BRAIN GAMES: CAN THEY *REALLY* MAKE YOU SMARTER? page 64

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July/August 2015 Mind.ScientificAmerican.com

"How I Learned to Walk Again"

The promise of exoskeleton technology

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WIRED FOR TOUCH

New discoveries about the sense that binds us to others

Simple Tips for Everyday Happiness

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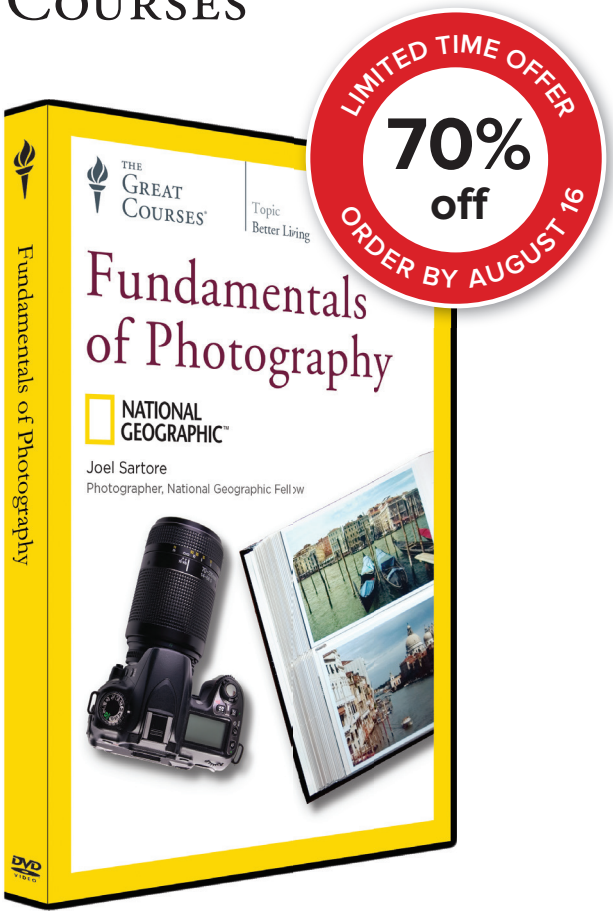

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From Touch to Technology

From the moment we emerge into this bright, bustling world, our perceptions and experiences are inscribed on the circuits and structures of our brain. Sights, sounds, tastes, personal encounters of all sorts leave their neural imprint, stamping us as unique individuals. But arguably, it all begins with that most rudimentary of senses: touch.

"Touch is the first sense to emerge in utero, and though far from mature, it is the most strongly developed sense at birth," writes Brooklyn, N.Y.–based science writer Lydia Denworth in our cover story, "The Social Power of Touch," beginning on page 30.

Scientists have long been familiar with the tactile nerves that transmit pain, texture and temperature. The surprising news is that we also have nerve fibers uniquely adapted for the kind of "social touching" we do when we soothe or greet one another or cuddle a child. These fibers are calibrated for strokes that are slow and gentle (below about five millinewtons), and they are abundant in the parts of the body we instinctively pat: the shoulders and back, the top of the head. Salespeople and politicians know how to use social touch to create trust. Intriguingly, this system may be impaired in people with autism.

At the other extreme from this primal sensation is a whole new world of stimulation from modern technology. Past stories in *Scientific American Mind* have touched on ways that cell phones and television affect cognitive function. In this issue, journalist and former researcher Simon Makin takes a hard look at whether brain-training games—such as those offered by Lumosity—really can improve your thinking and stave off dementia. Beginning on page 64, he sorts out hype from hope.

Technology also plays a starring role in an extraordinary first-person account by Amanda Boxtel, who tells how, 18 years after becoming paralyzed in a ski accident, she learned to walk again using a robotic exoskeleton. Turn to page 46 for "Walking 2.0." In a companion article, "Melding Mind and Machine," starting on page 52, Ariel Bleicher reports on next-generation exoskeletons that will have brain-machine interfaces to communicate directly with the user's nervous system.

This is the first issue I've had the privilege of overseeing as *Scientific American Mind*'s new managing editor. I'm eager to hear from you, our readers, about the stories you read here and those you would like to see. Find us at the e-mail address below and at that digital version of social touch—Facebook.

Claudia Wallis
Managing Editor
editors@SciAmMind.com

COVER IMAGE BY GETTY IMAGES; AARON GOODMAN (*Wallis*)

SCIENTIFIC AMERICAN MIND

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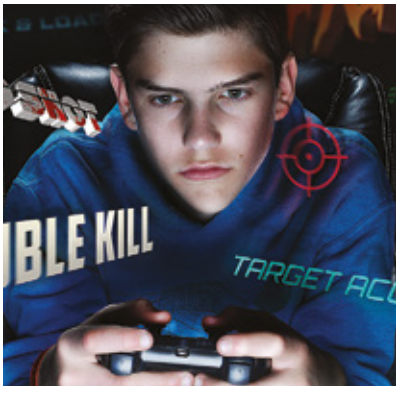

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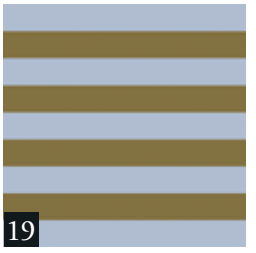

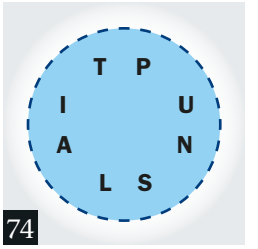

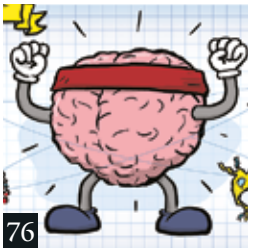

Scientific American Mind (ISSN 1555-2284), Volume 26, Number 4, July/August 2015, published bimonthly by Scientific American, a trading name of Nature America, Inc., 75 Varick Street, 9th Floor, New York, N.Y. 10013-1917. Periodicals postage paid at New York, N.Y., and additional mailing offices. Canada Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40012504. Canadian BN No. 127387652RT; TVQ1218059275 TQ0001. Publication Mail Agreement #40012504. Canada Post: Return undeliverables to 2835 Kew Dr., Windsor, ON N8T 3B7. Subscription rates: one year (six issues), $19.95; elsewhere, $30 USD. Postmaster: Send address changes to Scientific American Mind, P.O. Box 3187, Harlan, Iowa 51537. To purchase additional quantities: U.S., $10.95 each; elsewhere, $13.95 each. Send payment to SA Mind, P.O. Box 4002812, Des Moines, Iowa 50340.
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HELPING EBOLA'S ORPHANS

Thank you for the powerful article "Standing Up to Ebola," by Molly Knight Raskin. My heart pounded in my ears! I picked it up for an education on Ebola in Liberia and devoured it, heart racing, as I began to feel connected to Katie Meyer and West Point and to the families destroyed and traumatized.

And then I wanted to be connected, too. I wanted to read more about other grassroots organizations that are working to help the future generation in devastated countries. I wanted to learn more about how StrongMinds and Family Strengthening Intervention are working to help psychologically traumatized people eventually heal. This is not just in-and-out, "slap a Band-Aid on it" kind of help.

I look forward to many more excellent articles!

Cheryl Penner
via e-mail

Thank you for publishing such a raw, heartbreaking and eye-opening story.

Constantly bombarded by tragic news of endless crises, many times I resort to tuning out and ignoring news about Ebola, dismissing it as something horrible that is happening so far away that it almost doesn't concern me.

Reading this article, this story of one person who didn't ignore it and did something about it and who had the guts most of us don't, broke my heart and gave me hope all at once.

The world, with all its horror and beauty, isn't as far away as we think. Determination and love are a powerful combination, and I hope this story inspires other people, as it did me, to help.

Sol Escobar
via e-mail

SINGING HELPS A STUTTER

In "The Healing Power of Music," William Forde Thompson and Gottfried Schlaug describe how singing can help stroke patients recover language. People who are afflicted with stuttering are also sometimes able to overcome speech impediments by singing through the words. I think it's likely there is a common link.

"Maxadolf"
Commenting online at
Mind.ScientificAmerican.com

ILL, NOT VIOLENT

I want to make note of two articles. "First Aid for Mental Health," by Aliyah Baruchin, begins with an occurrence of a mass shooting, which happened to be committed by a person who had mental illness. As a person with mental illness, I am deeply offended by this article's implication that mass shootings and violence are mostly committed by people who are mentally ill.

In fact, the very next article, "A Reader's Guide to Baloney Detection," by Scott O. Lilienfeld and Hal Arkowitz [Facts and Fictions in Mental Health], states: "For example, the erroneous belief that people with schizophrenia are prone to violence can lead to unjustified stigma." That is just what Baruchin achieves in the former article, which emphasizes violence and even includes photographs of three famous mass shooters who happened to be mentally ill.

It may be true that some mentally ill people can become violent, but so can mentally healthy individuals. You should have stated the fact that not all violent crimes are perpetrated by people who have mental illness.

D. Domalski
Michigan

THE CAT-ASSISTED PARASITE

Regarding "Played by a Parasite," by Gustavo Arrizabalaga and Bill Sullivan: *Toxoplasma gondii* infects marine mammals when they are exposed in areas where city runoff transports cat feces and litter into the water, such as at sewage treatment plants. The parasite causes an encephalitis-type brain swelling, debilitating and killing great numbers of seals, dolphins and their ilk.

If the coyote is able to continue its recovery of habitat, the cat problem will diminish. Golden eagles, wolves and some other wonderful creatures could help, if they are allowed to return to normal numbers.

"Michael M"
Commenting online at
Mind.ScientificAmerican.com

WHEN DISTRACTION IS USEFUL

"The Distractible Aging Mind," by Esther Landhuis [Head Lines], assumes that being distracted by things other than that which we are focusing on is universally bad. That may be true in a safe environment but not when the distractions can indicate danger. For example, what about the sudden appearance in the corner of your eye of a rapidly approaching object when you are out driving? As we get older, our bodies have slower reaction times, less muscle mass, and so forth. I think that as we age, increased alertness to things outside our focus of attention might be beneficial. It may be evolution's way of compensating for the reduction in performance of our bodies.

"ThomasB"
Commenting online at
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JUST DO THE DISHES, OKAY?

In "How to Be a Better Spouse," by Sunny Sea Gold [Head Lines], the following sentence caught my eye: "The guy I'm married to … never loads the dishwasher correctly.…"

Correctly, huh? I, too, have a particular way of loading the dishwasher, and I would prefer that everyone in the household follow suit. But is my way really the correct way?

A lot can be gained by training ourselves to say things differently. The author could have written, "The guy I'm married to … never loads the dishwasher the way I want it.…" Doing so takes the "he's an idiot" out of the statement.

The effect of speaking about one's desires as being correct and by extension all other choices as being incorrect is likely to have a negative effect on relationships. I suspect that much of what is wrong in our relationships is how we choose to think about them.

"AmigoNico"
Commenting online at
Mind.ScientificAmerican.com

And yet there is an objectively correct way to load a dishwasher; you can find the instructions for doing so in every manual for every dishwasher invented.

That said, it's better to let a man misload the dishwasher for eternity than to argue yourself into doing the job for him.

"Isonomist"
Commenting online at
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MENTAL HEALTH MYTHS BUSTED

It's too bad the column "Facts and Fictions in Mental Health," by Hal Arkowitz and Scott O. Lilienfeld, is ending. It has a positive and reality-based perspective on the subject of mental illness.

I would add one thing to their discussion of common misperceptions of mental illness. Movies and television powerfully influence people's images of psychiatry and the mentally ill. News journalists may be tempted to emphasize the "juicier" aspects of a story, but Hollywood often goes to the next level and makes films entirely about, say, the homicidality of your stereotypical "maniac."

"thinker8214932"
Commenting online at
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ERRATA

Because of a translation error, Alexandra Freund was misquoted in "Debunking Midlife Myths," by Hanna Drimalla [March/April 2015]. Freund said the opposite of what was printed. Her original words were: "We *do not* [emphasis ours] retrieve our youthful goals from 20 years before and check off one by one what we have achieved and what not."

"How to Extract a Confession … Ethically," by Roni Jacobson [Head Lines, May/June 2015], stated psychologist Martin Seligman's first name incorrectly as Arthur.

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Head Lines

A USER'S GUIDE TO THE BRAIN

ILLUSTRATION BY
EIKO OJALA

Looking for Happiness?

M **NEWS FROM OUR WEB SITE** | Women who develop gestational diabetes during pregnancy are more likely to have a child with autism.

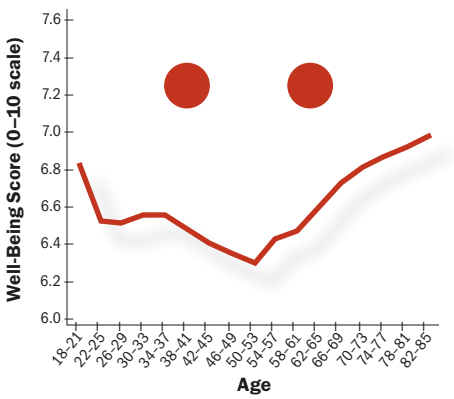
ILLUSTRATIONS BY EIKO OJALA

HOW TO FIND HAPPINESS

We all want to be content. Lasting happiness is more than just good feelings—it can lead to better health and a longer life. Yet trying to feel happier, making money and meeting goals tend to backfire as strategies for contentment. So what works? Recent research offers some clues. Following these tips may lead to a deeper, more meaningful life.

Older, Wiser, Happier

Many studies show that as people age in later life, they become happier. A 2010 study of more than 340,000 U.S. adults found that overall feelings of contentment and satisfaction with life peaked in the golden years:



SOURCE: "A SNAPSHOT OF THE AGE DISTRIBUTION OF PSYCHOLOGICAL WELL-BEING IN THE UNITED STATES," BY ARTHUR A. STONE ET AL., IN *PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA*, VOL. 107, NO. 22, JUNE 1, 2010 (*chart*)

The Richness of Routine

Life can be made to feel more meaningful by regularity

Think about the most meaningful experiences in your life. You will probably recall your wedding, or a trip across Europe, or your first skydive. You won't name brushing your teeth. Yet recent research suggests that the mundane regularities of life can very much contribute to your overall sense of meaning.

As squishy as the concept sounds, meaning in life is an integral part of our well-being. Research has associated it with good mental health, success at work and longevity. Psychologists have proposed three aspects: significance, purpose and coherence. In other words, life is meaningful when it feels important, when it seems to have a point and when it makes sense. The first two aspects have been widely studied, but the contribution of coherence was not directly tested until 2013, when University of Missouri psychologists Samantha Heintzelman, Jason Trent and Laura King reported in *Psychological Science* that even a simple visual pattern can engender larger meaning.

In the paper, 77 subjects looked at 16 photographs of trees, ordered randomly or according to the seasons. Those who saw the seasonal pattern reported that they found life more meaningful than the other subjects, as measured by a questionnaire completed shortly after the visual task. Another 229 volunteers saw triads of words for a few seconds at a time; some were semantically connected (for example, *falling, actor* and *dust* could each pair with *star*); others were not. Those who saw the coherent sets of words similarly reported life to have more value than did those who had seen random words.

Heintzelman and King reported last year in *American Psychologist* that people in general find life pretty meaningful. "So combining those two lines of thought," Heintzelman says, "that meaning is common and that it can be drawn from coherence, we started to think, what are the coherent aspects of our daily lives?"

