also take on critical importance in planning very long trips (*SN: 11/29/14, p. 22*).

With white feathers raised in display, a male houbara bustard throws back his head and runs for maximal allure.

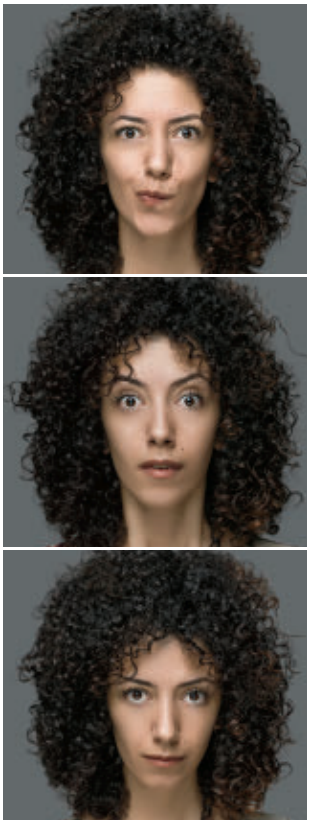
IT'S ALIVE

Flamboyant old bustards keep showing off

Nothing says romance like covering your face in white fluff and running like crazy through shrubbery.

That's the courtship display North African birds called houbara bustards (*Chlamydotis undulata*) perform repeatedly. At the peak of the breeding season, males start at dusk, around 4 or 5 p.m., and keep going until about 9 the next morning, says Yves Hingrat of RENECO for Wildlife Preservation in Abu Dhabi, United Arab Emirates. When it's showtime, feathers on their necks and heads rear up in a white froth. Whether or not a female is in sight, males run, sometimes round and round a bush. During befluffed sprinting, males breathe so loudly that a person 10 meters away can hear gasps.

The finale of the shrubbery rush can include calls pitched unusually low for



SAY WHAT?

Alexithymia \uh LEHK suh THY mee uh\ n.

An inability to find words to describe one's own feelings.

Mental health workers regard alexithymia as more akin to a personality trait than to a mental disorder. Many people with psychiatric conditions such as autism spectrum disorder and panic disorder — characterized by physical symptoms with emotional causes — also display alexithymia.

Researchers find that alexithymia has the same effect on people with and without mental disorders and that it undermines the ability to describe others' feelings as well as one's own. A study appearing online January 21 in *Royal Society Open Science* found that nine of 21 young women with eating disorders had difficulty recognizing others' facial emotions and that this characteristic was probably related to alexithymia, not some inherent feature of anorexia or bulimia. The researchers also looked at 21 women who had alexithymia but no psychiatric disorders and found that seven had comparable problems identifying others' expressions of happiness, fear and other emotions. — *Bruce Bower*

FROM TOP: Y. HINGRAT; OZGURDONMAZ/ISTOCKPHOTO

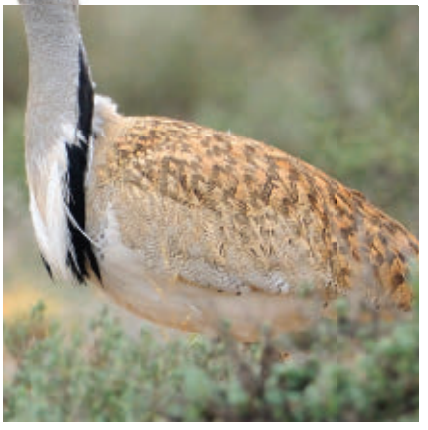
For a video of a bustard display, visit **bit.ly/SN_bustard**

a bird. When Hingrat worked at a captive breeding facility, staying late at his office meant "a concert of booms."

"Sexually extravagant" is what Brian Preston of Liverpool John Moores University in England has called the species' investment in courtship display. Males can live 23 years in captivity, so Preston and Hingrat wondered what toll such strenuous advertisement takes over time.

Male sperm quality peaks at about 4 years, with the next decade a slide downhill in sperm number and risk of malformation. And it turns out that sperm from older males retards chick growth, the researchers say February 3 in *Nature Communications*. The laggardly chicks may be poorer competitors and easier snacks for predators.

The sperm decline is so steep that it may undermine display as an indication of quality. In animals, some theories suggest that a good show in courtship indicates a good dad (in the narrowest meaning of dad). Male bustards vary in how much of the year they devote to all-night fluffing, sprinting and booming. The more dedicated flirts as youngsters are still extreme in old age, sometimes extending their display season to more than five months. Despite heroic efforts at self-salesmanship, old birds' sperm DNA has built up mutations. For female bustards, younger but less dedicated show-offs may be the better bets. — *Susan Milius*



FROM TOP: Y. HINGRAT; RON MILLER

FIRST

Giant rings encircle young exoplanet

Move over, Saturn. The rings around exoplanet J1407b have got you beat by a long shot. Thirty-seven rings extending 90 million kilometers from the planet — over half the distance from Earth to the sun — encircle the world. These planetary rings are the first found outside the solar system.

The rings (illustrated above) are probably shaped by moons forming around the young planet, which is 434 light-years away in the constellation Centaurus. One large gap in the rings is probably being cleared by a moon less than 80 percent the mass of Earth, astronomers report January 23 on arXiv.org.

Researchers mapped the rings using data from the SuperWASP project, a pair of observatories in the Canary Islands and South Africa. Scientists first reported the rings in 2012, when the unseen planet passed between its star and Earth, casting a series of shadows toward Earth that lasted for 56 days.

Scientists suspect that rings may be common around young giant planets. Debris that didn't fall onto the growing world is left to circle the planet, eventually sticking together to create a family of moons. — *Christopher Crockett*

SCIENCE STATS

Group protection against measles jeopardized

In the first six weeks of 2015, measles struck at least 121 people in 17 states and Washington, D.C. Most people in the United States are protected against the often severe fever and rash by having had one or more doses of the measles, mumps and rubella vaccine. But a small fraction of people either can't get the shot — they are too young or have weak immune systems — or choose not to.

The immunity of the crowd usually protects those people: Since most of the population has had measles or been vaccinated, an outbreak is unlikely to spread. But measles is so infectious that the fraction immune needs to be around 90 percent to provide "herd immunity." Seventeen states did not meet that goal in 2013, the most recent year for which data have been compiled.

California, the location of most of this year's cases, did meet the federal government's vaccination goal for children, suggesting that pockets of lower rates of vaccination exist.

90
percent
Approximate fraction of 19- to 35-month-old children needing measles vaccination to achieve herd immunity

92
percent
Fraction of 19- to 35-month-old children in the United States in 2013 who had received at least one dose of the MMR vaccine

86
percent
Fraction of 19- to 35-month-old children in Colorado, Ohio and West Virginia in 2013 who had received at least one dose of MMR

SOURCE: L.D. ELAM-EVANS *ET AL/MORBIDITY AND MORTALITY WEEKLY REPORT* 2014

EARTH & ENVIRONMENT

Earth's crust shifts over slippery base

Weak rock layer may help plates slide around planet

BY THOMAS SUMNER

Using ricocheted vibrations from dynamite blasts, researchers have glimpsed a layer of gooey material sandwiched between the Pacific Plate and the underlying mantle. If present beneath all tectonic plates, this layer of partially melted rock could help explain how tectonic plates slide around Earth's surface so easily, the researchers report in the Feb. 5 *Nature*.

"A weak, slippery base essentially decouples the plate from the sticky, underlying mantle," says Tim Stern, lead author and a geophysicist at Victoria University of Wellington in New Zealand. "This gives us a good idea about the forces required to push and pull the plates around."

Earth's outermost shell is a fragmented jigsaw puzzle of rocky plates sliding over the mantle below. The bottoms of these plates can be up to hundreds of kilometers underground, making them much too thick to drill through. Geophysicists instead typically study the deep Earth by listening to earthquake waves moving through the ground. When a downward wave hits the boundary between two layers with different compositions, part of the wave reflects back toward the surface. By eavesdropping on these echoes using seismometers, geophysicists can reconstruct the structure of Earth's interior.

Earthquake waves are too long to differentiate between underground features smaller than a few dozen kilometers thick, however. To precisely image the Pacific Plate where it dives beneath the Australian Plate near New Zealand, Stern and colleagues created their own vibrations using explosives. After placing 1,178 seismometers along an 85-kilometer stretch of New Zealand's North Island, the researchers buried 10 half-metric-ton shots and two 350-kilogram shots of dynamite 50 meters underground.

Over two nights in 2011, the team detonated one explosive charge roughly every hour. The explosions were set off between 9 p.m. and 5 a.m. to minimize the number of trucks on nearby roads shaking the ground as they passed by the seismometers. Stern says that safely detonating the charges required "military-style precision and timing."

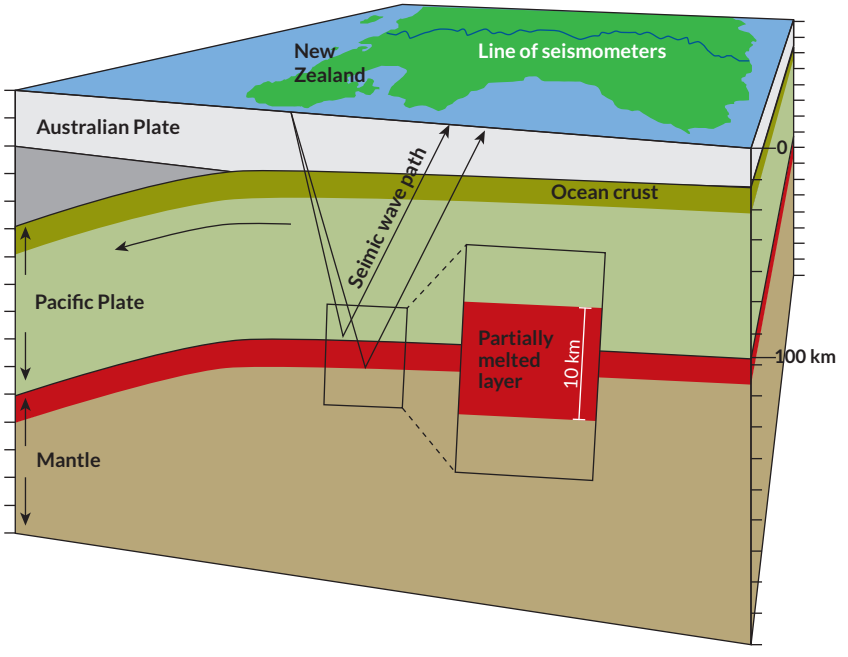
When the researchers inspected the vibrations reflected back to the surface, they were amazed to see a clear boundary less than 1 kilometer thick at the bottom of the Pacific Plate, about 100 kilometers belowground. "We only expected to look down about 30 kilometers, so it was a big surprise that we could see down so far," Stern says. "It was pure serendipity and luck that we got it."

Also surprising, Stern says, was a 10-kilometer-thick layer crammed between the plate and the mantle. Stern estimates that this layer contains about 2 percent molten rock, probably melted by the shear created as the tectonic plate grinds over the mantle. This small amount of melt drastically reduces the strength of the layer, Stern says, essentially lubricating the overlying plate's movements.

The combination of an abrupt plate boundary and a weak bottom layer probably means less force is required to move the plate around, says geophysicist Simon Klemperer of Stanford University. The team's findings suggest that the plate moves with less drag from the mantle than once thought, just like an ice-skater gliding on a thin layer of melted ice beneath her skates. This mechanism could help resolve the issue of plate tectonics appearing to require more force than available to shift the plates, a problem plaguing the theory since it first gained acceptance about 50 years ago, Klemperer says.

Stern and colleagues imaged the slippery layer beneath just one part of one plate, but previous studies may have caught fuzzy glimpses of the layer elsewhere in the world, says Vedran Lekic, a seismologist at the University of Maryland in College Park. "This discovery is so remarkable," he says, "that we really need to reconsider other data that we've looked at before and analyze them for a layer like this." ■

Slip and slide A layer of slippery, partially melted rock (red) may separate the Pacific Plate from the underlying mantle, reducing the amount of force required to shift the massive tectonic plate, new seismic research suggests.



T. STERN, ADAPTED BY E. OTWELL

GENES & CELLS

Genetic history of Darwin's finches

DNA analysis pinpoints source of birds' varied beaks

BY TINA HESMAN SAEY

Beak shape in Darwin's finches is strongly influenced by a single gene, new research suggests. Different versions of this gene push finches toward having blunt beaks (left) or pointy beaks (right).

FROM LEFT: K.T. GRANT; B.R. GRANT

Darwin's finches are once again making scientists rethink evolutionary history. A genetic analysis of the finches reveals three new species. And the birds' most iconic adaptation, beak shape, is largely controlled by a single gene, researchers report online February 11 in *Nature*. That gene is also known to shape faces in mammals, including humans.

The analysis "is rewriting the taxonomy of these birds, and that's a pretty big deal," says evolutionary biologist Scott Edwards of Harvard University, who was not involved in the work. "These birds are the epicenter of evolutionary theory."

