SPECIAL ISSUE: A MIND FOR MUSIC

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ScienceNews

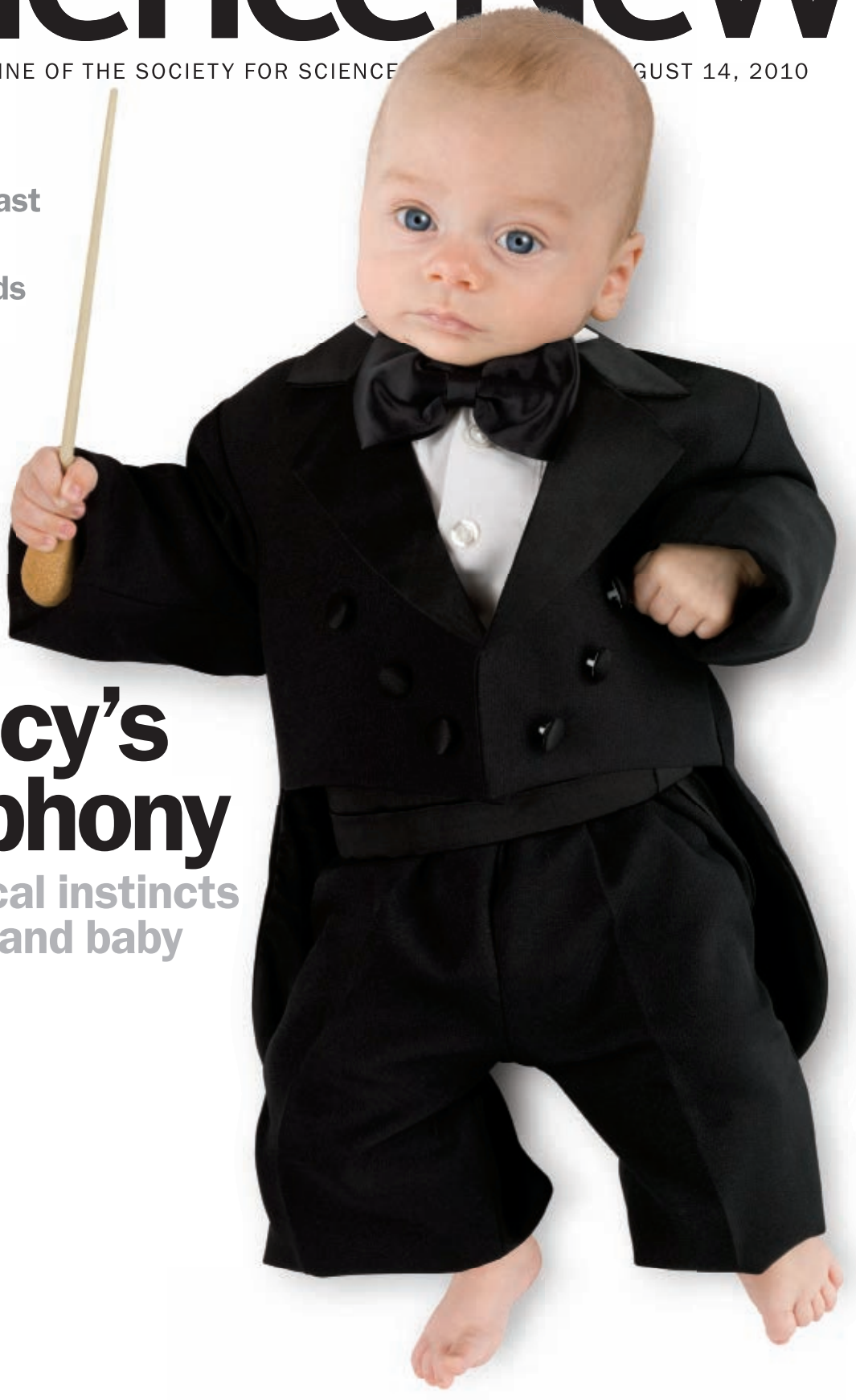
MAGAZINE OF THE SOCIETY FOR SCIENCE GUST 14, 2010

PLUS:

Stem Cells Stuck in the Past

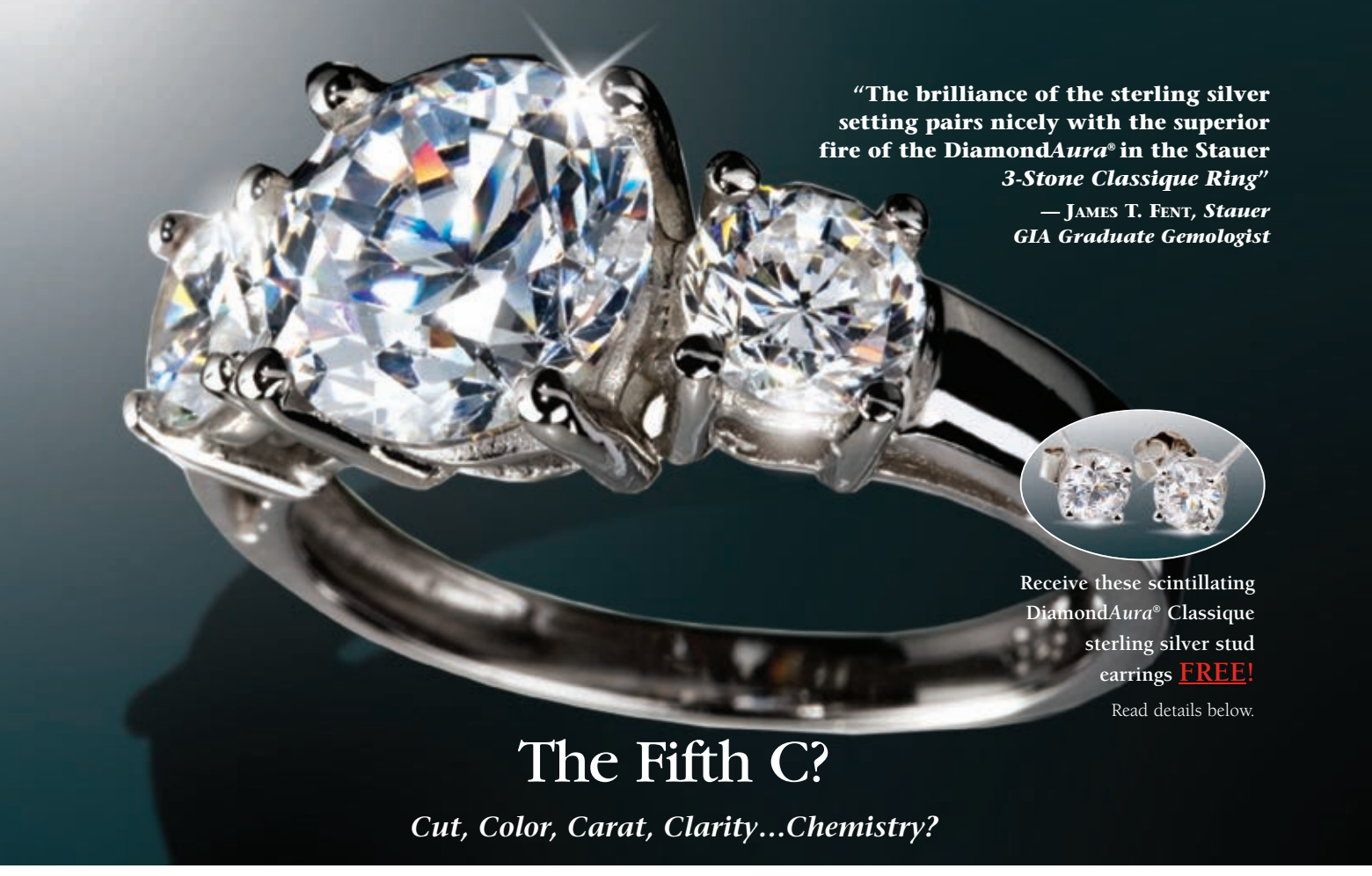
Time Travel with Safeguards

Needleless Vaccines



Infancy's Symphony

How musical instincts help mom and baby connect



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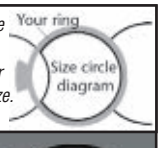

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AUGUST 14, 2010 • VOL. 178 • NO. 4

ScienceNews

In The News

Special Issue

Departments

COVER Though researchers differ on whether music is innate, studies suggest that rhythm and pitch play integral roles in a baby's earliest interactions.
Photo by Cary Wolinsky

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FROM THE EDITOR

Many curious scientists have music on their minds

And now for a musical interlude.

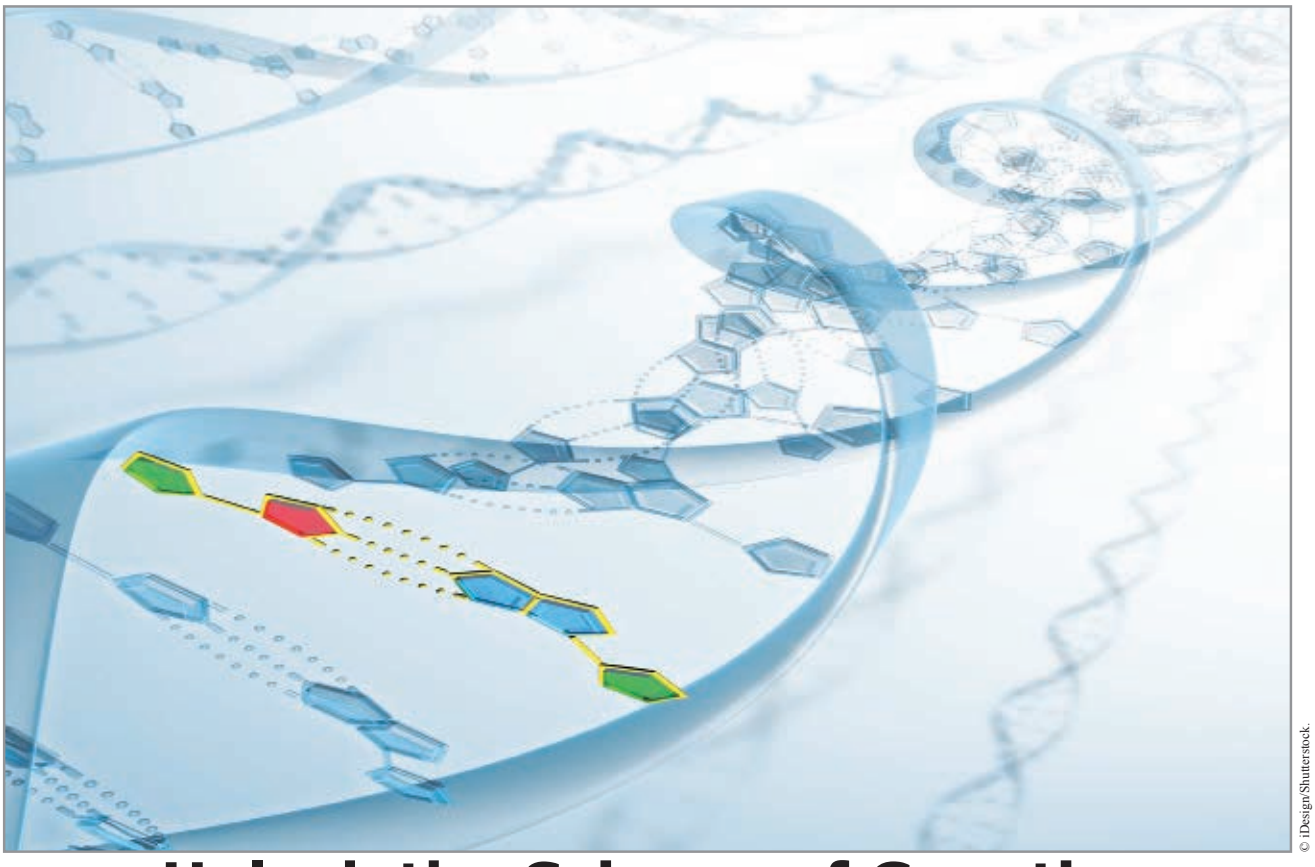
Ever since Pythagoras of Samos and his followers worked out the math of harmony and speculated about the ever-present (if inaudible) music of the spheres, scientists have been fascinated with song.

Galileo's father, Vincenzo Galilei, was a musician and composer; experiments that father and son performed with lute strings may have inspired Galileo's understanding of the physics of pendulums and falling bodies. As a college student, Isaac Newton dabbled in deriving logarithmic relationships among the notes of the musical scale. And Albert Einstein was notorious for his love of playing the violin.

In recent years music has become a popular topic of study among scientists with various perspectives, as documented in this issue's special section on music, introduced by *Science News* features editor Elizabeth Quill on Page 17. Bruce Bower (Page 18) relates the intriguing (though much debated) notion among psychologists that melodic vocalizations between mother and baby set the stage for more explicit communication. Neuroscientists have been probing music's power to modulate emotion, as Susan Gaidos reports (Page 24). And while neuroscientists have largely dismissed the "Mozart effect" myth that listening to music enhances mental skills, practicing and performing musical compositions does seem to elevate certain cognitive capabilities, as Rachel Ehrenberg describes (Page 30).

In all of these instances, music proves to be intimately engaged with the processes of the brain and mind. In fact, music engages "more of the brain than any other stimulus we know," says neuroscientist Istvan Molnar-Szakacs (see Page 24). Music can light the synaptic fires that animate memories, and it elevates the activity of the brain chemical dopamine in parts of the brain governing pleasure and reward. Playing musical instruments alters brain areas involved not only with hearing but also with muscle control. Music may or may not soothe savage breasts, but music therapy does appear to help alleviate several brain maladies (see "Take two stanzas and call me in the morning," Page 32).

Thomas Carlyle, the 19th century essayist, called music the "speech of angels"; to modern science, music is the voice of the brain, providing clues to its inner workings and expression of its deepest feelings. —*Tom Siegfried, Editor in Chief*



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Scientific Observations

"For years, mental health professionals were trained to see children as mere products of their environment who were intrinsically good until influenced otherwise; where there is chronic bad behavior, there must be a bad parent behind it. But while I do not mean to let bad parents off the hook—sadly, there are all too many of them, from malignant to merely apathetic—the fact remains that perfectly decent parents can produce toxic children.... Much has been written about psychopaths in the scientific literature, including their frequent histories of childhood abuse.... But there is little, if anything, in peer-reviewed journals about the paradox of good parents with toxic children.... [E]veryday character traits, like all human behavior, have hard-wired and genetic components that cannot be molded entirely by the best environment." —**PSYCHIATRIST RICHARD A. FRIEDMAN OF WEILL CORNELL MEDICAL COLLEGE IN NEW YORK CITY, IN A COMMENTARY PUBLISHED ONLINE JULY 12 IN THE *NEW YORK TIMES***

Science Past | FROM THE ISSUE OF AUGUST 13, 1960

SCIENTISTS CALCULATE HOW MAN MAY FLY LIKE BIRD — Man may some day be able to fly by flapping a set of artificial wings, two Chilean scientists assert.... A 154-pound man equipped with 66 pounds of flight accessories would need wings about 10 feet long with a flight surface of 60 square feet. To maintain a speed of 45 to 50 miles per hour, he should flap his wings 35 times a minute or a little faster than once every two seconds. The up-and-down speed of the wing tip should be 15 to 20 miles per hour or about 10 feet per second.... The man would be working about as hard as if he walked up 30 steps a minute. Under the right conditions, a man would be able to keep up this pace for from five to 30 minutes.

Science Future

September 12–13
A conference in Chicago focuses on the links between epilepsy and depression. See www.epilepsyanddepressivedisorders.com

September 15
The 2010 International Science & Engineering Visualization Challenge entry deadline. Go to www.nsf.gov/news/scivis

October 4–8
Planetary scientists meet in Pasadena, Calif. See dps.aas.org/meetings/2010

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SCIENCE & THE PUBLIC BLOG
Astronauts' stomachs may face more unpleasant things than space sickness. See "Food for Mars."

LIFE
Caterpillars' insides advance before their outsides do when the creatures crawl, new research finds. Read "Gut first."

MATTER & ENERGY
Scientists have created microswimmers that can loop the loop. The team hopes to someday make ones that can whiz through people's bodies. Read "Different strokes."

BODY & BRAIN
Individuals may each have a unique mix of gut viruses, like a microbe fingerprint. Read "Everyone poops his or her own viruses."

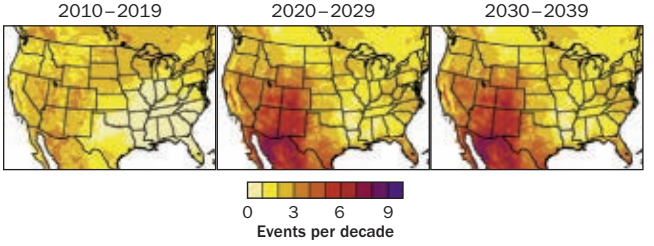
The (-est)

The European Space Agency's Rosetta Orbiter made its closest approach to the asteroid 21 Lutetia on July 10, whizzing within 3,162 kilometers of the space rock. The spacecraft snapped images of Lutetia's battered surface and the huge indentation stretching across one side with a resolution that caught details as small as 60 meters across. The new views will help determine whether the asteroid is an ancient body left over from the solar system's formation or a fragment of a larger object's core. Lutetia is Rosetta's last stop before it arrives at Comet 67P/Churyumov-Gerasimenko in 2014.

Science Stats | HEATIN' UP

Over the next 30 years, temperature extremes at many U.S. locations will be as hot or hotter than the sites' seasonal record high from 1951–1999, new climate modeling work shows.

Projected number of seasons that will meet or exceed the 1951–1999 heat record



SOURCE: N. DIFFENBAUGH AND M. ASHFAQ/*GEOPHYSICAL RESEARCH LETTERS* 2010

CLOCKWISE FROM TOP LEFT: AMELIA PANICO; TUFTS UNIV.; ESA 2010 MPS FOR OSIRIS TEAM, MPS/UPD/LAM/IAA/RSSD/INTA/UPM/DASP/IDA

“Now we have a product that can potentially ... save millions of lives by preventing HIV infection.” —QUARRAISHA ABDOOL KARIM, PAGE 9

In the News

STORY ONE

Time travel gets more plausible, yet weirder too

Physicists avoid paradoxes by forbidding the forbidden

By Laura Sanders

Novelists and screenwriters know that time travel can be accomplished in all sorts of ways: a plutonium-powered DeLorean, Hermione’s Time-Turner and, most recently, a spacetime-bending hot tub have allowed fictional heroes to jump between past and future.