One answer lies in routines. In work presented in February at the annual meeting of the Society for Personality and Social Psychology, the researchers asked subjects to complete five mazes. For some, all the mazes had similar solutions, thus inducing a habit. These subjects then reported greater meaning in life. The scientists also reported at the conference that they found that people who said they do "pretty much the same things every day," according to a survey of daily routines, found life more meaningful, even after the researchers controlled for mindfulness, positivity and religiousness.

The notion that meaning can be found in mundane habits and patterns is a bit surprising, Heintzelman says: "It's not the way that we've historically thought about meaning in life. It sort of knocks it off its pedestal."

Stepping away from trees, triads and weird mazes, Heintzelman suggests we might find meaning by maintaining a tidy office, keeping a daily schedule, having weekly dinners with friends or driving the same route every day. "The applications sort of jump out," she says. The coherence of an ordered life also lays the groundwork for pursuit of larger goals—and thus the equally important aspects of purpose and significance.

—Matthew Hutson

Studies show that remembering joy boosts well-being—but analyzing the memories has the opposite effect.

M Scientists used electrical stimulation to make sleeping mice associate a certain location with positive feelings. When the mice woke up, they

Spend Wisely to Buy Happiness

Get the biggest psychological bang for your buck

Great thinkers have often warned us: when seeking happiness, do not rely on worldly goods. Science bears out the advice—people with more wealth are not happier. Yet *how* you spend your funds does matter. Research reveals a few strategies that increase long-term contentment.

Spend on experiences, not goods. Many studies support the fact that spending on activities such as dining, concerts or travel makes people happier in the long term than does purchasing goods. A paper published earlier this year by Cornell psychologist Thomas D. Gilovich and his colleagues posits that the benefits may derive from the fact that experiences inherently involve more social relationships and tend to be more entwined with a person's identity—there may a satisfaction in defining ourselves through *doing*. "In terms of 'money well spent,' experiences come out ahead on all measures," Gilovich says.

Plan with abandon. It is well established that the anticipation of a reward often provides more joy than the reward itself. In ongoing work, Gilovich is further parsing the payoffs of expectation by asking subjects about their state of mind before and after making a purchase. He has found that the planning and anticipation of experiential purchases result in significantly more happiness and excitement than waiting for material purchases to arrive, which tends to be associated with edginess and impatience.

Delay gratification. Approaching an immediate reward—sex, drugs, your favorite cheeseburger—causes soaring levels of dopamine, a neurotransmitter that helps us feel good, whereas levels start to decline while receiving the reward. Gilovich thinks that perhaps the same dopaminergic dance is at play when we shop for presents for ourselves; the pleasure of seeking instant gratification is fleeting. He suggests we might gain more happiness from certain purchases by delaying them until a special date or occasion, so we have a chance to enjoy the buildup.

—Bret Stetka

A recent study found that over-the-counter painkillers such as acetaminophen (Tylenol) can ease the pain of a difficult decision.

A Smart Schedule for Contentment

Trying to be happier backfires, but consistently planning activities you enjoy may work

Happiness just can't be forced. Studies have shown that trying to feel happier in a given moment backfires, actually making people feel worse. And simply paying attention to one's level of happiness tends to make the glass look half-empty. So how can you gain the many rewards of happiness—which include better health and stronger relationships—without forcing it? New findings suggest rather than trying to boost happiness in the moment, a more effective route is to maximize your odds by making a concerted effort to plan your time around activities you think you will enjoy.

In a study reported last December in the journal *Emotion*, researchers named this concept "prioritizing positivity" and investigated its association with various measures of well-being in 233 adults who had a wide range of ages. Results show that people who followed this approach were more satisfied with life in general, and they reported more frequent positive emotions and fewer depressive symptoms. Those who prioritized positivity with concrete plans also had more psychological and social resources, such as resilience, mindfulness and positive relationships.

"Reflect on the activities that bring you contentment or joy and make time for these events in your daily life," says study co-author Lahnna I. Catalino, a postdoctoral psychology fellow at the University of California, San Francisco. "For some people, this could mean regularly setting aside time for gardening and cooking; for others, it could mean making time to connect with good friends." These kinds of efforts can be difficult for those battling depression, but they are in line with what therapists often advise. You cannot will yourself into a state of happiness, but you can be fairly certain you will enjoy more days that include the things that bring you pleasure.

—Tori Rodriguez

chose to spend more time there. | Most kids with ADHD get medication without behavioral therapy, despite expert recommendations to do both together.

Babies Learn from the Unexpected

Infants preferentially investigate objects that defy logic

Show an infant something unusual or surprising—say, reveal a toy that had been hidden—and the baby will perk up and pay attention. A new study investigates why this is so and finds evidence that young children are wired to focus on the unexpected to learn how the physical world works.

Aimee Stahl, a Ph.D. candidate in psychology at Johns Hopkins University, and her colleagues studied a group of 110 11-month-old babies. Some of the babies were shown confusing vignettes: they saw a toy seemingly pass through a wall, defy gravity or appear in an unexpected place. Other babies observed a toy that behaved normally. Then the researchers introduced a new toy to all the babies while demonstrating that the first one made noise. Now faced with two toys, the babies who observed only ordinary toys were equally enamored of both—but the babies who saw the first toy do strange things paid more attention to it and ignored the new one.

Next the babies were given a chance to play with the toys that seemed to defy logic. The experimenters found that the babies who saw the toy pass through a wall were more likely to bang it on the table, but those who saw the toy defy gravity liked dropping it on the ground—perhaps in an attempt to understand more about the toy's baffling physical properties.

The findings, published in *Science,* suggest that "babies have predictions about the world that they can use to guide their behavior, as well as what and how they learn," Stahl explains. Granted, objects in the real world do not often defy gravity. But Stahl suspects that babies also learn from more typical unexpected events, such as changes of routine and hearing new verbal phrases, and she is designing experiments to test this idea. "Our hunch is that these kinds of improbable events would also influence learning," she says.

—Melinda Wenner Moyer

Double-Jointed and Anxious

Collagen variations may underlie both flexibility and anxiety

Joint flexibility is an oft-coveted trait that provides a special advantage to dancers and athletes, but there can be too much of this good thing. A growing body of research suggests a surprising link between high levels of flexibility and anxiety. A study published last year in the journal *Frontiers in Psychology* is among the most recent to confirm the association, finding that people with hypermobile joints have heightened brain activity in anxiety regions.

Joint hypermobility, which affects approximately 20 percent of the population, confers an unusually large range of motion. Hypermobile people can often, for instance, touch their thumb to their inner forearm or place their hands flat on the floor without bending their knees. The trait appears to be genetic and is a result of variation in collagen, the main structural protein of connective tissue.

Being double-jointed has long been linked with an increased risk for asthma and irritable bowel syndrome, among other physical disorders. "Joint hypermobility has an impact on the whole body and not just joints," says Jessica Eccles, a psychiatrist and researcher at the University of Sussex in England. It was only a matter of time before scientists also looked at whether joint hypermobility was linked to mental disorders. The investigation began in 1993 and heated up in 1998 when researcher Rocío Martín-Santos, now at the Hospital Clinic of the University of Barcelona, and her colleagues discovered that patients with anxiety were 16 times more likely to have lax joints. Their findings have since been replicated numerous times in large populations.

A 2012 brain-imaging study conducted by Eccles and her colleagues found that individuals with joint hypermobility had a bigger amygdala, a part of the brain that is essential to processing emotion, especially fear. In the 2014 study, which was conducted by Eccles and her associates in collaboration with researchers from Spain, hypermobile participants displayed heightened neural reactivity to sad and angry scenes in brain regions implicated in anxiety. Researchers have also linked the condition with increased consumption of chocolate, tobacco and alcohol—items that are often used in an attempt to self-medicate anxiety.

Joint hypermobility may also be associated with an exaggerated fight-or-flight reaction. Eccles and her colleagues recently found support for this idea in a study of 400 psychiatric patients. They uncovered a simple yet powerful mechanism behind the link: the collagen abnormalities that make joints especially flexible seem to affect blood vessels, making patients prone to an accumulation of blood in the veins of the legs. This pooling may lead to exaggerated cardiovascular responses to maintain the output of blood from the heart. When the heart has to work extra hard just to circulate blood, it brings the entire body to the verge of a fight-or-flight reaction, requiring very little to set off panic.

Eccles hypothesizes that these patients might benefit in particular from beta blockers, drugs that ease anxiety by reducing symptoms of the body's fight-or-flight response. She hopes that future studies will investigate such targeted treatments for double-jointed people. In the meantime, the findings are an important reminder for clinicians to consider the possibility that a patient's mental disorder could have purely physical origins.

—Tori Rodriguez

GETTY IMAGES

M The street drug Molly (the crystal form of MDMA, known in pill form as ecstasy) may help people with PTSD learn to be less afraid of their

How to Be a Better *parent*

God help me, being a parent is hard. It's not necessarily the basic Abraham Maslow's "hierarchy of needs" stuff that gets me, although providing for one's family is a daily pressure. No, what makes parenting so tough (at least for me) is the knowledge that I—quirky, flawed, only human me—am responsible for how my kids will "turn out." There are 58,000 parenting books for sale on Amazon right now and thousands of parenting studies published every year. Sometimes I think I haven't read enough of them; other times I think I've read *way* too much. Either way, here are three bits of research-backed advice that have resonated with me recently. I hope they will help you, too.

#1 Let your kids get bored. As the mother of two girls younger than four, sometimes I feel like a cruise director. It takes dozens of play ideas to keep them busy for an entire rainy day here in Portland, Ore., and by the end of it I'm wrecked. Yet scheduling our kids with tons of classes and activities may backfire, according to a 2014 study in *Frontiers in Psychology.* The more structured activities such as soccer lessons or dance classes the six-year-old subjects had, the less "self-directed executive function" they showed. This mental process basically helps children regulate their emotions and set and reach goals on their own. And it has been linked to better health, grades and a more stable work life later on. So what is the alternative to planning out their time? Let your kids get bored and figure out what to do on their own, says psychologist Michael Ungar, co-director of the Resilience Research Center at Dalhousie University in Nova Scotia. "Boredom in our context of hyperstimulation may give children opportunities to exercise creativity and develop initiative, persistence and a sense that they can influence their world," he says. Another bonus of this more hands-off approach? Maybe Mommy can flip through a magazine once in awhile, or, I dunno, take a shower.

#2 Thou shalt not "snowplow." Like helicopter parents, snowplow parents tend to hover—they want to smooth the path in front of their growing children, clearing away obstacles. Unfortunately, research in self-determination theory shows that doing so undermines a person's sense of competence and autonomy, leading to higher levels of anxiety and depression, lower grades in school and less satisfaction with life—even into adulthood. "If there's not enough parental involvement, that's not good. If there's too much, that's not good either," says Holly H. Schiffrin, a developmental psychology researcher and associate professor at the University of Mary Washington. "Even in my college classroom I've had some parents e-mail me to set up their kids' class schedule or call me about grades I gave on their assignments. I tell them that their children need to make an appointment to speak to me about it." When parents do not adjust their involvement to a level that is developmentally appropriate as their children get older, the kids end up lacking the skills they need to function as adults, Schiffrin says.

#3 Secure your own oxygen mask first. If you are struggling to breathe, you are no help to anyone! The evidence for taking care of your own needs first in terms of parenting couldn't be clearer, especially when it comes to addressing unresolved medical and mental health issues. Mothers are more likely to either ignore or overreact to kids' misbehavior when they are mired in depression, for example, according to a two-year-long study in *Psychological Science.* Adults with ADHD also improve their parenting skills when they get treated, Pennsylvania State University researchers have found. All of our day-to-day health-related activities matter, too. A 2015 study of national health data from the U.K. suggests that parents' way of life may be just as important as genetics in passing down obesity. Further evidence: children in a London School of Economics and Political Science study from 2014 who had two overweight biological parents were 27 percent more likely than other kids to be overweight, yet adopted children of overweight parents were almost as equally more likely to be heavy—21 percent.

Okay, Universe, I get it. It's time to make a date with my New Balance sneakers. The size of my jeans may not matter much to me, but showing my kids a healthier way to live? That truly does.

—*Sunny Sea Gold*

MÁGOZ (*readers*); PAUL PANTAZESCU iStockphoto (*globe icon*)

memories. | Americans' beliefs about income inequality do not line up with reality—few people realize just how rich the very wealthy are.

Like Us, Apes Are Susceptible to Spin

Our human preference for a glass half-full may be hardwired

Are you likelier to buy an expensive diet pill when you hear it has helped 40 percent of people or failed to help 60 percent? That's easy. People are much more likely to go with a choice framed positively, even when the odds are 50–50. New research shows that our ape cousins share these tendencies, suggesting the response is rooted in our biology rather than in how we are socialized in our culture and economy.

The susceptibility to positive framing is what scientists call an irrational bias, and it is very powerful. To better understand why our psyche responds so deeply, Christopher Krupenye, a Duke University graduate student in evolutionary anthropology, and his colleagues Alexandra Rosati of Yale University and Brian Hare of Duke gathered 40 of our closest living relatives—23 chimpanzees and 17 bonobos—and offered them options for choosing food: either one or two fruits versus a constant number of peanuts. Sometimes the apes were shown one piece of fruit each time they made the selection, but half the time they were given two: positive framing. In other trials, the apes were initially presented two pieces of fruit, but half the time they got only one: negative framing. Regardless of the framing, the apes ended up with an identical quantity of fruit. Yet they were more likely to choose fruit when they were offered the single fruit with its frequent "bonus" than the double fruit with its frequent "loss."

Because these framing effects are shared with our nonhuman relatives, Krupenye says, the results suggest that these biases are hardwired into our biology and may have conferred some evolutionary benefit as apes foraged for food. Yet a hardwired tendency does not have to be a sentence. Although susceptibility to framing is in our blood, being aware of the bias can help us avoid making poor decisions. Next time you encounter a well-framed ad, try figuring out what the negative framing would be and see if you are still tempted. Chances are, you can use your brain to outwit your biology.

—Francine Russo

The Sexes Are Not Equally Swayed

As with humans, apes are likely to make decisions depending on whether their choices are presented positively or negatively. Yet in the Duke study discussed at the left, male apes were more affected than females by how their choices were framed. A body of research has shown that gender also affects how humans respond to framing. The studies show a range of intriguing and sometimes contradictory sex differences, which may have to do with the arenas (health, money, food) in which the choices are being made and how those interact with typical gender roles.

- In matters of life and death, such as the effectiveness of screening for cancer, women are more responsive to negative presentation (how many people will die) as opposed to positive (how many will survive). Men respond more to positive framing.
- In one money-negotiation study, in which people accepted or refused a share of $10 ("I give you $6" versus "I take $4"), women were unaffected by framing, but men were likelier to reject a negative presentation ("I take ...") and show physical responses akin to feeling competitive and defensive.
- In another study, women were more likely than men to choose positively framed 80 percent fat-free chocolate rather than the identical 20 percent fat chocolate.
- In some research, men were more persuaded than women by a negatively framed message about what they would lose by not complying with tax regulations (fines and jail) versus what they would gain by complying with regulations (no fines, no jail).

—F.R.