The finches, which live on the Galápagos Islands and an island off Costa Rica, have fascinated people since Charles Darwin brought back specimens from a voyage of the H.M.S. *Beagle* in the 1830s and mentioned the birds in *On the Origin of Species*.

For the new study, Leif Andersson, an evolutionary biologist at Uppsala University in Sweden and Texas A&M University in College Station, joined Peter Grant and B. Rosemary Grant of Princeton University, who have studied Darwin's finches for more than 40 years. Their team sequenced the genomes of 120 birds, including several birds from each of the 15 known species of Darwin's finches and two species of tanagers, close relatives of the finches.

By examining the birds' DNA, the researchers discovered the genetic underpinnings of the finches' beak shape. The common ancestor of the finches probably had a pointy beak, and some species later developed blunt beaks better for crushing seeds. The researchers found that blunt beaks are associated with a distinct form of a gene called *ALX1*.

The big effect that *ALX1* alone has on beak shape is surprising because other complex traits, such as height, are controlled by many genes, each with a tiny influence, says Richard Gibbs, a geneticist at Baylor College of Medicine in Houston. But "data trumps expectation," he says. "There is a clear, loud bell being rung here that a morphological trait like beak shape can be driven by a simple, strong genetic effector."

> "These birds are the epicenter of evolutionary theory."
>
> SCOTT EDWARDS

The researchers also uncovered evidence that the different forms of *ALX1* may help birds adapt to their surroundings. Medium ground finches (*Geospiza fortis*) on the island Daphne Major, for instance, evolved pointier beaks after a drought in 1985 and 1986. Pointy beaks may help the birds reach seeds that have fallen into cracks in rocks. The team determined that *G. fortis* finches had inherited the pointy version of *ALX1* after interbreeding with small ground finches (*G. fuliginosa*) and common cactus finches (*G. scandens*).

Hybridizing also played a big role in creating several new finch species, the team found after constructing a genetic family tree. A common ancestor of most of the finches arrived in the Galápagos about 1.5 million years ago. Like ancestry trees based on the way the birds look, the genetic tree suggests that warbler finches were the first to branch off, about 900,000 years ago. Ground and tree finches began rapidly branching into new species about 300,000 to 100,000 years ago.

The team found a few surprises, too. Scientists thought that sharp-beaked ground finches (*G. difficilis*) from six islands shared a single common ancestor. But the new data indicate that the birds are probably three species, each with its own ancestor. One of the species resides on Pinta, Santiago and Fernandina islands, a second on Wolf and Darwin islands, and a third on Genovesa Island. The three species may be products of hybridization. The Wolf and Darwin finches, for instance, get most of their ancestry from large ground finches (*G. magnirostris*), but may have inherited their defining physical characteristics through interbreeding with *G. difficilis*.

Similarly, the large cactus finch (*G. conirostris*) is actually two species — a blunt-beaked version that lives on the island of Española and a pointy-beaked variety from Genovesa. The birds from these islands have been interbreeding, perhaps accounting for their resemblance to each other.

The findings are somewhat surprising, as scientists have thought that these species cleanly branched from each other, Edwards says. The new results suggest that hybridization may be important for giving species genes that help them adapt to new environments or food sources. ■

BODY & BRAIN

New target for treating obesity

Distinct brain cells control overeating, normal feeding

BY ASHLEY YEAGER

Manipulating specific sets of brain cells can quash a mouse's overindulgence in sugar.

The cells are part of a previously unknown brain circuit that controls compulsive sugar consumption in mice, researchers report in the Jan. 29 *Cell*. This circuit appears to be distinct from the one that controls normal eating, suggesting that it could be a target for treating obesity caused by overeating.

"One of the biggest challenges with treating obesity that comes with compulsive overeating disorder is that most treatments are just a Band-Aid, treating the symptoms instead of the core problems," says MIT neuroscientist Kay Tye. "The real underlying problems are the cravings that lead to compulsive eating and the behavior of compulsive overeating itself."

Compulsive overeating is similar to drug addiction. Both are reward-seeking behaviors. Past work has linked drug addiction and other reward-seeking behaviors, such as sex and eating, to nerve cells, or neurons, that connect the lateral hypothalamus to the ventral tegmental area in the brain. Whether the neurons that control compulsive overeating also control normal eating had not been clear. The new study suggests that different brain circuits control these eating behaviors.

"This is exciting because one big difference between food addiction and drug addiction is that you don't need drugs to survive. You do need food to survive," Tye says. "The treatment of food addiction has to be more delicate, because you want to shut down the compulsive overeating, but you need to keep the desire to eat healthy food to survive intact. Our study suggests this is possible."

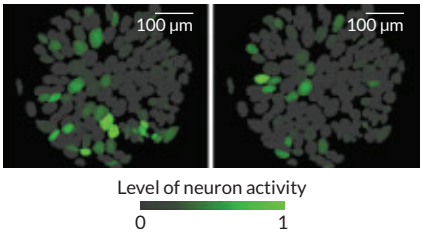
Neurons send messages using molecules and electrical signals, linking different brain regions in a way similar to an electrical circuit. Tye and her colleagues used optogenetics, a technique for controlling neurons with light, to determine that the compulsive consumption circuit was separate from the normal feeding circuit.

In one experiment, the team placed a sugary treat at the opposite end of a floor that delivered mild shocks to the mice's feet. When neurons in the newly identified circuit were activated with light, the mice would brave the shocks and go for the treat. "They seemed to think it was worth it," Tye says. When the neurons were deactivated, or shut off, the mice skipped the shocks and the sugar.

In a second experiment, the team put fully fed mice in an open chamber with easy access to food. When their compulsive eating neurons were activated, the mice hung around the chow longer. But when the scientists turned off these neurons in hungry mice, compulsive sugar-seeking dropped off and the mice ate normally.

A second paper in the Jan. 29 *Cell* further demonstrates that different neurons are responsible for different types of eating behaviors. Researchers recorded neuron activity in the lateral hypothalamus. One set of neurons was active when a mouse poked its nose into a slot to search for a high-calorie treat. A separate set was active when the mouse took a lick of the high-calorie treat.

"Differentiating the two sets of neurons opens the door for us to start looking at the precise cellular architecture in these brain regions and how it controls behavior," says study coauthor Garret Stuber, a neurobiologist at the University of North Carolina at Chapel Hill.



Maps of activity in a brain region involved in eating show how different nerve cells are active (green) when a mouse licks a high-calorie treat compared with when it pokes its nose in a slot looking for a treat.

Gina Leinninger, a neurophysiologist at Michigan State University in East Lansing, says that both teams have presented elegant data. "The data suggest that, rather than looking at neurons in the lateral hypothalamus area as all doing the same thing, we need to realize that there are different types of neurons in the region that exert different control over behavior," she says.

Tye says the next step is to determine the precise activation patterns of neurons in the overeating circuit during cravings and compulsive behaviors. Scientists could use this information to manipulate the neurons in the circuit and stop compulsive behavior before it starts, which could lead to new treatments for overeating and obesity. ■

FROM TOP: J.H. JENNINGS *ET AL/CELL* 2015; TOM OLLIVER/FLICKR (CC BY-NC-SA 2.0)

MATTER & ENERGY

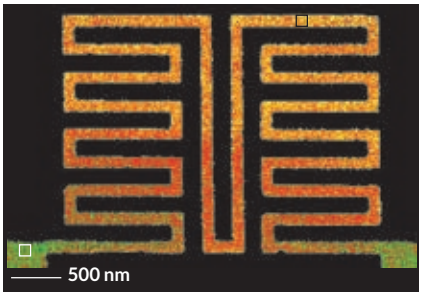
Taking temperatures at the nanoscale

Aluminum, other materials can become self-thermometers

BY ANDREW GRANT

To take the temperature of tiny things, scrap the thermometer. Aluminum and other materials can serve as their own thermometers, enabling temperature readings of objects nanometers in size, researchers report in the Feb. 6 *Science*.

The scientists probed temperature at various points on a tiny aluminum wire by measuring electrons that were fired through the wire. The electrons' energies exposed subtle changes in the aluminum's density, which corresponds to the temperature. If the technique passes further scrutiny — and not everyone believes it will — it could be used to measure the temperature of individual transistors.



By measuring electrons passing through a nano-sized aluminum wire, scientists turned the wire into its own thermometer. The marked area in the bottom left is about 37° Celsius; the marked area top right is about 117° C.

Temperature, which is related to the energy distribution of particles in a substance, is typically deduced indirectly by measuring another property. In the macroscopic world, that's easy: A bulb thermometer, for example, infers temperature from the expansion and contraction of a liquid as it is heated or cooled. But thermometers present complications at small scales because they transfer heat to or from the object being measured.

Physicist Matthew Mecklenburg of the University of Southern California and colleagues knew that heat-driven expansion of a material should also cause the material's electrons to spread out. The scientists set out to quantify the change in density and electron spacing in aluminum and use it to determine temperature.

The team fired a beam of electrons at an 80-nanometer-thick aluminum wire placed atop a roughly 10-nanometer-thick silicon nitride plate. As the electrons passed through the sample at about half the speed of light, Mecklenburg says, they disturbed the aluminum's resident electrons just as a boat zooming through a still lake disturbs the water. By measuring the energies of the electrons exiting the material, the team determined the frequency of those waves of disturbance. That frequency is determined by electron spacing, which depends on temperature.

The method enabled the team to determine the spectrum of temperatures along the wire as a current heated it. In another test, the team compared its temperature reading of a small aluminum wafer with that from a common but less spatially sensitive thermometer and the readings agreed to within about 10 percent.

Physicist David Cahill of the University of Illinois at Urbana-Champaign says the technique has fundamental flaws. He argues factors other than electron density determine the temperature of a particular spot on a material. Mecklenburg says there is no evidence that any other factors influence the temperature reading. ■

ATOM & COSMOS

Asteroids might spark supernovas

Rocky debris falling into white dwarfs may trigger explosions

BY CHRISTOPHER CROCKETT

A few well-aimed asteroids might be all it takes to make a star explode.

Rocky debris in the atmosphere of a white dwarf, the core of a long dead star, could trigger an explosion known as a type 1a supernova. The proposal, reported online February 1 at arXiv.org, suggests a new way to create this type of supernova, whose origins are debated.

While the mechanism that might destroy the white dwarf isn't clear, "the idea isn't pure speculation," says lead author Rosanne Di Stefano of the Harvard-Smithsonian Center for Astrophysics. The atmospheres of many of these stars are laced with elements such as carbon and silicon that should have sunk deep into the star. Since researchers can see these atoms, there must be a steady supply of material, most likely from asteroids that wander too close.

Most asteroids will be torn apart by a white dwarf's gravity. But Di Stefano and colleagues suggest that occasionally a few intact asteroids, or even a small planet, might hit a white dwarf directly. The influx of material might trigger thermonuclear fusion in the star's atmosphere that sends a shock wave through the star.

White dwarfs explode when their mass exceeds a threshold called the Chandrasekhar limit, about 1.4 times the mass of the sun. Astronomers debate how white dwarfs surpass that limit. A white dwarf might steal gas from a partner star. Or two white dwarfs orbiting each other might collide and destroy themselves. But scientists can't find companion stars in preexplosion images. And there don't seem to be enough binary white dwarfs with the mass to trigger a supernova.

An asteroid falling into a white dwarf might provide enough mass to push a star over the Chandrasekhar limit. Or more likely, Di Stefano says, an asteroid might trigger a thermonuclear explosion in the helium enveloping a lower-mass white dwarf that is well below the limit.

"It's interesting speculation that's not yet substantiated," says astrophysicist Adam Burrows of Princeton University.

Di Stefano acknowledges there are lots of unknowns. Future telescopes might detect flares from impacts, which could give scientists a better handle on what types of objects, if any, hit white dwarfs before being torn apart. ■

M. MECKLENBURG *ET AL*/*SCIENCE* 2015

BODY & BRAIN

Imaging pain's molecular anatomy

Brain scans tracking proteins could point to best therapy

BY ASHLEY YEAGER

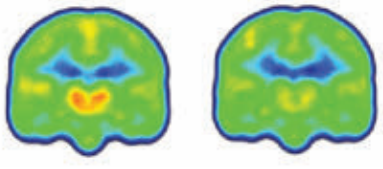
High-tech brain imaging could improve treatments for chronic pain, new research suggests.

Researchers from Uppsala University in Sweden and Harvard University have found that PET and MRI images can pinpoint cellular and molecular changes in the body and brain that accompany chronic pain. The scientists used chemical tracers that concentrated in the regions where chronic pain affected patients. Measuring changes in the concentration of the tracers during a patient's treatment can show how well a therapy works, Clas Linnman, a Harvard neuroscientist, said February 13.

"The images are good predictors of whether drugs in clinical trials for chronic pain are going to work," said Linnman. Such information could make the process of developing medications for chronic pain more efficient, he said.