But physicists know that time travel is more than just a compelling plot device — it’s a serious prediction of Einstein’s general relativity equations. In a new study posted online July 15, researchers led by Seth Lloyd of MIT analyze how some of the quirks and peculiarities of real-life time travel might play out. This particular kind of time travel evades some of the paradoxical possibilities that might arise from jumping forward or backward in time, Lloyd says.

Any theory of time travel has to confront the devastating “grandfather paradox,” in which a traveler jumps back in time and kills his grandfather, which prevents his own existence, which then prevents the murder in the first place, and so on.

One model, put forth in the early 1990s by Oxford University physicist David Deutsch, can allow inconsistencies between the past a traveler remembers and the past he experiences. So a person could remember killing his grandfather without ever having done it.

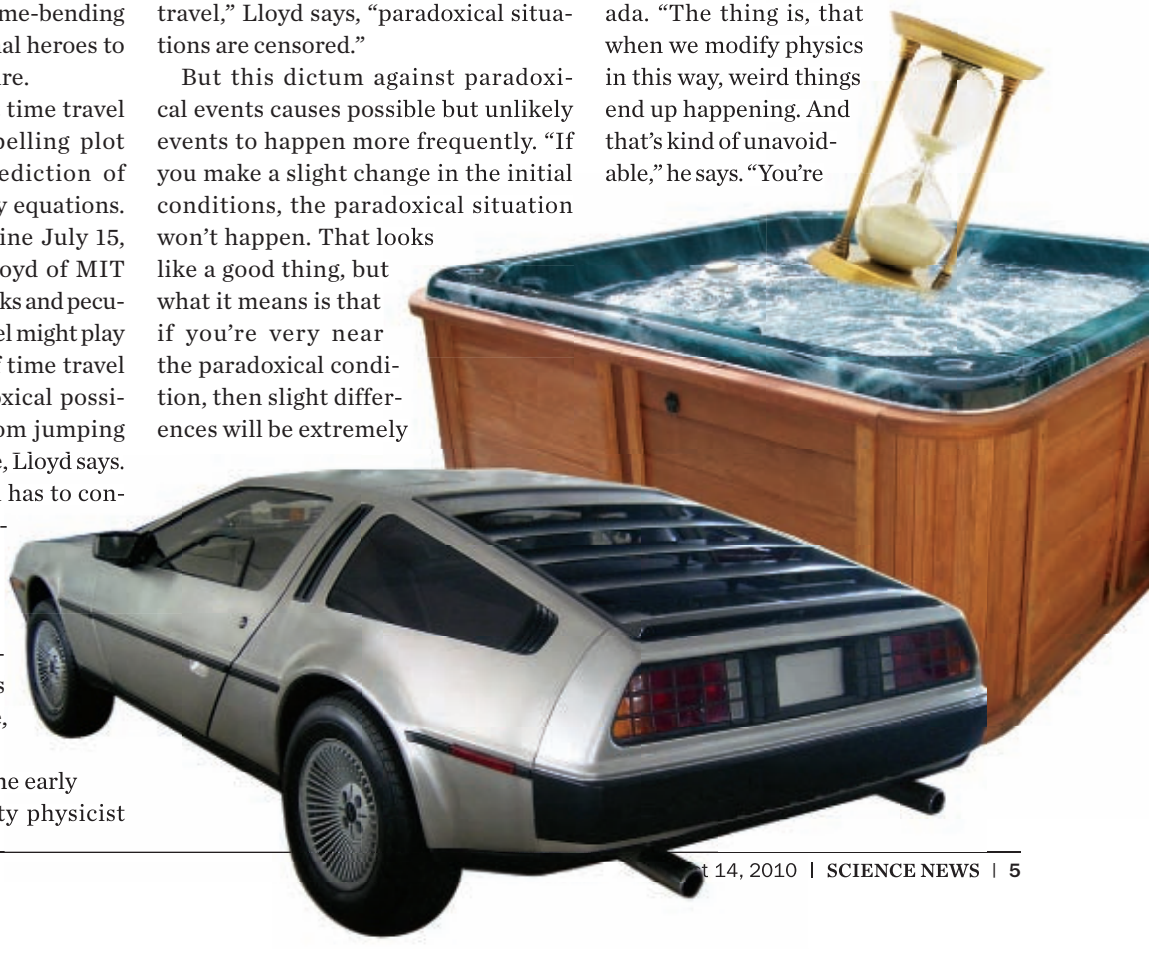
“It has some weird features that don’t square with what we thought time travel might work out as,” Lloyd says.

Lloyd prefers a model of time travel that doesn’t just cover up, but explicitly forbids these inconsistencies. Posted at arXiv.org, this version is called a post-selected model. By outlawing any events that would later prove paradoxical, this theory gets rid of the uncomfortable idea that a time traveler could prevent his own existence. “In our version of time travel,” Lloyd says, “paradoxical situations are censored.”

But this dictum against paradoxical events causes possible but unlikely events to happen more frequently. “If you make a slight change in the initial conditions, the paradoxical situation won’t happen. That looks like a good thing, but what it means is that if you’re very near the paradoxical condition, then slight differences will be extremely amplified,” says Charles Bennett of IBM’s Watson Research Center in Yorktown Heights, N.Y.

For instance, a bullet maker would be inordinately more likely to produce a defective bullet if that bullet was going to be used later to kill a time traveler’s grandfather. Or the gun would misfire, or “some little quantum fluctuation has to whisk the bullet away at the last moment,” Lloyd says. In this version of time travel, the grandfather, he says, is “a tough guy to kill.”

This distorted probability close to the paradoxical situation is still strange, says physicist Daniel Gottesman of the Perimeter Institute in Waterloo, Canada. “The thing is, that when we modify physics in this way, weird things end up happening. And that’s kind of unavoidable,” he says. “You’re



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dealing with time travel. Maybe you should expect it to be weird."

Although the post-selected model has floated around among physicists informally, until now no one had constructed a detailed theory of it, Lloyd says. "Our theory has the benefit that you can calculate what's going to happen really easily, and you can compare it with other theories really easily and you can test how the theory works experimentally," he says.

In an earlier paper posted in May at arXiv.org, Lloyd and his team present experiments designed to simulate this post-selection model using photons. Though photons can't be sent into the past, they can be put in quantum situations similar to those that might be encountered by a time traveler. As the photons got closer to being in self-inconsistent, paradoxical situations, the experiments succeeded with less frequency, the team found, hinting that true time travel might work the same way.

The experiments were meant to simulate freaky paths through spacetime called closed timelike curves, which carry anything traveling along them into the past and then back to the future. Einstein's equations predicted that travelers on a closed timelike curve would eventually end up back in spacetime where they started. Although predicted to exist on paper, no such paths have been observed in the wild. Some physicists predict that these loops might exist in exotic regions where spacetime is drastically different, such as in the depths of black holes.

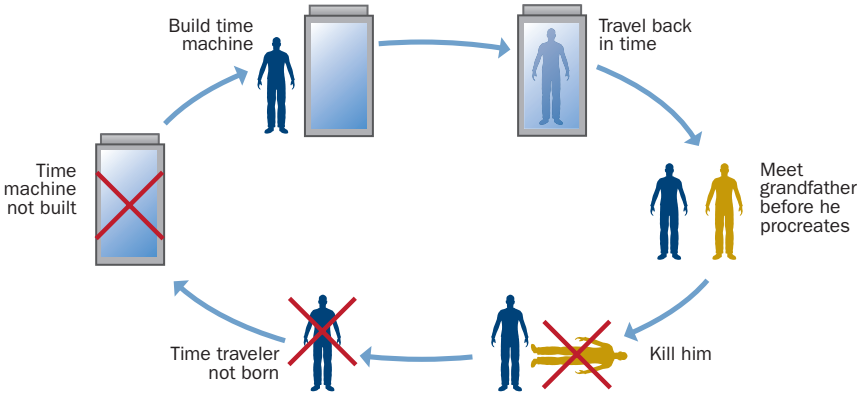
Despite its strange predictions, the new model forms "a nice, consistent loop," says theoretical physicist Todd Brun of the University of Southern California in Los Angeles. The new papers make up "a really interesting body of work."

These days, deciding which theory of time travel is best is largely a matter of taste. Until someone discovers a real closed timelike curve, or figures out how to build a time machine, no one will know the answer, says Brun. "I don't expect these will be tested anytime soon. These are ideas. They're fun to play with."

Though going back to 2004 to get in on the Google IPO is out of the question, Lloyd and his colleagues propose that their version of closed timelike curves could have some utility as the basis of powerful quantum computers that could solve complicated problems "with ease."

Bennett isn't convinced, though. People have tried to use similar systems to solve hard problems, he says, "but it turns out always that there's some aspect of the physical model that has to be too perfect or too noise-resistant or use too much energy," he says. "Not that I have a really worked-out reason, but I think there's a reason for being skeptical about the computational power of any closed timelike curve, even the post-selected ones." ■

Physicists have proposed several ways of getting around the grandfather paradox (shown). In a new model, quantum probabilities simply rule out such situations.



Back Story

MOVIE TIME

Time travel is a well-worn plot device in Hollywood, but few films seriously consider the paradoxes that a time traveler might face. Here are some that do, although not always in a serious manner.

Back to the Future (1985)
Marty McFly (Michael J. Fox) confronts a variant of the grandfather paradox when he goes back to 1955 and unintentionally prevents his parents from marrying.

Bill and Ted's Excellent Adventure (1989)
Bill (Alex Winter) and Ted (Keanu Reeves) romp through the past collecting historical figures for a class report. The story contains several examples of the ontological paradox, in which information is conveyed to people in the present by visitors from the future, rendering it impossible to determine when the knowledge originated.

Twelve Monkeys (1995)
A convict (Bruce Willis) goes back to the 1990s to prevent an epidemic that has forced the surviving remnants of humankind into a dystopian underground existence. Though his efforts may ultimately advance the cause, his own fate is sealed.

Primer (2004)
Two engineers (Shane Carruth and David Sullivan) accidentally invent a machine that allows them to travel back in time, where they confront the paradox of interacting with their past selves.

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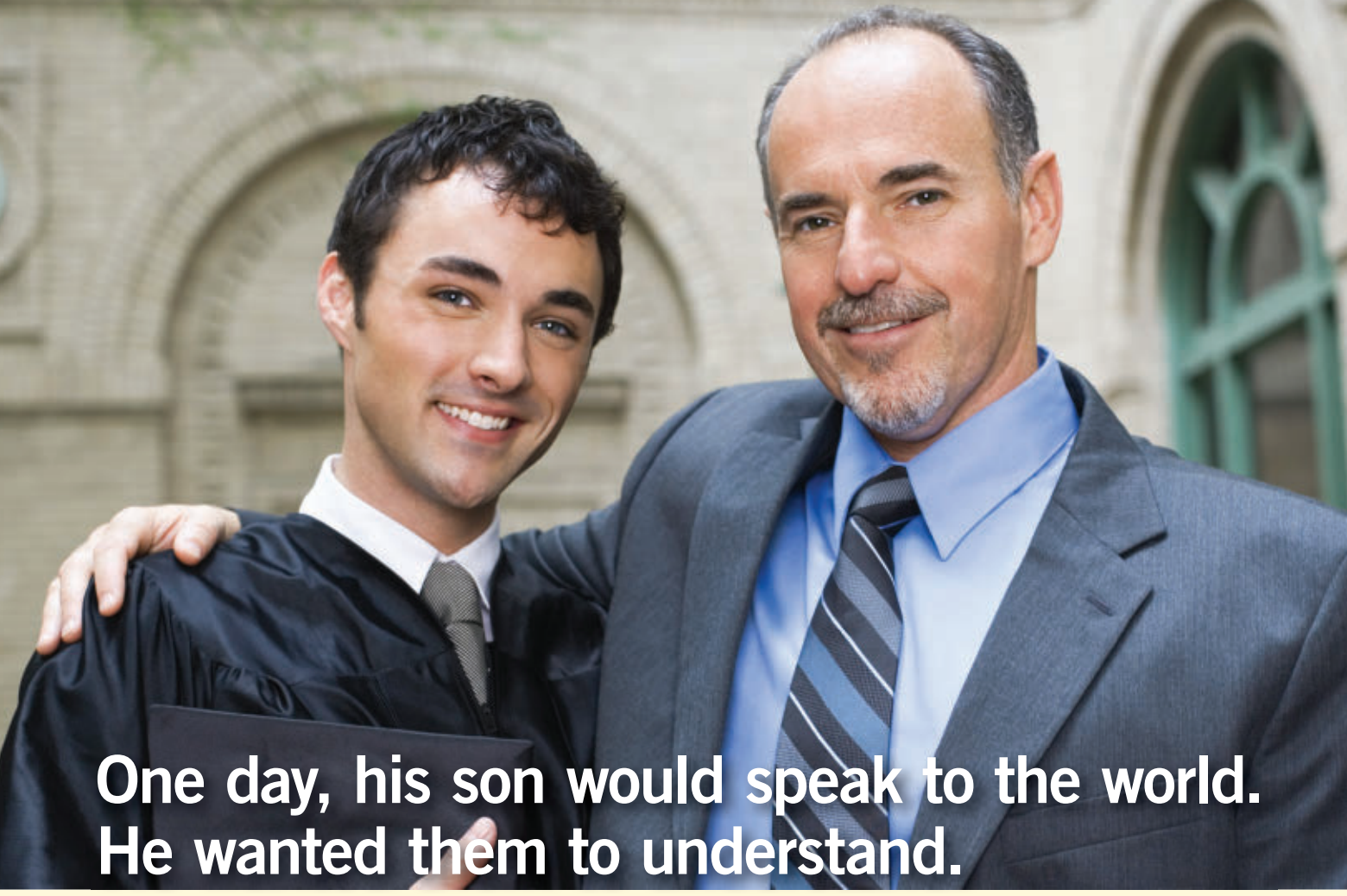

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Body & Brain

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Tool gives odds for IVF success

Algorithm could help patients considering a second round

By Nathan Seppa

Couples contemplating a second attempt at having a child through in vitro fertilization after failing the first time may now have a tool that takes some of the guesswork out of the decision to try again.

By incorporating dozens of factors pertaining to a couple's fertility and health, a new algorithm more accurately predicts the probability that IVF will succeed compared with a currently used standard calculation, researchers report online July 19 in the *Proceedings of the National Academy of Sciences*.

In IVF, eggs are retrieved from a woman and fertilized in a lab dish with sperm from a male donor. If a healthy embryo develops, it is reinserted into the woman's uterus. In the best-case scenario, this embryo attaches to the uterine wall and a normal pregnancy ensues. This happens only about 25 to 30 percent of the time.

What's more, IVF can cost $7,000 to $15,000 per attempt and often is not covered by insurance. Thus, apart from emotional stress, a failed first attempt can leave couples with hard financial choices.

Aside from knowing that younger women have better success rates, researchers know little about what influences a woman's chances of becoming pregnant and giving birth through IVF. A predictive model that uses factors in addition to a woman's age would provide doctors and patients with a better idea of the probability that a second try will succeed, says Mylene Yao, an obstetric gynecologist at Stanford University School of Medicine and a coauthor of the new study.

Researchers know little about what influences a woman's chances of giving birth through IVF.

Yao and her colleagues used information from 1,676 IVF attempts, 29 percent of which resulted in a live birth. The researchers analyzed 52 variables that might affect IVF success, such as the drugs given to boost fertility in the mother, the number of embryos with more than four cells reinserted, the woman's age and so on. The scientists then devised a predictive algorithm that weighed the effects of these factors on the chances of success.

The research team then tested this new algorithm using data from 230 other women who tried IVF a second time after a first attempt failed. The new algorithm was more accurate than the standard age-based model overall; in about 60 percent of cases, the probability of success generated by the new algorithm differed substantially from that of the standard model, Yao says. Because the technique is experimental, this analysis was completed after the second IVF round and was not used to predict outcomes for these 230 women in real time.

Yacoub Khalaf, an IVF physician at King's College London, says that while the finding is interesting, it leaves many questions unanswered. In particular, he says, it's unclear whether this algorithm would be better than a simple clinical assessment using the woman's age plus a few key facts obtainable from a first IVF attempt, such as the number of eggs retrieved, the number of embryos available for reinsertion and the woman's previous history of live births.

Study IDs triggers in celiac disease

Separating wheat from chaff in an immune reaction to gluten

By Nathan Seppa

Three protein fragments are looking like the guilty parties in celiac disease, an intestinal ailment that affects as many as one in 133 people in the United States. These partial proteins, or peptides, are the components of gluten in wheat, rye and barley that trigger the immune systems of celiac patients, damaging the small intestine, a team reports in the July 21 *Science Translational Medicine*.

Pinpointing these peptides opens the way for development of a vaccine that might help celiac patients tolerate these foods. The research team, led by gastroenterologist Robert Anderson of the Walter and Eliza Hall Institute of Medical Research in Parkville, Australia, is now pursuing this line of work.

As it is, celiac patients deal with their condition by avoiding wheat, rye and barley. Most people digest these cereals effortlessly, but people with celiac disease have a genetic predisposition that causes an aberrant immune response to the gluten in the grains, damaging the walls of the small intestine. Celiac disease can cause painful bloating, diarrhea, constipation, lethargy and other problems.

Researchers fed more than 200 celiac patients wheat, barley and rye for three days, mobilizing the patients' immune T cells to mount an attack on gluten. Using these T cells, scientists measured the patients' immune reactions to 2,700 compounds from gluten. While dozens of peptides elicited some response, three stood apart. One appears in a type of wheat gluten. Another is found in rye gluten. And a third shows up on certain gluten proteins in all three cereals.

Nexpep, a biotech firm cofounded by Anderson, has begun a clinical trial using the peptides in a vaccine that aims to help celiac patients tolerate the compounds.

10.5 percent — Proportion of South Africans living with HIV

43 percent — Proportion of deaths in South Africa due to HIV

410 thousand — Projected new HIV infections in So. Africa, 2010

Antiviral gel promising against HIV

Topical treatment cuts infection rates in South African women

By Gwyneth Dickey

A new vaginal gel is the first to show promise in preventing HIV infection among women, researchers report online July 19 in *Science*. The gel could be an effective female-initiated means of HIV prevention in places like Africa, where HIV infection is common and condom use can be difficult for women to negotiate.