BRAD WILSON *Getty Images*

M Bioelectrical signals can stunt or grow brain tissue in an embryo, possibly providing a window for treating genetic neurological disorders. | A series

WEIGHTY SIDE EFFECTS

Some psychiatric drugs can trigger significant weight change

Unexpectedly losing a loved one launched 18-year-old Debra* into an episode of major depression, triggering dangerous delusions that landed her in a hospital. Her doctor immediately started her on an antidepressant and on risperidone (Risperdal), an antipsychotic. In little more than a month, her weight shot up by 15 pounds. "Gaining weight made it even more difficult for me to want to leave my house because I felt self-conscious," Debra says.

In the medical community, antipsychotics are well known to cause significant weight gain. Gains of 20 to 35 pounds or more over the course of a year or two are not unusual. Debra's doctor never warned her, though, leaving her feeling like she was losing herself both mentally and physically. The situation is not uncommon, according to psychiatrist Matthew Rudorfer, chief of the somatic treatments program at the National Institute of Mental Health, who points out that although the U.S. Food and Drug Administration carefully tracks acute side effects such as seizures, it pays less attention to longer-term complications such as weight change. Perhaps taking their cue from the FDA, doctors tend to downplay weight-related risks that accompany many psychiatric drugs, Rudorfer says. But for Debra and many others, these side effects are not trivial. The three types of psychiatric drugs that can seriously affect body weight are reviewed below. —*Andrea Alfano*

Antipsychotics

According to a 2014 review of eight studies, as many as 55 percent of patients who take modern antipsychotics experience weight gain—a side effect that appears to be caused by a disruption of the chemical signals controlling appetite. Olanzapine (Zyprexa) and clozapine (Clozaril) are the top two offenders; studies have shown that on average these drugs cause patients to gain more than eight pounds in just 10 weeks. These two drugs also bear the highest risk of metabolic syndrome, which encompasses weight gain and other related disorders, including type 2 diabetes, according to a 2011 study of 90 people with schizophrenia. Although most antipsychotics are associated with weight gain, aripiprazole (Abilify) and ziprasidone (Geodon) stand out for their lower risk.

As Debra's case demonstrates, antipsychotics are by no means reserved for treating people with schizophrenia. A growing body of evidence supports the use of antipsychotics in combination with antidepressants for addressing treatment-resistant depression.

Studies show that metformin, a diabetes drug, and topiramate, an anticonvulsant, can be effective at reducing antipsychotic-induced weight gain. Behavioral interventions may also help people maintain their weight while on these drugs, according to a 2015 study of 200 people with severe mental illness who had been taking an antipsychotic for at least one month and were overweight or obese. The study found that a personalized diet and exercise plan was helpful to 40 percent of the participants, who dropped at least 5 percent of their body weight after six months of dieting and exercise and six months of maintenance.

Antidepressants

A massive 2014 study of 22,610 people revealed that antidepressants generally cause more modest weight gain than antipsychotics, although the outcome varies greatly from one drug to the next. Of the 11 antidepressants analyzed, mirtazapine (Remeron) caused the greatest weight gain, followed by paroxetine (Paxil). A quarter of those who took mirtazapine for a year gained more than 7 percent of their initial weight. Only one antidepressant, bupropion (Wellbutrin and other brands), was associated with a small degree of weight loss.

Depression itself, however, is linked with an increased risk of becoming obese, according to a 2010 analysis that included more than 58,000 people. The reverse holds true as well, the study found; obese people are more likely to suffer from depression. As a result, "it is easy to misattribute the weight gain to a medicine when, in fact, it may largely be related to the illness being treated," cautions Richard Shelton, a professor of psychiatry at the University of Alabama at Birmingham.

Stimulants

Typically used to treat attention-deficit disorders, stimulants such as Ritalin are consistently associated with weight loss. Many stimulants are specifically marketed as antiobesity drugs, including phentermine and lisdexamfetamine dimesylate (Vyvanse), which earlier this year became the first drug approved for the treatment of binge-eating disorder. Although the evidence is limited, early studies have shown that some young adults abuse prescription stimulants for weight-loss purposes. About 12 percent of the 705 undergraduate participants in a 2013 study reported that they had attempted to lose weight by taking a stimulant without a doctor's prescription.

For people who are prescribed stimulants to treat psychiatric conditions such as ADHD, however, weight loss comes as a side effect. A 2014 study that included 163,820 children between the ages of three and 18 showed that those taking stimulants to treat their ADHD had slower rates of growth from early childhood to the middle years compared with control subjects who had no history of ADHD or stimulant use. Yet the authors noted that stimulant-treated youngsters with ADHD experienced a growth rebound in late childhood, resulting in a higher weight-to-height ratio in adolescence compared with controls. This association may explain the previously observed link between ADHD in childhood and obesity in adulthood.

**Real name withheld for privacy*

ISTOCKPHOTO

of studies reveals a growing "health gap" between poor and rich teenagers, with poorer teens suffering from more physical and mental illnesses.

WHAT HAPPENS IN THE BRAIN WHEN WE READ?

Recent findings suggest that reading is a far more multisensory experience than we might think

We Recognize Words as Pictures

As your eyes scan these words, your brain seems to derive their meaning instantaneously. How are we able to recognize and interpret marks on a page so rapidly? A small new study confirms that a specialized brain area recognizes printed words as pictures rather than by their meaning.

Researchers led by neuroscientist Maximilian Riesenhuber of Georgetown University Medical Center scanned the brains of 12 subjects with functional MRI. They focused on a tiny area of the brain known to be involved in recognizing words, the visual word form area (VWFA), found on the surface of the brain, behind the left ear. The VWFA's right hemisphere analogue is the fusiform face area, which allows us to recognize faces. In young children and people who are illiterate, the VWFA region and the fusiform face area both respond to faces. As people learn to read, the VWFA region is co-opted for word recognition.

We "Hear" Written Words in Our Head

Sound may have been the original vehicle for language, but writing allows us to create and understand words without it. Yet new research shows that sound remains a critical element of reading.

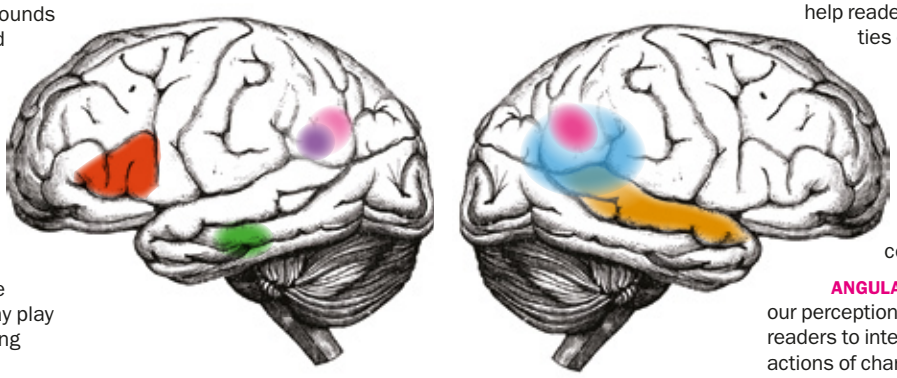
When people listen to speech, neural activity is correlated with each word's "sound envelope"—the fluctuation of the audio signal over time corresponds to the fluctuation of neural activity over time. In the new study, Lorenzo Magrassi, a neurosurgeon at the University of Pavia in Italy, and his colleagues made electrocorticographic (ECoG) recordings from 16 individuals. The researchers measured neural activity directly from the surface of the language-generating structure known as Broca's area as subjects read text silently or aloud. (This measurement was made possible by the fact that participants were undergoing brain surgery while awake.)

Deciphering the Written Word

BROCA'S AREA: Known as the language center of the brain; creates the sounds of words in our head as we read.

VISUAL WORD FORM AREA: Allows us to recognize whole words as objects while reading.

WERNICKE'S AREA: Involved in language comprehension; may play a role in remembering what we read.



RIGHT POSTERIOR SUPERIOR TEMPORAL GYRUS: Facilitates theory of mind; may help readers distinguish the identities of story characters.

RIGHT PARIETO-TEMPORAL CORTEX: Found to be more active in good readers; may allow people to unpack longer and more complex sentences.

ANGULAR GYRUS: Involved in our perception of motion; may allow readers to interpret the physical actions of characters.

The researchers presented the subjects with a series of real words and made-up words. The nonsense words elicited responses from a wide pool of neurons in the VWFA, whereas distinct subsets of neurons responded to real words. After subjects were trained to recognize pseudo words, however, neurons responded as they did to real words, according to the paper published in March in the *Journal of Neuroscience*. Because the nonsense words had no meaning, Riesenhuber deduced that our neurons must respond to words' orthography—how they look—rather than their meaning.

As we become more proficient at reading, then, we build up a visual dictionary in the VWFA—much as we accumulate a catalogue of familiar faces on the opposite side of our brain.

—*Stephani Sutherland*

Their neural activity was correlated with the sound envelope of the text they read, which was generated well before they spoke and even when they were not planning to speak, according to the report published in February in the *Proceedings of the National Academy of Sciences USA*. In other words, Broca's area responded to silent reading much in the same way auditory neurons respond to text spoken aloud—as if Broca's area was generating the sound of the words so the readers heard them internally. The finding speaks to a debate about whether words are encoded in the brain by a neural pattern symbolic of their meaning or if they are encoded via simpler attributes, such as how they sound. The results add to mounting evidence that words are fundamentally processed and catalogued by their basic sounds and shapes.

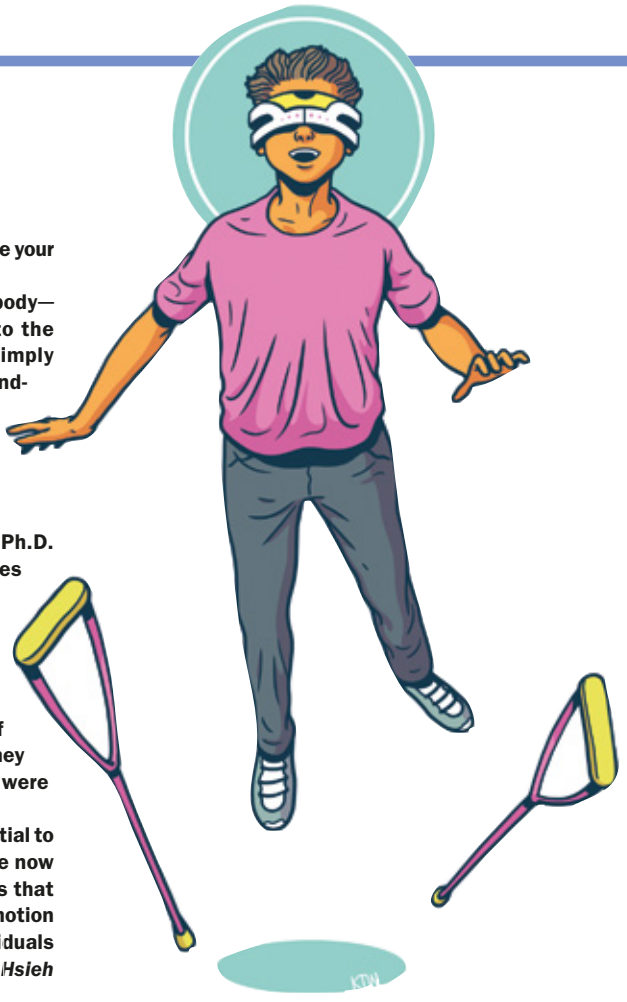
—*S.S.*

ISTOCKPHOTO

M Future stroke drugs may one day target the opposite side of the brain, boosting the healthy hemisphere's natural attempts to heal its neighbor.

ON THE HORIZON

VIRTUAL REALITY THAT TREATS CHRONIC PAIN



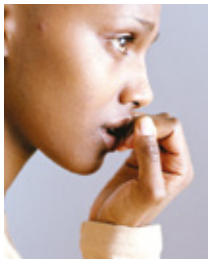
Strap on a headset, immerse yourself in an alternate reality and cure your pain—that's the idea of a recent study in *Psychological Science.*

Most people think of pain as something that happens in the body—I twist my head too far, and my neck sends a "pain signal" to the brain to indicate that the twisting hurts. In reality, pain is simply the brain telling us we are in danger. Although certain nerve endings throughout the body can indeed detect bodily harm, their signals are only one factor that the brain uses to determine if we should experience pain. Many cases of chronic pain are thought to be the result of obsolete brain associations between movement and pain.

To explore the mind's influence over pain, Daniel Harvie, a Ph.D. candidate at the University of South Australia, and his colleagues asked 24 participants who suffer from chronic neck pain to sit in a chair while wearing virtual-reality glasses and turn their head. The displays were manipulated to make the participants think that they were turning their head more or less than they actually were.

Subjects could swivel their head 6 percent more than usual if the virtual reality made them think they were turning less, and they could rotate 7 percent less than usual when they thought they were turning more.

The findings suggest that virtual-reality therapy has the potential to retrain the brain to understand that once painful movements are now safe, extinguishing the association with danger. Harvie believes that such therapy has the potential to restore full pain-free range of motion to people recovering from injuries and could perhaps help individuals with neurodegenerative diseases such as Parkinson's. *—Esther Hsieh*



KYLE T. WEBSTER (*illustration*); SCOTT DUNLOP /*Stockphoto* (*sun icon*); CORBIS (*woman*)

Nail Biting May Arise from Perfectionism

Body-focused repetitive behaviors may be a reaction to boredom or frustration

Many people think of nail biting as a nervous habit, but the driving force may not be anxiety. Mounting evidence shows that people who compulsively bite their nails, pick their skin or pull their hair are often perfectionists, and their actions may help soothe boredom, irritation and dissatisfaction.

As many as one in 20 people suffer from body-focused repetitive disorders, engaging in behaviors such as biting their nails or plucking out hair until they damage their appearance or cause themselves pain. These disorders are related to tic disorders and, more distantly, obsessive-compulsive disorder. As such, the repetitive behavior is extremely difficult to quit—yet many people continue to think they simply have a nervous habit and are too weak-willed to overcome it.

A new study adds evidence to a theory that perfectionism rather than anxiety is at the root of these behaviors. The researchers first surveyed 48 participants, half of whom had these disorders and half of whom did not, on their organizational behavior and ability to regulate their emotions. Those with the disorders scored as organizational perfectionists, indicating a tendency to overplan, overwork themselves and get frustrated quickly without high levels of activity.

Researchers then put the subjects in situations designed to provoke four different emotions: to incite stress, they showed a movie of a plane crash; to promote relaxation, they showed a movie of waves; to elicit frustration, they presented a difficult puzzle but said it was easy; and to evoke boredom, they made participants sit in a room alone. People who had the disorders engaged in the body-focused behaviors during all the situations except the relaxing movie.

The work, which was published earlier this year in the *Journal of Behavior Therapy and Experimental Psychiatry,* jibes with a recent theory that stress is far from the sole cause of these compulsions. Boredom and frustration, easily elicited by an underlying perfectionist personality, may be more important triggers. Past research suggests that the biting or scratching indeed makes people feel better temporarily—perhaps satisfying the perfectionist urge to be doing something rather than nothing. After the initial relief, however, comes pain, shame and embarrassment.

The findings could help therapists treat patients who suffer from the disorders; studies have shown that these types of perfectionist beliefs and behaviors can be eased with cognitive-behavior therapy. If patients can learn to think and act differently when tension builds, they may be able to stop the urge before it starts. *—Susan Cosier*

An over-the-counter antifungal medicine used to treat athlete's foot may reverse the damage multiple sclerosis causes to nerve-insulator myelin.