> "The images are good predictors of whether drugs in clinical trials for chronic pain are going to work."
> CLAS LINNMAN

Scientists have struggled for decades to identify changes to the structure and chemistry of the brain that occur with chronic pain. Linnman described recent studies that have begun to identify molecules and proteins that hint at where and how chronic pain reshapes nerve cells and alters the brain's biochemistry (*SN: 6/30/12, p. 22*). One of the most recent studies, published January 12 in *Brain*, found that glial cells, which support and protect nerve cells, can also play a role in chronic pain.



People with chronic pain (left) make more of a protein linked with inflammation (orange and red) in their brains than do people without chronic pain (right), new PET/MRI images show. The finding may lead to better pain treatments.

In that study, researchers measured amounts of a radioactive tracer attached to the translocator protein, which is an indicator of inflammation, in the brains of people with and without chronic pain. The translocator protein acts as a marker for the activity of glial cells. Images combining PET and MRI scans showed that healthy people had less translocator protein in their brains than did people with chronic back pain (*SN Online: 1/13/15*). Linnman said that unpublished data from his own research validate the study's findings.

Marco Loggia, a neuroscientist at Massachusetts General Hospital in Charlestown, led the *Brain* study. He agrees that tracking the translocator protein in the brains of chronic pain patients as they are treated could help scientists identify which therapies are most effective. Imaging may also help in developing new drugs that act on the protein to reduce glial cell activation and reduce pain, said Loggia, who was not at the meeting.

When it comes to treating patients, such advanced imaging may not always be necessary, said neuroscientist A. Vania Apkarian of Northwestern University School of Medicine in Chicago. Scientists can already use standard functional MRI scans to identify people with chronic pain and those at risk of chronic pain. The same technologies can measure the effectiveness of treatments — even those as basic as placebo sugar pills.

But Linnman said that combining PET with MRI "gives us a whole new perspective on pain." Functional MRI can only identify which brain regions are affected by pain. Advanced imaging, however, is more precise, revealing changes at the molecular level, he said. ■

EARTH & ENVIRONMENT

Megadroughts predicted for U.S.

Some states may see driest conditions in a millennium

BY ASHLEY YEAGER

Record-setting droughts are in the forecast for the central and southwestern United States, a study comparing past and predicted drought conditions shows.

Researchers compared drought predictions for the second half of the 21st century with reconstructions of drought conditions dating back to the 11th century and found that the Central Plains and the Southwest could experience the driest conditions in nearly a millennium. The results were presented February 12 and published in *Science Advances*.

"These droughts at the end of the 21st century are going to be unlike anything in our modern experience," said study coauthor Benjamin Cook, a climate scientist at NASA's Goddard Institute for Space Studies in New York City. "It's very likely that we will get a megadrought at the end of the century."

Scientists have previously predicted that many regions will become much drier during the 21st century, but it has been hard to put the severity of the drought predictions in context with conditions that people have already experienced. The new study is the first to compare the severity of droughts at the end of the 21st century with past drought conditions dating back to the year 1000.

The severity of a drought is based on soil moisture, specifically how much is added when it rains and how much evaporates as temperatures increase. In the study, the team looked at three kinds of soil moisture metrics from 17 models for climate from 2050 to 2099 and at reconstructions of drought conditions going back a millennium. The reconstructions are based on tree-ring measurements. In North America, trees grow a new ring each year, and how wide the ring grows depends on the amount of water in the soil. If the year was extremely dry,

M. LOGGIA/MARTINOS CENTER FOR BIOMEDICAL IMAGING/MASSACHUSETTS GENERAL HOSPITAL

the resulting ring isn't visible at all.

The tree ring data create a comprehensive history of drought conditions in the Southwest and Central Plains from about 1,000 years ago to 2005 and show a severely dry period in the 1100s, which may have contributed to the decline of ancient Pueblo peoples of the Colorado Plateau in the late 13th century.

Cook and colleagues looked at the severity of future drought in two different scenarios. In one, greenhouse gas emissions continue at the current levels. In the other, attempts are made to reduce them. Greenhouse gas emissions contribute to rising temperatures, which affect soil moisture and ultimately the severity of a drought. Under both scenarios, the end of the century will be much drier than the medieval megadrought. Under the "business as usual" model, there's an 80 percent chance of a megadrought at the end of the century.

By the end of the 21st century, drought conditions could become unprecedented in the U.S. Central Plains and Southwest (a reservoir in drought-stricken California is shown).

California is now experiencing extreme drought, the worst since the year 800 (*SN: 1/10/15, p. 16*). The predicted megadroughts would take current conditions in California and extend them for decades, Cook said.

"This could likely happen if we do nothing to slow down global warming," said climate scientist Aiguo Dai of the State University of New York at Albany, who was not involved in the study.

Reconstructing past periods of dryness provides a range of the natural swings in drought severity. "If the future drought change induced by greenhouse gases is outside of this range, then we know the future drought conditions will be unprecedented and troublesome," he said. The authors make a convincing argument for an exceptional drought at the end of the century, Dai said.

He noted, however, that the team did not factor in natural swings in drought severity in the future. These natural variations, such as what was seen in the medieval megadrought, will be superimposed on top of the future changes due to greenhouse gases. The combination of these two, Dai said, could either enhance or reduce the drought by the end of the 21st century, depending on the nature and extent of those swings in the future. ■

MATTER & ENERGY

Old discovery gives jolt to batteries

Chemical reaction described in 1800s may boost energy storage

BY RACHEL EHRENBERG

Some very old chemistry may provide a new trick for making better batteries.

Scientists have developed a strategy that makes sulfur-based batteries more efficient by exploiting chemical reactions discovered in the 19th century. The work, described February 14, brings scientists closer to developing cheap, long-lasting batteries to power cars and computers or store energy for the electricity grid.

Lithium-sulfur batteries are a promising alternative to lithium-ion batteries, the rechargeable batteries used in cellphones, laptops and other electronic devices. Sulfur is relatively lightweight, plentiful and cheap, and lithium-sulfur batteries should be able to store much more energy than the lithium-ion variety. But sulfur-based batteries die quickly because sulfur used as a cathode tends to dissolve into the electrolyte solution that the ions move through as the battery charges and discharges. Now scientists led by Linda Nazar of the University of Waterloo in Canada have figured out a way to stabilize the sulfur cathode.

The trick was to find a chemical middleman that binds to the sulfur and keeps it from dissolving, Nazar said. Without a middleman, the sulfur exists in rings of eight atoms that, as they receive electrons, break into sulfur chains of various lengths. These sulfur tidbits — technically polysulfides — dissolve and tend to drift to the negative electrode of the battery, glomming up the surface and making the battery short-circuit.

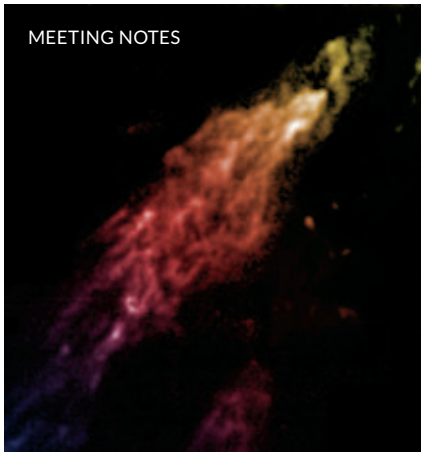
"Sulfur is really loosey-goosey with electrons," said Nazar. "All these polysulfides are doing their molecular dance and going all over the place."

So Nazar and her team looked for something that would trap the sulfur in place. After testing several materials, the team found that superthin sheets of manganese dioxide do the trick, catching the intermediate sulfur compounds so they don't dissolve away. The scientists think that as the manganese oxide grabs the sulfur chains, it spits off other sulfur chains that aren't soluble, so they don't wander off into the electrolyte solution.

"It binds them and drops them on the surface of the cathode," Nazar said. The precise chemistry of the sulfur molecules isn't completely understood, but the fundamentals of the reaction were described by German chemist Heinrich Wilhelm Ferdinand Wackenroder in the 1840s.

The research is an example of scientists devising new strategies to overcome the hurdles of better energy storage. "New materials are very important," said chemist Yi Cui of Stanford University.

The sulfur-manganese oxide cathodes make batteries that would allow a car to go three times as far as existing car batteries would before needing a recharge, Nazar said. Batteries made with sulfur cathodes might also work well to power cellphones and to provide energy storage in electric power grids. ■



ATOM & COSMOS

Hydrogen cloud headed for Milky Way

A high-speed hydrogen cloud on a crash course with the Milky Way appears to be an exotic interloper, preliminary data suggest. The cometlike streak, called the Smith Cloud (shown), is as massive as a million suns and is about 40,000 light-years away. Shooting toward the galaxy at roughly 850,000 kilometers per hour, the cloud is on schedule to collide with one of the Milky Way's spiral arms in roughly 30 million years. When it does, it could deliver extragalactic material, said Jay Lockman of the National Radio Astronomy Observatory. Lockman and colleagues used the Green Bank Telescope in West Virginia to compare the Smith Cloud with others near the galaxy and seven massive clouds that sit between the Andromeda and Triangulum galaxies. Smith's Cloud is more similar to the distant ones, which suggests that the cloud originated billions of years ago in a far-off region of space. The cloud's trajectory indicates that it has collided with the Milky Way before. With each interaction, the cloud brings fresh nongalactic material, Lockman said February 15. The results reinforce the idea that the space between galaxies is not empty.
—Ashley Yeager

MATH & TECHNOLOGY

Facebook can reveal signs of postpartum depression

New moms suffering from postpartum depression change their activity on Facebook, suggesting that the social media site could help detect mothers who need support. Many new parents share pictures and videos of their babies on Facebook. But compared with most typical new moms, those suffering from postpartum depression are less active on the social media site, Munmun De Choudhury of Georgia Tech in Atlanta reported February 14. She and colleagues at Microsoft Research in Redmond, Wash., conducted a study of 165 mothers before and after they had their babies. The study included a depression screening questionnaire, interviews and an analysis of Facebook activity and interactions. Women suffering from postpartum depression tended to keep a stiff upper lip on the site, refraining from reporting on their emotional well-being and instead posting objective content geared toward getting feedback or advice on a specific matter, De Choudhury and colleagues discovered. The scientists also found they could train a computer program to identify which moms had the blues. Such research might help with designing interventions, whereby moms could be warned that they might be sinking into depression and encouraged to reach out for social support or medical attention.
—Rachel Ehrenberg

GENES & CELLS

Ebola virus evolution tracked by DNA

Genetic data are beginning to reveal how the Ebola virus (*Zaire ebolavirus*) in West Africa is evolving. Scientists have deciphered the entire catalog of genetic data, or genomes, for 96 Ebola viruses taken from patients infected between June and September 2014. The results show that one particular version of the virus is now dominant among patients in Sierra Leone, and that two other types dominant early on in the outbreak may have since died out. The now-dominant type appears to have evolved starting with a single mutation in the virus's genome, said Stephen Gire of Harvard University and the Broad Institute. He presented the preliminary findings February 14. An earlier analysis of 99 genomes collected within three weeks of the outbreak's arrival in Sierra Leone (*SN: 9/20/14, p. 7*) found that the virus can develop mutations that reduce the effectiveness of an experimental therapy based on short interfering RNAs, or siRNAs, Gire said. Having data from more Ebola virus genomes will allow scientists to identify additional mutations that can thwart the therapy. Gire said several hundred more genomes should be cataloged and made available within the next month. The data are available at virological.org. *—Ashley Yeager*

BODY & BRAIN

E-cigarettes may be gateway to addiction for teens

Teenagers are using e-cigarettes more than any other tobacco product, and for many, it's the first time they've tried a tobacco product at all, a new survey finds. The data are concerning, said Wilson Compton, deputy director of the National Institute on Drug Abuse. While e-cigarettes are touted as a means to help adult smokers quit, the devices might prime young brains for addiction, Compton said during a news conference February 13. The data come from the National Institutes of Health's Monitoring the Future survey, conducted by the University of Michigan, which tracks substance use trends in eighth-, 10th- and 12th-graders. Each year the researchers survey about 40,000 to 50,000 teens. While daily cigarette smoking by teens has decreased significantly in the last five years, e-cigarette smoking, or vaping, is popular, even among teens who have never smoked, data from 2014 reveal. Among eighth-graders who reported using e-cigarettes in the past month, 36 percent had never used other forms of tobacco. For 10th-graders, 30 percent of e-cigarettes users had no other tobacco use and for 12th-graders, 21 percent had otherwise not used tobacco. Studies in rodents have shown that nicotine accelerates addiction to cocaine in adolescents but not adults, said Compton, suggesting that e-cigarettes might make teens more susceptible to other addictions.
—Rachel Ehrenberg

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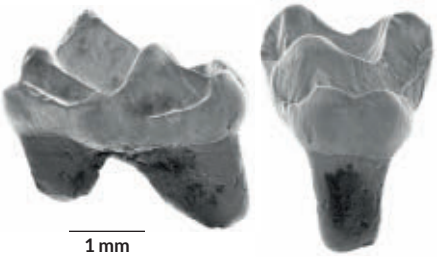
LIFE & EVOLUTION

Earliest New World monkey unearthed

Fossils suggest primates came to South America from Africa



Peaks and valleys on the chewing surface of a tooth from an ancient South American primate underscore the creature's evolutionary ties to an African primate with similar teeth.