"Now we have a product that can potentially alter this and save millions of lives by preventing HIV infection and preventing death," says epidemiologist and study coauthor Quarraisha Abdool Karim of Columbia University.

In sub-Saharan Africa, women and girls account for about 60 percent of those living with HIV infections. Women in the region are less able to protect themselves against HIV if their male partners refuse to use condoms. Researchers have been working for over a decade to create a topical gel that can be used vaginally to prevent infection, but none had proven successful till now.

The new gel contains an anti-HIV drug called tenofovir. Tenofovir's success may come from its ability to be absorbed into the vaginal wall and into the cells targeted by HIV, says study coauthor Salim Abdool Karim, also of Columbia University. That absorption allows the gel to be applied hours before sexual activity.

Researchers recruited 889 sexually active women between the ages of 18 and 40 in KwaZulu-Natal, South Africa. Previous work suggested that sexual contact with migrant workers place some women in this region at high risk of HIV exposure.

Half of the women were given the tenofovir gel, while the other half were given a placebo gel. They were instructed to use the gel within 12 hours both before and after intercourse. Both groups were told the drug was experimental and were counseled to also use condoms or another means of HIV prevention.

Compared with the placebo group, women in the tenofovir group had 39 percent fewer HIV infections after 2.5 years of follow-up. Women who reported using the tenofovir gel more than 80 percent of the time had 54 percent fewer infections than women who used the placebo gel with similar diligence.

Charlene Dezzutti of the University of Pittsburgh calls the results good news. "A 54 percent protection rate in people who have used the gel consistently is excellent," she says.

Getting the shot without the jab

Vaccine patch could make for ouchless immunizations

By Laura Sanders

For most people, the worst thing about getting vaccinated is the long, scary needle. So researchers have invented a new vaccine-delivery system that replaces one big needle with 100 tiny dissolvable ones embedded in an adhesive patch. The patch can immunize mice against influenza just as effectively as conventional needle vaccination, its developers report online July 18 in *Nature Medicine*.

Lead study author Sean Sullivan, who conducted the research while at the Georgia Institute of Technology in Atlanta, likens the patch to a Band-Aid with a bunch of tiny needles sticking out on the sticky side.

Shorter than a nickel's thickness, the microneedles pierce the mouse's skin and dissolve into the surrounding bodily fluid, releasing the vaccine in the process. The whole thing takes anywhere from 30 seconds to five minutes, Sullivan says.

Microneedles (pink) for delivering vaccines stand just 650 micrometers tall, shorter than a nickel is thick.

S. SULLIVAN

The patch just needs to be slapped on and can be stored at room temperature, so medical training and careful handling aren't required, says Sullivan, who now works for medical device manufacturer Becton, Dickinson and Co. The researchers say that the patch could be used to replace a variety of needle vaccinations, including the annual flu shot.

"This is an attractive approach," comments vaccine researcher Kathryn Edwards of Vanderbilt University in Nashville. But she adds that more studies are needed before this method could be adopted by people.

Physician Wilbur Chen of the Center for Vaccine Development at the University of Maryland School of Medicine in Baltimore says the new patch "might prove a powerful public health tool." Chen points out that the patch could be especially helpful in developing countries — where electricity to keep liquid vaccines cold is in short supply, and needles and trained medical personnel are scarce. The team hasn't conducted studies to see how long the patches last at room temperature, but Sullivan predicts that they would be stable on the order of months.

Life

To watch videos of pancake batfish, follow the "walking" link at **www.sciencenews.org/batfish**

Mmm, you smell like Cheez Whiz

Rodents check each other's breath to learn what to eat

By Rachel Ehrenberg

For most people, catching a whiff of someone's pizza breath doesn't inspire cravings for a slice. But for rodents, any food smell combined with breath odor sends an irresistible "eat this" message to the brain. Now scientists have uncovered exactly how that signal gets transmitted.

Carbon disulfide, a by-product of metabolism found in the breath of many mammals, stimulates a subset of cells in the mouse nose, scientists report in a paper to appear in the Aug. 24 *Current Biology*. When one mouse smells another's breath, these nose cells trigger a signal that ultimately reaches specialized structures within the mouse brain that associate a simultaneously incoming odor with food that's safe to eat.

"One mouse is saying, 'My friend here just ate some food that smells like this — and he's still breathing, he's alive — so it must be safe," says study coauthor Steven Munger of the University of Maryland School of Medicine in Baltimore.

Special nasal cells called GC-D cells seem to respond to the carbon disulfide in rodent breath, experiments by Munger and his colleagues reveal. A mouse that smells cinnamon on a buddy's breath will choose cinnamon-scented food over any other flavor, the researchers found. And the smell doesn't even have to come from another mouse: Cotton balls laced with a food odor and carbon disulfide did the trick. But mice without working GC-D cells lost most of their ability to interpret this chemical message and didn't copy their compatriots' food choices, the team reports.

Any food smell combined with breath odor sends an "eat this" message to the brain.

The new work provides a molecular explanation for how these rodents learn what's OK to eat, says neuroscientist Emily Liman of the University of Southern California in Los Angeles. For people and other primates, food preferences are mostly learned visually (or compelled via threats of no dessert). But for nocturnal creatures such as rodents, visual cues are limited. So it makes sense that there's a scent signal, Liman says.

This safe-to-eat signal is so powerful that a mouse that has eaten poison will return for more if it catches a whiff of the poison on another mouse's breath, says behavioral scientist Bennett Galef of McMaster University in Hamilton, Canada. "The strength of this social learning on food choice is huge," says Galef, whose research has found that mixing carbon disulfide with rat poison draws four times as many rodents to the bait.

In most primates, including people, the gene in charge of making the GC-D cells no longer functions — though it appears to work in dogs and presumably many other mammals, Liman says. Perhaps this loss of specialized cells for detecting carbon disulfide coincided with other changes in the primate lifestyle, including a shift to daytime activity and improved eyesight, which made vision as important as smell for evaluating food. ■

H.-C. HO

New species in spill zone

Two new species of pancake batfish have been found in the Gulf of Mexico near the Deepwater Horizon oil leak. One of them, the Louisiana pancake batfish, appears to live entirely within the northern Gulf, where waters are tainted. Pancake batfish, a type of anglerfish, have flattened bodies, wiggling lures on their faces and elbowed fins for "walking" on the seafloor. They're about as thick as an exceptionally fluffy pancake, and they're small: Pancake batfish grow only "that big," says Prosanta Chakrabarty of Louisiana State University's Museum of Natural Sciences in Baton Rouge, making a circle of his thumb and forefinger. It remains to be seen how the newly discovered species will be affected by the spreading oil, he says. Chakrabarty, Hsuan-Ching Ho of the Academia Sinica in Taiwan and John Sparks of the American Museum of Natural History in New York City present formal descriptions of the new pancake batfish species online July 15 in the *Journal of Fish Biology*. —*Susan Milius*

"This is a wonderful discovery, a real missing link." —JOHN FLEAGLE

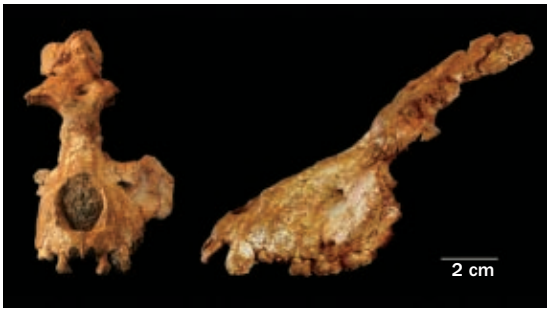
Primates' evolutionary clock reset

Fossil find moves split between apes and Old World monkeys

By Bruce Bower

A slope-faced, big-toothed creature from the distant past has led scientists to recalibrate the ancient evolutionary split between apes and Old World monkeys.

A partial skull found in western Saudi Arabia suggests that those two primate groups split between 29 million and 24 million years ago, the fossil's discoverers say. A 2004 analysis of DNA from living apes and monkeys in Africa and Asia had estimated an earlier divergence, between 34.5 million and 29.2 million years ago.



Pieces of a skull suggest that apes and Old World monkeys diverged no more than 29 million years ago.

An intriguing mosaic of features on the newly unearthed fossil, which dates to between 29 million and 28 million years ago, suggests that it predates a common ancestor that gave rise to hominoids — a primate lineage that includes apes and humans — and the monkeys of Africa, Asia and Europe. A team led by anthropology graduate student Iyad Zalmout of the University of Michigan in Ann Arbor reports the find in the July 15 *Nature*, assigning the skull to a new primate genus and species, *Saadanius hijazensis*.

"This is a wonderful discovery, a real missing link that fills in a gap in our understanding of the timing and pattern of anatomical change involved in the evolution of Old World monkeys and apes," remarks anthropologist John Fleagle of Stony Brook University in New York.

Zalmout found the partial skull in 2009, working with members of the Saudi Geological Survey in Jeddah. Based on the specimen's size and shape, the researchers estimate that *Saadanius* weighed 15 to 20 kilograms (33 to 44 pounds), making it a medium-sized primate for its time.

Saadanius sports a projecting snout, a relatively tall face with long, narrow nasal bones, broad cheek teeth and other traits resembling those of older primates previously unearthed on the edge of Egypt's Sahara Desert. Researchers estimate that those creatures lived between 35 million and 30 million years ago.

But a few crucial anatomical features, including a long, tube-shaped ear canal, distinguish *Saadanius* from its primate predecessors, the scientists say. And unlike Old World monkeys and hominoids that evolved after about 24 million years ago, *Saadanius* — which Zalmout's group identifies as a male based on dental characteristics — lacked nasal sinuses and large canine teeth typical of later ape and monkey males.

For that reason, the researchers use 24 million years as the most recent estimate of when Old World monkeys diverged from apes.

The new fossil "fits in exactly as it should" in primate evolution, says anthropologist Elwyn Simons of Duke University in Durham, N.C.

I. ZALMOUT, WILLIAM SANDERS

Celebrated frogs advance science

Athletic amphibians leap easily into the record books

By Susan Milius

PROVIDENCE, R.I. — Rumors of the great jumping frogs of Calaveras County have not been greatly exaggerated.

The longest jump reported in scientific papers for an American bullfrog is almost 1.3 meters, says Henry Astley of Brown University in Providence, R.I. Yet new measurements have added almost a meter to that record by using California's Calaveras County Fair as a testing ground.

Inspired by a Mark Twain story from 1865, the fair has for 83 years featured a highly competitive jumping-frog contest. Contest officials don't let scientists set up equipment in the jumping arena, Astley says. So he and his colleagues measured jump distance using computer analysis of video from a camera carefully positioned in the viewing area. More than half the 3,449 frog jumps that researchers recorded in the 2009 contest beat the record from the scientific literature, Astley reported July 10 at the 2010 Joint Meeting of Ichthyologists and Herpetologists.

The Calaveras competition is actually a three-leap event, with the winner at the 2009 contest covering 21 feet even, or 6.4 meters. Astley's team recorded a different frog as covering the most ground on a single jump, a leap of 2.2 meters, or more than 7 feet.

Such great leaps exceed the calculated power of bullfrog muscles, Astley says. He speculates that the frogs get the extra power by using their leg tendons as a spring, stretching the tendons and letting them snap back all at once.

By now the Calaveras County frogs may be reaching the outer limits of what bullfrogs can do, Astley says. Winning jumps at the fair tended to lengthen during the early days of the contest but haven't improved much since the 1980s.

Matter & Energy

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Triple slits don't add interference

Pillar of quantum mechanics stands up to new experiment

By Laura Sanders

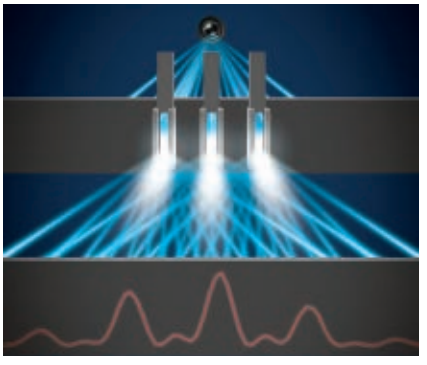
Extending an experiment at the foundation of quantum physics shows that two is company but three isn't a crowd. In a new twist on the famous double-slit experiment, researchers have verified a basic tenet of quantum mechanics by showing that adding a third slit doesn't create additional interference between packets of light.

In 1926, German physicist Max Born proposed that only particle pairs — not triplets, quadruplets or more — can interfere, causing their wavelike forms to boost and diminish one another. Born's math puts interference contributed by a third slit (and any more slits) at exactly zero. Although the reason why quantum interference stops at two isn't clear, Born's postulate has been widely accepted by physicists. Yet until now it hadn't been explicitly tested in experiments.

"It's important that you test all the postulates of quantum mechanics," says study coauthor Urbasi Sinha of the University of Waterloo in Canada. "What is the point of just advancing a theory in its theoretical form if you don't have experiments backing things up?"

Sinha and colleagues made three parallel slits in a stainless steel plate, each 30 micrometers wide and 300 micrometers tall. As light was sent through the slits, detectors on the other side tallied up the photons that passed through. A blocking mask allowed the researchers to open and close the three slits independently.

If quantum mechanics and Born's postulate are right, three-slit interference doesn't happen, and the pattern observed when all three slits are open should be explained entirely by the combined patterns when single and double slits are open. So the researchers shot photons at all eight combinations of open and closed slits. Subtracting the interference pattern caused by the seven other possibilities from the pattern seen with three open slits resulted in a number very close to zero. The results, published in *Science* July 23, leave very little room for Born's postulate to be incorrect.



A three-slit photon interference pattern (bottom) can be explained by combining the patterns formed with fewer slits.

Detecting third-party interference would have had tremendous consequences, says theoretical physicist Fay Dowker of Imperial College London in England. "If a nonzero result were ever to be obtained, it would mean that quantum mechanics is wrong, in the same way that the double-slit experiment proves that classical physics is wrong."

Most physicists expect that as triple-slit experiments are conducted with other particles, such as electrons and buckyballs, the case for Born's postulate will get stronger, Dowker says. But there's a small chance that the value might get stuck at a small number hovering just above zero, she says. "That's the exciting thing."

Erasing wrinkles, without injection

Studies reveal nature's tricks for smoothing deformations

By Alexandra Witze

Physicists have figured out how wrinkles erase themselves naturally — no Botox needed. But Joan Rivers shouldn't visit the lab just yet. These wrinkles appear not on skin, but on thin sheets of polymers.

In a pair of papers published online July 14 in *Physical Review Letters*, scientists report how sharp folds make a transition to smoother wrinkles, and how wrinkles themselves vanish toward the edges.

On a basic level, the research describes the math behind everyday experiences of wrinkles, everywhere from the surface of pudding to a poorly made bed. "These are things you see everywhere, in beautiful and amazing deformation," says materials scientist Douglas Holmes of Princeton University, coauthor of one of the studies.

More practically, such insights could one day improve technologies that incorporate thin films, like flexible solar panels or tissues grown for biological uses.

In one study, a team led by Jiangshui Huang of the University of Massachusetts Amherst tackled how wrinkles smooth out toward the edge of an elastic sheet.

Imagine cramming a corrugated sheet edge-to-edge against a smooth one. One way the sheets can accommodate the incompatibility is for the corrugated one to develop a series of sharp, branching folds along its edge. But when Huang floated a thin, wrinkly sheet of polystyrene on water and butted it up against a smooth one, more and more tiny wrinkles appeared toward the edge to accommodate the difference between the sheets.

Similar elastic films, from shrink-wrap to skin to biomembranes, should exhibit the same sort of smooth cascade.

In the second study, another Amherst team mapped out how sharp folds fade into smooth wrinkles when a sheet is pinched in one spot and pulled up, like pulling a tissue out of a box.

SCIENCE/AAAS

Earth

45 meters — Diameter of recently discovered Egyptian crater

300 kilometers — Diameter of largest impact crater on Earth

10,600 kilometers — Diameter of solar system's largest impact feature (Mars)

Rare rayed crater found in Sahara

Meteor impact site was first detected on Google Earth

By Sid Perkins

Researchers poring over Google Earth images have discovered one of the planet's freshest impact craters — a 45-meter-wide pock in southwestern Egypt that probably was excavated by a fast-moving iron meteorite no more than a few thousand years ago.

Although the crater was first noticed in autumn 2008, researchers have since spotted the blemish on satellite images taken as far back as 1972, says Luigi Folco, a cosmochemist at the University of Siena in Italy. He and his colleagues report their find online July 22 in *Science*.

This 45-meter-wide crater in Egypt probably formed less than 5,000 years ago.

The crater's rim stands about 3 meters above the surrounding plain, which is partially covered with distinct swaths of light-colored material blasted from the ground by the impact. These rays, which emanate from the impact site like spokes from the hub of a wheel, are what drew researchers' attention to the crater, says Folco. Though common on the moon and other airless bodies of the solar system, such "rayed" craters are exceedingly rare on Earth because erosion and other geological processes quickly erase the rays.

During expeditions to the site early in 2009 and again this year, scientists found more than 5,000 iron meteorites that together weigh more than 1.7 metric tons. The team estimates that the original lump of iron weighed between 5 and 10 tons when it struck the ground at a speed of around 3.5 kilometers per second, vaporizing most of the object.

Analyses of soil samples from the site and of sand fused into glass by the impact's intense heat and pressure may help the team estimate when the event occurred. Preliminary analyses suggest that it happened sometime during the past 10,000 years, probably no more than 5,000 years ago, Folco says.

Genes & Cells

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Gene variants double-edged

Sleeping sickness protection, but a risk of kidney disease

By Nathan Seppa

In a case of natural selection with a twist, genetic variants that confer protection against a disease in Africa seem to place African-Americans half a world away at elevated risk of kidney failure, a new study finds.

U.S. blacks are three times as likely as whites to develop chronic kidney disease. "We think this explains perhaps most of it," says study coauthor Martin Pollak, a nephrologist and geneticist at Harvard Medical School.

The gene in question is called *APOL1*, short for apolipoprotein L-1. Among people of African descent, *APOL1* can appear in two variant forms that protect against African sleeping sickness but increase the risk of kidney failure, Pollak and his colleagues report online July 15 in *Science*.