Picky Eaters Are Not All Alike

Some mealtime behaviors may not even be about the food

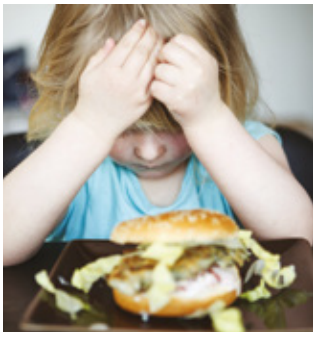
There is no scientific definition of picky eating, but parents say they know it when they see it, and according to new research, they are likely to be right. Their kids are different. But picky eaters are not all the same, this study finds. What parents call picky eating is actually a broad spectrum of behaviors, and knowing which category a child falls into may help parents develop constructive responses.

The researchers gathered 170 two- to four-year-olds, about half of whom were described by parents as choosy. For two weeks the parents fed the family standardized meals provided by the investigators. The parents observed and recorded their children's responses.

Nonpicky kids ate more and did not make a fuss about eating. Those seen as picky acted differently before and during meals, with behaviors that ranged from refusing to come to the table, to showing mild suspicion of certain foods, to cringing or gagging.

From focus groups with parents, says study co-author Sharon M. Donovan, a professor of nutrition at the University of Illinois at Urbana-Champaign, the researchers identified four possibly overlapping categories of behavior that could cause parents to identify their children as picky eaters [*see box at right*].

Some of these preferences, such as shunning broccoli, Donovan notes, may be hardwired. Research indicates that some children are genetically more sensitive to bitter flavors than others and may therefore take longer to acquire a taste for certain vegetables. Other mealtime antics, such as looking sad or even gagging, may not have to do with the food at all—for example, a child may be upset that she had to stop playing but attempts to express her independence by refusing to eat, explains study co-author Soo-Yeun Lee, also a nutrition professor at Illinois.



ANDERS ANDERSSON *Getty Images*

Four Types of Finicky Eaters

Sensory-dependent eaters reject a food because of its texture or smell ("Yuck, slimy!").

Preferential eaters shun new or mixed foods.

General perfectionists have specific needs, such as foods not touching one another.

Behavioral responders may cringe or gag when food is not "right" ("Ham and cheese should be on white bread, not brown!") or may refuse to come to the table before they even know what's for dinner.

Picky eating is not uncommon: Donovan says that 19 to 50 percent of kids up to age two, when the phenomenon peaks, are considered finicky eaters by their caregivers. How parents react can influence its staying power.

The researchers do not yet have scientifically validated strategies for each kind of picky eater, but Lee says it may help parents to recognize that their kids' reaction to mealtime may not always be about food or eating. As such, it does not make much sense for parents to get into power struggles with youngsters about eating—especially because the behavior usually goes away or lessens after age five.

Until they develop more targeted approaches, the nutritionists recommend a few time-tested strategies. For a child who does not like mixed foods, show him or her the individual ingredients the first time you serve the item. Acknowledge that your child has preferences but serve foods that are deemed unacceptable along with favorite foods. Don't force your child to eat something new but encourage him or her to take a taste. Most of all, keep trying, Donovan says. "Children may need 10 exposures to a new food before accepting it. Parents often give up before then." —*Francine Russo*

JAMES PORTER *Getty Images*

The Other Dementia

A cluster of symptoms helps to predict who will acquire Lewy body dementia

Shouting during a nightmare. Struggling to balance a checkbook. A weakened sense of smell. Hallucinations. Chronic constipation. This bizarre mix of symptoms often stumps doctors, but they are some of the telltale signs of Lewy body dementia—the second most common type (after Alzheimer's disease), affecting an estimated 1.4 million Americans.

Lewy bodies are protein clumps that kill neurons. Depending on where they cluster in the brain, they can cause either Parkinson's disease or Lewy body dementia, although the two conditions tend to overlap as they progress. Lewy body dementia is more difficult to diagnose and treat, in part because the earliest warning signs have remained unknown. Now a new study finds that certain sensory and motor symptoms can help predict who will acquire the disease, paving the way for targeted studies.

Researchers at the Center for Advanced Research in Sleep Medicine (which is associated with the University of Montreal) and at

M Prolonged eye contact between dogs and their owners releases a spike of oxytocin, the "love hormone," in both species' brains. | People who prioritize

Big Role for Fat in Brain Evolution

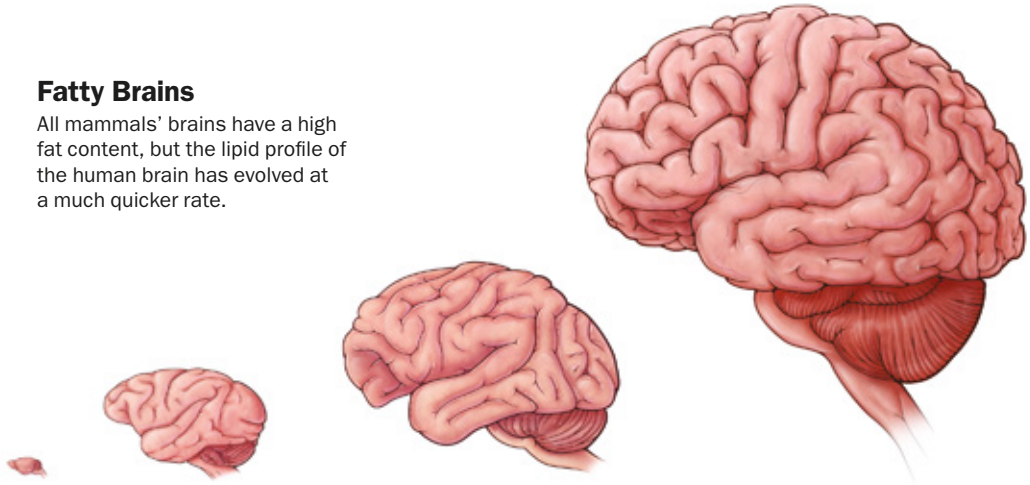
Human intelligence may be tied to changes in the lipid profile in the neocortex

Forget the insult "fathead." We may actually owe our extraordinary smarts to the fat in our brain. A study published in *Neuron* in February revealed that the variety of fat molecules found in the human neocortex, the brain region responsible for advanced cognitive functions such as language, evolved at an exceptionally fast rate after the human-ape split.

The researchers analyzed the concentrations of 5,713 different lipids, or fat molecules and their derivatives, present in samples of brain, kidney and muscle tissues taken from humans, chimpanzees, macaques and mice. Lipids have a variety of critical functions in all cells, including their role as the primary component of a cell's membrane. They are particularly important in the brain because they enable electrical signal transmission among neurons. Yet until this study, it was unknown whether the lipids in the human brain differed significantly from lipids in other mammals.

Fatty Brains

All mammals' brains have a high fat content, but the lipid profile of the human brain has evolved at a much quicker rate.



EVAN OTO *Science Source*

The team discovered that the levels of various lipids found in human brain samples, especially from the neocortex, stood out. Humans and chimps diverged from their common ancestor around the same time, according to much evolutionary evidence. Because the two species have had about the same amount of time to rack up changes to their lipid profiles, the investigators expected them to have roughly the same number of species-specific lipid concentrations, explains computational biologist and study leader Kasia Bozek of the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany. Indeed, lipid changes in the cerebellum, a primitive part of the brain similar in all vertebrates, were comparable between humans and chimps. But the human neocortex has accumulated about three times more lipid changes than the chimpanzee cortex has since we split from our common ancestor.

The results suggest that as human cognition evolved, the types and amounts of fat in key brain areas were rapidly shifting and mutating—and this growth was crucial to the development of our complex abilities. Genes tend to get the most attention, but they are only part of the story, the researchers explain. An enzyme encoded by a single gene, for example, can regulate the synthesis of many different lipids. "The significance of this study is that we're going to see more comparative studies of macromolecular concentrations—such as differences in proteins and lipids—which reveal things that can't be read out directly" from the genome, says Todd Preuss, a neuroscientist at Emory University who specializes in the evolution of the human brain and who was not involved in the study. Learning that lipids played an essential role in the evolution of human intelligence, he says, is "the tip of a very big iceberg."

—Andrea Alfano

McGill University followed 89 patients with a history of acting out their dreams—not sleepwalking but moving or vocalizing in bed during rapid eye movement (REM) sleep. The failure to suppress such nighttime activity can be an early sign that something is going wrong in the brain; past studies have shown that up to 80 percent of patients who act out their dreams will eventually develop some form of neurodegeneration.

Over 10 years the McGill researchers carefully tracked the patients' other potential symptoms of neural disease, such as mild cognitive impairment, depression and movement problems. They found a cluster of symptoms—abnormal color vision, loss of smell and motor dysfunction—that doubled the chance that a person with the REM sleep disorder would develop Parkinson's or Lewy body dementia within three years, according to the study published in February in *Neurology*.

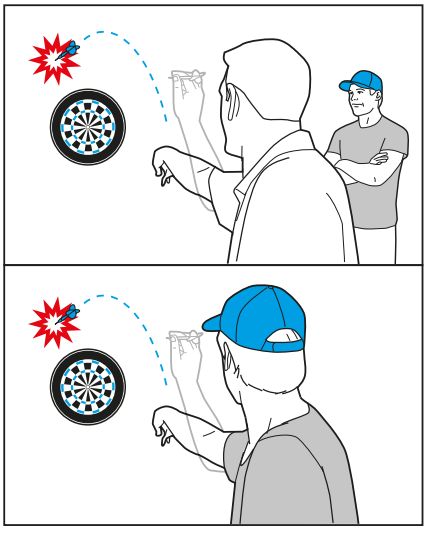
People with this cluster of symptoms have a three-year risk of 65 percent, which is high enough to justify enrolling them in studies of early warning signs and treatments. Such studies are sorely needed because doctors are currently often stumped by what looks like a mix of Alzheimer's, Parkinson's and schizophrenia—and an incorrect diagnosis can cause harm. For instance, if a patient's most troubling symptom is hallucinations, doctors may try an antipsychotic—but such drugs rapidly worsen the condition of a person with Lewy body dementia. Even if the disease is correctly identified, doctors can do little more than treat each symptom that arises. The McGill researchers hope that their findings will quickly lead to more focused studies to determine how Lewy body dementia progresses over time. A better understanding of the disease could one day lead to more effective therapies or even preventive measures.

—Katie Free

creativity in their life tend to be happier and more fulfilled. | ADHD rates are higher in children who are exposed to secondhand smoke at home.

Don't Watch That Clumsy Player Too Closely

The brain's motor system is swayed by analyzing a novice's actions



If you excel at a sport, you may want to look away when greener athletes take their turn. A new study finds that watching a novice's actions can deteriorate expert performance.

In experiments reported online last fall in *Scientific Reports*, researchers asked expert dart throwers to watch videos of novices and predict where their darts would land. The experts got feedback throughout the process, which helped to improve their predictive abilities. The findings show that as the experts became more accurate in predicting the novice dart throwers' actions, their own performance declined. The effect was task-specific: their performance was not affected by predicting the actions of novice bowlers.

Researchers have long debated whether motor system neurons are involved in understanding others' actions because past studies have been correlative or inconclusive. In the new study, the fact that experts' performance degraded steadily as their predictive ability improved provides causal evidence that the motor system is involved in at least some aspects—specifically outcome prediction—of understanding others' actions, explains Gowrishankar Ganesh, a neuroscientist and roboticist at the National Institute of Advanced Industrial Science and Technology in Japan, who co-authored the study with Tsuyoshi Ikegami, a neuroscientist at the Center for Information and Neural Networks in Osaka.

The authors hope their work will one day help in cognitive and motor rehabilitation. More immediately, they suggest that athletes should avoid focusing too much on the performance of less skilled teammates. Teachers and coaches, on the other hand, may not need to worry about averting their eyes from their students' efforts. "Although the evidence is preliminary, our data found that experts who teach show less deterioration," Ganesh says. "We believe that because of their extensive experience with students, teachers can learn to not be affected by the process of understanding." —*Tori Rodriguez*

Thinking with the Body

In a new study, expert dart players became worse at throwing after studying novice players. The effect is an example of embodied cognition: the motor system is necessary to comprehend the actions of others—and the body's movements are affected by the new understanding. Here we sketch out a few other examples of this type of bodily cognition, as revealed in past studies.

Baseball players' ability to predict where a fly ball will land depends on how they move in relation to the ball, not their brain's ability to calculate its trajectory. Players move in whatever direction keeps the ball at a constant speed in their field of vision.

When dancers watch someone perform a familiar style of dance, their brain activity looks like it would if they were making the movements themselves. Neural response is less focused when dancers watch an unfamiliar style.

Acting out a story helps people remember it. One study showed that participants who acted out a monologue had better recall of the text 30 minutes later compared with people who read, discussed or answered questions about the story.

Without Enough Sleep, Teenagers' Mental Health Suffers

Every hour less per night raises their risk

Many studies have examined the effects of sufficient versus insufficient sleep on mental health. A new study, published in February in the *Journal of Youth and Adolescence,* takes a more nuanced look, attempting to determine just how much each hour less per night really costs—where teenagers are concerned.

The researchers surveyed an ethnically diverse sample of 27,939 suburban high school students in Virginia. Although teenagers need about nine hours of sleep a night on average, according to the National Institutes of Health, only 3 percent of students reported getting that amount, and 20 percent of participants indicated that they got five hours or less. The average amount reported was 6.5 hours every weekday night. After controlling for background variables such as family status and income, the researchers determined that each hour of lost sleep was associated with a 38 percent increase in the odds of feeling sad and hopeless, a 42 percent increase in considering suicide, a 58 percent increase in suicide attempts and a 23 percent increase in substance abuse.

These correlational findings do not prove that lack of sleep is causing these problems. Certainly the reverse can be true: depression and anxiety can cause insomnia. "But the majority of the research evidence supports the causal direction being lack of sleep leading to problems rather than the other way around," says study co-author Adam Winsler, a psychology professor at George Mason University. Sleep deficits reduce brain function, further disturbing areas in which even well-rested adolescents struggle: executive function, self-control and judgment. "Parents, educators and therapists need to pay attention to the role of sleep in preventing mental illness among youth," Winsler says. "Its effect is likely larger than most therapies and medications." —*Tori Rodriguez*

JASON LEE (*darts*); ISTOCKPHOTO (*action icons*)

M Childhood trauma is linked to higher blood pressure later in life. For full stories: ScientificAmerican.com/Mind/jul2015/stories

Unraveling "The Dress"

Is it blue and black? White and gold? Dozens of labs are working to explain the mystifying Internet sensation

This past February a photograph of a dress nearly broke the Internet. It all started when a proud mother-in-law-to-be snapped a picture of the dress she planned to wear to her daughter's wedding. When she shared her picture with her daughter and almost-son-in-law, the couple could not agree on the color: she saw white and gold, but he saw blue and black. A friend of the bride posted the confusing photo on Tumblr. Followers then reposted it to Twitter, and the image went viral. "The Dress" pitted the opinions of superstar celebrities against one another (Kanye and Kim disagreed, for instance) and attracted millions of views on social media. The public at large was split into white-and-gold and blue-and-black camps. So much attention was drawn, you would have thought the garment was conjured by a fairy godmother and accessorized with glass slippers.