BY BRUCE BOWER

A handful of roughly 36-million-year-old fossil teeth unearthed in Peru have put new bite into the idea that ancient African monkeylike primates somehow reached South America and sparked the evolution of New World monkeys. Scientists had suspected that African animals got the primate ball rolling in the Americas, but the new finds provide the first fossil backup for the scenario.

Two complete and two partial molar teeth excavated in Peru's Amazon region represent the oldest known New World primates, says a team led by paleontologist Mariano Bond of the Museo de Ciencias Naturales de La Plata in Argentina. The finds, from a species the authors dub *Perupithecus ucayaliensis*, closely resemble teeth of North African primates that lived between 39 million and 35 million years ago, the investigators report online February 4 in *Nature*.

Teeth of living and extinct South American monkeys — including those of a 26-million-year-old Bolivian primate that was until now the oldest known New World primate — differ in many ways from the newly discovered teeth, the researchers say. *Perupithecus* looks like it was a recent arrival to South America that retained teeth resembling those of African monkeylike creatures.

An evolutionary connection between North African and Peruvian primates could have arisen in one of two ways, the researchers propose. *Perupithecus* might have originated in Africa and, after reaching South America, evolved into a New World monkey. Or *Perupithecus* may have possessed signature traits of New World monkeys, such as a broad, flat nose and a long tail, before leaving Africa.

Either way, at least one band of ancient African primates may have crossed the Atlantic Ocean, possibly after getting trapped on rafts of floating vegetation. Masses of floating vegetation can appear after storms or tsunamis hit coastal areas.

Dating of *Perupithecus* relies on comparisons with primate fossils of known age found elsewhere in South America and the age of the geologic formation from which the fossils were excavated. Further research will attempt to secure a more accurate age estimate.

"These new finds are a first," remarks biological anthropologist Daniel Gebo of Northern Illinois University in DeKalb. "We have struggled for years to find older and more primitive primate fossils in South America." ■

EARTH & ENVIRONMENT

Artificial climate fixes nixed for now

But experts advise further research on geoengineering

BY BETH MOLE

Scientists shouldn't tinker with Earth's climate — at least not yet, conclude two new analyses released February 10 by the National Academies.

Schemes to lower the planet's temperature and dodge devastating effects of climate change are still too immature, risky and costly to try now, the studies assert. But scientists should keep working on those plans, the authors say.

The two main plans are to suck planet-warming carbon dioxide out of the air and — the dicier option — to shield the globe from sunlight by reflecting it back into space. Each plan is reviewed in a separate report by the National Research Council, which advises the federal government.

Research into even the riskiest ideas needs to continue, says climate scientist Waleed Abdalati of the University of Colorado Boulder, a coauthor of the reports. People may one day find themselves in a climate emergency when the risks of doing nothing outweigh the risks of an intervention, he warns.

The gentle encouragement is a boon to many in the small field of climate interventions. Also called geoengineering, the field has been plagued by controversy (*SN: 6/5/10, p. 16*). Critics argue that the push for climate interventions draws public attention away from reducing greenhouse gas emissions. And tweaking climate could trigger unexpected and potentially unmanageable side effects.

In the first report, the council reviewed ways to cull CO_2. Strategies include ways to snatch the gas from air, then collect it and pump it deep underground for storage (*SN: 9/6/14, p. 22*). Such methods are either too costly or not ready for prime time, the council found.

The other report, on solar reflection, had a harsher take, saying it would be "irrational and irresponsible" to try the method. Researchers have suggested spraying tiny particles into the atmosphere that could reflect solar radiation. This approach would mimic volcanic eruptions, which can have wide-scale (but temporary) cooling effects. Other ideas include amplifying clouds.

Solar reflection would merely cool the planet rather than counteract the effects of CO_2. If people ever stopped altering clouds or spewing particles into the air, global warming would return.

But if things ever get really bad, we don't want to still be doing early-stage experiments, says international relations specialist David Victor of the University of California, San Diego. The council's recommendation to keep doing research is important. "It decisively opens the door," to backup options, he says. ■

M. BOND *ET AL*/*NATURE* 2015

LIFE & EVOLUTION

Chicks look to left for tiny quantities

Bias suggests similarity to human view of number line

BY SUSAN MILIUS

Chicken Little knows small — and like many humans may have a left-to-right bias for a mental number line of small to big quantities.

In a new kind of test, more chicks appeared to favor smaller numbers of items on the left and larger ones on the right, says experimental psychologist Rosa Rugani of the University of Padua in Italy. The total area or density of the items didn't matter. This left-to-right bias for magnitudes showed up even when researchers tweaked the test so the same quantity, eight dots, appeared small or large depending on the context, Rugani and colleagues report in the Jan. 30 *Science*.

It's the only convincing evidence so far in animals for associating one direction with smaller quantities and the other with larger ones, says Peter Brugger of University Hospital Zurich. It's a simple version of what many people do — creating a left-to-right mental number line like an invisible ruler. But it's not easy to test for a similar preference in animals.

Animals may not use symbolic numerals, but a growing number of studies show that various creatures have their own ways of coping with quantities. In earlier studies, chicks seemed able to do simple addition (*SN: 4/25/09, p. 15*); even blind cave fish may be able to differentiate quantities. Such powers in animals hint that humankind may have built its complex mathematics on a foundation that evolved before the origin of language.

Earlier tests looked for a version of mental number lines in animals by showing lines of objects to rhesus macaques, chickens and seed-caching birds called Clark's nutcrackers. First, the animals were positioned at the beginning of a line of objects, as if on a street corner looking down the block at the houses. Researchers trained the animals to pick a certain object in the series by numerical order, such as the fourth in the row. For the test, the object row was turned 90 degrees. The animal now faced the row as if standing in the street in the middle of the block looking head-on at the houses. In this case, fourth from the end could mean fourth from the right or fourth from the left. Animals often chose the object by starting from the left, and researchers took that as a suggestion of a left-to-right bias in mental arrangements of quantity.

Rugani, who tested birds this way, wasn't satisfied. The birds could be doing the task with spatial cues instead of numerical ones, she says. In any case, many birds — like humans — have a bias to pay extra attention to whatever is to their left.

After several years of fiddling with alternatives she calls "not so elegant," she and her colleagues devised a new method. They trained 15 recently hatched chicks to poke behind a card with five dots on the front to find a mealworm treat. The researchers then offered the chicks pairs of other cards, with matching numbers of dots, to see which one the birds checked first for goodies.

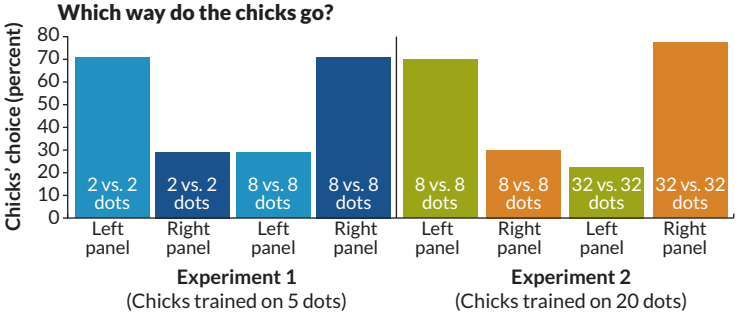
If the matching cards had a smaller number of dots compared with the training card, chicks tended to investigate the left card first, the researchers found. If the matching cards had more dots than the trainer, chicks tended to investigate the right-hand card.

When both cards in the pair had only two dots, for instance, birds in 71 percent of the trials first went left, as if they had a mental predisposition to link small stuff with leftward space. When both cards showed eight dots, 71 percent of the time birds went right, as if they assumed that bigger quantities belong on the right.

Then researchers manipulated the setup so that the same eight dots seemed like a relatively small quantity. In this experiment, researchers trained a different group of 12 chicks to find a treat behind a card with 20 dots. When tested with eight-dot cards, now just a measly speckling, most chicks turned left — toward the small side. And when shown cards with a number larger than 20, the chicks were much more likely to go right.

Calling the birds' links between direction and quantity a mental number line is just a metaphor, Brugger cautions. But some form of spatial bias for small and large does explain the results of this test, he says. "I can't think of an alternative."

Evolutionarily, the apparent similarity between a human and chick bias could be "deep and ancient or it could be a fluke of convergence," says behavioral neuroscientist Randy Gallistel of Rutgers University in New Brunswick, N.J. As for why the chicks may have evolved a bias for small stuff on the left instead of the right, he suspects there's no profound story of a benefit. "One thing that doesn't get emphasized enough," he says, "is that important parts of the evolutionary story may be just accidents we get stuck with." ■



Biased Chicks looking for a treat behind cards tended to first look behind the left-hand card if the number of dots on the cards was smaller than what they had seen before and behind the right-hand card if the dot number was larger.

SOURCE: R. RUGANI *ET AL*/ *SCIENCE* 2015

R. RUGANI

Watch experiments testing chicks' bias at **bit.ly/SN_chicks**

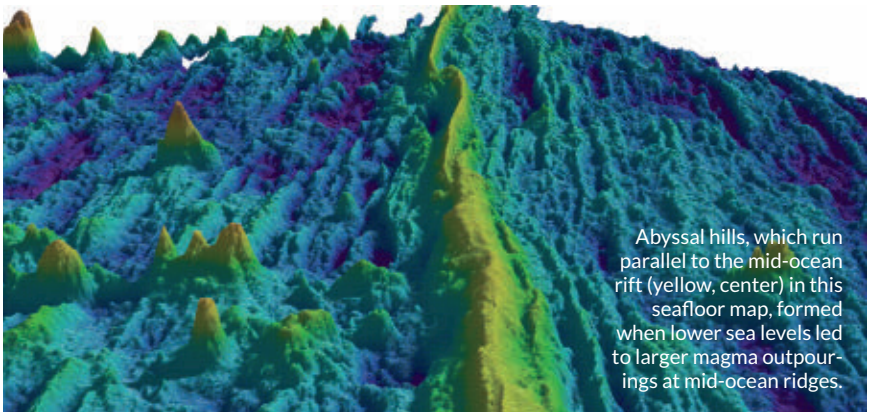
EARTH & ENVIRONMENT

Ice ages boost production of ocean crust

Lowered sea levels during ice ages can increase the amount of magma bubbling up at mid-ocean ridges, researchers propose online February 5 in *Science*. The work suggests that long stretches of thick oceanic crust called abyssal hills, among the most common landforms on the planet, are the result of worldwide climate changes. Gradual variations in Earth's orbit and tilt over tens of thousands of years trigger periodic ice ages. As water amasses in massive ice sheets on land, the global sea level can drop by roughly 100 meters. Geophysicist John Crowley, now at Engineering Seismology Group Canada in Kingston, and colleagues noticed that the abyssal hills that line the ocean floor between Australia and Antarctica appear to have been laid down during these sea level lows. Using computer simulations, the researchers show that low sea levels reduce by about 10 percent the amount of pressure pushing down on mid-ocean ridges where new crust forms. Less pressure makes it easier for rock in Earth's upper mantle to melt, resulting in more magma rising to the surface and therefore thicker newly formed crust. The increase in thickness could form abyssal hills rising up to 300 meters above the surrounding seafloor, the researchers say. — *Thomas Sumner*

Funding canceled for clean coal plant

Under a looming budget deadline, the U.S. Department of Energy has dropped its plan to give $1 billion in funding to FutureGen 2.0, a $1.65 billion clean coal project in Illinois. The project would have retrofitted a coal power plant with new technology to sequester 1.1 million metric tons of carbon pollution underground each year (*SN: 9/6/14, p. 22*). The cut most likely means the project will not continue. The funding, awarded to the FutureGen Alliance in 2010, was set to expire in September. But the alliance had used only $200 million to date, and DOE was not convinced that FutureGen could spend the rest and complete the project by the deadline. — *Beth Mole*



Abyssal hills, which run parallel to the mid-ocean rift (yellow, center) in this seafloor map, formed when lower sea levels led to larger magma outpourings at mid-ocean ridges.