The team analyzed blood from more than 1,400 African-Americans and found that more than 30 percent carried at least one variant copy of *APOL1*. About 10 percent harbored two variant copies.

Roughly half of the people in the study had kidney disease and half didn't. The researchers found that those carrying two copies of an *APOL1* gene variant were 10.5 times more likely to have kidney disease marked by loss of blood filtration capacity than were people who carried the normal *APOL1* gene. The double-copy carriers were also 7.3 times more likely to have severe kidney disease marked by high blood pressure requiring dialysis or a transplant. People harboring two variant copies were also more prone to such end-stage disease compared with people having one variant copy. Having just one variant copy conferred no extra risk.

The double-edged nature of these variants is eerily similar to the sickle-cell genetic trait.

APOL1 exists only in humans and other primates. The protein it encodes is a component of HDL, the good cholesterol, and might contribute to HDL's activity in the body, says Chien-an Hu of the University of New Mexico School of Medicine in Albuquerque. Other work suggests that the *APOL1* protein regulates a routine cell-recycling process called autophagy.

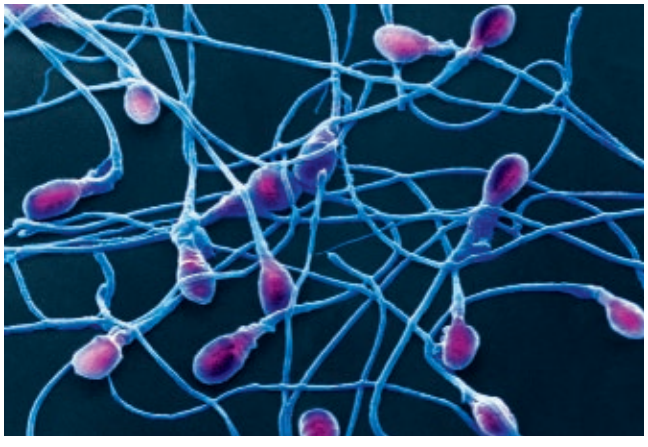
How the *APOL1* variants harm kidneys is unclear, but the effects could be related to dysfunctional autophagy, Hu surmises.

Deciphering how variants of the *APOL1* protein behave may someday benefit people at risk of kidney disease. But until the variants' effects are known, Pollak says, genetic testing would be premature.

Meanwhile, the double-edged nature of these *APOL1* genetic variants — latching on to and inactivating the parasite that causes sleeping sickness but apparently damaging kidneys — is eerily similar to the sickle-cell genetic trait. Many Africans have the sickle-cell mutation; inheriting a copy of it from one parent protects against malaria. Unfortunately, getting a copy from both parents results in sickle-cell disease.

"This whole story can be viewed as an outstanding illustration of the arms race taking place between [human] hosts and parasites during evolution," says Luc Vanhamme, a microbiologist at the University of Brussels campus in Gosselies, Belgium. Long ago the single-celled parasite that causes sleeping sickness developed a way to evade the human immune system. But people acquired a way to kill the parasite using a weapon that is not part of the immune system: the *APOL1* protein.

The parasite retaliated. The current East African sleeping sickness is spread by a parasite with a mutation allowing it to dodge the normal *APOL1* protein. The newly discovered gene variants, which seem to protect against this subspecies, represent the most recent skirmish in this war, Vanhamme says.



D. PHILLIPS/VISUALS UNLIMITED, INC.

Animal sperm all related

A sperm-producing gene that appeared at the dawn of animal evolution is present in nearly every animal from sea anemones to people, suggesting that the male reproductive cell evolved from a common ancestor. Most animals' sperm cells (human, left) have similar developmental stages, suggesting a common origin. Yet no one had found a reproductive gene common to all animals. A report July 15 in *PLoS Genetics* suggests that the *BOULE* gene, which arose about 600 million years ago, is crucial to sperm production. "This is the first human sperm gene that has been found functionally conserved in insects and in mammals," says study coauthor Eugene Xu of Northwestern University Feinberg School of Medicine in Chicago. —*Gwyneth Dickey*

"This whole story can be viewed as an outstanding illustration of the arms race ... between [human] hosts and parasites." —LUC VANHAMME

Hanging on to molecular memories

Reprogrammed stem cells may not be quite as good as new

By Tina Hesman Saey

Barbra Streisand probably wasn't thinking about reprogrammed stem cells when she crooned "The Way We Were," but it turns out that the cells do retain misty watercolor memories of their former selves.

In most respects, a cocktail of four proteins can reprogram skin or blood cells into stem cells indistinguishable from those isolated from embryos (*SN: 11/24/07, p. 323; SN: 9/13/08, p. 16*). But two new studies show that reprogrammed cells, known as induced pluripotent stem cells or iPS cells, hang on to molecular memories of their former identities.

The findings, published online July 19 in *Nature* and *Nature Biotechnology*, may spell trouble for researchers who hope to transform reprogrammed cells into adult cell types for transplant into patients or for disease research.

All stem cells aren't equally flexible, scientists have found. Stem cells made from skin cells called fibroblasts in the tip of a mouse's tail aren't very good at becoming blood cells, for instance, says George Daley, a stem cell biologist at Children's Hospital Boston and Harvard University who coauthored the paper in *Nature*. His group turned fibroblasts and bone marrow cells (*SN: 7/31/10, p. 10*) into stem cells that were pluripotent — able to make any type of cell in the body. But when the researchers tried to coax those cells into making blood cells, the ones that came from bone marrow (where blood is made) had an easier time than did reprogrammed fibroblasts, which were better at making bone cells.

Reprogramming is supposed to wipe a cell's molecular slate clean, but clearly something was preventing the cells from being as flexible as the embryonic stem cells they were supposed to resemble. Looking closer, Daley's group discovered that DNA in the reprogrammed cells still retained a kind of molecular tag that blocks access to some genes in adult cells.

"Even though we can get back to a pluripotent state, we haven't erased all of the history of that cell," Daley says.

Another research team led by Konrad Hochedlinger of Massachusetts General Hospital in Boston and the Harvard Stem Cell Institute also found that gene activity and DNA tags in reprogrammed cells echo those of the original cell type. But like memories of lost love, those molecular remnants faded over time. When grown in a lab dish, reprogrammed mouse cells held on to some tags for two to three weeks. But after a month or two the tags had been nearly erased, the researchers report in *Nature Biotechnology*.

Daley's group found that unlike embryonic stem cells, reprogrammed fibroblasts contained 5,304 spots on their DNA where the chemical tags, called methyl groups, hung on. Stem cells created by cloning, in which a cell's nucleus is transferred, had far fewer residual tags — only 229. Cloned stem cells were also able to transform more easily than induced pluripotent stem cells could. Those results indicate that the cloning process reprograms cells more completely than does adding a protein cocktail to adult cells.

Because the new studies were done in mice, the implications for human stem cell research are unclear. Previous work suggested that human embryonic stem cells are less flexible than those from mice, says genomics researcher Louise Laurent of the University of California, San Diego. "One could imagine then that reprogramming human cells to full pluripotency could be a little more challenging."

Atom & Cosmos

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Search for Higgs is hot, not heavy

New data indicate lower mass is probable for elusive particle

By Ron Cowen

The God particle has fewer places to hide.

New data offer evidence that the heft of the Higgs boson lies in the low end of the range being probed by particle colliders on two continents.

The new result comes from two ongoing experiments at the Fermi National Accelerator Laboratory's Tevatron accelerator in Batavia, Ill., suggesting that the elusive Higgs does not have a mass between 158 billion and 175 billion electron volts. (A billion electron volts, or 1 GeV, is slightly heavier than the mass of a proton.) Ben Kilminster of Fermilab reported the result July 26 in Paris at the International Conference on High Energy Physics, and a paper was posted online at arXiv.org.

Studies from the Large Electron-Positron Collider, which shut down in 2000 at the European research organization CERN, along with indirect constraints, had indicated that the Higgs could weigh in anywhere between 114 and 185 GeV. In late 2009, the two Tevatron experiments, known as CDF and DZero, excluded the range between 162 GeV and 166 GeV. The new data have ruled out nearly 25 percent of the mass range for the Higgs allowed before 2009.

Dubbed the God particle because it would explain why some subatomic particles have mass, the existence of the Higgs was proposed in 1964 by physicist Peter Higgs, who posited a quantum field pervading the vacuum of space. The field would slow down some particles traveling through it, causing them to acquire mass. Other particles, like photons, would be impervious to the field and continue to travel at the speed of light. Although the field couldn't be detected directly, it could be excited at high energies to produce the Higgs particle.

The new limit on the particle's mass "is important, as it demonstrates the power of the Tevatron experiments to search for the Higgs," says theorist JoAnne Hewett of the SLAC National Accelerator Laboratory in Menlo Park, Calif. "They just keep getting better and better."

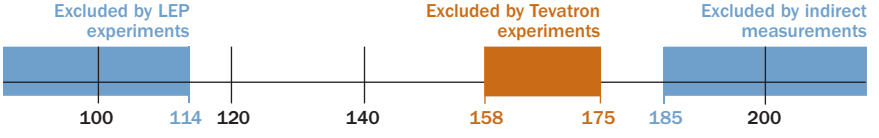
However, Hewett notes, excluding the region from 158 to 175 GeV for the mass of the Higgs won't have much effect on theory, because most physicists expect the Higgs to be lighter than 135 GeV.

The latest analysis of data recorded by Tevatron's CDF experiment has turned up intriguing hints of a 140-GeV Higgs, Abid Patwa of the Brookhaven National Laboratory reported at ICHEP on July 23. That development "has the theory community abuzz," Hewett says.

CDF cospokesman Rob Roser of Fermilab says, "We see something. It could be consistent with many things," including a low-mass Higgs. "I am not sure I would agree that 'the community is all abuzz,' but perhaps the theorists are excited — they are an excitable lot."

Narrowing the Higgs hunt

Combined data from two experiments at Fermilab's Tevatron particle accelerator indicate that the elusive Higgs boson does not have a mass between 158 and 175 billion electron volts.



SOURCE: FERMILAB

Among stars, heavyweight champ

Stellar record-holder weighs in at 265 times mass of sun

By Ron Cowen

Astronomers have discovered a star about 265 times the mass of the sun, more massive than any other star known in the universe. At birth, the hefty body tipped the scales at 320 suns, more than twice the generally accepted limit for a newborn.

Paul Crowther of the University of Sheffield in England and colleagues describe the star in an upcoming *Monthly Notices of the Royal Astronomical Society*.

Crowther and collaborators examined massive stars in two clusters, one in the Milky Way and the other in the Large Magellanic Cloud, a satellite galaxy of the Milky Way. The team used the European Southern Observatory's Very Large Telescope atop Cerro Paranal in Chile and looked at archival data from the Hubble Space Telescope. Four stars in the Large Magellanic Cloud cluster, dubbed R136, had temperatures more than seven times that of the sun and were several million times brighter and tens of times larger.

Those properties, combined with the age of the four stars, indicate that each weighed more than 150 suns at birth. One, R136a1, was more than twice that mass when it formed, the researchers calculate. The results suggest that present-day stars may become as heavy as 300 suns. Theoretical studies indicated that such heavyweights could have formed only during the first few hundred million years of the universe, when its chemical makeup favored formation of massive stars.

Stars from eight to 150 sun masses eventually die as supernovas. Stars from 150 to 300 suns may end their brief lives in bigger explosions known as pair-instability supernovas, once thought to have occurred only in the early universe. ■

A mind for music

There are very few activities for which your birthday suit and a three-piece suit are equally appropriate attire. Music is one of them.

Belting an improvised ditty alone in the shower and performing Handel's "Messiah" on stage with a full choral ensemble and orchestra both qualify as "song." Simple or intricate, practiced or spontaneous, individual or collective, highbrow or honky-tonk — music covers the gamut. And though instruments aren't instrumental, they are welcome and multifarious. Bells, drums, strings, woodwinds, harps or horns can certainly spice up a tune. (Though a Stradivarius may not survive a shower.)

But music's broad scope doesn't stop with its production. More fascinating than how people make music (and greater mysteries, perhaps) are why people make it, why others listen and how a beat of any sort can have such a profound impact on the body and the brain.

Coos and ahs exchanged by moms and babies around the globe may form a musical conversation that lays the groundwork for language, some scientists now propose. That notion joins others — including the desire to impress mates and the drive to build social bonds — in suggesting an evolutionary source of chanteys, dirges and ballads. Others see music as a pleasing diversion, and research shows that emotionally charged music — whether moving a person to tears of joy or calling forth memories of a failed romance — appears to activate the brain's reward circuitry. And while listening to music brings on an emotional rush, playing music may provide a mental boost. It turns out that musical training has benefits to the tune of improved understanding of grammatical rules and sharper auditory perception.

Though music's tendency to get charged with cultural, religious and emotional meaning may complicate things for scientists seeking its roots and benefits, it's that same tendency that makes pursuing the "what," "why" and "how" of music worthwhile. — Elizabeth Quill

In this section

Web edition

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Birth of the beat

Music's roots may lie in melodic exchanges between mothers and babies

By Bruce Bower
Photograph by Cary Wolinsky

At scientific meetings, psychobiologist Colwyn Trevarthen often plays a video of a 5-month-old Swedish girl giving her mother a musical surprise. Blind from birth, the girl reaches for a bottle and laughs appreciatively as her mother launches into a familiar song about feeding blueberries to a bear. As in baby songs everywhere, Trevarthen says, each line of the Swedish tune runs about four seconds and each stanza lasts about 20.

In a flash, the girl raises her left arm — an arm she has never seen — and begins conducting her mother's performance. The baby, named Maria, moves her arm just before many of the song's lines begin, leading her mother by about one-third of a second. In some cases, Maria synchronizes her hand movements with the rise and fall of her mother's voice. Mom's face glows in response to Maria's playful directions.

"Babies are born with a musical readiness that includes a basic sense of timing and rhythm," declares Trevarthen, of the University of Edinburgh.

Scientists have been finding that these chubby-cheeked cherubs heed a musical sense that moves them and grooves them long before they utter a word. Within a day or two after birth, babies recognize the first beat in a sound sequence; neural signs of surprise appear when that initial "downbeat" goes missing. Classical music lights up specific hearing areas in newborns' right brains. Even more intriguingly, babies enter the world crying in melodic patterns that the little ones have heard in their mothers' conversations for at least two months while in the womb (*SN: 12/5/09, p. 14*).

But infants do much more than pick up beats and mimic melodies, says Trevarthen. An inborn musical knack gets parlayed by babies into emotional banter with attending adults, who possess their own musical feel for infant care. Adults around the world intuitively

"Itsy Bitsy Spider" and other sing-alongs may prepare babies to learn social rituals, scientists propose.

speak to infants using a singsong, vocally exaggerated mix of words and sounds known as motherese.

Trevarthen rejects the notion that babies passively absorb adults' googly-eyed gab. Instead, he holds, infants intentionally prompt musical exchanges with adults, and infants know when they're being invited by a grown-up to interact. Here, the currency of communication consists of coordinated exchanges of gestures, facial expressions, coos, squeals and other sounds. Trevarthen and like-minded researchers call this wordless conversation "communicative musicality." Babies' natural musical aptitude gets them in sync with mothers. Within weeks of birth, mom and baby compose brief musical vignettes that tune up a budding relationship.

"Our brains possess a storytelling sense that is an essential component of musicality from the beginning," says Trevarthen.

From his perspective, musical storytelling prepares infants to learn the rhythms and format of a native language. Adult forms of music, as well as dance and drama, spring from the intricately structured yarns spun by babies and mothers.

New research probing these early musical stories indicates that moms and tots vocally express and share emotions in finely calibrated ways that differ in some respects across cultures. Other findings suggest that mothers everywhere prod babies to sing and act out simple songs as a prelude to learning cultural practices.

And women who suffer from personality and mental disorders fail to connect musically with their babies, investigators find. Infants whose first relationship strikes a sour note may display social and emotional problems later in childhood.

But like healthy babies, Trevarthen notes, these unfortunate tykes try their darndest to relate musically with whoever is available.

Trevarthen's views draw criticism, though, from many cognitive psychologists and musicologists. They regard music as a universal practice, with still-mysterious evolutionary origins, that infants learn from their native cultures without the help of an innate timekeeper. From their first days, babies seamlessly learn to keep a beat and to prefer the same melodies that adults do, from this perspective. Some critics suspect that Trevarthen and his colleagues, not babies and mothers, are telling musical stories.

Story time

Stephen Malloch has no problem with Trevarthen's take on communicative musicality. Malloch, a musicologist at the University of Western Sydney in Australia, coined the term in 1996.

While listening to the chatter of a mother and her 6-week-old daughter, who Trevarthen had videotaped 17 years earlier, Malloch noticed he was tapping his foot. As a trained violinist whose stage fright pushed him into research, Malloch was accustomed to feeling the beat of musical sounds.

"I sensed a rhythmic, melodious give-and-take to the mother's gentle promptings and the baby's pitched vocal replies," he recalls. A few weeks later, communicative musicality came to mind as a shorthand term for emotional exchanges based on musical principles.

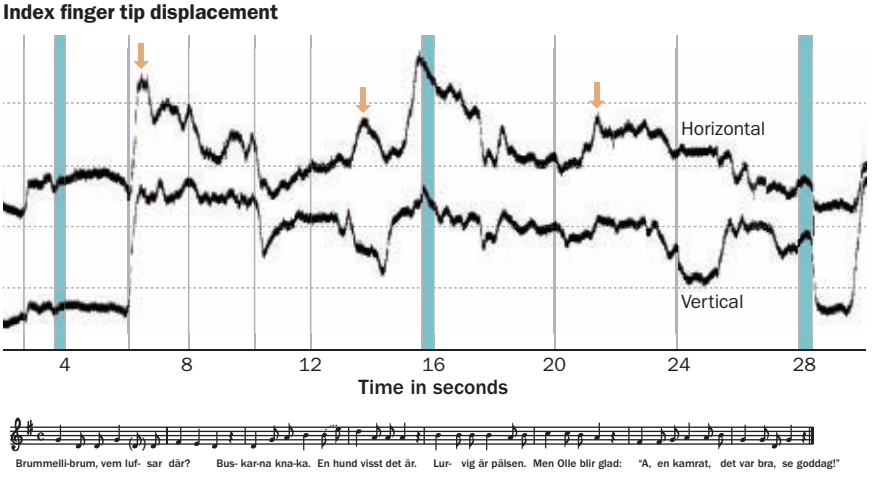
Malloch wasn't the first to have this idea. In 1981, European researchers Hanuš and Mechthild Papoušek asserted that mothers and babies intuitively communicate using melodies and other musical sounds. Malloch developed a way to identify the musical stories that he thinks are created during these intimate encounters.