To sort out the conundrum, the media tapped dozens of neuroscientists and psychologists for comment. Pride in our heightened relevance to society gave way to embarrassment as we realized that our scientific explanations for the color wars were not only diverse but also incomplete. Especially perplexing was the fact that people saw it differently on the same device under the same viewing conditions. This curious inconsistency suggests that The Dress is a new type of perceptual phenomenon, previously unknown to scientists.

Although some early explanations for the illusion focused on individual differences in the ocular structure of the eye, such as the patterning and function of rod and cone photoreceptor cells or the light-filtering properties internal to the eye, the most important culprit may be the brain's color-processing mechanisms. These might vary from one person to the next and can depend on prior experiences and beliefs.

TUMBLR/SWIKED (*dress*); BOSCO TJAN (*color swatch frame*); SEAN McCABE (*Macknik and Martinez-Conde*)

PICK A COLOR

In one of the first experiments with The Dress, Bosco Tjan of the University of Southern California and his colleagues asked students to match the blues and golds in the photograph above to color patches along a continuum of yellows and blues without naming the colors. People's perceptions fell on multiple spots along the continuum, indicating a wide variability in the way the general population sees color. Yet when the team asked the same students to name the colors, they got two main responses: blue/black and white/gold. This finding suggests that the dramatic split may have to do with how the question is posed. A different color-matching study conducted at the Massachusetts Institute of Technology by Rosa Lafer-Sousa, Katherine Hermann and one of us (Conway), involving more than 1,000 subjects, showed that perceptions fell into three main camps: white/gold, blue/black and blue/brown.

BY STEPHEN L. MACKNIK AND SUSANA MARTINEZ-CONDE

Stephen L. Macknik and Susana Martinez-Conde are professors of ophthalmology at SUNY Downstate Medical Center in Brooklyn, N.Y. They are authors of *Sleights of Mind,* with Sandra Blakeslee (http://sleightsofmind.com), which recently won the Prisma Prize for best science book of the year.

With special contributor Bevil R. Conway, an associate professor of neuroscience at Wellesley College and principal research scientist at the Massachusetts Institute of Technology.

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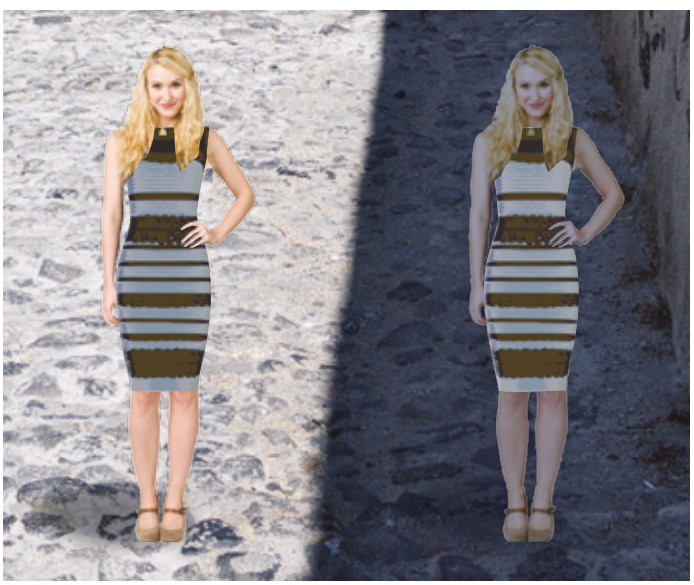
For example, people may have different assumptions about color constancy—the phenomenon that enables us to see an object's color as constant despite changing illumination sources [see "Color Contrast and Constancy," on opposite page]. Light in the natural world typically comes either from direct golden sunlight or from the blue sky, and our perception thus assumes that most illumination has these colors. It follows that people looking at The Dress might assume the fabric is lit by either blue sky or sunlight. If the observers conclude—even unconsciously—that the source of illumination is the blue sky, their brain will helpfully subtract the blue from their perception of the image, and The Dress will appear white and gold. The brain of observers who assume The Dress is sunlit will subtract gold from the image and consequently see it as blue and black.

Before the discovery of The Dress, vision scientists had thought that people with normal vision experienced color illusions similarly. Earlier examples of ambiguous images were constrained to shape effects, such as when people see a vase or two faces in the same picture. Ambiguous shape illusions differ from The Dress in one fundamental aspect, however: whereas observers can usually flip their perception from vase to faces with little trouble, people often appear stuck in either the white-and-gold or the blue-and-black camp. Strangely, these differences can be irreconcilable. It is as if—in addition to clichéd dichotomies such as glass-half-full versus glass-half-empty or cat versus dog people—The Dress has now presented us with a new divide for humanity. Could it be that different people have different prejudices about the color of the light source? Or maybe about the type of fabric (shiny or matte) The Dress is made of?

Perhaps more than any previous perceptual observation, The Dress demonstrates that we can see the world in strikingly different ways depending on what our individual brain brings to the table. Although by and large the reason for the various interpretations of The Dress remains a scientific mystery, vision laboratories all around the world are conducting dozens of experiments to investigate the enigma. Here we offer a roundup of some of the most promising theories to date—and curious readers can visit our blog, Illusion Chasers, (http://blogs.scientificamerican.com/illusion-chasers) for new developments. **M**

DOES *THIS* LOOK BLACK AND BLUE TO YOU?

Famed illusion creator Akiyoshi Kitaoka of Ritsumeikan University in Kyoto summed up the problem succinctly with this simple pattern (*left*). If you take the colors directly out of the original picture, this is what you get. Keep in mind that The Dress actually is blue and black in real life, so those people who see it that way are not wrong. If you cannot see blue and black here, squint your eyes, view this image in dim lighting or turn down the brightness of your screen. Viewing conditions matter to how we see color.



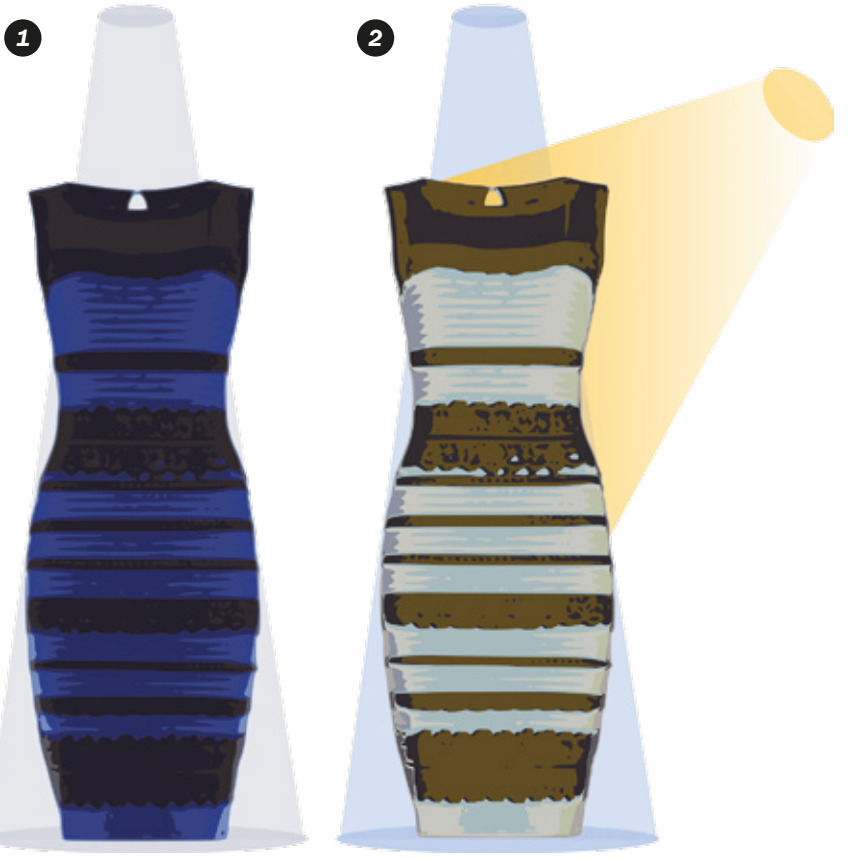
DRESSING UP THE ILLUSION

Demonstrations isolating the various factors that contribute to perceptions of The Dress are pouring in from vision labs everywhere. The image at the right shows that two identical pictures of The Dress look different in the context of shade versus direct sunlight. The garment's actual colors—blue and black—come across more clearly in the outdoor light. As Conway had previously predicted, our brain's color-processing mechanisms are especially powerful when we assume the sun and sky are the primary sources of light for a scene.

AKIYOSHI KITAOKA *Ritsumeikan University (stripes)*; ISTOCKPHOTO (*woman*); GETTY IMAGES (*light and shade background*)

ILLUMINATING THE DRESS

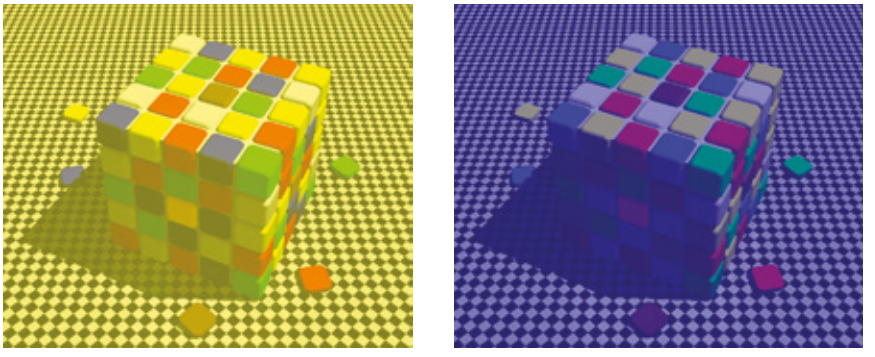
Neuroscientists Anya Hurlbert and her colleagues Bradley Pearce and Stacey Aston of Newcastle University in England and independently Rosa Lafer-Sousa of M.I.T. combined two light sources to photograph The Dress, as shown at the right: a diffuse cool blue light and a direct warm gold light. In the resulting image, the black regions of The Dress look golden-brown to some people, with the blue regions white or very pale blue. Others see black lace, nonetheless, along with blue cloth. This peculiar combination of light sources promotes the ambiguity that viewers experience.



1 **Unambiguous**—White lighting

2 **Ambiguous**—Two sources of light

COLOR CONTRAST AND CONSTANCY



Visual neuroscientists R. Beau Lotto of University College London and Dale Purves of Duke University have created perhaps the most dramatic demonstration to date of color effects in the brain.

See the blue chips on the top of the left cube and the yellow chips on the top of the right cube? They are identical and appear as plain gray when the surrounding colors are removed. This phenomenon, called color contrast, causes red apples to appear redder against a background of green leaves. More generally, it makes equal colors look different because of context.

The two cubes also demonstrate color constancy, which Conway has predicted plays a role in The Dress phenomenon. Take a look at the red chips on both cubes. They are actually orange on the left and purple on the right, if you look at them in isolation. They appear more or less equally red across the images because your brain is interpreting them as red chips lit by either yellow or blue light.

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THIS PAGE AND OPPOSITE PAGE: BRADLEY PEARCE AND ANYA HURLBERT *Newcastle University (dress photoillustration)*; ROMAN ORIGINALS *(dress)*; FROM *WHY WE SEE WHAT WE DO: AN EMPIRICAL THEORY OF VISION*, BY DALE PURVES AND R. BEAU LOTTO. SINAUER ASSOCIATES, 2003 *(cubes)*

MENTAL HEALTH

Schizophrenia May Be the Price We Pay for a Big Brain

The disease is linked to genetic changes on the evolutionary road from ape to human

By Bret Stetka

Plenty of us have known a dog on Prozac. We have also witnessed the eye rolls that come with the mention of canine psychiatry. Doting pet owners—myself included—ascribe all kinds of questionable psychological ills to our pawed companions. But in fact, the science suggests that numerous nonhuman species do suffer from psychiatric symptoms. Birds obsess; horses on occasion get pathologically compulsive; dolphins and whales, especially those in captivity, self-mutilate. And that thing when your dog woefully watches you pull out of the driveway from the window—that might be *DSM*-certified separation anxiety. "Every animal with a mind has the capacity to lose hold of it from time to time," wrote science historian and author Laurel Braitman in her 2014 book *Animal Madness*.

But at least one mental malady, while common in humans, seems to have spared other animals: schizophrenia, which affects an estimated 0.4 to 1 percent of adults. Although animal models of psychosis exist in laboratories, and odd behavior has been observed in creatures confined to cages, most experts agree that psychosis has not typically been seen in other species, whereas depression, obsessive-compulsive disorder and anxiety traits have been reported in many nonhuman species.

This raises the question of why such a potentially devastating, often lethal disease is still hanging around plaguing humanity. We know from an abundance of recent research that schizophrenia is heavily genetic in origin. One would think that natural selection would have eliminated the genes that predispose to psychosis. A study published earlier this year in *Molecular Biology and Evolution* provides clues as to how the potential for schizophrenia may have arisen in the human brain and, in doing so, suggests possible treatment targets. It turns out that psychosis may be an unfortunate cost of having a big brain that is capable of complex cognition.

Hotspots in the Human Genome

The study, led by Joel Dudley, a genomics professor at the Icahn School of Medicine at Mount Sinai, proposes that because schizophrenia is relatively prevalent in humans, it perhaps has a complex evolutionary backstory that would explain its persistence and apparent exclusivity to humans. Specifically, Dudley and his colleagues were curious about segments of our genome called human accelerated regions, or HARs, first identified in 2006. HARs are short stretches of DNA that were conserved in other species but underwent rapid evolution in humans following our split with chimpanzees, presumably because they provided some benefit specific to our species. Rather than encoding for proteins themselves, HARs often help to regulate neighboring genes. Because both schizo-

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SKIP STERLING

phrenia and HARs appear to be, for the most part, human-specific, the researchers wondered if there might be a connection between the two.

To find out, Dudley and his colleagues used data culled from the Psychiatric Genomics Consortium, a massive study identifying genetic variants associated with schizophrenia. They first assessed whether schizophrenia-related genes sit close to HARs along the human genome—closer than would be expected by chance. It turns out they do, suggesting that HARs play a role in regulating genes contributing to schizophrenia. Furthermore, by comparing the patterns of change in humans and chimpanzees, it was revealed that HAR-associated schizophrenia genes were under stronger evolutionary selective pressure than other schizophrenia genes. This observation implies that the human variants of these genes are essential to us in some way, despite the risk they harbor.

To help understand what these benefits might be, Dudley's group then turned to gene expression profiles. Gene sequencing provides an organism's genome sequence, but gene expression profiling reveals where and when in the body certain genes are active. Dudley's team found that HAR-associated schizophrenia genes are found in regions of the genome that influence other genes expressed in the prefrontal cortex, a brain region just behind the forehead that is involved in higher-order thinking. Impaired function in the prefrontal cortex is thought to contribute to psychosis.

They also found that these culprit genes are involved in various key human neurological functions within the prefrontal cortex, including the transmission of the neurotransmitter GABA across a synapse from one neuron to another. GABA serves as an inhibitor or regulator of neuronal activity, in part by suppressing dopamine in certain parts of the brain. In schizophrenia, GABA appears to malfunction, and dopamine runs wild, contributing to the hallucinations, delusions and disorganized thinking that are common to psychosis. In other words, the schizophrenic brain lacks restraint.