LARRY MAYER/UNIV. OF NEW BRUNSWICK OCEAN MAPPING GROUP

ATOM & COSMOS

Earliest stars younger than thought

Some of the earliest stars in the universe came on the scene a little later than previously thought. New results from the Planck satellite, which mapped light from the early universe, pinpoint the start of reionization, an era when starlight became powerful enough to strip electrons from hydrogen atoms throughout the universe. Stars triggered the cosmological makeover about 13.25 billion years ago, a mere 550 million years after the Big Bang, Planck researchers report online February 5 at arXiv.org. Previous results from the WMAP satellite suggested that reionization began about 100 million years earlier, but galaxies from that epoch don't seem to have enough stars to ionize hydrogen. The delayed start implied by Planck means galaxies had a little more time to build the stars that they needed to drive reionization. — *Christopher Crockett*

BODY & BRAIN

E-cigarettes lower immunity to germs

Electronic cigarette vapors can trigger substantial inflammation in the lungs, a study in mice finds. The inflammation may make the animals more susceptible to infection, researchers report February 4 in *PLOS ONE*. In experiments that simulated "vaping," lab mice exposed to e-cigarette vapors for two weeks had markers of blood nicotine comparable to those in people who smoke cigarettes and e-cigarettes. E-cigarette vapors also "produced mild effects on the lungs, including inflammation and protein damage," notes lead author Thomas Sussan of the Johns Hopkins Bloomberg School of Public Health. Inhaling free radicals, harmful reactive molecules, may be responsible for the inflammation. Sussan's group found that each vaping puff contains 700 billion free radicals, which ultimately triggered "a significant increase in oxidative stress." After two weeks of vaping, some mice were exposed to *Streptococcus* bacteria or influenza viruses. Compared with nonvaping mice, these mice were far less able to resist infection. Some even died from flu. No mice that had been breathing clean air died from flu exposures. Vaping's impacts may trace to nicotine, Sussan's group posits. But the liquid solvent used to deliver nicotine in each e-cigarette puff may also be toxic. So even nicotine-free vaping might prove harmful, the authors conclude. — *Janet Raloff*

LIFE & EVOLUTION

Termite mounds help buffer dry land against climate change

Termite mounds may help protect arid landscapes in Africa from turning into deserts as climate change exacerbates droughts. New computer simulations of stressed arid lands show that termite mounds and the lush green growth they foster can slow the slide into desert, Corina Tarnita of Princeton University and colleagues report in the Feb. 6 *Science*. These aren't the termites that bedevil human houses; they are master architects that create vast underground tunnel networks topped by mounds. Nutrients collected by the colonies and water held by termite-tunneled soil nourish plants, creating small islands of fertility. While that's good news for the landscape, it may make it more difficult to detect looming desertification via satellite, Tarnita notes. As rain dwindles, those termite islands stay green for a long time, forming a rough hexagonal lattice. This vegetation pattern resembles the final stages of a mound-free landscape's collapse. — *Susan Milius*

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The Mess That Is Stress

Chronic angst triggers a slew of changes that harm long-term health

By Nathan Seppa

Ask anybody — stress is bad news. The negative view of stress has been expressed so consistently that the concept is now built into our vernacular, which is spiced with advice on avoiding it: Take it easy. Calm down. Chill.

Of course, a good case of stress comes in handy during an encounter with a grizzly bear on a hiking trail. In that situation, a stress reaction delivers a burst of hormones that revs up the heart and sharpens attention. This automatic response has served humans well throughout evolution, improving our odds of seeing another day.

Problems arise, however, when stress becomes a feature of daily life. Chronic stress is the kind that comes from recurring pain, post-traumatic memories, unemployment, family tension, poverty, childhood abuse, caring for a sick spouse or just living in a sketchy neighborhood. Nonstop, low-grade stress contributes directly to physical deterioration, adding to the risk of heart attack, stroke, infection and asthma. Even recovery from cancer becomes harder.

All downhill The effects of stress start in the brain and extend through the action of hormones to reach all corners of the body. Scientists define emotional stress as a negative reaction to a perceived threat or other problem.

JEFF ROGERS

Scientists have now identified many of the biological factors linking stress to these medical problems. The evidence centers on nagging inflammation and genetic twists that steer cells off a healthy course, resulting in immune changes that allow ailments to take hold or worsen.

Despite the bad rap stress has acquired throughout history, researchers have only recently been able to convince others that it's dangerous. "It's taken much more seriously now," says Janice Kiecolt-Glaser, a clinical psychologist at Ohio State University in Columbus. "In the 1980s, we were still in the dark ages on this stuff."

Stress research gained traction with a master stroke of health science called the Whitehall Study, in which British researchers showed that stressed workers were suffering ill effects. Scientists have since described how a stressed brain triggers rampant hormone release, which leads to imbalanced immunity and long-term physical wear and tear. Those effects take a toll quite apart from the anxiety and other psychological challenges that stressed individuals deal with day to day.

First come the stressors

"Take This Job and Shove It" was a No. 1 country hit in 1977. Perhaps songwriter David Allan Coe had heard about the Whitehall Study, because around that time scientists in London were finding out that some guys might live longer if they found other work.

The researchers were tapping a national health registry and work records to get vital information on thousands of male British civil servants.

Men in the lowest-level jobs were more than three times as likely to die of heart problems during the long-term study as men in more lucrative positions, the researchers found. Those low on the job ladder smoked more, had higher blood pressure, exercised less and reported less leisure-time activity on average than the higher-ups. No wonder they died sooner, or so it seemed.

But even when the researchers removed extra variables by comparing the low-tier men with those in higher-level jobs who were similar in weight, smoking status and other factors, the lower-achieving men still died sooner and had more heart attacks. The Whitehall researchers concluded by 1978 that the health disparity "can be only partly explained by the established coronary risk factors." That left hereditary differences and factors not accounted for — such as stress. Women were added to the Whitehall Study in the mid-1980s, and by 2003, the study had linked heart disease in both sexes with high job demands and little latitude in decision making.

Other research has supported these work-stress findings. Some forms of work are naturally stressful, and sure enough, they carry health risks. Police are 21 times as likely to die of a heart attack while in an altercation with a suspect as they would be normally. It figures that exertion poses a risk, but cardiac mortality risk was up only sevenfold during physical training. The stress of a dangerous encounter made the difference, researchers concluded in *BMJ* in 2014.

Some people bring their own stress to the table, such as Type A personalities — those hard-driving, competitive types. Researchers at San Carlos University in Madrid identified 150 adults who had survived a stroke and asked them to fill out a questionnaire. Stroke survivors' neighbors of a similar age then answered the same questions. The stroke patients scored lower on self-assessed quality of life. And they scored twice as high on Type A behavior measurements and were nearly four times as likely to have had a stressful experience in the preceding year.

Even when the researchers accounted for differences in smoking, diabetes, alcohol use, energy drink consumption and other conditions and habits, the stroke survivors were more likely to have a Type A profile or a high-stress history. The study appeared in 2012 in the *Journal of Neurology, Neurosurgery & Psychiatry*.

In laboratory settings, researchers can zero in on particular stressors and their effects on health measures, such as how well the immune system responds to injury. In 2005, Kiecolt-Glaser and her microbiologist husband Ronald Glaser enlisted 42 healthy couples to test how interpersonal stress might affect wound healing. On two separate occasions, the couples came to a clinic in the morning, ate breakfast, gave a blood sample and endured some mild discomfort as a nurse used a medical device to raise a small suction blister wound on one arm. Next the couples underwent either positive social support counseling about their marriage or, at a separate visit, were led into a discussion of their marital disagreements.

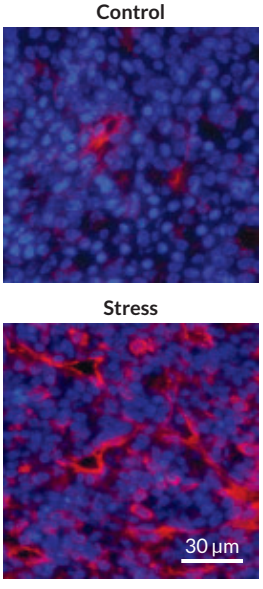
The scientists checked the wounds in the following days. Couples healed in a median of five days after friendly counseling but took six days after a session about marital conflicts. When the conflict sessions were split into couples who got confrontational versus those who were more

7x

Increased risk of heart attack death among police officers during exertion training

21x

Increased risk of heart attack death among police officers subduing a suspect



High density Tumors need a network of blood vessels to grow, and stress helps. These images show greater density of vessels (red) in breast cancer tissue in stressed mice (bottom) than in mice with cancer but no stress (top). Stressed mice also made more norepinephrine, which induced immune macrophage cells to release compounds promoting tumor vessel growth.

easygoing, the hostile couples took a median of two days longer to heal, the researchers reported in *JAMA Psychiatry*.

"Minor, everyday stressors have an impact on immune responses," Kiecolt-Glaser says. Chronic stress can also diminish the immune protection a person garners from a vaccine, raise blood pressure and even enable a case of herpes to flare up.

Isolation's impact

Some forms of chronic stress don't involve argument or debate, but they are just as damaging.

High on the list is loneliness.

Social species, from fruit flies to *Homo sapiens*, fare poorly when isolated, says John Cacioppo, a social neuroscientist at the University of Chicago. Lonely people are more apt to have high blood pressure, fragmented sleep and diminished immunity. Older lonely people are more likely to have deteriorating lung health than those with better social support, research shows.

This makes sense from an evolutionary perspective, Cacioppo says. "Early in our history as a species, we survived and prospered by banding together — in couples, in families, in tribes — to provide mutual protection and assistance. The aversive feeling of loneliness serves to prompt us to renew the connections we need," he and psychologist Stephanie Cacioppo, his wife, wrote in *Social & Personality Psychology Compass* in 2014. "Finding oneself on the social perimeter is not just sad but also dangerous."

Caregivers frequently wind up on the frayed edge of their social circle because they spend a lot of time with an ill spouse or parent. Caregivers are often lonely even though they aren't alone, and they become chronically stressed. They show poor immune defense against infectious diseases.

To make matters worse, immunity weakens naturally with age. "By superimposing stress on the aging of the immune system, you accelerate those effects," says Kathi Heffner, a psychologist at the University of Rochester in New York.

Loneliness and other chronic stressors are particularly detrimental in people with cancer. The major cause of death from cancer is metastasis, the disease's spread within the body. A test in mice with breast cancer showed that stress — induced by putting the animals in a confined space for two hours a day for 20 days — increased the likelihood of metastasis by 30-fold.

In a study of 68 women with ovarian cancer, higher levels of the stress hormone norepinephrine were found in the tumors of patients with advanced or aggressive cancers than in women with cancers that were more under control. Notably, the researchers also found that patients with good social support had less norepinephrine in their tumors, as reported in *Brain, Behavior, and Immunity* in 2011.

Norepinephrine and its cousin epinephrine, also known as adrenaline, are stress hormones that act like fuel for some cancers, including prostate cancer. They help tumors build the blood vessels they need to nourish themselves and grow.

The stress-related hormones don't seem to cause cancer, says Anil Sood, a gynecologic oncologist at M.D. Anderson Cancer Center in Houston. "It's more about cancer growth progression," he says. "That's where the data seem to be more convincing."

The benefits of fending off stress showed up in women awaiting tests to see whether their pelvic growths were cancerous or benign. Those who reported good social support had more immune attack cells directed at these masses, Sood and his colleagues reported in 2005.

Changing cell behavior

A century ago, Harvard's Walter Bradford Cannon introduced the concept of "fight or flight" to summarize the two best options prehistoric people faced upon running into trouble. But only recently has research revealed the microscopic fallout of having stress hormones switched on day after day.

Stress reactions start in the brain, the master interpreter of events occurring around us. A stressed brain trips excessive release of epinephrine and norepinephrine plus the stress hormone cortisol. Like all hormones, these molecules exert their effects by binding to receptor proteins in and on cells, changing the cells' behavior. The hiker fleeing the bear does so because receptors by the millions are suddenly telling cells to kick into gear. The pulse rate quickens. That's also how epinephrine helps resuscitate a person in cardiac arrest.

But an everyday, steady release of stress hormones trips other switches throughout the body in a drumbeat that steadily poisons the system — spreading biological changes like wildfire.

For instance, epinephrine and norepinephrine normally keep a leash on NF-kappa-B, a master regulator of immune processes that is also considered an agent of inflammation. But overproduction of epinephrine and norepinephrine desensitizes their receptors. This bogs down signaling and their ability to rein in NF-kappa-B and inflammation.

Chronic stress also disrupts cortisol's effects. In a 2014 study in *Psychoneuroendocrinology*, researchers found that declining self-esteem in people age 64 and older coincided with increased cortisol levels in the saliva. That's a dicey prospect since cortisol is normally tightly controlled. It affects blood pressure, metabolism, blood sugar levels, bone health, behavior and immune reactions such as inflammation.

When cortisol latches onto a receptor on an immune cell, it tones down that cell. It's basically an off-switch for inflammation, which is why people with inflamed joints sometimes get relief from a shot of cortisone, a cortisol mimic.

But too much cortisol exposure is no good. "When you bathe immune cells in glucocorticoids [cortisol] in a dish, they shut down their receptors," says Heffner, the Rochester psychologist.

Researchers tested the effect of disrupted cortisol signaling in 276 healthy volunteers, taking note of those who had previously reported a recent major stressful life event. Blood tests showed the stressed individuals had more muted cortisol receptors. "The receptors on immune cells ... become less sticky and less available to cortisol," says study coauthor Sheldon Cohen, a psychologist at Carnegie Mellon University in Pittsburgh. Without proper cortisol signaling, inflammation ran unchecked.