He probed mom-baby conversations by measuring sound waves, pitch patterns and timbre, or tone attributes, starting with those in Trevarthen's video. An acoustic analysis revealed three features of communicative musicality — pulse, quality and narrative.

Pulse refers to a timed series of sounds and words in an interaction. Each utterance by mother and daughter lasted about one and a half seconds, with little variation. Quality consists of emotional signals conveyed by voice and gestures. One example is the swoop of a mother's hand accompanying a dropping, then rising vocal pitch. In the recorded encounter, mother and daughter used the pulse and quality of the interaction to create musical narratives lasting no more than about 30 seconds.

One narrative begins with the mother uttering low-pitched phrases, such as "come on" and "that's clever," for five seconds. Her daughter's voice rises in response and the mother moves her vocal pitch an octave higher. Mom

Baby conductor Maria, a Swedish infant who has been blind since birth, showed scientists her sense of rhythm by lifting her arm and conducting her mother's singing. The figure below shows how Maria's left index finger moved (horizontally and vertically) throughout the familiar tune.



■ Maria moved her finger just before each phrase of the Swedish song began. In this way, she anticipated the movement in her mother's voice.

↓ Maria also synchronized finger movement when she heard sharp consonant sounds in words at the end of a line — "sar där," "visst det är" and "glad."

C. TREVARTHEN, ADAPTED BY T. DUBÉ

prompts responses from baby for about eight seconds. Their voices rise to a peak of intensity during a back-and-forth exchange that lasts another seven seconds. Mother and daughter then take six seconds to return to the mother's original, low voice pitch. So, Malloch says, each collaborative story contained an introduction, development, climax and resolution.

Feel the vowel

Musical storytelling of this kind largely depends on varying the pitch, timbre and rhythm of vowel sounds, which are more emotionally expressive than consonants, according to Trevarthen and University of Edinburgh psychologist Niki Powers. Mothers and infants in Scotland and Japan make these emotionally tinged sounds in culturally distinctive ways, the researchers say.

"Even with limited powers to produce learned sounds, infants in different countries express vocal emotions and parents intuitively respond to them," Powers says.

She and Trevarthen videotaped a dozen pairs of mothers and their 3- to 4-month-olds playing together at home, six in Scotland and six in Japan. The researchers' findings and those of several other teams appear in the 2009 book *Communicative Musicality*, edited by Malloch and Trevarthen.

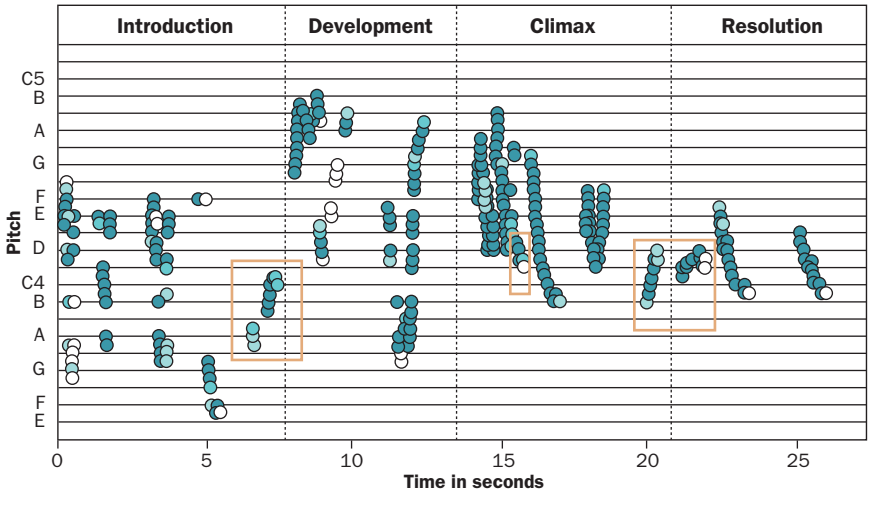
Language and cultural differences shape emotional communication, says Powers. Occasional high-pitched vowel sounds, interspersed among a stream of low vowel sounds of moderate intensity, denoted emotional responses by Scottish mothers to their babies, she suggests. Each low sound usually lasted no more than three-quarters of a second.

Japanese mothers consistently made high, intense vowel sounds. Swings from short to long vowels helped the moms convey emotion to the infants, in Powers' view. These women held many vowel sounds for less than one-quarter of a second but articulated others for a second or more.

Infants in both countries tended to produce vowel sounds that lasted up to one second, much longer than vowels used in speech. Japanese babies emitted high-pitched, acoustically intense vowels, much as their mothers did.

In an upcoming issue of *Infant and Child Development*, Trevarthen marshals evidence suggesting that even newborns purposely coordinate vocalizations and movements with those of caretakers. An innate impulse to forge emotional ties with others drives such behavior, he posits. In the months after birth, babies build on this impulse by adopting a native culture's style of emoting vowel sounds.

A story in song Musical conversations between mom and baby can take the shape of stories, some scientists propose. The figure below shows the rise and fall of one such exchange. Mom's voice increases in pitch and intensity as the story reaches a climax. Baby often makes sounds (highlighted in boxes) as the story shifts from one stage to another.



Up the waterspout

At about the time that babies start to put emotional oomph into their voices, communicative musicality enters a ritualized arena dominated by simple tunes that must be performed, not just sung. Parents combine simple melodies and lyrics with activities that include knee bouncing, hand clapping and pantomime.

Physician Patricia Eckerdal of Sweden's Uppsala University Hospital and Björn Merker, an independent neuroscientist in Segeltorp, Sweden, have begun to chart the developmental trajectory of what they call action songs. Merker and Eckerdal videotaped 25 pairs of Swedish mothers and their infants playing together at home when the babies were 6, 9 and 12 months old.

The well-known sing-along "Itsy Bitsy Spider" is one example of an action song that babies learn as they grow. In its first incarnation, up to about age 3 months, the infant lies down as the adult does all the work. Mom forms a spider hand, makes it crawl it up the baby's body and tickles his or her chin at the "waterspout" ending of the first line. Mom spreads her fingers and runs them down the baby's body for "down comes the rain." At "out comes the sun," mom places her spread fingers in front of the baby's face. Gestures from the first line are then repeated with a final tickle.

By 6 months of age, adult and infant sit close together so that the child's hands and arms can be gently guided through the pantomime sequence while singing. By 9 months of age, infants perform "Itsy Bitsy Spider" on their own.

In this way, infants practice performing intricately structured acts and discover what those acts mean, an essential skill for learning a slew of cultural rituals. It's a short hop from getting the hang of "Itsy Bitsy Spider" to mastering dinner table etiquette and conversational rules, the scientists hypothesize.

"Action songs are the 'baby rituals' of human culture," Merker says.

Only people, not singing birds or other musical animals (*SN: 5/23/09, p. 8*), incorporate musical communication into social rites, he and Eckerdal assert.

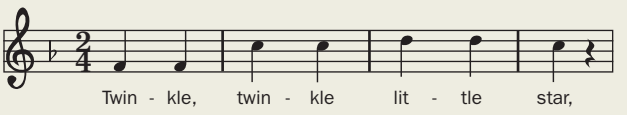
S. MALLOCH AND C. TREVARTHEN, EDS. *COMMUNICATIVE MUSICALITY*. BY PERMISSION OF OXFORD UNIV. PRESS. ADAPTED BY T. DUBÉ

Seeking a definition

Whether strummed by a guitarist who has gone platinum or sung by a mom who is playing with her child, music at its most basic level is a sequence of notes that can vary in a number of ways.

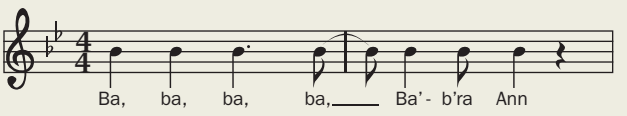
Pitch is determined by a sound's frequency. Notes that sit in different positions on a musical scale, called tones, have different pitches. Modern Western music, for example, combines 12 tones, with the A at the middle of a piano keyboard having a frequency of 440 hertz. Other cultures work with fewer tones. The first few notes of "Twinkle, Twinkle, Little Star" vary only in pitch.

"Twinkle, Twinkle, Little Star"



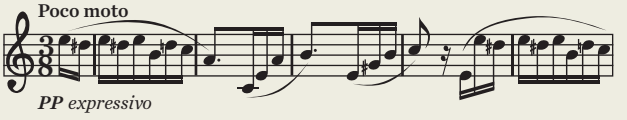
Rhythm emerges because different notes can last for varying amounts of time. Notes with different durations are represented differently in written music: Some have little flags, dots or open circles. A quarter note, for example, is drawn as a closed circle with a vertical line; it lasts for one beat. The first several notes of the Beach Boys' "Barbara Ann" vary only in note duration.

"Barbara Ann"

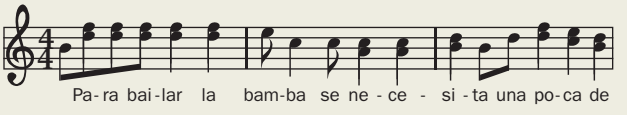


Combining different pitches and rhythms allows for the creation of **melodies**, the same way the combination of words makes a sentence. And when different notes are played at the same time to create chords, rather than just successively, they can lead to **harmony**. Other factors mix in to affect the character of the piece. **Dynamics**, how loud each note is and how that loudness changes over the course of several notes, opens even more room for variation. And **timbre**, or tonal quality, distinguishes one instrument from another—a piano sounds different from a tuba, and Celine Dion sounds different from Macy Gray. **Tempo** characterizes the overall speed of a piece. Changing multiple factors at a time leads to endless musical possibilities, from "Für Elise" to "La Bamba."

"Für Elise"



"La Bamba"



Considering beauty

While some would argue that any variation of sound with the above features makes music, others say music is more than the sum of its parts. Perhaps sound has to be pleasing to qualify? Pythagoras, an ancient Greek philosopher, recognized that when notes with pitches forming simple ratios are played together, they sound pleasant. Using a single string with a movable bridge—which allowed him to pluck two notes at once—he found that when one side of the string was half the length of the other, it created two notes that sound lovely together. (In Western music today, if a string producing the note A at 440 hertz is halved, it creates another A an octave higher.) A pleasing blend also occurred when one side was two-thirds or three-fourths the length of the other. Using these ratios, Pythagoras built a seven-note scale, and his ideas still help musicians understand why some music sings and other tunes fall flat. —*Elizabeth Quill*

FROM TOP: MUSIC NOTES - AALTAZAR/ISTOCKPHOTO ARRANGEMENT OF NOTES T DUBÉ; SPL/PHOTO RESEARCHERS, INC.

Unhinged melody

Some babies, though, face a form of ritualized rejection that would test even an itsy-bitsy spider's determination. Their mothers feel so alienated and alone that efforts to pull mom into melodic exchanges are like trying to grab fistfuls of water.

Psychologist Maya Gratier of Université Paris X–Nanterre and psychiatrist Gisèle Apter-Danon of Université Paris Diderot have examined communication breakdowns that afflict babies born to mothers diagnosed with borderline personality disorder. This condition revolves around a tendency to form intense, unstable relationships.

People with borderline personalities act impulsively, feel emotionally empty and constantly fear abandonment. Many have survived severe child abuse and neglect.

Gratier and Apter-Danon codirect a project that has tracked the interactions of about 150 pairs of French mothers and their babies from birth to about age 5. Many mothers qualify as having borderline personality disorder. Others have obsessive-compulsive personality disorder, paranoid personality disorder or no mental ailments.

In brief laboratory exchanges, these mothers awkwardly repeat one phrase over and over or produce strings of unusual sounds, such as tongue clicking and whistling. No rhythmic flow characteristic of typical baby talk emerges. It's almost as if a baby isn't there at all.

That leaves infants unable to get a

sound in edgewise. They withdraw from mothers with borderline personalities, vocalize little or get fussy and upset.

One 3-month-old boy in the French study tried his best to spark an emotional dialog with his mother during a 27-second encounter, Gratier says. The woman drearily repeated the same line from a French nursery rhyme four times. Her son then blurted out "ahhh!" just as she launched into a fifth rendition. Caught off guard, the woman exclaimed "What?" before regaining composure and resuming her dry recitation.

Undaunted, the boy immediately belted out a louder sound. That stopped his mother long enough so that he could utter a cooing sound, with a few emotionally tinged pitch changes, for about as long as the nursery rhyme's initial phrase.

Gratier and Apter-Danon interpret the 3-month-old's behavior as an attempt to lure his mother into a musical exchange. It briefly worked, they say. The woman imitated his cooing sound once with her characteristic flat tone. Then she returned to her signature line. Once again, the boy became an observer, not a participant.

"The interactions of borderline mothers with their babies appear more like compilations of isolated moments that probably impede the creation of shared musical story lines," Gratier says.

Depressed mothers offer a more varied verbal diet to their babies than borderline mothers, but in an unusually low, unexpressive voice devoid of rhythmic timing, according to studies directed by psychologist Lynne Murray of the University of Reading in Eng-

Not just a pleasant sound

When people use music to share stories, comfort peers or worship gods, it takes on new meaning. Music's roles vary depending on time and place.

Bonding: Battle hymns, national anthems and alma maters unite people for a common cause and make them feel that they are a part of something larger. Marching bands (above), for example, can rile up crowds and promote pride at sporting events.

Relaxation: Mothers in almost all societies sing lullabies to put little ones to sleep. Called a *huluna* in the Philippines province of Batangas, the lullaby is so popular there that almost every mother has composed at least one for her child. And in Denmark, writing lullabies is an art form. A classic Danish lullaby, "The Sun is So Red, Mother," was written by a novelist, playwright and poet named Harald Bergstedt and arranged by famous composer and violinist Carl Nielsen.

Creative expression: The Chopi people of Mozambique are known for their timbila music, played on xylophones. The music and accompanying dance is developed like a symphony and also has room for individual players to improvise and show their creativity. Like music elsewhere, timbila helps the Chopi share who they are and where they come from.

Meditation/Trance: Music is believed to provide a way for shamans (one shown above in British Columbia) to enter a trance state and get in touch with the spiritual world. The Sami, indigenous people of northern Europe, have a traditional form of song called yoik said to open the door for communication with animal spirits. Drumming helps the shamans enter the spiritual world.

Learning: The "Alphabet Song," among other simple rhymes, helps children learn and remember facts. Some researchers believe that early songs, such as "Itsy Bitsy Spider," may also prepare infants to learn cultural rules and practices.

Revolt: Music can represent the emergence of a subculture that turns against traditional ways. All-night dance parties popular in the 1980s offered a way for people to let loose, experiment and declare their independence. In the early 1990s, municipalities across the United States and United Kingdom passed bylaws to limit the organization of these raves.

Worship: A wide range of religions employ music. In Indian tradition, bhajans express love for God (holy men shown above). Gospel music helps Christians praise God. And, though music is not a large part of Islamic tradition, five times a day Muslims are called to prayer as a muezzin chants in praise of Allah from the top of a mosque's minaret.

Social pressure: In rural Sudan, women known as hakamas (shown above) use chant-like songs to motivate men to fight in wartime and to call people to brotherhood during times of peace. In a society where men hold higher status than women, the songs empower women: Going against the songs is considered shameful.

Mourning: Dirges are an integral part of funerals for the Akpafu of southeastern Ghana. A ceremony begins when drums are beaten to announce the death to various clans. While clans are assembling, women begin to sing the first funeral dirge. Each activity of the burial ceremony has special dirges. And 30 to 40 different songs may be heard while family keeps watch over the body.

Declarations of love: The ncas, a brass mouth harp, is played by Hmong men outside the wall of a lover's house. Though the men may also whisper softly during courting,

CLOCKWISE, TOP LEFT: TED SPIEGEL/CORBIS; ROBERT HARDING IMAGES/MASTERFILE; WORLDPICTURENETWORK/STOCKPHOTOFINDER.COM; FRÉDÉRIC NOY/COSMOS/AURORA PHOTOS

land. Infants interact hesitantly with depressed mothers, mimicking their low, flat vocal delivery.

Borderline personality disorder and depression alike deprive women of the flexibility and expressiveness needed for communicating musically with babies, Gratier holds. When there's no room for playful musical exchanges, interactive sync is sunk. In their long-term study, Gratier and Apter-Danon find that disrupted musical communication between mothers and babies heralds social difficulties for these children in preschool.

they will inevitably switch to the ncas to woo a chosen gal. Lloyd (John Cusack) may have had the same idea in *Say Anything* when he lifted a boom box playing Peter Gabriel's "In Your Eyes" above his head.

Work: Sea chanteys are onboard working songs, the rhythm of which helps synchronize the repetitive movements of sailors. There are different songs that provide the right tempo for hoisting sails, hauling nets and pulling up anchors.

Social interaction: Much of African music takes the form of call and response, meaning the activity is participatory. A leader will sing or play an instrument and the rest of the group will respond with hoots, hollers, clapping or a traditional refrain. In this way, much of the music becomes cyclical, with no clear end.

Mythology: Among Aboriginal Australians, each clan may share songs that tell stories about the journeys that mythical ancestors took as they carved valleys and built mountains to create the Earth's landscape. The songs trace ancestral history, tie the people to the land and lay down rules of conduct.

Entertainment: Music is a whole-body phenomenon. In some cases, it lightens the mood or passes the time. From noh, a traditional form of Japanese musical theater that dates to the 14th century, to the pop concerts of today, watching others make music makes people feel good. —*Elizabeth Quill*

Musical divide

Under better circumstances, mom and baby embark on a maiden voyage of improvisation, says Ellen Dissanayake, a professor of art and music at the University of Washington in Seattle. Musical ad-libbing of this type relies on timing techniques similar to those used by jazz musicians, Dissanayake proposes. A regular beat and timed melodic passages provide a structure for jazz instrumentalists to synchronize their playing and take turns soloing. Like jazz musicians, mothers and babies negotiate novel twists and turns in the flow of communication, building up emotional tension that they resolve together.