"The ultimate goal of the study was to see if evolution may help provide additional insights into the genetic architecture of schizophrenia so that we can better understand and diagnose the disease," Dudley explains. Identifying which genes are most implicated in schizophrenia and how they are expressed could lead to more effective therapies such as those influencing the function of GABA.

When Bigger Isn't Better

Dudley's findings offer a possible explanation for why schizophrenia arose in humans in the first place and why it does not seem to occur in other animals. "It's been suggested," Dudley explains, "that the emergence of human speech and language bears a relationship with schizophrenia genetics and, incidentally, autism." Indeed, language dysfunction—typified by disorganized speech or jumping from one topic to another—is a feature of schizophrenia, and GABA is critical to speech, language and many other aspects of higher-order cognition. "The fact that our evolutionary analysis converged on GABA function in the prefrontal cortex seems to tell an evolutionary story connecting schizophrenia risk with intelligence."

Put another way, with complicated, highly social human thought—and the complicated genetics at the root of higher cognition—perhaps there is just more that can go wrong: complex function begets complex malfunction.

Dudley is careful not to exaggerate the evolutionary implications of his work. "It is important to note that our study was not specifically designed to evaluate an evolutionary trade-off," he observes, "but our findings support the hypothesis that evolution of our advanced cognitive abilities may have come at a cost—a predisposition to schizophrenia." He also acknowledges that the new work did not identify any "smoking gun genes" and that schizophrenia genetics is profoundly complex. Still, Dudley feels that evolutionary genetic analysis can help identify the most relevant genes and pathological mechanisms at play in schizophrenia and possibly other mental illnesses that preferentially affect humans—that is, neurodevelopmental disorders related to higher cognition and GABA activity, including autism and attention-deficit/hyperactivity disorder.

In fact, a study published online this past March in *Molecular Psychiatry* reported a link between gene variants associated with autism spectrum disorder and better cognitive function in the general population—specifically, enhanced general cognitive ability, memory and verbal intelligence. "It would suggest that some of these variants can have beneficial effects on cognition," says lead author Toni-Kim Clarke of the University of Edinburgh. The findings might also help explain why individuals with autism sometimes exhibit unusual cognitive gifts.

Clarke's findings support Dudley's speculation that higher cognition might have come at a price. As we broke away from our primate cousins, our genomes—HARs especially—hastily evolved, granting us an increasing cache of abilities that other species lack. In doing so, they may have left our brains prone to occasional complex dysfunction—but also capable of biomedical research aimed at one day curing the ailing brain. M

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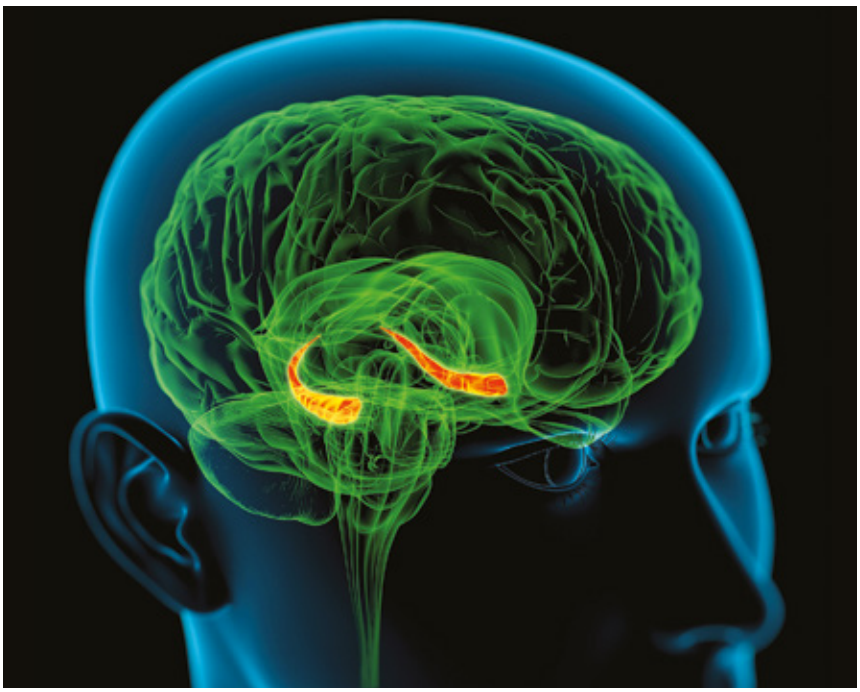

MEMORY

Adapt and Overcome

Can a single brain system compensate for autism, dyslexia and OCD?

By Michael T. Ullman and Mariel Y. Pullman

The human brain possesses an incredible capacity to adapt to new conditions. This plasticity enables us not only to constantly learn but also to overcome brain injury and loss of function. Take away one capability, and little by little we often compensate for these deficits.

Our brain may be especially well suited to overcome limitations in the case of psychiatric or neurological conditions that originate early in life, what clinicians call neurodevelopmental disorders. Given the brain's considerable plasticity during early years, children with these disorders may have particular advantages in learning compensatory strategies.

It now appears that a single brain system—declarative memory—can pick up slack for many kinds of problems across multiple neurodevelopmental disorders. This system, rooted in the brain's hippocampus, is what we typically refer to when we think of learning and memory. It allows us to memorize facts and names or recall a first grade teacher or a shopping list. Whereas other memory systems are more specialized—helping us learn movements or recall emotional events, for instance—declarative memory absorbs and retains a much broader range of knowledge. In fact, it may allow us to learn just about anything.

Given declarative memory's powerful role in learning, one might expect it to help individuals acquire all kinds of compensatory strategies—as long as it remains functional. Indeed, research suggests that it not only remains largely intact but also compensates for diverse impairments in five common conditions that are rarely studied in conjunction: autism spectrum disorder, obsessive-compulsive disorder (OCD), Tourette's syndrome, dyslexia and developmental language disorder (which is often referred to as specific language impairment, or SLI).

In 2015 we laid out this idea in a review article. We presented evidence suggesting that declarative memory enables people with OCD or Tourette's syndrome to learn to control compulsions and tics; allows individuals with autism to memorize strategies that improve social interactions; and helps people with dyslexia or SLI overcome reading and language difficulties. Overall, we believe that a better understanding of declarative memory could yield new ways to both identify and treat people with neurodevelopmental disorders.

Evaluating the Evidence

Multiple lines of evidence suggest compensation by declarative memory. One element supporting the hypothesis is the fact that many strategies for helping people with neurodevelopmental disorders involve consciously mastering a set of behavioral steps. Because declarative memory is the only brain system that supports such explicit learning, these strategies must depend on this system.

For instance, a popular and effective therapy called "social stories" is used to guide children with autism through specific types of social situations, such as how to behave at a birthday party. By practicing social scripts in this explicit manner, children on the spectrum can acquire behaviors that neurotypical children generally learn implicitly. Individuals with autism can also learn explicit strategies on their own. As Temple Gran-

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ROGER HARRIS *Science Source*

din, the noted author with autism, has said, "You gradually get less and less autistic … you keep learning how to behave. It's like being in a play."

Moreover, explicit learning supports habit-reversal therapy—a particularly effective approach for Tourette's syndrome, according to a 2013 review by neurologists Madeleine Frank and Andrea Cavanna, both then at the University of Birmingham in England. This therapy, which can also benefit individuals with OCD, teaches people to consciously recognize a tic or compulsion as it occurs and to learn to explicitly perform a competing response to suppress the problem behavior. For example, learning to close one's eyes for a few seconds when one feels an eyeblink tic coming on can suppress the tic.

Another compensatory strategy engaging declarative memory involves memorizing whole phrases or sentences. Typically developing kids generally combine individual words into phrases and sentences, but the grammatical deficits of children with SLI impair this process. Instead they often simply memorize phrases as chunks—that is, recalling a phrase such as "I like pie" as a single unit.

Evidence from brain imaging underscores the importance of declarative memory for compensation. A number of studies have found that people with autism, OCD or SLI (but not the control subjects) show activation in the hippocampus or other declarative memory brain regions when performing tasks involving social skills, planning or grammar. In some of these tasks, individuals with these disorders actually perform as well as the control subjects, suggesting that their compensation was highly successful.

Finally, if declarative memory underlies compensation, then those individuals with stronger declarative memory should compensate more effectively. Many studies have reported this kind of correlational evidence. In 2012 psychologist Jarrad A. G. Lum of Deakin University in Australia and his colleagues (including one of us, Ullman) examined 51 children with SLI and 51 children without language impairment. We gave the children several tests, including an assessment of declarative memory, which incorporated tasks such as recalling pairs of words after a delay. In addition, by giving the children a grammar test, we discovered that, among those with SLI (but not among the unimpaired children), better declarative memory was indeed linked to better grammatical abilities. Similar links have emerged between this memory system and the ability to overcome difficulties in dyslexia, Tourette's syndrome and OCD.

DECLARATIVE MEMORY MAY HOLD THE KEY TO **CONTROLLING TICS AND LEARNING SOCIAL STRATEGIES.**

Helping Patients

Recognizing the compensatory role of declarative memory could improve treatment in several ways. First, therapists can make greater use of techniques that rely on declarative memory, such as approaches that employ explicit knowledge. These treatments could also be combined with drugs such as acetylcholinesterase inhibitors, which can strengthen this memory system.

Paradoxically, another therapeutic option could involve approaches that *avoid* engaging declarative memory. For example, children with SLI might be presented with sentences whose grammatical structures are too complex to be learned as chunks, increasing the likelihood of engaging the impaired grammatical system. Such an approach could stimulate and strengthen the dysfunctional circuitry. This method is akin to therapies that prevent stroke patients from using their good hand so that they are forced to use their bad one, which can increase its functionality.

Additionally, declarative memory's role in neurodevelopmental disorders has implications for diagnosis. Many individuals might compensate so well that clinicians do not recognize their condition. This could help explain a major conundrum of these disorders: why they are diagnosed more commonly in boys than girls. Declarative memory seems to be better, on average, in girls and women than in boys and men. Thus, females are likely to compensate and even mask symptoms more successfully than males.

Given the power and flexibility of declarative memory, it could enable compensation in many other contexts. Evidence hints that it plays a part in ADHD, Parkinson's disease, aphasia and even normal aging. On a larger level, the brain's ability to replace the functionality of one system with that of another offers an important reminder to researchers: it is not only the deficits that matter. Sometimes we need to look beyond weaknesses and focus on strengths. M

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MACHINE LEARNING

Intelligence without Sentience

Artificial intelligence is coming of age and challenging our belief that being smart and being conscious go hand-in-hand

Throughout human history, intelligence and consciousness have been two closely allied concepts. If you have lots of the former, you are assumed, in some ill-defined way, to be more conscious than the dim-witted guy down the street. A smart gal would also be a very conscious one, somebody who could tell you in detail about her experiences (for that is what consciousness is, the ability to experience something, anything, whether it's a toothache, the sight of a canary-yellow house or searing anger). But this intimate relation may be unraveling.

Consider the latest advance from DeepMind, a small company in London co-founded in 2011 by Demis Hassabis, a British child chess prodigy, video game designer and computational neuroscientist. DeepMind was bought last year for hundreds of millions of dollars by Google. What its new code does is breathtaking: it teaches itself to play video games, often much better than human players. The technical breakthrough is described in a study published in February in *Nature*. (*Scientific American Mind* is part of Nature Publishing Group.)

To get a whiff of the excitement, go online and look for a YouTube video called *DeepMind Artificial Intelligence @ FDOT14*. It's a short excerpt, taken by smartphone, from Hassabis's talk at a 2014 tech conference, featuring a computer algorithm that learns to play the classic arcade game Breakout. The aim of the game, a variant of Pong, is for the player to break bricks aligned in rows on the top of the screen using a ball that bounces off the top and sidewalls. If the ball touches the bottom of the screen, the player loses one of three lives. To prevent that outcome, the player moves a paddle along the bottom to deflect the ball upward.

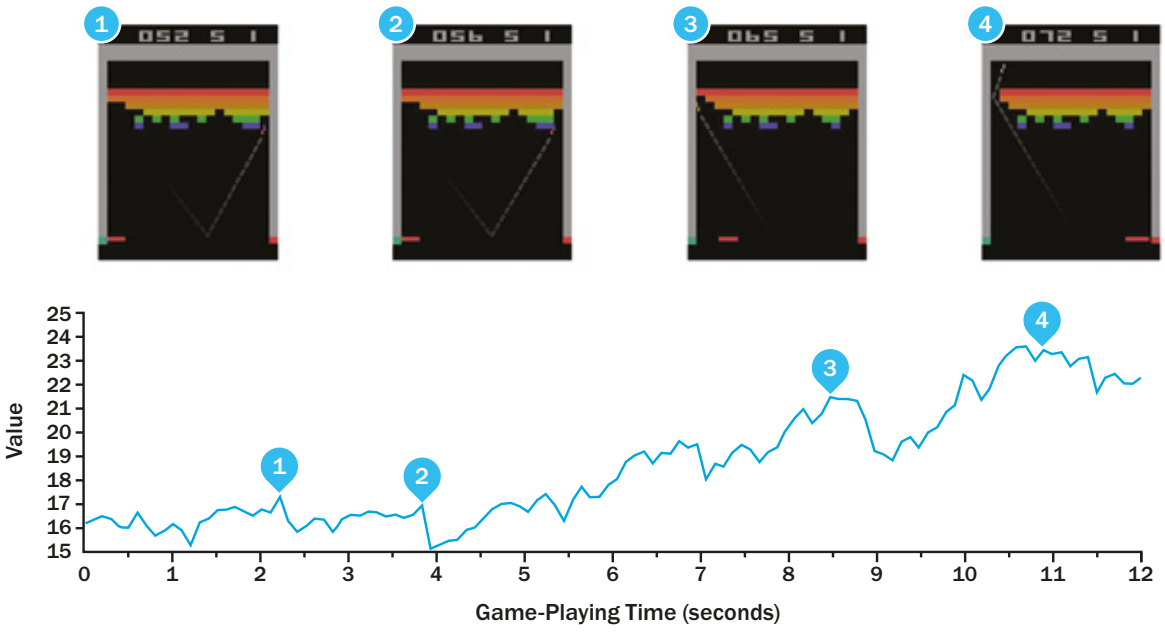
Co-created by Steve Wozniak of Apple fame, the game is primitive by today's standards yet compelling. Hassabis explained this onstage as he introduced the audience to the algorithm. It started out knowing nothing and randomly fumbled the paddle, without much coordination, only occasionally hitting the ball. After an hour of training, playing over and over again, its performance improved, frequently returning the ball and breaking bricks. After two hours of training, it became better than most humans, returning balls fast and at steep angles.

The programmers let the algorithm continue to play on its own, and it kept on improving. After four hours of gaming, the algorithm discovered an innovative strategy to Breakout that boosted its performance way past that of any human. The algorithm accomplished this feat by learning to dig a tunnel through the wall on the side, allowing the ball to quickly destroy a large number of bricks from behind. Very clever. The achievement was so impressive that the assembled experts broke into spontaneous applause (a rare occurrence at scientific conferences).

BY CHRISTOF KOCH

Christof Koch is president and chief scientific officer at the Allen Institute for Brain Science in Seattle. He serves on *Scientific American Mind*'s board of advisers.

DAVID PLUNKERT; SEAN MCCABE (*Koch*)



DeepMind's artificial-intelligence algorithm learns to master Breakout, an arcade game that involves clearing away bricks using a ball and paddle. As it gains experience after many moves, the software finds new ways to raise its performance, including an innovative strategy (*shown in panel 4*) that digs through the wall to break a large number of bricks from behind.