The researchers then quarantined all of the volunteers and exposed them to one of two common cold viruses. After five days, the stressed people with muted receptors were twice as likely to develop a cold as nonstressed volunteers, the researchers reported in the *Proceedings of the National Academy of Sciences* in 2012.

In a separate study, Cohen tested parents of children with cancer, a high-stress group. "They show receptor resistance, even though they aren't making a lot of cortisol anymore," he says.

The body is just trying to right the ship. When too much cortisol is turned loose too frequently, the body "adapts" by muting receptors, Heffner explains. "The cells stop paying attention."

This receptor muting appears tied to professional burnout, a condition marked by emotional exhaustion, cynicism and a sense of diminished accomplishment. A review in the June 2013 *International Journal of Occupational Medicine and Environmental Health* notes that burnout also involves a decreased capacity to cope with stress and with less of the awakening response. Scientists are still trying to nail down the links between off-kilter cortisol signaling and burnout.

Asthma and adversity

Throughout much of history, asthma was considered a nervous condition. Hippocrates counseled a patient with asthma "to guard himself against his own anger." Well into the 20th century, the condition was dubbed "asthma nervosa."

Hippocrates wasn't completely off target. Chronic stress and systemic inflammation are tightly linked in people with asthma, particularly in inner cities. Of course, there are many asthma contributors: ozone, diesel exhaust, smoke, mold, cockroach allergens and vermin. Heredity plays a role as well. Many city kids also have a strike against them because they don't come into contact with much soil-based dirt, the kind that helps youngsters develop normal immune systems, says James Gern, a pediatrician at the University of Wisconsin–Madison. "The 'dirt' is in the form of [settled] auto exhaust and ground up tires instead of biologics," he says.

Adding chronic stress to this mix might tip the scales toward asthma, even before birth, research shows. Researchers measured inner-city pregnant women's exposure to stress and then tested the umbilical cord blood of their newborns. Most of the 557 women in the analysis were in low-income black families. Greater maternal stress during gestation was linked to higher cord-blood levels of interleukin-8, an inflammatory protein. Stressors included domestic violence, lack of money, poor neighborhood safety and housing uncertainties, says Rosalind Wright, a pulmonary physician at Mount Sinai Hospital in New York City. The report appeared in the *American Journal of Respiratory and Critical Care Medicine* in 2010.

In another inner-city study, wheezing, which is linked with asthma risk, was tripled in children up to age 2 whose moms reported living in highly stressed conditions before and after giving birth. "I think of stress as just under the surface there, pushing the immune system in certain directions," Wright says. "When individuals are hit by another asthma trigger such as air pollution, they just fall off the cliff."

The asthma rates in inner cities have not been well-defined. A recent report from Johns Hopkins University researchers using nationwide census data found that while more urban kids than nonurban indeed have asthma — 12.9 percent versus 10.6 percent — that difference may be better explained by race and ethnicity, and in some cases household poverty, than city living.

But urban stress factors show up consistently in asthma work. In an analysis of 25 inner-city schools appearing in the January *Pediatric Pulmonology*, children whose caregivers deemed their neighborhoods unsafe had twice the odds of having asthma as did kids living in safer neighborhoods. A similar effect was found in children in urban Salvador, Brazil, who were exposed to excessive violence.

Air pollution, tobacco smoke and other factors affect a person's asthma risk, Wright says. "Stress does that, too. It's not just affecting your head." — *Nathan Seppa*

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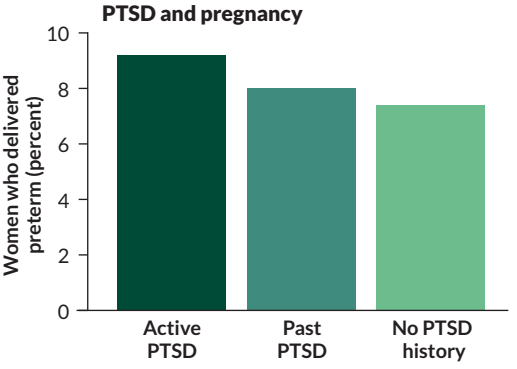


Generation next Women with ongoing post-traumatic stress disorder were more apt to give birth prematurely than were women who had never had PTSD. SOURCE: J.G. SHAW *ET AL/OBSTETRICS & GYNECOLOGY* 2014

Inflammation's green light

Taking the brakes off inflammation underlies many of the ailments that crop up in population studies of chronic stress.

A prime concern, from the Whitehall Study and others, has been heart disease. Inflammatory immune cells form part of the plaques that clutter the coronary arteries that nourish the heart muscle. Normally, fibrous caps hold these plaques together, preventing problems. But too much inflammation can weaken the caps, a 2011 study in pigs showed. If a cap ruptures and a plaque is dislodged, the vascular equivalent of a fire alarm goes off, triggering a blood clot to form instantly at the rupture site. If the clot blocks a coronary artery, hello heart attack.

One way to measure inflammation is by tracking blood levels of interleukin-6, an immune signaling protein. A 2013 Whitehall analysis in the *Canadian Medical Association Journal* tracked IL-6 for five years in more than 3,000 adults. People with at least two high IL-6 readings over that time were more likely to have some sort of heart problem as people with consistently lower IL-6.

Also in Whitehall, scientists linked high IL-6 levels and another inflammatory marker, called C-reactive protein, with stress and diabetes. People who grew up facing stress because of poor socioeconomic conditions faced a doubled risk of type 2 diabetes as adults. The authors attributed one-fourth of the added risk to chronically elevated inflammation.

Other work ties high IL-6 to a history of childhood abuse and to the strains of caregiving. A 2013 review revealed that while IL-6 levels rise naturally with age, 75-year-old caregivers have the IL-6 levels of a 90-year-old.

Scientists are now digging deeper, sorting through changes in gene activity that underlie inflammation and receptor shutdown. For example, childhood stress might get embedded in immune cells called macrophages through epigenetic changes — alterations that affect the activity levels of genes without changing the underlying DNA. Psychologist Gregory Miller of Northwestern University in Evanston, Ill., suggests that these changes can endow the macrophages with pro-inflammatory tendencies that later

Six ways to beat chronic stress

Counseling, mindfulness training and purposeful social contact may counteract the effects of nagging stress.

1. Parenting classes

In a trial of 272 low-income black women in rural Georgia, each with an 11-year-old child, scientists randomly assigned 173 to receive parenting training. "This was a set of coping strategies that may be particularly adaptive in these difficult settings," says psychologist Edith Chen of Northwestern University. At age 19, the children whose families received the seven-week intervention had lower levels of six blood markers of inflammation, Chen and colleagues reported in August in the *Proceedings of the National Academy of Sciences*. Inflammation markers were lowest among kids who got the least harsh and most consistent parenting.

2. Cognitive behavioral therapy

For people with depression, anxiety and other woes, cognitive behavioral therapy seeks to replace self-destructive habits and negative thinking with improved coping skills. CBT stress management groups seem to boost the body's immune responses to viruses, research shows. In a sleep study, older people with insomnia and joint pain were randomly assigned to receive CBT and therapy that emphasized setting a consistent waking time, only going to bed when sleepy and so on. They slept much better and reported less pain than those who didn't have CBT, researchers reported in 2009 in the *Journal of Clinical Sleep Medicine*.

3. Yoga and tai chi

These practices, which focus attention on posture, positive thoughts and breathing, can unwind stress at the clinical and molecular levels. Researchers in Germany scanned 44 trials in which healthy people were randomly assigned to do yoga or not and found the practice knocked nearly 6 points off their top blood pressure number. In breast cancer survivors, three months of tai chi reduced the inflammatory agents IL-6 and TNF-alpha, UCLA researchers report.

4. Real-time monitoring

Doctors make a good group in which to study stress treatments, says Jane

foster chronic diseases.

That line of research circles back to NF-kappa-B, the inflammatory molecule. When Miller and colleagues tested immune cells from 33 adults caring for a family member with brain cancer and compared those with cells from 47 people without such a major stressor, the caregivers' cells had increased activity in genes tied to NF-kappa-B.

The negatives of chronic stress and inflammation extend down to the chromosomal level in other ways. When inflammatory genes get activated in people with high stress, their telomeres get shortened. Telomeres are the tips that hold chromosomes together — like the plastic ends of shoelaces — and prevent unraveling. Eli Puterman, a health psychologist at the University of California, San Francisco, and his colleagues monitored 239 healthy women for a year to test their telomere length in response to stressors. Each major life stressor encountered in that time was matched by a substantial shortening of telomeres in white blood cells, Puterman and collaborators reported in *Molecular Psychiatry* in June. On the plus side, the telomere shrinkage stopped when the women improved their health behaviors by emphasizing good nutrition, exercise and sleep.

Why stress affects some people more than others is unclear. So researchers are examining variant forms of the genes encoding the receptors for stress hormones and for immune signaling proteins. A gene called *Adcyap1*, which encodes pituitary adenylate cyclase-activating polypeptide, also seems tied to the stress responses. Researchers writing in *Nature* in 2011 linked a variant form of the peptide's receptor with PTSD in women. Other work ties the variant form of this receptor to a greater startle reflex in kids and women. And epigenetic changes and variant forms of the receptor's gene were associated with stress from exposure to violence and appear linked to asthma risk in Puerto Rican children, a 2013 study found.

Researchers are now pursuing treatments for stress (see sidebar, below). Some studies show that antidepression and antianxiety medications can help as can beta-blocker drugs. The lingering question is whether improved social support and self-help practices can halt the physical ravages of stress, as with those women whose telomeres stopped shrinking. "My hunch is it might depend on the level of exposure people have over time," says Bert Uchino, a psychologist at the University of Utah in Salt Lake City.

Chronic stress ultimately predicts disease, mainly via inflammation, Kiecolt-Glaser and colleagues wrote in *Social & Personality Psychology Compass* in 2011. "People who have supportive, close relationships have lower levels of systemic inflammation compared to people who have cold, unsupportive and conflict-ridden relationships." ■

Explore more

- The Perceived Stress Scale. Sample questions at: bit.ly/SN_stresstest

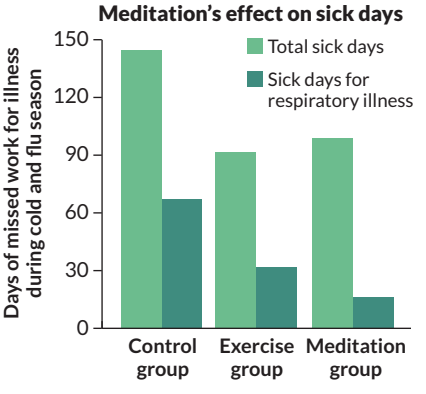
Lemaire, an internist at the University of Calgary in Canada, because they have a high-stress occupation and they like high-tech gizmos. She assigned some docs to carry monitors to get real-time snapshots of their stress levels based on heart-rate variability. Doctors checked their scores three times a day, and took five minutes to cool themselves down each time. By the end of the four-week test, their overall stress scores had dropped substantially. Doctors without the devices or cool-down periods had unchanged scores.

5. Friendly Fido

Pets are touted to reduce stress, and dogs might live up to that claim. Researchers enrolled 47 young boys who had attachment difficulties and gave them a standard stress test in which they learn a story and then are asked to stand in front of a panel of adults and make up an ending for it, plus do some math off the cuff. The kids were accompanied by a real dog, a toy dog or a friendly person. Salivary levels of the stress hormone cortisol, which typically rise in this test, rose but then dropped in those with the real dog — well below the levels in the other two groups, researchers reported in *Frontiers in Psychology* in 2012.

6. Meditation

In 94 people randomly assigned to meditate, exercise or pursue other activities for eight weeks, the meditation and exercise groups completed 2½-hour weekly sessions and continued these activities at home. The control group did neither. During the cold and flu season, the controls and exercisers missed more work days due to respiratory infections than did the meditators, scientists at the University of Wisconsin–Madison reported in 2012.



SOURCE: B. BARRETT *ET AL/ANNALS OF FAMILY MEDICINE* 2012

Tough to swallow

Athletes who use antioxidant supplements may not be getting the boost they expect

By Laura Beil

In the fickle world of sports nutrition fads, few trends have shown the staying power of antioxidants. For more than three decades, athletes have remained devoted fans of supplements; the American College of Sports Medicine estimates that around half of elite athletes take vitamins in hopes of keeping their bodies fit and boosting endurance.

The idea makes intuitive sense: Energy consumption within a cell leaves a trail of spent oxygen molecules that can damage tissues and contribute to fatigue. Although the body has internal garbage collectors to clean up the waste products of metabolism, the demands of strenuous physical activity overwhelm the system. Cells need a boost. Food can supply antioxidants naturally — some of the best known are vitamins C and E — but why rely on vegetables when pills or sports drinks can deliver hundreds of times the vitamin E that comes in a serving of spinach?