Scientists already knew, she notes, that 4-month-olds who coordinate pauses, turn taking and other conversational rhythms with mothers — without becoming rigidly synchronized and unable to adjust — interact well with others at age 1 (*SN: 6/23/01, p. 390*). That's consistent with the idea that mothers and babies employ just enough musical structure in their encounters to enable creative storytelling, thus grooming the child to deal flexibly with others.

Dissanayake theorizes that musical communication between mothers and babies emerged roughly 2 million years ago in the *Homo* genus, well before the emergence of language. With the evolution of physically helpless babies needing years to grow big brains, nonverbal exchanges that bonded infants to their mothers became essential.

In her view, Stone Age foragers transformed two-way musical communication into the temporal arts — singing, playing instruments, dancing, making expressive gestures, reciting poetic stories, clapping hands and beating out rhythms. In small-scale societies, she says, the temporal arts convey messages in ritual ceremonies, such as the need to appease gods believed to control vital resources. Such practices lessen worries about life's uncertainties and fuel group cohesion.

By creating stories out of precisely timed sounds and movements, Stone Age mothers and babies laid the groundwork for spoken language, says Dissanayake.

Today's music, from Ludwig van Beethoven to Lady Gaga, has transformed the temporal arts into a commercial enterprise that can still draw people from around the world into tribes bound by shared feelings and rituals (*SN: 4/11/09, p. 14*), Dissanayake asserts. Consider the pilgrimages that far-flung opera lovers take to hear famed vocalists and the popularity of all-night raves.

Her evolutionary scenario, like communicative musicality itself, stands defiantly outside mainstream music research. "This mother-infant stuff seems a little squishy to many scientists," Dissanayake says.

Trevarthen and colleagues weave a fanciful story around a threadbare body of data, asserts psychologist Sandra Trehub of the University of Toronto at Mississauga, a pioneer in studying infants' music perception. Music's evolutionary origins remain unknown, she emphasizes (see "Songs from the Stone Age," Page 28).

"According to its proponents, communicative musicality has boundless scope, so it's an idea than can neither be proven nor falsified," Trehub says.

Babies notice rhythmic downbeats and react to melodies with wondrous expressions even when by themselves, "so social communication is unlikely to provide a complete answer to early musicality," adds psychologist Marcel Zentner of the University of York in England.

Trevarthen remains undeterred. The next scientific step, he says, is to devise a measure of musical interactions that combines facial expressions and gestures with vocalizations.

Eventually, Trevarthen insists, researchers everywhere will tap their feet to the sounds of music reverberating in mother-baby chatter. ■

Explore more

- S. Malloch and C. Trevarthen, eds. *Communicative Musicality: Exploring the Basis of Human Companionship*. Oxford University Press, 2009.

More than a feeling

Emotionally evocative, yes, but music goes much deeper

By Susan Gaidos ▪ Photograph by Cary Wolinsky

Anyone who has felt the sting of tears while listening to a bugler play "Taps," swooned to a love song or cringed with irritation as a neighbor cranked the heavy metal knows that music can exert a powerful emotive effect.

And you don't need a neuroscientist to tell you that manipulating a melody's pace, tone and intensity can stir the emotions. Composers of symphonies, pop tunes, movie sound tracks and TV ads all know how to tune an audience's mood along a dial ranging from sad and glum to cheerful and chipper.

But neuroscientists might have something to say about how music orchestrates such profound emotional effects on the brain. And understanding the how may offer a hint as to why music affects humans so powerfully.

Over the past decade or so, studies have shown that music stimulates numerous regions of the brain all at once, including those responsible for emotion, memory, motor control, timing and language. While the lyrics of a song activate language centers, such as Broca's area, other parts of the brain may connect the tune to a long-ago association — a first kiss or a road trip down the coast, perhaps.

"It's like the brain is on fire when you're listening to music," says Istvan Molnar-Szakacs, a neuroscientist at the University of California, Los Angeles. "In terms of brain imaging, studies have

shown listening to music lights up, or activates, more of the brain than any other stimulus we know."

That music can activate so many brain systems at once is the reason it packs such a mental wallop. It exerts its most profound effect in the brain's emotional core, the limbic system. There, music changes virtually all areas of the brain responsible for regulating emotion, as neuroscientist Stefan Koelsch of Freie Universität Berlin describes in the March *Trends in Cognitive Sciences*. Music automatically engages areas essential to pleasure and reward. So much so, in fact, that the same pleasure centers in the brain light up whether you're listening to a favorite tune, eating chocolate or having sex.

These dramatic effects make music a valuable instrument for probing the brain's emotional circuitry. Koelsch and others are now using music as a tool to see how the brain processes a wide range of feelings such as sorrow, joy, longing and wonder. Some of these emotions, so easily felt in response to music, are otherwise difficult to evoke in an experimental setup. Other researchers are using music to explore how children with autism spectrum disorders process emotion. While these kids often have difficulty recognizing how others feel, they readily respond to the sentiments of a song.

Using music to study and stimulate the brain's emotional circuits may lead to new therapies for treating a wide range of emotional disorders, including depression, anxiety and post-traumatic stress disorder, scientists say. By understanding how music activates and coordinates the various emotional mechanisms in the brain, scientists may find ways to rewire a brain affected by illness or injury, or provide a work-around for damaged or underperforming brain regions.

Despite the long list of potential benefits for health and happiness, Koelsch contends that the deep, complex experience that music delivers is primarily a social, rather than an individual, phenomenon (see "Not just a pleasant sound," Page 22). Ages before people walked around with little wires in their ears to listen to music anytime, anywhere, tunes piped on flutes and reeds were probably used in tribal rituals to unify hunters and warriors about to do battle. Today, music helps pull people together at weddings, funerals and countless social events.

Musician Moussa Traoré, far left, leads a djembe drum circle in a West African rhythm. New brain studies highlight the emotional and social aspects of music.

Moody tunes

To explore the effect that music has on the mind, *Science News* asked researchers to share a song they enjoy and the emotion it evokes.

Ethan Ross, physician
SONG: "Dark Star" by the Grateful Dead
EMOTION: "Elation, euphoria and wonder."

Virginia Naples, vertebrate paleontologist
SONG: "The Wreck of the Edmund Fitzgerald" by Gordon Lightfoot
EMOTION: "Sadness and nostalgia for knowing about past events."

Alan Boss, planetary scientist
SONG: Beethoven's Ninth
EMOTION: "... the joy of being alive, at least for a while, and in spite of the struggles we face in living."

Eugenie Scott, physical anthropologist
SONG: "The Green and the Blue" by the Battlefield Band
EMOTION: "Empathy and sympathy."

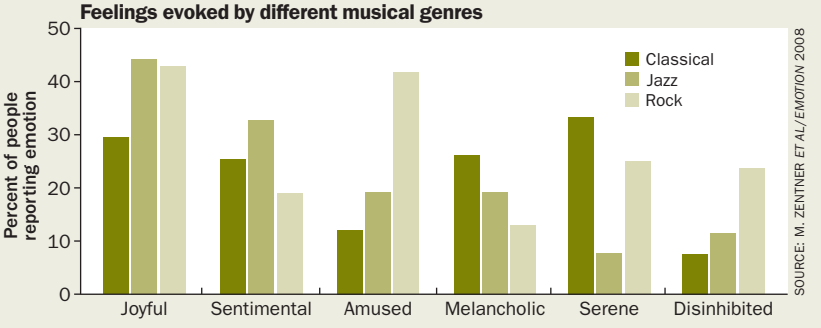
Chuck Steidel, astrophysicist
SONG: "Halah" by Mazzy Star
EMOTION: "We used to play this around 3:30 a.m. while observing on the Mauna Kea summit, so an exhilarated exhaustion, a partial dream state."

Holly Gibbs, conservation scientist
SONG: "Wagon Wheel" by Old Crow Medicine Show
EMOTION: "Anticipation and longing."

Kevin Padian, evolutionary biologist
SONG: "Won't Get Fooled Again" by The Who
EMOTION: "Rage and hope at the same time."

Margaret McFall-Ngai, microbiologist
SONG: "Girls Just Wanna Have Fun" by Cyndi Lauper
EMOTION: "Carefree life. It makes me smile big."

Feelings evoked by different musical genres



SOURCE: M. ZENTNER *ET AL./EMOTION* 2008

In my head

Music is universal. It occurs in all human cultures in some form, and extends deep into human history. Archaeologists have unearthed flutes made of bone that date back nearly 40,000 years. And scientists say that long before someone went to the trouble of carving a flute, humans banged out tunes using sticks and stones. Given that music gave early flutists and their fans no direct biological advantage over rival creatures — sweet melodies couldn't put food on the stone slab or guarantee grandchildren — researchers have long wondered why humans developed the capacity to perform and enjoy it.

Though music may not have evolved for survival purposes, modern-day imaging techniques reveal that it can have the same effects on the brain as many survival-related activities. In 2001, neuroscientists Anne Blood and Robert Zatorre of McGill University in Montreal asked people to listen to music deemed so moving by these participants that it "sent shivers down the spine." Blood, now at Harvard, and Zatorre showed that

music activates neural systems of reward and emotion similar to those stimulated by food, sex and addictive drugs.

Brain scans done using positron emission tomography, or PET, showed that increases in the "chill" intensity of the music correlated with changes in activity in the pleasure centers of the brain, including increases in blood flow to the brain's reward circuit — the midbrain, the ventral striatum and parts of the cortex.

At the same time, decreases in blood flow were seen in the brain's limbic system, a primitive region that governs the emotional response to a given situation. Structures in this region include the amygdala, known as the brain's fear center; the hippocampus, which is important for memory; and the nucleus accumbens, involved in pleasure.

In 2006, Koelsch and his group found that simply listening to joyful, pleasant music can lead to activity changes in all of these structures, even if people don't report having intense "chilling" experiences. Since then, studies carried out by him and others have elucidated additional areas of the brain specifically activated by music. Findings show that the brain areas stimulated depend on the type of music: Listening to a favorite tune will light up the brain's reward centers — and boost activity of the brain chemical dopamine, a molecule involved in desire and reward. The more you like a particular piece of music, the more jazzed you may get. Last fall, in a study in *PLoS One*, Zatorre and his group showed that the higher participants rated a song, the more emotionally aroused they got.

Other studies show that the amygdala kicks into action when volunteers listen to eerie-sounding or unpleasant music. (Consider waking at 2 a.m. to the sound of a partying neighbor's heavy metal.)

Together, the findings suggest that music has the capacity to both turn on and tone down neural activity in the brain.

Good vibrations

Knowing how music activates and coordinates the brain's emotional and reward circuits could help scientists develop new types of music therapies, Koelsch says. Information on how the amygdala responds to various types of music, for example, would allow researchers to target this area: tweaking it to calm fear-related activity in patients with anxiety disorders or boost pleasure-related activity in depressed patients. By listening to a specially designed music program for 30 minutes a day, five days a week, patients may tune the brain to improve mood (see "Take two stanzas and call me in the morning," Page 32).

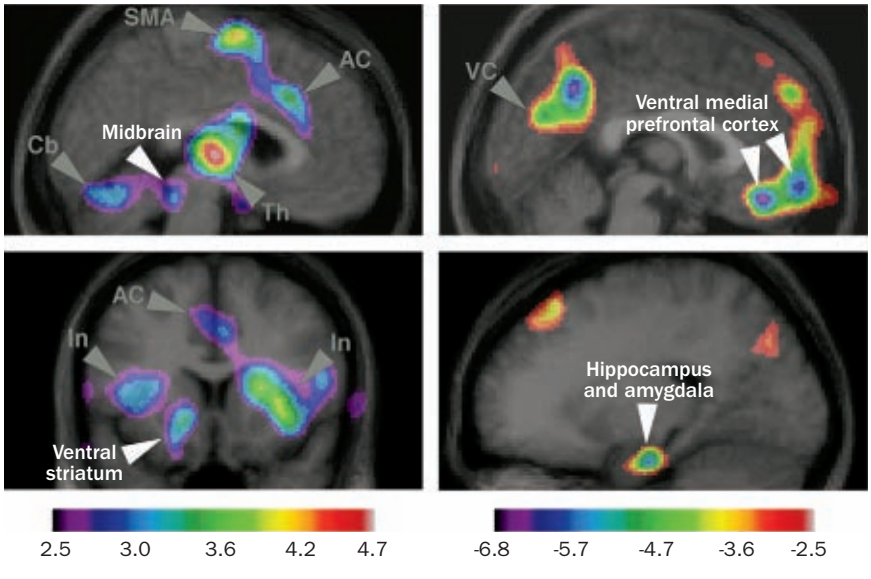
Already, research confirms that most people are better off with a dose of music. Soothing music seems to lower heart rate and blood pressure, and studies show that music can be a valuable companion to traditional treatments for cancer, stroke and postoperative pain.

Recently, Koelsch's team showed that making music boosts mood, even if you're not musically inclined. In the study, 81 nonmusicians broke into small groups and played instruments while listening to excerpts of classical, jazz, Irish folk, salsa and reggae music. A control group of 73 listened to recorded music played on a computer, using sticks to keep in time with the beat. Before and after their jam sessions, participants completed a questionnaire designed to assess mood. Those in the instrument group reported lower levels of depression, anxiety and fatigue, and an increase in vigor after the session. Volunteers in the control group showed no such boost in mood.

Koelsch credits the change, at least in part, to music's ability to engage various social functions. He plans to test this idea by comparing people who make music in a group with those who play solo.

Getting chills Listening to music you find moving can change activity in brain areas associated with emotion and reward. One study found that blood flow increased in the midbrain and ventral striatum (left) and decreased in the ventral medial prefrontal cortex, hippocampus and amygdala (right).

SOURCE: MODIFIED FROM A. BLOOD AND R. ZATORRE/*PNAS* 2001



Emotional rescue

While music's power can easily be seen in ordinary people, its effects may be even more marked in those with autism. Music therapy has long been used to treat autism, but how and to what extent such therapy worked was not well understood. Four years ago, UCLA's Molnar-Szakacs began thinking of ways to study music and emotional processing in children with autism spectrum disorders.

In a recent study using functional MRI, he and his colleagues compared brain activity in autistic children with that in typically developing kids tasked to identify emotions in music. The findings, presented in Barcelona in June at the Organization for Human Brain Mapping's annual meeting, reveal that children with autism spectrum disorder are

Your brain on music

Music lights up almost every area of the brain, which shouldn't be a surprise since it makes people tap their feet, encourages the recollection of vivid memories and has the potential to lighten the mood.

Around the outside

1. **Prefrontal cortex:** This brain region plays a role in the creation, satisfaction and violation of expectations. It may react, for instance, when a beat goes missing. Recent work has shown that during improvisation a part of the prefrontal cortex involved in monitoring performance shuts down, while parts involved in self-initiated thoughts ramp up.

2. **Motor cortex:** Music is not independent of motion. Foot-tapping and dancing often accompany a good beat, meaning the motor cortex gets involved. And playing an instrument requires carefully timed physical movements. In some cases, this area of the brain is engaged when a person simply hears notes, suggesting a strong link to the auditory cortex.

3. **Sensory cortex:** Playing an instrument sends tactile messages to the sensory cortex, as keys are hit, for example.

4. **Auditory cortex:** Hearing any sound, including music, involves this region, which contains a map of pitches for the perception and analysis of tones.

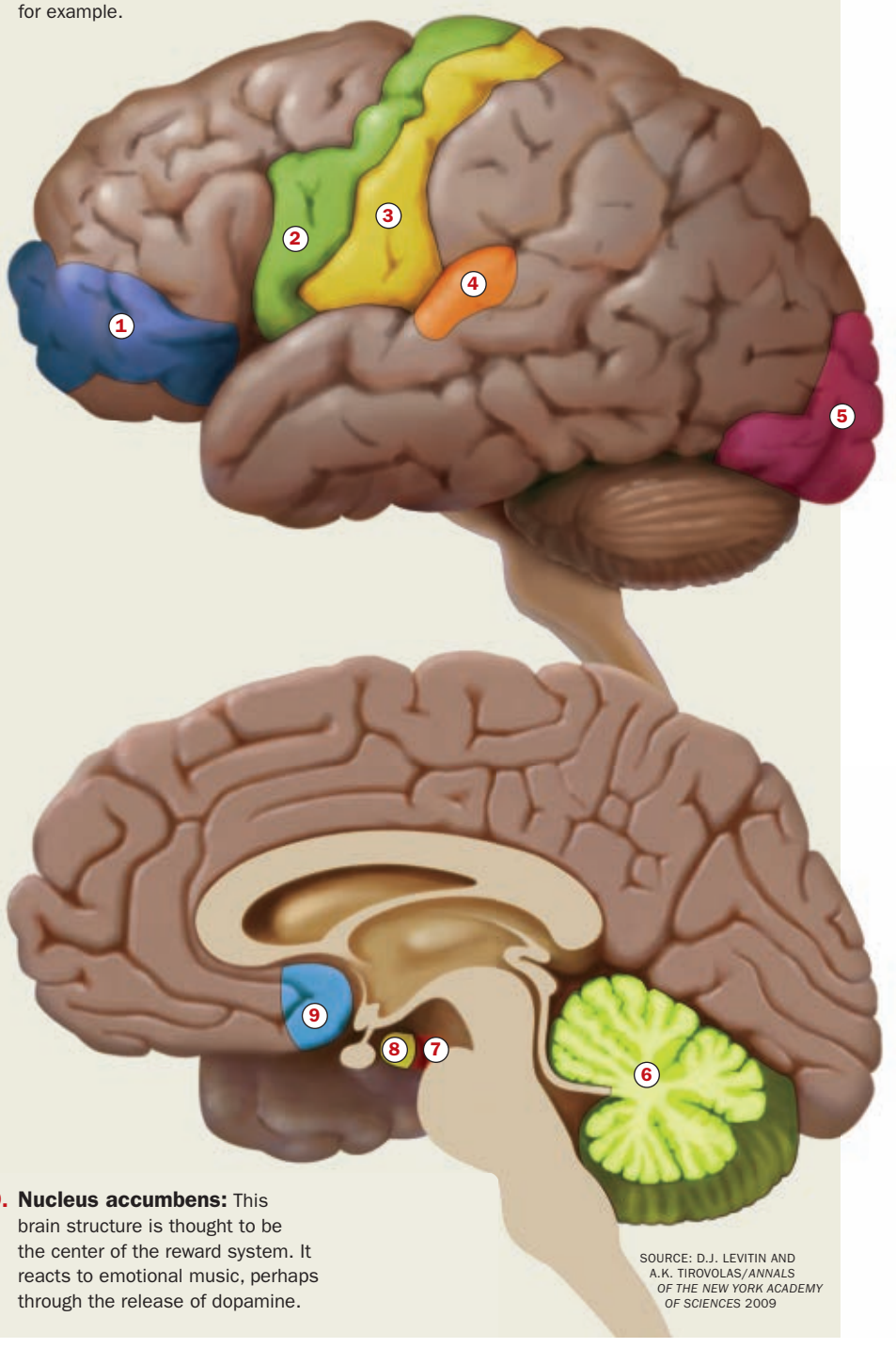
5. **Visual cortex:** Reading music or watching a performer's movements activates the visual cortex.