To understand what's going on and why it's such a big deal, let's look under the hood. The algorithm incorporates three features, all gleaned from neurobiology: reinforcement learning, deep convolutional networks and selective memory replay.

A lasting legacy of behaviorism, the field that dominated the study of human and animal behavior in the first part of the 20th century, was the idea that organisms learn optimal behavior by relating the consequence of a particular action to a specific stimulus that preceded it. This stimulus is said to reinforce the behavior.

Consider my Bernese mountain dog, Ruby, as a puppy, when I had to housebreak her. After giving Ruby water to drink at prescribed intervals, I immediately took her to a particular spot in the garden and waited—and waited. At some point, she would spontaneously pee, and I would lavishly praise her. If an indoor accident happened, I talked sternly to her. Dogs respond well to such positive and negative social signals. Over a month or two Ruby learned that an internal stimulus—a full bladder—followed by a behavior—peeing in her special spot—predicted a reward and avoided punishment.

Reinforcement learning has been formalized and implemented in neural networks to teach computers how to play games. Gerald Tesauro of IBM used a particular version of reinforcement learning—temporal-difference learning—to design a network that played backgammon. The program analyzes the board and examines all the possible legal moves and responses of the opposing player to these moves. All the resulting board positions are fed into the program's heart, its value function.

The action that is chosen by the program is the one that leads to the board position with the highest score. After a turn, the network is slightly tweaked so that the program predicts what happens next a little bit better than what it predicted following its previous move. Starting from scratch, the program becomes better and better by trial and error. What makes reinforcement learning a challenge is that there is usually a substantial delay between any one particular move and its eventual beneficial or detrimental outcome. Overcoming this handicap requires training, training and more training—beating human experts at backgammon required Tesauro's program to play 200,000 games against itself.

The second ingredient of DeepMind's success is called a deep convolutional network. It is based on a model of the brain circuitry found in the mammalian visual system by Torsten Wiesel and the late David H. Hubel, both then at Harvard University, in the late 1950s and early 1960s (work for which they would later be awarded a Nobel Prize). The model postulates a layer of processing elements, or units, that compute a weighted sum of an input. If the sum is sufficiently large, the model turns the unit's output on; otherwise, it remains off.

The visual system is thought by some theoreticians to be essentially nothing but a cascade of such processing layers—what is labeled a feed-forward network. Each layer receives input from a previous layer and passes on the output to the next level. The first layer is the retina that captures the rain of arriving photons. It accounts for variations in image brightness and passes these data on to the next processing stage. The last layer consists of a bunch of units that signal whether or not

SOURCE: "HUMAN-LEVEL CONTROL THROUGH DEEP REINFORCEMENT LEARNING," BY VOLODYMYR MNIH ET AL., IN *NATURE*, VOL. 518; FEBRUARY 26, 2015

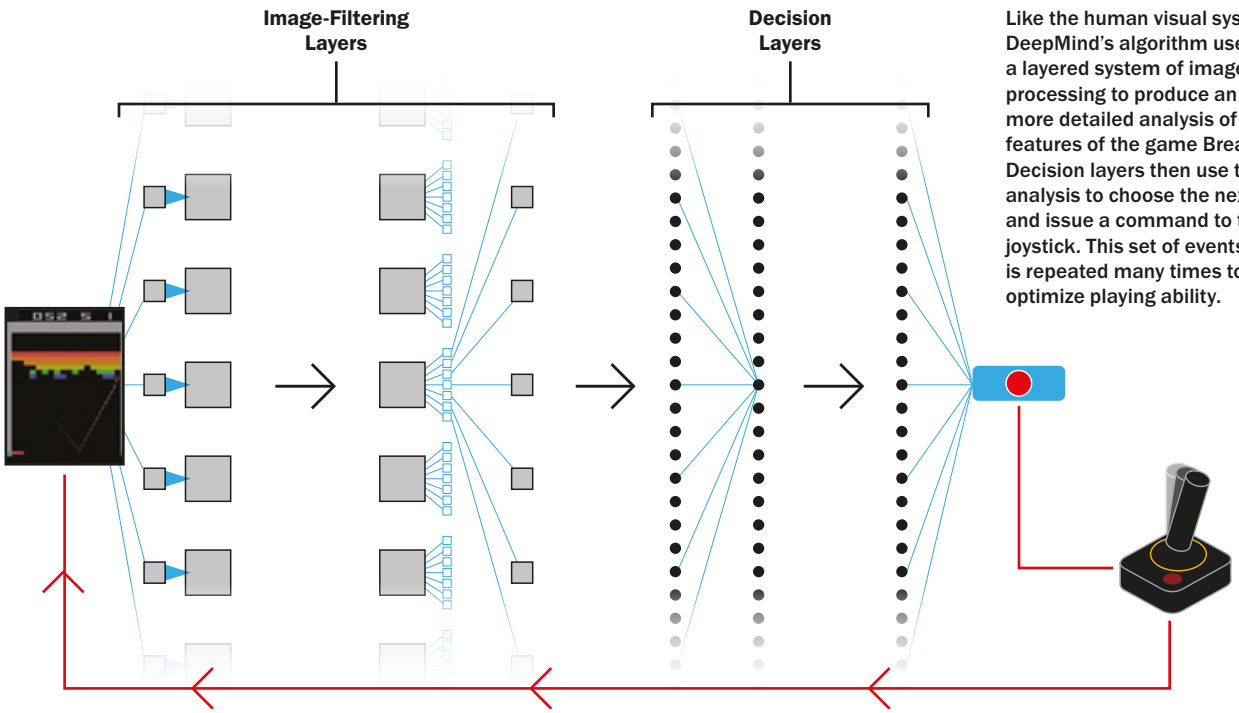
some high-level feature, such as your grandmother or Jennifer Aniston, is present in that image.

Learning theorists developed mathematically sound methods to adjust the weights on these units—how influential one input should be relative to another one—to get such feed-forward networks to learn to perform specific recognition tasks. For instance, a network is exposed to tens of thousands of images from the Internet, each one labeled according to whether or not the photograph includes a cat. After every exposure, all weights are slightly adjusted. If the training is sufficiently long (again, the training is very computer-intensive) and the images are processed in deep enough networks—those with many layers of processing elements—the neural network generalizes and can accurately recognize a new photograph as containing a feline. The network has learned, in a supervised manner, to distinguish cat images from those of dogs, people, cars, and so on. The situation is not that dissimilar from a mother going through a picture book with her toddler while pointing out all the cats to the child. Deep convolutional networks are all the rage at Google, Facebook, Apple and other Silicon Valley companies seeking to automatically label images, translate speech to text, detect pedestrians in videos and find tumors in breast scans.

The supervised learning differs from reinforcement learning. In the former, every input image is paired with a label—one image contains a cat; another does not. In reinforcement learning, the consequence of any action in the game score unfolds in time—the actions may yield benefits (improved scores) but only many moves later.

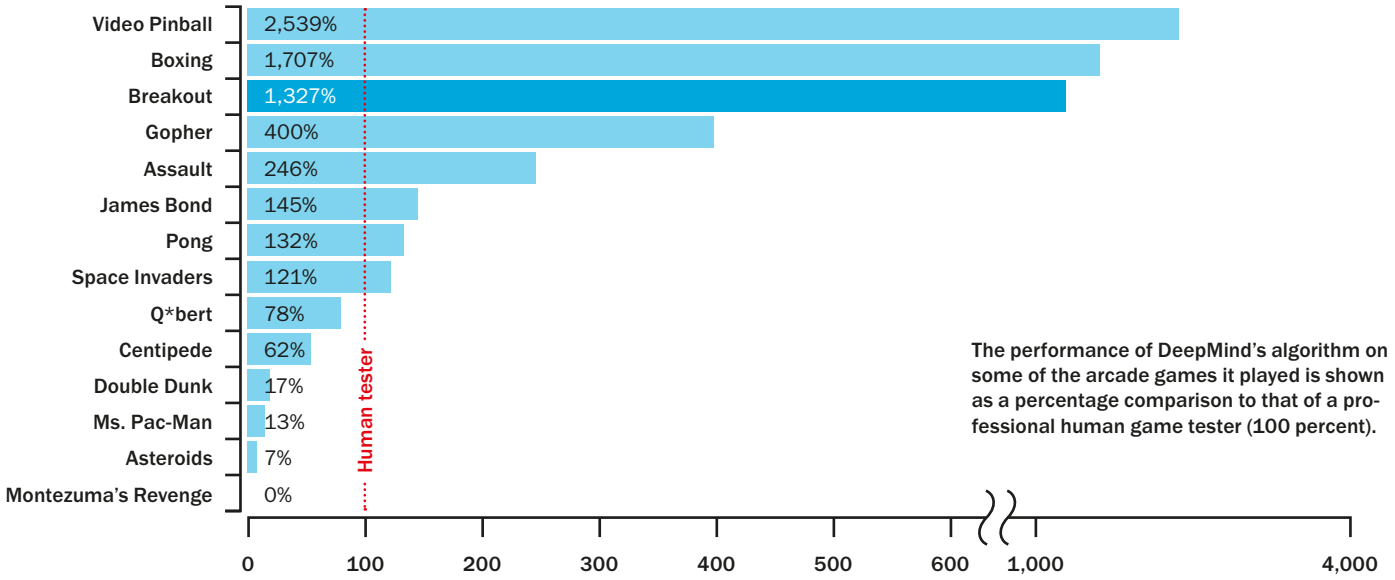
Hassabis and his large team (the *Nature* paper included 19 co-authors in all) used a variant of reinforcement learning called Q-learning to act as a supervisor for the deep-learning network. The input to the network consisted of a blurry version of the colored game screen, including the game score—the same as seen by a human player—as well as the screens associated with the last three moves. The output of the network was a command to the joystick—to move in one of the eight cardinal directions, with or without activating the red "fire" button. Starting with a random setting of its weights, the proverbial blank slate, the algorithm figured out which actions would lead the all-important score to increase—when exactly the paddle was most likely to successfully intercept the ball on the bottom to break a brick on its upward trajectory. In this manner, the network learned and, through repetition, reinforced training of successful ways to play Breakout, outperforming a professional human game tester by a stunning 1,327 percent.

The third critical component of the algorithm was selective memory replay—similar to what is thought to occur in the hippocampus, a brain region associated with memory. In the hippocampus, activity patterns of nerve cells associated with a particular experience, such as running a maze, reoccur but at a faster pace on replay. That is, the algorithm would randomly recall a particular game episode, including its own actions, that it encountered earlier on from its memory bank



Like the human visual system, DeepMind's algorithm uses a layered system of image processing to produce an ever more detailed analysis of visual features of the game Breakout. Decision layers then use this analysis to choose the next move and issue a command to the joystick. This set of events is repeated many times to optimize playing ability.

THIS PAGE AND OPPOSITE PAGE: SOURCE: "HUMAN-LEVEL CONTROL THROUGH DEEP REINFORCEMENT LEARNING," BY VOLODYMYR MNIH ET AL., IN *NATURE*, VOL. 518; FEBRUARY 26, 2015



The performance of DeepMind's algorithm on some of the arcade games it played is shown as a percentage comparison to that of a professional human game tester (100 percent).

and would retrain itself using this earlier experience, updating its evaluation function appropriately.

The folks at DeepMind were not content to let their algorithm learn just one game. They trained the same algorithm on 49 different Atari 2600 games, all of which were designed to engage generations of teenagers. They included Video Pinball, Stargunner, Robot Tank, Road Runner, Pong, Space Invaders, Ms. Pac-Man, Alien and Montezuma's Revenge. The same algorithm, with the same settings, was used in all cases. Solely the output differed according to the specific needs of each game. The results blew all competing game-playing algorithms out of the water. What's more, the algorithm performed at 75 percent or better than the level achieved by a human professional game tester in 29 of these games, sometimes by a very large margin.

The algorithm did have its limitations. Its performance grew progressively worse as games demanded ever more long-term planning. For instance, the algorithm's performance in Ms. Pac-Man was pretty dismal because the game requires one to, say, choose which path in the maze to take to avoid being gobbled up by a ghost that is still 10 or more moves away in the future.

The program, however, heralds a new sophistication in AI. Deep Blue, the IBM program that beat chess grandmaster Garry Kasparov in 1997, and Watson, the IBM system that bested Ken Jennings and Brad Rutter in the quiz show *Jeopardy*, were highly specialized collections of algorithms carefully handcrafted to their particular problem domain. The hallmark of the new generation of algorithms is that they learn, like people, from their triumphs and their failures. Starting with nothing but the raw pixels from the game screen, they eventually compete in side-scrolling shooters, boxing games and car-racing games. Of course, the worlds in which they operate are physically highly simplistic, obeying restrictive rules, and their actions are severely limited.

There is no hint of sentience in these algorithms. They have none of the behaviors we associate with consciousness. Existing theoretical models of consciousness would predict that deep convolutional networks are not conscious. They are zombies, acting in the world but doing so without any feeling, displaying a limited form of alien, cold intelligence: an algorithm "ruthlessly exploits the weakness in the system that it has found. This is all automatic," Hassabis said in his 2014 talk. Such algorithms, including those that control Google's self-driving cars or the ones that execute trades in the financial markets, demonstrate that for the first time in the planet's history, intelligence can be completely dissociated from sentience, from consciousness.

They are smart in the sense that they can learn to adapt to new worlds, motivated by nothing but maximizing cumulative reward, as defined by the game score. I have no doubt that DeepMind designers are busy working on more sophisticated learning engines, teaching their algorithms to dominate first-person shooter games, such as Doom or Halo, or strategy games, such as StarCraft. These algorithms will become better and better at executing specific tasks in narrowly defined niches of the kind that abound in the modern world. They will neither create nor appreciate art, nor will they wonder at the beautiful sunset.

Whether this is a good thing for humankind in the long run remains to be seen. The reason we dominate the natural world is not because we are faster or stronger, let alone wiser, than other animals but because we are smarter. Perhaps these learning algorithms are the dark clouds on humanity's horizon. Perhaps they will be our final invention. **M**

FURTHER READING

- **Human-Level Control through Deep Reinforcement Learning.** Volodymyr Mnih et al. in *Nature,* Vol. 518, pages 529–533; February 26, 2015.

The Social Power of TOUCH

A long-overlooked system of nerves that respond to gentle strokes may be crucial to our ability to form connections with one another

By Lydia Denworth

Pleasurable touch may encourage us to engage in more social interaction with one another, building bonds between individuals.

My three sons are nearly all teenagers, and some of the details of their earliest years have begun to blur. Which boy was it who said that funny thing about the dog? Who lost a tooth while crossing the street? But I remember the minutes immediately after each child's birth as sharply as if the boys had entered the world this morning. Given my new baby to hold, I hugged him to my chest, caressed his back and kissed the top of his tiny head. And then we stayed there like that for quite awhile, mother and child.

The sense of touch had a lot to do with why those moments were so powerful. Touch has long been understood to be important in nurturing relationships—so much so that babies who were raised in orphanages without it often died. Those first moments with my children, followed by years of cuddles and hugs, no doubt contributed mightily to the deep bonds between us.