That line of thinking helped drive U.S. sales of vitamin and dietary supplements to almost $25 billion in 2014, according to the market research firm Euromonitor International. Of those, vitamin C was the second most popular supplement after multivitamins, accounting for $1.1 billion in sales, which are rising.

"It's that American mentality," says Jay Williams, a professor in the department of human nutrition, foods and exercise at Virginia Tech in Blacksburg. "If some is good, more is better."

Except when it might be worse. In a scientific reboot, many newer, more rigorous studies are contradicting decades of previous thinking, finding little support for — if not outright harm from — antioxidant supplements for athletes. Although antioxidants obtained from food appear to do a body good, the colossal doses in supplements may disrupt a cell's built-in system for coping with oxidative stress. And it appears that muscles under exertion may need a certain level of oxidative beating to adapt and strengthen over time. If the recent research holds up, it means one of the very things athletes commonly do to help their bodies could not only waste money but may even undermine the benefit from those hours of dedication.

One group of European researchers went so far as to call antioxidant pills "worse than useless" in a 2012 letter to the *American Journal of Physiology–Endocrinology and Metabolism*. The bottom line of a 2011 study: "In certain situations, loading the cell with high doses of antioxidants leads to a blunting of the positive effects of exercise training."

At best, overall results have been neutral. A recent meta-analysis of studies published in September in *Applied Physiology, Nutrition, and Metabolism* concluded that vitamin E supplements did not protect against oxidation or muscle damage. Writing in February 2014 in the *Journal of the International Society of Sports Nutrition*, researchers from Brazil tallied the results of

M. TELFER

12 studies comparing the performance and physiology of athletes who took antioxidants with those who took a placebo instead. The team found "no consistent evidence suggesting that supplementation reduces oxidative stress and ensures better results in exercise."

The report also notes that the topic has been challenging to study because there are no uniform standards for doses or research design. But there's enough concern that many prominent scientists in the field are warning athletes not to be too enamored with vitamin and dietary supplements. "There are papers on both sides of the fence," says Scott Powers, a physiologist at the University of Florida in Gainesville. "But my work in animal models suggests that there is a risk."

Radical, man

Oxidation is a chemical reaction that occurs when a molecule loses at least one electron. It happens throughout nature and can include many different elements, but commonly involves oxygen (thus the name). Oxidation is why a freshly cut apple turns brown and the Statue of Liberty's copper skin has aged to green. In living cells, oxidation occurs in the mitochondria, the combustion engines of the body. In the process of liberating the energy locked in sugar and other molecules, an electron from oxygen gets siphoned off. The result is a free radical, a molecule so unstable it will react indiscriminately with nearby molecules to scavenge another electron. Sometimes during the chemical frenzy, the electron gets snatched from molecules that make up DNA or cell membranes and other structures, potentially harming them. The higher the cell's energy demand, the more free radicals appear.

While experts in the 1960s had theorized about protection from vitamins, the beginning of the golden era of antioxidants is often traced to an experiment published in 1978 from the University of California, Davis. Researchers asked 10 volunteers to ride an exercise bike for one hour. In part of the experiment, the scientists captured exhaled breath from the cyclists and measured levels of pentane. That compound is a marker of what would come to be called "oxidative stress," which occurs when free radicals are grabbing electrons faster than cells can neutralize the radicals. When the study participants started breathing harder, levels of pentane, and therefore oxidative stress, rose.

The next part of the study is what helped launch a worldwide sports nutrition craze and a multibillion-dollar industry. After the volunteers took vitamin E for two weeks and then got back on the bikes, oxidative stress seemed to plummet. The study appeared in the *Journal of Applied Physiology*. Many more like it would follow. Athletes took note, chief among them Kenneth Cooper, the renowned physician and former U.S. Air Force flight surgeon who coined the term "aerobics" and inspired generations of people to exercise their way to better health. His 1994 book, *The Antioxidant Revolution*, promoted megadoses of antioxidant vitamins, especially for elite athletes, who consume the most oxygen.

"Starting in the 1970s and '80s, all that was written about free radicals is that these are damaging molecules," Powers says. If free radicals are dangerous, the thinking went, neutralizing them would do nothing but good. Research at the time was relatively consistent with this idea, both in animal and human studies.

As investigations have probed deeper, using

Go for the reds, greens and yellows The benefits of supplements may be in question, but antioxidants obtained from food look like winners. Here are some antioxidants found in fruits, vegetables and grains. SOURCE: J. BOUAYED AND T. BOHN/*OXID. MED. CELL. LONGEV.* 2010

- Vitamins: vitamin C, vitamin E
- Trace elements: zinc, selenium
- Carotenoids: beta-carotene, lycopene, lutein, zeaxanthin
- Phenolic acids: chlorogenic acids, gallic acid, caffeic acid
- Flavonols: quercetin, kaempferol, myricetin
- Flavanols: proanthocyanidins, catechins
- Anthocyanidins: cyanidin, pelargonidin
- Isoflavones: genistein, daidzein, glycitein
- Flavanones: naringenin, eriodictyol, hesperetin
- Flavones: luteolin, apigenin

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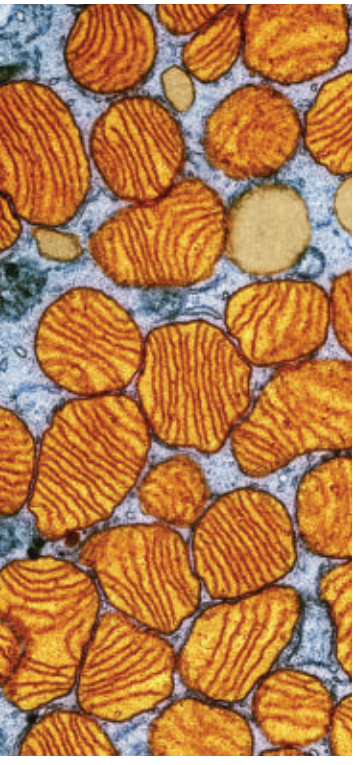


Mitochondria are a cell's power engines. Here, they are colored orange to stand out in fat cells.

CNRI/SCIENCE SOURCE

ever more sophisticated measures of oxidative stress and its role in the body, the shiny reputation of antioxidants has begun to tarnish. Steven McAnulty and colleagues performed one of the earliest experiments to question whether the theoretical benefits of antioxidants were real.

In the early 2000s, McAnulty, of Appalachian State University in Boone, N.C., recruited 38 athletes training for an Ironman triathlon, which requires a two-mile swim, a 26-mile run and a 112-mile bike ride. Two months before the race, the researchers gave 19 of the athletes 800 international units of vitamin E every day, more than 35 times the recommended daily amount. Before and just after the event, the scientists measured the compound isoprostane in blood and urine samples as a newly established, state-of-the-art marker of oxidative stress. Instead of a protective effect, they found that the amount of oxidative stress in the group taking the antioxidant was higher — twice as high, in fact — compared with athletes who were taking a placebo.

"We were pretty floored," McAnulty says. In a similar experiment with ultramarathon runners, he found that giving them 1,500 milligrams of vitamin C daily for a week before the race did not make any difference in measures of oxidative stress. Both papers were published more than a decade ago, the Ironman study in the journal *Medicine & Science in Sports & Exercise* and the study of ultramarathoners in the *European Journal of Applied Physiology*.

But experiments like these, questioning the conventional wisdom of antioxidants, got little notice until 2009, when the *New York Times* wrote about a report in the *Proceedings of the National Academy of Sciences*. A team of researchers from two German universities and Harvard Medical School measured how taking vitamin E and C supplements affected insulin sensitivity, and by implication diabetes risk, in a group of 40 healthy young men. Half of the participants were fit, while the other half did not regularly exercise. All were randomly assigned to take either antioxidant supplements or a placebo as they went through a four-week period of exercise training.

At the end of the study, the men who had taken the antioxidants did not see a boost in insulin sensitivity, which usually occurs under the demands of exercise. It's one reason why exercise is viewed as an important part of diabetes prevention and management. "Supplementation with antioxidants may preclude these health-promoting effects of exercise in humans," the researchers reported.

11
percent
Endurance boost (measured as VO_2 max) in men taking daily vitamin C supplements during training

22
percent
Endurance boost in men who took no supplements during training

At the time, skeptics rightly pointed out that this was only one study. But the bad news kept coming. The same year as the *PNAS* paper, researchers in Australia reported experiments in *Cell Metabolism* involving mice genetically unable to produce a key enzyme involved in the elimination of free radicals, the very function championed with antioxidants. When the mice unprotected from free radicals were fed a high-fat diet, they did not develop insulin resistance, which is normally a consequence of eating poorly. Free radicals, it seemed, were offering some protection against diabetes. Researchers at the time increasingly noted a paradox — namely, that high doses of antioxidants were not only allowing free radical damage, but in certain cases, promoting it.

A power boost

More recent research has carried these concerns further, suggesting that muscles in training perform best when they have to cope with blasts of free radicals. Prolonged oxidative stress might damage cells and contribute to aging and chronic disease, but the brief bursts that come from physical activity could perhaps sharpen internal mechanisms that mop up free radicals and build muscle endurance.

"In order for physiological systems to adapt, they need to be overloaded," says Arthur Weltman, who heads the exercise physiology laboratory at the University of Virginia in Charlottesville. One possible reason: Active muscles need an abundance of mitochondria to produce a lot of energy in a hurry. Powers, from Florida, published a study in 2008 suggesting that the free radical oxygen produced from exercise in rats, rather than hurting cells, triggers changes in cardiac muscle that help mitochondria stay plentiful — the very thing athletes need.

Other studies have found similar effects. A team of Spanish researchers writing in the *American Journal of Clinical Nutrition* conducted one of the few studies taking the same oxidative stress measures in both humans and rats given daily vitamin C supplements. In the animal studies, when muscle cells were flooded with the vitamin, mechanisms that normally stimulate mitochondria production did not engage.

Among the human volunteers, those who did not receive supplements experienced a 22 percent increase in VO_2 max, a measurement of the maximum amount of oxygen the body is using, and a key indicator of endurance. (The higher the number, the more energy you're squeezing out of

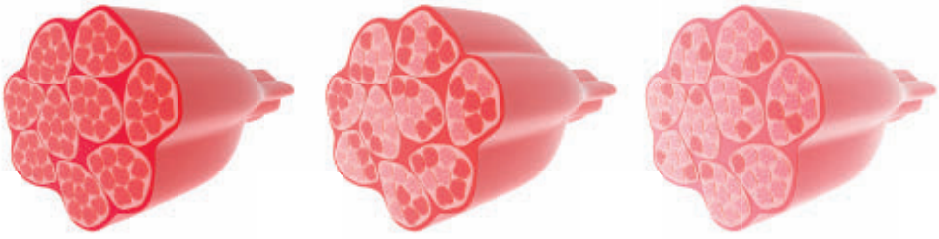
Too much of a good thing?

New research suggests that, for athletes, high-dose antioxidant supplements do little good and may harm performance. Supplements may reduce soreness in the short run, but blunt long-term fitness improvements.

Antioxidants from supplements may mean:
- Fewer new mitochondria
- Less muscle soreness
- Fewer gains in aerobic fitness

Antioxidants from food may mean:
- Mitochondria multiply for long-term improvement in power and endurance
- Soreness with increased training
- Bigger gains in aerobic fitness

Mitochondria in different muscle types



Red muscle
Many mitochondria for endurance in leg and back muscles

Mixed muscle
Medium mitochondrial content found throughout the body

White muscle
Low mitochondrial content; for quick eye movements

SOURCE: CYRUS KHAMBATTA

each breath.) The vitamin C group experienced an increase of about 11 percent.

Some studies even question multivitamins. Last year in the *Journal of Sports Medicine and Physical Fitness*, researchers from Norway found that athletes who took a mix of B vitamins, antioxidants and minerals for six weeks had significantly lower gains in VO_2 max than athletes given a placebo.

Still, taken as a whole, placebo-controlled trials of the effects of antioxidants on sports performance have produced a mixed bag of conclusions. Most studies cited in last year's review by the Brazilian research team were equivocal, while two found an advantage in the placebo group and two an advantage in the supplement group. The authors say the lack of consistency arises from the fact that study methodology varies greatly, from sample sizes to the vitamin doses given, length of study and the underlying fitness level of the volunteers. It's not unheard of for two sets of researchers to arrive at different conclusions with the same data (*SN: 1/24/15, p. 21*).

Researchers also caution that although antioxidants often get lumped together, they are in fact a heterogeneous bunch, with varying mechanisms of action inside cells. So experimental results from one supplement might not apply to another.

Even studies of antioxidants with fancy names have not gathered enough evidence to say whether they offer athletes a benefit. A study in *Medicine & Science in Sports & Exercise* last June reported that cyclists who took the popular dietary supplement *N*-acetylcysteine (which maintains levels of the antioxidant glutathione) showed improved times on sprints and better internal adaptations to oxidation. But other studies have raised concerns about the compound's role in promoting tumor growth.