The inside track

6. **Cerebellum:** Movements such as foot-tapping and dancing activate this part of the brain. This could be because of the cerebellum's role in timing and synchrony; it helps people track the beat. The cerebellum is also involved in the emotional side of music, lighting up with likable or familiar music, and appears to sense the difference between major and minor chords.

7. **Hippocampus:** Known to play a role in long-term memory, the hippocampus (part of which is shown) may help the brain retrieve memories that give a sound meaning or context. It also helps people link music they have heard before to an experience and to a given context, possibly explaining why it is activated during pleasant or emotionally charged music.

8. **Amygdala:** The amygdala seems to be involved in musical memories. It reacts differently to major and minor chords, and music that leads to chills tends to affect it. Studies suggest the skillful repetition heard in music is emotionally satisfying.



9. **Nucleus accumbens:** This brain structure is thought to be the center of the reward system. It reacts to emotional music, perhaps through the release of dopamine.

SOURCE: D.J. LEVITIN AND A.K. TIROVOLAS/*ANNALS OF THE NEW YORK ACADEMY OF SCIENCES* 2009

CHARLES FLOYD

as accurate as "neurotypical" children at identifying emotion in music and show the same level of brain activation. Previous studies have shown less brain activity in kids with autism than in typical kids when looking at emotional faces.

"It seems like music acts as a sort of in, or doorway, to the [emotional] recognition system of children with autism," Molnar-Szakacs says. "telling us that at a biological level, emotional music has the same impact on children with ASD as it does on neurotypical children."

In the study, children with autism seemed adept at picking up on patterns in the music to identify the emotion, Molnar-Szakacs says. When asked how they made their decisions, the kids said that fast, loud, jumpy rhythms sounded happy, while slower, quiet music seemed sad.

His group is now looking to see how music activates certain neural systems that aren't active when these children look at faces. The studies may one day help scientists develop better interventions. Meanwhile, Molnar-Szakacs' group has developed a music-based program to help kids match and recognize various emotions — such as happiness, sadness and surprise — in social settings.

"It sounds a little like Pavlovian learning, but it's not," he says. "The goal is to not just have happy music playing with a happy face, but to have children learn to recognize different emotions so no matter what situation they find themselves in, they are able to reliably recognize an emotional face, and perhaps even the tone of an emotional reaction or voice."

Songs from the Stone Age

No one knows for sure whether music played a key role in human evolution or came about as a kind of ear candy. But there are several scientifically inspired proposals for the origins of music, some included below.

Da ya think I'm sexy?

Charles Darwin, an avid music fan, suggested in 1871 that humans' tunes evolved from courtship songs like those of birds, apes and other animals. In 2000, psychologist Geoffrey Miller of the University of New Mexico in Albuquerque elaborated on Darwin's idea, arguing that music-making abilities evolved along with intelligence and creativity as an advertisement of reproductive fitness to potential mates.

I feel good

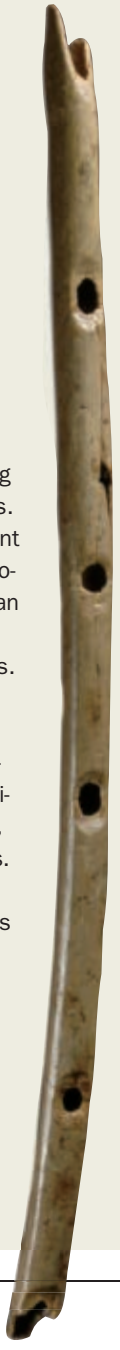
Harvard University psychologist Steven Pinker thinks of music as a gratifying diversion that offered no survival or mating advantages to human ancestors. In 1997, he dubbed music "auditory cheesecake," a pleasurable amusement that people concocted from evolved mental faculties such as language, emotions and motor control. Aniruddh Patel of the Neurosciences Institute in San Diego also views music as a human invention built on neural circuitry that serves other purposes, but he sees it as having biologically powerful effects.

Let's get together

One popular idea posits that music and dance evolved to bind groups of people together. Swedish neuroscientist Björn Merker suggests that musical abilities and activities originated in groups of ancestral males chorusing together, possibly to scare off males from rival groups and to attract migrating females. Anthropologist Robin Dunbar of the University of Oxford in England has suggested that music and language became increasingly vital social lubricants as hominid groups increased in size over the ages.

Mother and child reunion

With the emergence of the *Homo* genus roughly 2 million years ago, pairs of mothers and babies forged emotional ties by communicating musically, says Ellen Dissanayake of the University of Washington in Seattle. Prehistoric groups exploited mom-infant interactions and added music and dance to rituals, she proposes (see "Birth of the beat," Page 18). What people now think of as music emerged much later, in her view. — *Bruce Bower*



Evidence of ancient roots

Though early hominids may have made sweet sounds by banging sticks and stones together, the oldest distinguishable instrument dates to 40,000 years ago.

A flute made from vulture bone (shown) and others made from mammoth ivory have been found in Hohle Fels cave near Ulm, Germany, and date from 35,000 to 40,000 years ago. Holes in other bones dating to about 43,000 years ago were dismissed as bite marks from cave bears.

Gudi, literally "bone flutes," found in Jiahu in Henan Province, China, date to 9,000 years ago. Made from the wing bones of red-crowned cranes, the early instruments possess five to eight finger holes.

Pieces of several harps found in 1929 by Leonard Woolley in what was ancient Mesopotamia date back to almost 5,000 years ago. The most famous was the bull-headed lyre (replica shown), which had been preserved in a Baghdad museum until it was looted in 2003.

Two marble statues dating from 4,700 to 4,500 years ago depict a double flute player (shown) and a harpist. Found on the island of Keros, near Crete, the statues' purpose is unclear.

Six graded cylindrical wooden pipes discovered south of Dublin date to 4,000 years ago. The pipes, the largest of which is 50 centimeters long, lack holes and appear as if they were attached together as part of a larger instrument.

FROM LEFT: N. CONRAD, *ET AL./NATURE* 2009; SILVIO FIORE/GETTY IMAGES; GIANNI DAGLI ORTI/CORBIS; WOLFGANG SAUBER/WIKIMEDIA COMMONS

Happy together

Scientists say music's ability to touch emotion lies in its ability to forge social bonds and foster cooperative behavior. Koelsch and Nikolaus Steinbeis of the University of Zurich showed in 2009 that just listening to music creates a firestorm of activity in brain areas commonly used to understand another person's thoughts. "It was as if they were trying to figure out the intentions and desires of the composer," Koelsch says.

Studies show that listening to music stimulates brain areas specialized for imitation and empathy that contain what researchers call mirror neurons. These brain circuits, first described in monkeys, act like mirrors in the mind, reflecting others' actions and intentions as if they were one's own. The neurons allow you to feel loved ones' pain or simulate their actions, even if only in your mind.

But mirror neurons are active not only when a monkey sees or performs an action, but also when it hears the sound associated with an action. Molnar-Szakacs says that this sound-related function may have developed for survival reasons, enabling the understanding of actions that couldn't be seen, such as detecting footsteps in the dark.

Because music has historically brought people together to sing, dance and celebrate rituals, it can make people feel like they are in a social interaction, he says. Until recently, whenever people heard music, they would also see feet tapping, hands drumming or instruments being strummed, plucked or hit.

"If you think about music in terms of human evolution, rather than in terms of the iPod, music has for the majority of human history been made in the physical presence of others," Molnar-Szakacs says.

Last year, writing in *Social Cognitive & Affective Neuroscience*, he and Katie Overy of the University of Edinburgh added new details to their theory, first described in 2006, that ties together the mirror neuron system and the limbic system to explain why music has such a profound emotional impact in humans.

I will survive

Probing music's effects on emotion may also help answer a long-standing puzzle: why music, a pleasurable but seemingly unnecessary part of life, is universal across cultures. Some experts believe that the ability to perceive and enjoy music is an inborn human trait. Others see it as human invention, born from the brain's ability to coordinate various functions.

In the March *Physics of Life Reviews*, Harvard physicist Leonid Perlovsky suggests that the development of language itself may have set the stage for the human brain to appreciate music. Before spoken language emerged, early people might have used simple hand gestures and vocal signals to communicate. Such signals were probably closely tied to emotion, says Perlovsky.

As the rational, language-based part of the brain began to dominate, humans were able to differentiate among ideas, concepts and feelings. But the emergence of language, and the "thinking mind," created a disconnect from the emotional mind, he contends.

Music, though, helps humans maintain the ability to tap into these more ancient, emotive systems, and is an instinct rooted in the human evolutionary past, Perlovsky says.

In contrast, Aniruddh Patel of the Neurosciences Institute in San Diego sees music as a human invention — not an evolutionary adaptation — built on neural circuitry that ordinarily serves other functions. He compares humans' desire to create and enjoy music to their ability to control fire.

"Nobody argues that our brains have been specifically shaped by evolution to make fire, yet it's universal in human culture because it's so valuable to us," he says.

Music serves a similar purpose, Patel says, providing things people value deeply, such as the ability to remember information over time and a way to conduct rituals with power and efficiency. "Therefore it stuck," he says.

Koelsch offers yet another reason why music appears across human culture: It provides a crucial social glue. Humans are social animals, and music automatically engages systems for social cognition, communication and cooperation, he says.

Music "is particularly effective in establishing a sense of unity, belongingness and trust among individuals," says Koelsch. "I don't say that music always does this — apparently it doesn't. But it can be very powerful in doing so." ■

Explore more

- Oliver Sacks. *Musicophilia: Tales of Music and the Brain*. Vintage, 2008.

A cuneiform tablet dating to 4,000 years ago from Nippur, an ancient Sumerian city, includes instructions for performing music on string instruments and suggests people had a sophisticated idea of octaves more than 4,000 years ago.

The tomb of Ramses III, who ruled Egypt more than 3,000 years ago, contains a bas-relief including two blind musicians playing before the gods. Discovered in 1768 by James Bruce, the tomb was dubbed "The Tomb of the Harpists" and is sometimes called "Bruce's tomb."

Bronze carnyces found buried beneath a temple in Corrèze, France, date to more than 2,000 years ago. The carnyx was a Celtic battle horn (two replicas shown), sometimes with a boar's head at its top. —*Elizabeth Quill*

Music of the hemispheres

Playing instruments gives brains a boost

By Rachel Ehrenberg ▪ Photograph by Cary Wolinsky

Not so long ago, Mozart mania swept the nation. A small study found that students who listened to 10 minutes of a Mozart sonata performed better on a paper-folding task than their peers, and suddenly a flourishing industry sprouted. Mozart's music sang from CDs and videos marketed for children, babies and moms-to-be. The craze reached a crescendo when Georgia's governor Zell Miller included $105,000 in his state budget to send every child born in a Georgia hospital home with a classical music tape or CD.

"No one questions that listening to music at a very early age affects the spatial, temporal reasoning that underlies math and engineering and even chess," Miller said.

Actually, a lot of researchers questioned the link between listening to music and smarts. In the original study, the "Mozart effect" was minor and lasted only minutes. Follow-up studies found the effect specific neither to the composer nor to music. Students listening to Mozart were just more stimulated than those listening to a relaxation tape or silence. And while arousal can improve learning, research suggests, the effects can be fleeting and aren't limited to music. Assessments of the original report now tend to be dirges: In the May-June issue of *Intelligence*, researchers from the University of Vienna published a paper titled "Mozart effect–Shmozart effect."

"It's a short-lived effect and it spawned a huge industry of baby Einstein, baby Mozart CDs, all sorts of stuff," says Aniruddh Patel of the Neurosciences Institute in San Diego. "But the science behind it is pretty thin."

Yet even though listening to Mozart won't make you smarter, a growing body of evidence suggests that playing his music will. Musical training doesn't just make you a better musician — the acquired skills seem to transfer to other areas, various studies have found. And research focused on the brain's particular relationship with music and language suggests that engaging the mind with musical training could remedy language impairments such as dyslexia.

"There really is now so much evidence showing that musical experience has a pervasive effect on how the nervous system gets molded and shaped throughout our lifetimes," says Nina Kraus, head of the Auditory Neuroscience Laboratory at Northwestern University in Evanston, Ill. "This kind of transformation comes about only with active engagement with sound. My daddy always said, 'You never get something for nothing.' You're not going to get big biceps by watching wrestlers — you've got to do it."

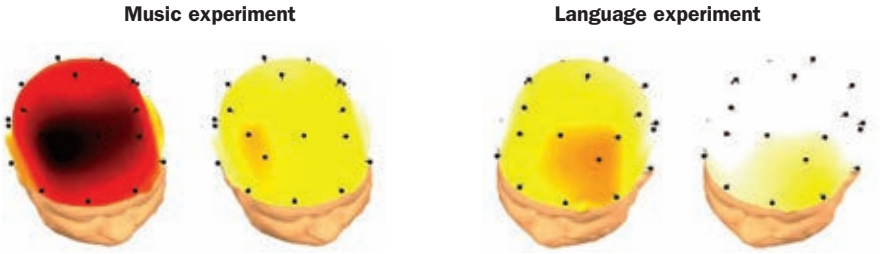
In the long run, musical training appears to improve a suite of verbal and nonverbal skills. Playing an instrument may add finesse to how people move their bodies. Making music makes you hear better, fine-tuning the ability to extract a signal from noise. Musical training also may improve grammar skills, the ability to grasp meaning from words and to distinguish a question from a command.

Until recently, establishing cause and effect for music's mental impact has been difficult. But long-term studies peering into brain structure and activity are now showing that musical training changes the brain in lasting ways.

The brain on beats

Playing an instrument calls upon circuitry from many areas of the brain, says Daniel Levitin, director of the music perception, cognition and expertise laboratory at McGill University in Montreal. For a long time, music was considered a creative "right brain" endeavor. That idea has now gone the way of the Macarena. Music processing is distributed throughout the brain, says Levitin, and playing an instrument, in particular, is an ensemble activity. It involves paying attention, thinking ahead, remembering, coordinating movement and interpreting constant feedback to the ears, fingers and, in some cases, lips.

"It's one of the most complicated tasks that we have," Levitin says. "Take a symphony orchestra. What you have is 80 or 100 of the most highly trained members of our society — more highly trained than astronauts or surgeons in terms of the numbers of hours and years of preparation — and they are performing the works of some of the greatest minds that ever lived. It's really extraordinary."



S. JENTSCHKE AND S. KOELSCH/*NEUROIMAGE 2009*; PHOTO: THANKS TO THE SOUTH SHORE CONSERVATORY

Say what? When children with musical training hear a sequence that ends with a "hanging" chord, their brains respond more strongly than do other children (shown at left, darker is more intense). These kids also show stronger responses to violations in sentence syntax (shown at right).

The breadth of the musician's task and the required cognitive effort are probably behind much of the enhancement of other skills, says neuroscientist Laurel Trainor, director of the auditory development lab at McMaster University in Hamilton, Canada. Playing an instrument "engages basically most of your brain," Trainor says. The activity appears to boost executive function, being the boss of your body and mind. Evidence suggests that with musical training comes improved memory, finer motor skills and better attention control — the ability to ignore one thing and pay attention to something else. "Our working hypothesis is that it's these control processes that are what is key for the transfer effects," Trainor says.

Some musicians are certainly musically inclined to begin with. But recent work suggests that the superior performance demonstrated by musicians on some tasks is more about nurture than nature. Teasing out that balance has been a recent focus of Gottfried Schlaug's music and neuroimaging research at the Beth Israel Deaconess Medical Center and Harvard Medical School.

A study by Schlaug's team found that after 15 months of weekly keyboard lessons, 6-year-olds showed greater change in their brains than kids who attended a weekly music class without instrument training. Among the most changed were a part of the auditory cortex and brain regions involved in control of movements. Kids with training also did better on tests related to finger movement and discerning melodies and rhythm, Schlaug and colleagues reported last year in the *Journal of Neuroscience*.

For most people, the transfer effects

Though the "Mozart effect" appears to be hype, studies do show that musical training can improve language and auditory skills.

of musical training are probably modest, says Trainor. "Otherwise, we'd expect musicians to be the most intelligent people on the planet," she says. But musical training may strike a particularly rich chord for people with language difficulties. "There is quite a bit of evidence now that musical training does have benefits for people with dyslexia and language impairments," Trainor says.

Peas in a syntactic pod

Evidence that the brain holds music and language in one embrace began to mount when imaging studies by Patel, Stefan Koelsch of the Freie Universität Berlin and others suggested that areas of the brain instrumental for processing language are also important for music. While some circuitry appears to be specific to music or language, new evidence emphasizes areas of overlap. Both music and language have syntax — just as there are rules governing the construction of sentences from words, there are rules for "building" a piece of instrumental music. You don't just randomly throw notes together. (As with language, these rules may differ across cultures.) The brain seems to tap into the same neural circuitry when processing how the building blocks of language or music fit together into a greater, hierarchical structure.

"You can have overlap in the machinery that puts the pieces together," Patel says. "They may be different pieces, but the machinery that puts them together is shared."

Shared processing of music's and language's building blocks is evidenced by the brain's recognition of construction gone awry. Within milliseconds of hearing a sentence spoken with irregular structure, neurons fire in a specific area of the brain, researchers have learned. The brain also reacts to violations in chord structure.