Another popular antioxidant, quercetin, has also shown unpredictable results. "We've published four different papers and we didn't find meaningful effects," says Kirk Cureton, retired head of kinesiology at the University of Georgia in Athens. A 2011 review rated the benefit of quercetin "between trivial and small."

The Goldilocks zone

Doubts over antioxidant supplements should not be extrapolated to antioxidants found in the diet, scientists say. "The compounds are different in foods, and you're getting normal amounts," McAnulty says. He published a 2011 study of blueberry powder, finding reduced levels of oxidative stress after volunteers consumed it daily for six weeks. (The amount was equivalent to about a cup of blueberries; food in capsules is often used in studies to standardize the dose.) Another example: Researchers in New Zealand recently compared oxidative stress and performance of runners taking a vitamin C solution or a black currant juice drink with natural levels of antioxidants but the same number of calories. The researchers saw increased oxidative damage with vitamin C and only the black currant users dropped time.

Antioxidants from fruits and vegetables, as opposed to supplements, may keep the body in a kind of Goldilocks zone, McAnulty says, permitting enough oxidation to keep natural coping mechanisms engaged, but not so much that cells suffer harm. In the end, athletes may be better off paying attention to what goes on their plates, while scientists try to figure out whether anything in the medicine cabinet is worth the price. ■

Explore more

- Michalis G. Nikolaidis *et al.* "Does vitamin C and E supplementation impair the favorable adaptations of regular exercise?" *Oxidative Medicine and Cellular Longevity*. 2012.

SOMERSAULT1824/SHUTTERSTOCK; ADAPTED BY E. OTWELL

Ross Kelly purchased this thermometer in Switzerland and displays it online.

SCREENTIME

Enjoy scientific curios collected over decades

In Renaissance Europe, scholars and collectors built curiosity cabinets and filled them with marvels of art and natural history. Catalogs of the contents of these privately held "wonder rooms" were sometimes published to share scientific knowledge, and larger collections formed the basis for museums. Fast-forward to 2013, when chemist Ross Kelly of Boston College realized that his own collection of wondrous objects could be shared in that most 21st century mode: over the Internet.

The result is a series of more than 30 short videos highlighting the gadgets he has collected over more than 25 years in his "Scientist's Curiosity Cabinet" (bit.ly/scicabinet). He and two undergraduates demonstrate toy cannons, a levitating globe that spins, flash paper and many other devices. If the videos' brief explanations of the science underlying a boom or bubble don't satisfy, Kelly has provided links to more in-depth discussions. *— Lila Guterman*

This Idea Must Die
John Brockman, Ed.
HARPER PERENNIAL, $15.99

BOOKSHELF

Scientific theories ready for retirement

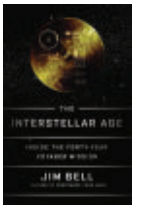
"Science advances by a series of funerals," writes John Brockman, founder of the online discussion forum Edge.org. Sometimes, he says, old ideas have to be put to bed before new ones can flourish. With that in mind, he asked researchers, journalists and other science enthusiasts to weigh in on which established theories need to go. From the replies, Brockman compiled *This Idea Must Die*, a fascinating smorgasbord of 175 short essays about every field and facet of research.

Many of the responses offer tweaks to theories to better fit new discoveries. A psychologist points out that sadness and other "negative" emotions are not inherently bad, that they can help sharpen analytical thinking and enhance memory (*SN: 11/2/13, p. 18*). Other essays call for more radical changes. Laboratory mice make lousy stand-ins for people when developing new drugs, argues an oncologist. It's time to stop using them as furry human surrogates, she says. And a number of physicists would be happy to toss out string theory for good. "What we've learned is that this is an empty idea," one physicist writes. "It predicts nothing about anything."

Some of the essays tackle broader subjects, suggesting ways scientists can improve how they design experiments, crunch numbers and publish papers (*SN: 1/24/15, p. 20*). Other writers lament poor communication between scientists and the general public, especially when misconceptions allow old theories to linger in the media long after they've been debunked. Take, for example, the notion of nature versus nurture — it still crops up in politics and the press, even though biologists have long known that genetics and environment are inextricably intertwined.

A few of the arguments are bound to be controversial. For example, a journalist asserts that the information gleaned from massive particle accelerators isn't worth their equally massive price tags. And while Brockman's question inspired some thought-provoking responses, the short essays can provide only a brief overview of complex problems. Readers will want to do some research of their own before deciding which, if any, of these ideas really requires a funeral. *— Allison Bohac*

BOOKSHELF



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A planetary scientist tells the tale of the Voyager mission, from idea to visiting planets and moons, to reaching the edge of interstellar space.
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JACLYN LUNDBERG

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Ocean Worlds
Jan Zalasiewicz and Mark Williams
OXFORD UNIV., $29.95

BOOKSHELF

The story of water on Earth and across the cosmos

The oceans of other worlds might look nothing like Earth's tranquil blue seas. Under the right high-pressure conditions, the water could exist in a weird supercritical state that is neither liquid nor steam. And yet the key to understanding such alien landscapes may lie close to home, around submarine volcanoes right here on Earth.

Ocean Worlds looks at the inner workings of Earth's oceans — and of other worlds' seas as well. Drawing on the latest research, Jan Zalasiewicz and Mark Williams trace the history of our planet's water. The authors begin the story not long after the Big Bang, with water vapor swirling around a black hole. From there, the authors follow the comets and asteroids that may have delivered water to Earth, trace water's motion through deep ocean currents and recount water's role in the origin of life.

Other worlds in the solar system offer a glimpse of the many ways seas can form and evolve. Zalasiewicz and Williams look to the moons of Jupiter and Saturn, where liquid oceans of saltwater hide beneath thick crusts of ice. Our two neighboring planets, Venus and Mars, once harbored water as well. Venus, in particular, provides a peek at what's in store for Earth over the next billion years as our planet loses its oceans to a slowly brightening sun.

Zalasiewicz, a geologist, and Williams, a paleontologist, aren't afraid to step well beyond their fields to dabble in astrophysics, planetary science, oceanography and microbiology. If the book sounds ambitious, it is. But their clear, descriptive writing is a joy to read. Anecdotes sprinkled throughout keep *Ocean Worlds* from reading like a textbook; the authors describe how slave-trading ships discovered the cold waters of the deep ocean and what the movie *Waterworld* got wrong about climate.

Between the birth of the solar system and the eventual desertification of the Earth, the authors pause to consider humankind's role in shaping the oceans. And not surprisingly, it's not good. Overfishing, rising temperatures and growing acidity threaten to destroy ecosystems. These are all trends that could be reversed with prompt action, but political reality seems to make this an unlikely outcome. "It would be ironic," the authors write, "to discover a wealth of strange and bizarre oceans out in the cosmos just as we are dismantling the beautiful and unique oceans on our own doorstep."
— Christopher Crockett

JANUARY 10, 2015

JANUARY 24, 2015

Water's origin story

New evidence suggests that comets may not have delivered water to Earth. Water detected in comet 67P/Churyumov–Gerasimenko's hazy atmosphere isn't a chemical match for Earth's oceans, as ***Ashley Yeager*** *reported in "Ocean water may not be from comets"* (SN: 1/10/15, p. 8).

The Rosetta spacecraft searched for a heavy form of hydrogen known as deuterium around 67P and found that the comet's water had a deuterium-to-hydrogen ratio about three times as high as that of Earth's water. "Might it not be true, though, that this comet and others have periodically had lighter molecules swept away by the solar wind as they have neared the sun and formed tails?" suggested **Greg Skala**. "Might that not mean that proportionally more heavy water gets concentrated over the eons, at least for those comets that orbit close to the sun? In the very same issue, in **Thomas Sumner**'s article 'Solar wind may leach Mars' air' (*SN: 1/10/15, p. 10*), the process is discussed whereby gas molecules with heavier isotopes could get left behind."

Mars sits in the inner solar system, where it has taken a constant beating from the solar wind for billions of years, says **Yeager**. Comets like 67P spend most of their lives in a deep freeze at the outer edges of the solar system, so their atmospheres have been largely untouched by the sun. Any differences in heavy and light elements are more likely to be influenced by how the comet was formed in the early days of the solar system, **Yeager** notes.

Solutions that shake

Sealing carbon dioxide into underground reservoirs could help stave off climate change. But pumping the greenhouse gas deep below Earth's surface may also trigger rumblings along geologic faults, as ***Charles Petit*** *explained in "Carbon quakes"* (SN: 1/24/15, p. 14).

Most readers didn't think much of this plan to put away carbon. "Really! Someone thinks injecting carbon dioxide underground is a good idea?" asked **Nancy Patterson** in an e-mail. "After all, it only makes the very ground upon which we build our homes, highways, bridges, nuclear power plants and railroad tracks unstable. What could go wrong?" For **Paul Baker**, the story "immediately brought to mind a favorite saying of John W. Campbell, the longtime editor of *Analog Science Fiction and Fact* magazine: 'You can't do just one thing.' In other words, everything we do will have unexpected, unforeseen and/or undesirable consequences."

But others believe that the project has merit. "Injecting CO_2 into the ground seems problematic and expensive, but there is a lot to say for the all-of-the-above approach which pursues every option, even the more far-fetched ones," argued commenter **KokoTheTalkingApe**.

Hollywood's rewritten history

*In "*The Imitation Game *entertains at the expense of accuracy"* (SN: 1/24/15, p. 28), ***Andrew Grant*** *took a critical look at a new film depicting the life of mathematician Alan Turing.*

The movie took some liberties with the historical events surrounding Turing's role in cracking the German's Enigma code during World War II. But some readers weren't bothered by the discrepancies. "When people see movies such as this one, they expect inaccuracies or fabrications designed to increase the dramatic effect of the narrative," wrote commenter **WannabeTesla**. "The important question to me is, 'Did the filmmakers do Alan Turing justice?' I think they did, and his exposure via this film will probably inspire many to learn more about the real historical man. That's a success in my book."

Correction

"Insect-eating bats implicated as Ebola outbreak source" (*SN: 1/24/15, p. 12*) mentioned that bats pollinate fruit crops, including bananas. Reader **Todd Brethauer** correctly pointed out by e-mail that unlike wild bananas, the species of bananas cultivated in Africa are seedless and don't require pollination.

Join the conversation

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Glassy blue iceberg goes belly up

Roughly 90 percent of an iceberg's volume hides beneath the waves. But every so often an iceberg's underbelly makes an appearance above the waterline.

Filmmaker Alex Cornell photographed this recently overturned iceberg jutting about 9 meters skyward in Cierva Cove, Antarctica, in December. It's a rare sight, says oceanographer Louise Biddle of the University of East Anglia in Norwich, England. Over time accumulating snow and debris whiten exposed ice, so Biddle suspects this iceberg had flipped at most a few days earlier. An iceberg can flip shortly after snapping off its parent glacier, she says, or when uneven melting causes the berg to shift its balance like a sailboat with a broken mast.

The newly exposed ice probably originated deep within the glacier, where high pressures squeeze out tiny air bubbles that scatter white light. Bubble-free ice absorbs red and yellow light while reflecting blue light, giving the upturned iceberg its spectacular color.

Despite their beauty, icebergs can be dangerous when they roll over. Biddle says research vessels and tourist ships steer clear of large bergs, fearing huge splashes and capsize-inducing waves in the event of a flip. — *Thomas Sumner*

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Our Time Gives You More Money. This stunning, vintage-inspired timepiece is the *Brava Watch*, available only from Stauer. Priced at $199, it can be yours today for **ONLY $99!** Mention the Insider Offer Code (in the gold box) and we'll automatically upgrade you to ***Gold Status** and ship your watch with four (4) $50 Stauer discount certificates, good toward any future qualifying Stauer purchase with no minimum required!

A Gentleman's Classic Returns. The *Brava* is a study in classic elegance. Inspired by important wristwatches of the 1940's and 50s, its rose gold-finished case frames a textured ivory dial anchored by four bold, black numerals. Inside beats the heart of a precision time machine with a movement that oscillates at 32,768 times per second. This is time stripped to its boldest design essentials... a watch for the man of today who knows exactly what he wants tomorrow.

Buy Now, Shop Later. Don't forget—the watch is just the beginning. Your $200 in bonus Stauer certificates will give you the power to save the day on special occasions all year long. Need jewelry for a birthday or anniversary gift? Choose a pair of $59 earrings, use one of your discount certificates, and get them for $9! Yes, it really is that simple. You save $50 instantly on any future qualifying Stauer purchase!

Your satisfaction is 100% guaranteed. Try out the *Brava* Watch for 60 days and if you're not completely impressed, send it back for a full refund of your purchase price. Even if you decide to return the watch, you get to keep the $200 in Stauer discount certificates. You have nothing to lose. This is the watch that pays for itself... twice! Quite simply, this is the best luxury deal on the planet.

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