Musically trained kids are better at hearing these violations than kids without training, says Sebastian Jentschke, now at University College London. Musically trained brains are also better at detecting violations in sentence structure, Koelsch and Jentschke reported in *NeuroImage* last year. The inverse relationship also holds; kids with Specific Language Impairment, marked by difficulties with grammar and complex syntax, also have trouble processing musical syntax, Koelsch, Jentschke and collaborators reported in 2008 in the *Journal of Cognitive Neuroscience*.

These studies highlight the neural intimacy of processing music and processing language. "It's a reasonable assumption that musical training might help with kids with impairments with processing skills in the language domain," Jentschke says.

From the top … down

Scrutinizing brains on music suggests that training influences more than the higher-level circuitry relevant to language skills.

Playing music can also change the brain from the top down, says Kraus, influencing language processing. The highfalutin circuitry of the cerebral cortex, which plays a key role in memory, perception and consciousness, can be shaped by music and in turn can fine-tune circuitry in the lower, evolutionarily ancient "lizard brain," changing how people hear.

"We used to think in a very hierarchical way — sound goes into your ear, up into your brain stem, then into your cortex and meaning happens," Kraus says. "But the lizard brain is not what it used to be. We know now that the pathways that connect the cortex and feed down to the brain

Take two stanzas and call me in the morning

From poets to politicians, people have long described music as medicine for the heart and soul. Now scientists are taking a literal look at such musings, investigating music as a means to alleviate pain and enhance recovery. Though some studies are still in the early stages, your favorite soundtrack may one day accompany a prescription.

Alzheimer's disease: Studies have shown that individuals with Alzheimer's have a better memory for lyrics when they are sung rather than spoken. The findings suggest that song may help these patients learn practical, everyday information.

Pain and nausea: Cancer patients who participated in music and relaxation-imagery sessions while recovering from bone marrow transplants had less pain and nausea than patients undergoing the standard treatment alone.

Anxiety: Listening to music before glaucoma or cataract removal surgery soothed patient anxiety, lowering blood pressure levels during and after the surgery, one study found. Another study showed that pregnant women who listen to music for 30 minutes a day report reduced levels of stress, anxiety and depression after two weeks.

Stroke: Patients who listened to music of their choosing for one to two hours a day did better on word recall tests and had fewer bouts of sadness and confusion than patients who listened to audio books or nothing at all. Research also suggests that simulating movement with music of a particular tempo may improve walking in stroke patients, and stroke patients report improved vision while listening to music.

Respiratory disease: Over eight weeks, subjects with serious lung disease who listened to music while walking showed improved fitness, a study found. Those patients covered 24 percent more ground than a nonmusic group.

Traumatic brain injury: Some patients who underwent music therapy that involved following tempo, loudness and rhythmic pattern performed better on tests of mental flexibility, suggesting such therapy may help people with brain injuries manage switching between important tasks during daily life.

— Rachel Ehrenberg

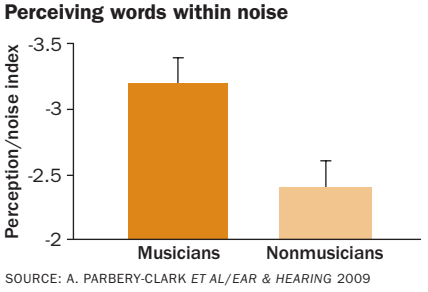
DANTODDY/ISTOCK IMAGES, PHOTO ILLUSTRATION BY E. FELICIANO

stem ... are actually more massive than the ones going upstairs."

This top-down tuning may influence a person's ability to discriminate sounds of different frequencies, the processing of pitch. Pitch is the brain's interpretation of frequency, both in terms of absolute frequency and relative position on the musical scale. (Levitin notes that pitch is the only musical attribute that varies in the first seven notes of "Mary Had a Little Lamb.") Pitch is crucial for conveying information: It determines whether the phrase "You are going to wash the dishes" is a question or a command. In languages such as Mandarin Chinese, saying the same syllable at a different pitch level gives the word an entirely different meaning.

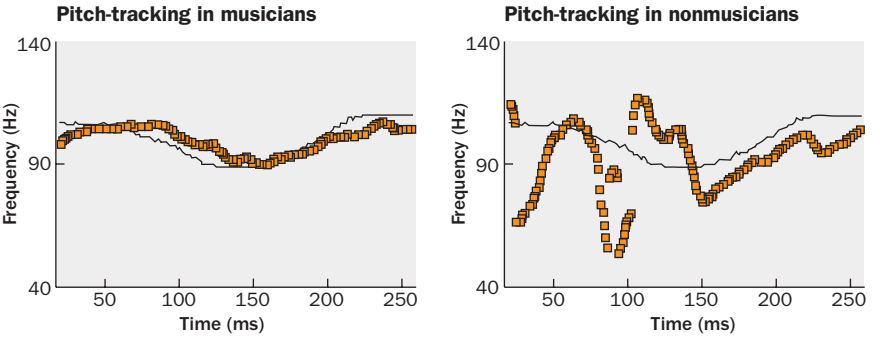
Among people unfamiliar with Mandarin, musicians are better than nonmusicians at discriminating between Mandarin syllables, Patrick Wong, Kraus and others reported in *Nature Neuroscience* in 2007. Electrodes recording brain activity revealed that a particular pitch-related neural response, thought to originate in the brain stem, was more robust in the musicians.

Other work on the effects of musical training suggests that it improves overall pitch processing. After six months, Portuguese third graders in a musical training group performed better on a reading task and on a pitch discrimination task than kids in a painting group, researchers reported last year in *Cerebral Cortex*. These results were also reflected in brain wave activity, says study coauthor Sylvain Moreno of the Rotman Research Institute and York University in Toronto.



SOURCE: A. PARBERY-CLARK *ET AL/EAR & HEARING* 2009

Hear this Musically trained adults can hear words in background noise better than untrained peers (more negative index, better detection).



SOURCE: P.C.M. WONG *ET AL/NATURE NEUROSCIENCE* 2007

Follow that tone The Mandarin language conveys word meanings with tone. When a musician with no knowledge of the language hears a Mandarin tone, activity in the brain stem (orange) tracks the frequency of the changing tone (black). The nonmusician's brain is out of sync.

This training-induced, top-down tuning appears to affect hearing in general. On a task known as backward masking, in which subjects detect a sound masked by a second sound, musicians with more than 10 years of musical training outperformed nonmusical peers, Kraus' team reports in the March *Hearing Research*. The musicians also performed better at distinguishing cartoon characters based on the pitch of their sounds.

Listening skills such as the ability to discriminate pitch or discern a signal from noise are related to some language impairments, including dyslexia, research suggests. People with dyslexia often have a hard time reading — a difficulty that is thought to result from trouble transforming the letters on a page into the sounds of language. This sound-meaning connection happens before children learn to read, says Kraus, and may be crucial for reading skills to develop.

A team that included Kraus and Jane Hornickel, also from Northwestern, looked at how the auditory brain stem responded to the sounds of different syllables for kids with a wide range of reading abilities. Kids with the weakest reading skills had a harder time distinguishing the sounds *ba*, *da* and *ga*, the team reported last year in *Proceedings of the National Academy of Sciences*.

Everyone has trouble hearing in a noisy restaurant. But children with dyslexia can have an even harder time perceiving sounds in noisy conditions. "If you've got a kid who is just struggling to hear what the teacher is saying, he's got very little extra neural resources to be thinking about 'What does this mean?' " Kraus says.

If musicians' responses are much less affected by background noise, she says, musicians can devote more neural resources to meaning rather than just hearing. That suggests musical skill could give children a learning benefit.

"If you have a nervous system in which the signal still comes through loud and clear in a noisy classroom, now that kid has an advantage," Kraus says.

For a clearer picture of the relationship between musical training and learning, more studies are needed. But the accumulating research is tantalizing, and it suggests that upping the quality and quantity of musical training in schools is warranted, Kraus and Northwestern colleague Bharath Chandrasekaran write in the August *Nature Reviews Neuroscience*.

"Music has the power to transform our nervous system in substantial, enormous, unambiguous ways," says Kraus.

Many researchers now equate musical training with learning to read. (Patel calls each of them a "transformative technology of the mind.") Perfectly intelligent, capable people can do fine in life without cracking a book or strumming a tune. But both can make the mind sing. ■

Explore more

- Nina Kraus' laboratory: www.soc.northwestern.edu/brainvolts/
- Daniel J. Levitin. *This Is Your Brain on Music: The Science of a Human Obsession.* Dutton, 2006.

Time's arrow

I've enjoyed reading *Science News* since I was a kid; thanks very much for producing such a fine periodical! This is the first time I've felt compelled to write to you about an article you've published: "Law and disorder" (*SN: 6/19/10, p. 26*). I can't help but feel that the time theory that Sean Carroll proposes misses the point of time. Time is the observation of forces acting on matter or energy. Take an event such as dropping a ball: Gravity acts on the ball, pulling it to the ground. If we reverse time, the ball will be repelled from the Earth. The ball can't just do this of its own accord; some force would have to be repelling the ball from the ground. Therefore, if we reverse time, we also have to reverse gravity in order to get the required result. But, to the best of my knowledge, gravity acts only in one direction. Because gravity is a force of attraction and reversing time would make it a force of repulsion, going back in time, unlike Tom Siegfried's article suggests, is not allowed by the laws of physics.
Joshua Feinberg, Portland, Ore.

The laws of physics are time-reversible only on the microscopic level, where molecular collision processes do appear the same in a movie running forward or backward. The reader is quite right that many macroscopic processes are not reversible — the mystery is how such irreversible phenomena can arise from the time-reversible microworld. — Tom Siegfried

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Tom Siegfried's essay and book review about time raise an issue that has troubled me for some years. I have observed that, because math is so beautifully able to describe nature, scientists in general seem to have overlooked the fact that our math and its equations are descriptive, not prescriptive. "The math allows ..." is heard over and over. Simply because an equation, or even a chemical reaction, is reversible in no way means anything else is too. Nature does not obey the laws of physics. The laws only describe nature.
P.M. deLaubenfels, Corvallis, Ore.

The essay "Law and disorder" states, "Equations describing the forces that guide matter in motion work just as well going backward in time as forward." However, it was widely believed (I don't know if this was ever actually proven) that time (T) symmetry is violated at the subatomic level (since the symmetry of CP, the combination of charge and parity, is known to be violated, either T or CPT must also be). This is particularly interesting since a CP violation may explain why the universe contains more matter than antimatter ("Muons offer clue to why universe isn't just space," *SN: 6/19/10, p. 8*). Perhaps there is a link between these two mysteries.
Bobby Baum, Bethesda, Md.

CP violation does imply that time symmetry must be violated to preserve CPT symmetry. But CP violation occurs only in a very small number of specific interactions. Some physicists have explored the possibility that this quirk of the subatomic world might be linked to the macroscopic arrow of time, but such efforts did not succeed in finding a convincing explanation. — Tom Siegfried

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In the essay "Law and disorder," time is not defined at the outset, or anywhere else in the article. I remember the definition "time is the separation between two events." Is there another that applies to most of the discussion in this article?

Another comment about this article, as well as many others I have read in *Science News*: Many people think that math models *are* reality. The "Law and disorder" essay reads: "Wolfram cited computer simulations that he claimed were evidence that the second law is simply wrong."

Math models or simulations don't "prove" a thing. I have put together math models, but I never assumed that they were reality. They were my best guess at how things might behave.
Ron Erickson, Missoula, Mont.

Time for a new law?

I'm sure that Tom Siegfried is more than familiar with the Law of Conservation of Energy. From his editorial ("For source of time's arrow, consult a good dictionary," *SN: 6/19/10, p. 2*), it would appear that he is less familiar with the Law of Conservation of Italics.
Harry Frank, Ann Arbor, Mich.

The problem of time's arrow and our equations probably lies in our equations, not in the dictionary. Just as the laws of relativity enlarged our perspective while preserving the everyday of classical physics, so, I would wager, new and better equations will preserve the dictionary even as they enlarge our perspective on the world. Perhaps I quibble.
Charles R. Smith, Fort Collins, Colo.

Real hype over artificial life

The hype about the Venter Institute's "synthetic," "man-made," "made-from-scratch" genome ("Genome from a bottle turns one bacterium into another," *SN: 6/19/10, p. 5*) is overblown. The only thing the Venter scientists made from scratch was a DNA molecule. The actual genome — the gene sequence encoded by that molecule — was a copy-and-paste job (with minor modifications) from an existing, naturally occurring organism.

To be sure, the synthesis of that DNA molecule and its insertion into a functioning cell is an amazing technical feat, comparable perhaps to the Gutenberg Bible. But Gutenberg did not write that Bible; he merely printed it out, as these scientists have done with their synthetic DNA. A truly synthetic genome would imply the ability to design organisms from first principles, which science is still a long, long way from achieving.
Gregory Kusnick, Seattle, Wash.

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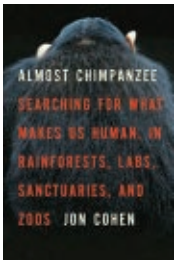
Almost Chimpanzee: Searching for What Makes Us Human, in Rainforests, Labs, Sanctuaries, and Zoos
Jon Cohen

Chimpanzees tantalize and taunt scientists. Some researchers see these expressive-faced apes as dandy models of human ancestors; others cite the perils of viewing another species as "almost human." In his new book, Cohen, a science writer, takes a largely entertaining journey into the fractious world of chimp studies. He falls short, though, of fulfilling the title's promise of showing that people are "almost chimpanzee."



Cohen is at his best in recounting colorful stories of chimp researchers and their findings on chimp biology, behavior and thinking. Consider the Soviet scientist who in 1927 almost started a program to breed human-chimp hybrids, or humanzees. Cohen also paints a compelling portrait of primatologist Tetsuro Matsuzawa, who shows his chops as a scientific chimp whisperer through his deft dealings with ape antics at his research facility.

One of the most memorable human characters in the book is researcher Geza Teleki. An ardent champion of chimp conservation, Teleki says he intuitively understands what chimps are doing—teasing one another, showing friendship and more—because they behave much like people. Cohen cites this as a sign of people's "almost chimpanzee" pedigree.

What's left unaddressed is whether a chimp could in turn understand human cultural activities, such as what's going on at a church service or a yard sale. If chimps are not "almost human" in this sense, can humans be "almost chimpanzee"? —*Bruce Bower*
Times Books, 2010, 384 p., $27.50.

Planet Hunter: Geoff Marcy and the Search for Other Earths
Vicki Oransky Wittenstein
A look at exoplanet hunting based on one astronomer's life and work. Aimed at young adults. *Boyds Mills Press, 2010, 48 p., $17.95.*

The Nesting Season: Cuckoos, Cuckolds, and the Invention of Monogamy
Bernd Heinrich
A naturalist explores how birds find a mate and what this process says—and what it doesn't say—about human relationships. *Belknap Press, 2010, 404 p., $29.95.*

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Ian Cross

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Whatever music is, it's a basic part of being human

Scientists are increasingly interested in the nature and origins of music, as this special edition on music illustrates (see Page 17). As director of the Centre for Music and Science at the University of Cambridge in England, Ian Cross studies music perception and culture's role in musical experience. A former professional classical guitarist who still performs occasionally, Cross is the only Cambridge music faculty member to have declined a chance to join iconic '70s pop band the Bay City Rollers. He recently discussed music's scientific standing with Science News *writer Bruce Bower.*

What is music?

I can't give a good definition for music. The contemporary Western view of music is that it consists of complex, patterned sounds with a structure that we find pleasurable to listen to. But music is much more than that. All cultures have music, but many cultures don't have a word for music. In traditional societies, there are musical performers, but music is primarily interactive, so everybody participates and it's embedded in daily experience.

Music brings people together by having flexible meanings. Two people are unlikely to agree on precisely what a piece of music means because it triggers different sets of associations for each person. That makes music well-suited to uncertain social situations, such as funerary rites, circumcision rites and ceremonies for greetings and departures of visitors and group members.

How did music evolve?

People made sophisticated kinds of music long ago, as shown by 40,000-year-old flutes recently found in Germany (*SN: 7/18/09, p. 13*). Musical practices must have come out of Africa and predated humanity's emergence around 200,000 years ago. I suspect music evolved along with speech, probably by the time of *Homo heidelbergensis* [around 600,000 years ago]. So Neandertals and the first humans would have had music.

Modern cultures separate music from language, but music and speech are probably the same thing. Speech can be very music-like. Think of a Southern Baptist preacher acting out his message in a musical way. And musical interactions typically involve vocal sounds, words and gestures. There is a rhythmic and emotional complexity to both music and speech. But language by itself is not as flexible in its meanings to different people as music is.

Musical behaviors of nonhuman animals may have contributed to musical evolution. Primates and other animals use musical sounds to communicate about whether to approach or avoid certain areas. They use tempos and pitch ranges for danger and safety that are associated with people's emotional responses to music. In the famous shower scene from the movie *Psycho*, the soundtrack uses carefully fashioned violin phrases that viewers experience as screams, a clear danger sign for many animals.

Although there have been some fabulous experimental studies of music perception, music is a bit too wild to be trapped in the lab.

What are the biggest public and scientific misconceptions about music?

People think that there are musicians and nonmusicians. Yet nearly everyone can finely distinguish between various musical genres and styles. Musical performers just engage with music in a more direct way.

No, wait. An even bigger misunderstanding is the assumption that music doesn't matter. Music programs in schools are often the first casualties of economic recessions. Without these programs, we're not enabling the expression of a deep, biologically grounded communication system.

I started playing the piano at age 6 and decided I didn't like it. Then I tried the violin and didn't like it. Then I took up the clarinet and hated it. I started with the guitar at age 9 and still play today. Kids need to be given the chance to try different instruments and find one that feels right.

Too many scientists think that Mozart is music but two kids singing a street chant is not music. In our culture, music has become a commodity that's divorced from action. It's thought of as entertainment, not as a fundamental communication system.

What are the prospects for a better scientific understanding of music?

Although there have been some fabulous experimental studies of music perception, music is a bit too wild to be trapped in the lab. I've worked with ethnomusicologists who play recorded music to members of non-Western groups and try to measure how they perceive and react to it. But these people don't think of a recording as music. They're bored by it. It makes no sense to them because it's not interactive. Researchers need to devise better ways to study music across cultures and in real-life situations. ■

JANE WOODS

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