The question of why that should be so has traditionally been the province of psychologists, who have proposed a number of explanations such as attachment theory and increases in oxytocin. Yet these suggestions do not adequately elucidate the immediacy and power of touch, and they leave the underlying biology unexamined. Meanwhile neuroscientists had until recently focused only on the discriminative nature of tactile perception—how touch allows us to tell a baby's skin from his or her blanket and whether that skin feels feverish. They assumed any emotional aspects of touch came later, after the brain had processed the sensation and had a few hundred milliseconds to add the context of feelings.

That view changed a few years ago, when a small but determined group of neuroscientists proposed that something far more fundamental was going on when I held my babies. Their growing body of research has uncovered another dimension of touch that is separate from its discriminative function. This newly recognized system, known as affective or emotional touch, consists of nerve fibers triggered by exactly the kind of loving caress a mother gives her child. It is possible that these neurobiological foundations of attachment might play a far more significant role in human behavior than has been recognized, forging connections and increasing our chance of survival. These fibers may also help our minds construct and integrate a sense of self and other, informing our awareness of our own bodies and ability to relate to people around us.

"Affective touch is a potential way in to understanding the development of the normal social brain," says Francis McGlone, a neuroscientist at Liverpool John Moores University in England and a leader in the field. "It's giving the brain knowledge of me and you, and the emotional quality of gentle, nurturing touch is a very important feeling that underpins a lot of social interaction."

FAST FACTS
FULL OF FEELING

1. A set of nerve fibers called C-tactile (CT) afferents appears to convey information about pleasant touch.
2. Given how attuned these fibers are to human touch, they may play a role in reinforcing social connections.
3. The functioning of these nerves may someday serve as a biomarker for conditions such as autism and addiction.

PRECEDING PAGES AND THIS PAGE: GETTY IMAGES

Touch is the first sense to emerge in utero, and though far from mature, it is the most strongly developed at birth.

A New Kind of Nerve Fiber

Neurons in the skin take in information about everything we contact through a variety of nerve fibers and sensory receptors called mechanoreceptors that are specialized for touch. Like the rods and cones of the eye, which deliver separate pieces of information to make up the entirety of what we see, different nerve fibers respond best to different kinds of touch [*see box on next page*]. They play favorites. Some like to be pushed, for instance, and others like to be stretched. One class of fiber, A-beta, does most of the work of discriminating, and these fibers are all over the body, especially in the palm. Because they are sheathed in a fatty insulation called myelin, they are able to conduct the nervous system's electrical messages rapidly. Speed is of the essence if you are stepping on a tack after all. C fibers are touch fibers of a different kind. They are unmyelinated and carry information at a much more leisurely pace, up to 50 times slower than their neighbors.

The two C fibers that have received the most scientific attention to date are those for pain and itch. (Although some information about painful stimuli travels quickly, the rich details carried in the C fibers take more time, which is why there is sometimes a delay between when you cut yourself and when it starts to hurt.) Now, says McGlone, who began his career studying pain, "there's another kid on the block." Found only in hairy skin such as that of the forearm or back, as opposed to the nonhairy, or glabrous, skin of the palm and sole of the foot, the new fiber is known as a C-tactile (CT) afferent, a name that indicates that it conveys messages toward the central nervous system. CT afferents are keenly tuned to the gentle velocity and comfortable skin temperature of a caress, an affectionate pat, or any other form of so-called light or innocuous touch. (Sexual responses are something different, although the line between the two is hard to define because sensual touch can, of course, lead to sex.) Technically speaking, anything below five millinewtons of pressure—about as light as a postcard—on the skin qualifies as light touch, in contrast to the high pressure of pain, which is why another term for the relevant nerve fiber is the C low-threshold mechanoreceptor.

The discovery of these fibers actually dates back to 1939, when Swedish neurophysiologist Yngve Zotterman discovered a population of C fibers in the skin of a cat that were different from the receptors that convey pain. Zotterman initially speculated they might play a role in the perception of tickling, although later findings would debunk this notion. No one paid much attention to the discovery, however, and it was thought that if such fibers existed in humans, they must be evolutionary leftovers.

The technique of microneurography, a painstakingly pre-

GETTY IMAGES (*feet*); TRINETTE REED *Corbis* (*massage*)

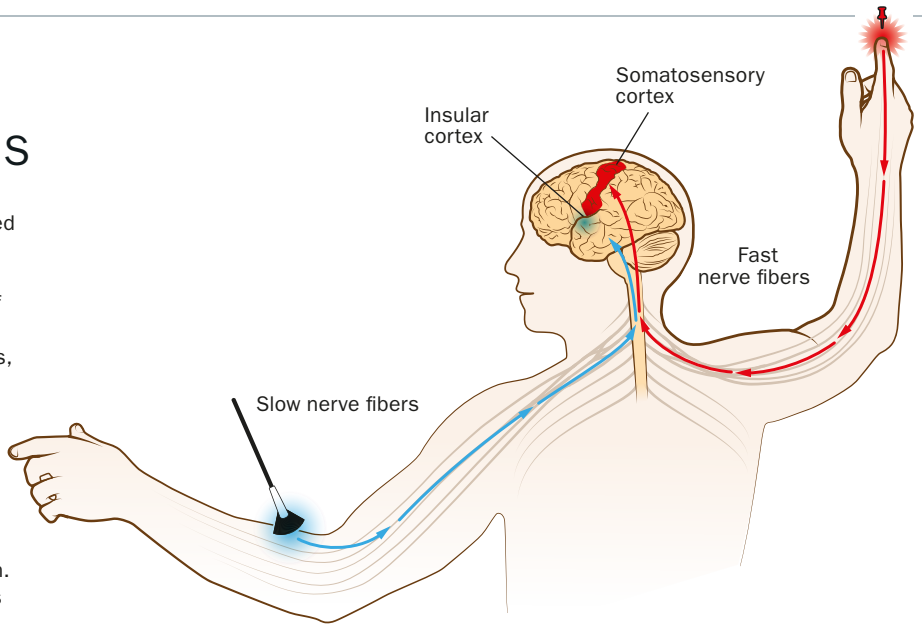
Various types of touch, such as the pain of stepping on a nail (*left*) or the pleasure of a relaxing massage (*right*), may engage different nerves in the body to convey their unique messages. Whereas the sharp agony of a cut requires a fast initial response from specialized nerve fibers, the system of nerves involved in gentler sensations are comparatively slow to act.

A TOUR OF TOUCH FIBERS

Within your skin is an array of touch sensors, each associated with nerve fibers that connect to the central nervous system. These sensors are made up of specialized nerve endings and skin cells. Along with the fibers, they translate our physical interactions with the world into electrical signals that our brain can process. They help to bridge the gap between the physical act of touching and the cognitive awareness of tactile sensation.

Even a simple stroke across the forearm engages several distinct nerve fibers. Three main types of nerve fibers—A-beta, A-delta and C—have subtypes that are specialized for sensing particular types of touch; other subtypes carry information related to pain. The integration of information from these fibers is what allows us to gain such rich sensory experiences through our skin, but it has also made it more challenging for researchers to understand the fibers' individual roles. Although these fibers do not act in isolation, the examples at the right highlight the primary nerve fibers engaged by the different types of touch.

—*Andrea Alfano*



FAST RESPONSE / SLOW RESPONSE

TYPE OF FIBER	INFORMATION CARRIED BY FIBER	EXAMPLE OF SPECIFIC FIBER IN ACTION
A-beta (5 subtypes involved in touch)	Vibration	Noticing a wobbly table tremble under your elbows
	Movement	Sensing a greasy bowl slipping out of your hands
	Indentation	Feeling the weight of a cat curled up in your lap
	Stretch	Realizing that your bare legs got stuck to your chair on a humid day
	Movement of longer hairs	Feeling the wind whip the hair on your head in various directions
A-delta (1 subtype involved in touch)	Movement of shorter hairs (unpleasant)	Reacting to the creeping sensation of a spider climbing up your forearm
C (1 subtype involved in touch)	Movement of shorter hairs (pleasant)	Responding to a pleasurable back rub
	Temperature	Enjoying the warmth of a hug

SOURCES: Victoria Abraira and David Ginty of Harvard University and Mark Hoon of the National Institute of Dental and Craniofacial Research

cise method of recording electrical activity in individual nerve fibers using very thin electrodes, allowed scientists to study CT afferents in humans. The first comprehensive report of such fibers in a human face was made in 1990, again by Swedish scientists. Another researcher, Åke Vallbo, a neurophysiologist at the University of Gothenburg, and his colleagues soon found a similar nerve fiber in the hairy skin of the forearm. Like other unmyelinated C fibers, this one was slow to react, but it responded to light touch, not pain or itch. "This was completely new," says Håkan Olausson, then a Ph.D. student in Vallbo's laboratory and now a neuroscientist at Linköping University in Sweden who is working with McGlone. The discovery led to the question that has guided work on these fibers ever since: What are they for?

It is obvious why we need a system to alert us to pain. Without it, we would have trouble surviving. Olausson and Vallbo, who is now emeritus, hypothesized that these new fibers did not function in the way we typically think about touch. Perhaps, they said, they are less about sensing and more about feeling, and

THE AUTHOR

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TAMI TOLPA; SOURCE: FRANCIS McGLONE *Liverpool John Moores University (top illustration)*

the rewards of pleasant touch were more than just a happy byproduct of a reassuring pat on the back or a sensual caress. In short, the pleasures of gentle touch might encourage human interaction. "The reward system in our brains promotes behavior that is beneficial to survival," McGlone says. "Looking back in evolution, it became apparent that organisms that work together were far more successful. To promote that togetherness, there was a need to promote the value of close physical contact."

Research into grooming behaviors in other animal species supports that hypothesis. Robin Dunbar, an anthropologist and evolutionary psychologist at the University of Oxford, has argued that grooming in primates supports social bonding and reproductive success. And neuroscientist Michael Meaney of McGill University has shown that rat mothers that lick and groom their babies more often raise less stress-prone pups that go on to be better parents themselves.

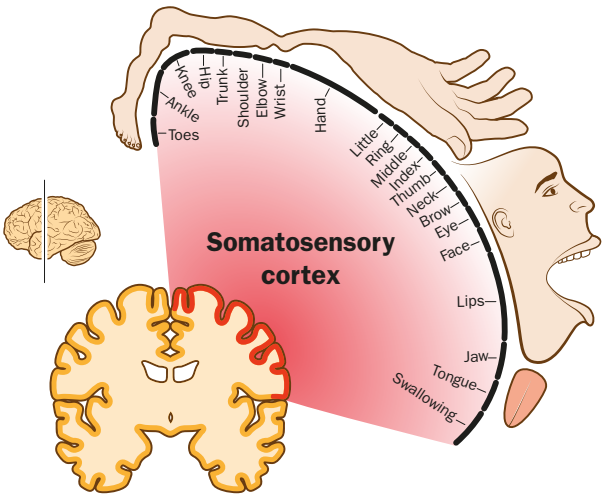
Although much about touch remains to be explored in both humans and animals, McGlone admits to getting a little giddy when he considers the possibilities and implications of CT afferents in the field: "I feel affective touch may be the Higgs boson of the social brain."

Attuned to Tenderness

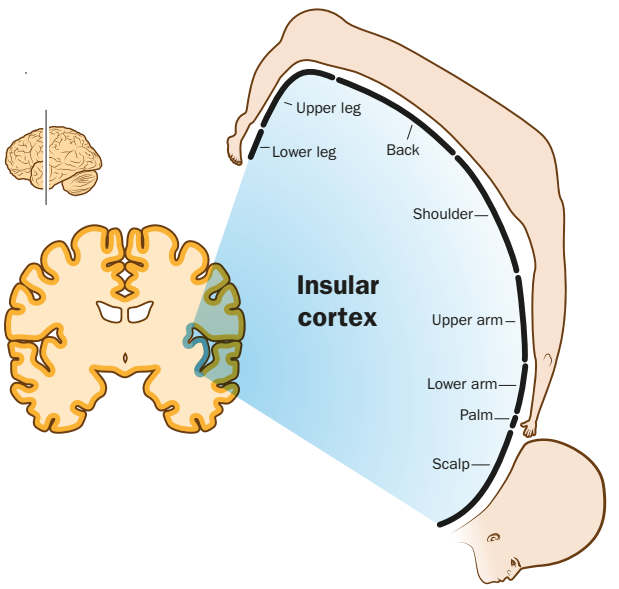
Olausson, McGlone and their colleagues have spent much of the past 20 years piecing together the properties of CT afferents. McGlone, for instance, began by asking whether it was even possible to quantify something called "pleasant touch." Beginning in 1999, he and his colleagues reported on a set of psychophysical studies in which robots brushed people's forearms at 0.5, five or 50 centimeters a second. The subjects described five centimeters a second as the most pleasant. In a related 2009 study, neurophysiologists Johan Wessberg and Line S. Löken, both then at Gothenburg, used microneurography to determine that the subjects' report of what was most pleasant was reflected in neurobiology. CT afferents responded most vigorously to being brushed at an average velocity of five centimeters a second, a speed that corresponds nicely to the gentle stroking of affectionate touch—reassuring pats on the shoulder, for example, or a back rub. A study led by their Gothenburg colleague Rochelle Ackerley added to the emerging portrait of CT afferents in 2014 by showing that they are tuned to temperature as well, preferring that of the skin to anything colder or hotter.

In 2002 Olausson and his colleagues published one of the earliest and most important findings about CT afferents, based on studies of a patient known as "G.L." who had a rare condition called neuronopathy that had left her without myelinated afferents but with intact unmyelinated nerve fibers. Initially, when brushed on the forearm, which should have stimulated her remaining CT afferents, G.L. said she felt nothing. But in a forced-choice scenario in which G.L. could not see what he was doing, Olausson stroked her forearm periodically with a small brush and asked her to say whether or not she had been touched. She was almost 100 percent accurate. Clearly, G.L. was capable of detecting this gentle touch, but she had so little experi-

The Sensory Body

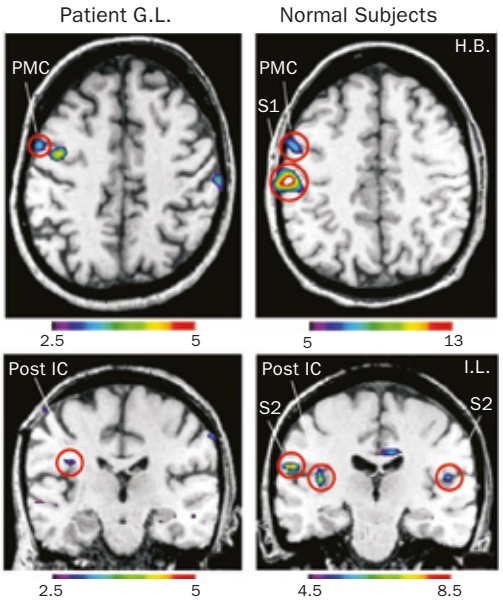


Neuroscientists have long used a peculiar illustration known as the sensory homunculus to depict sensitivity to touch. Each human body part, from toes at the top to tongue at the bottom, is mapped out along the somatosensory cortex, a brain region that processes tactile sensation. (In the example above, the location of the somatosensory cortex is also indicated on the brain.) The size of each body part is in proportion to the number of touch receptors present in that area. Hands and lips, for example, provide far more touch sensitivity than the neck or wrists.



In 2014 neuroscientists Susannah Walker and Francis McGlone of Liverpool John Moores University developed an analogous illustration of emotional touch mapped onto the insular cortex, which processes this recently discovered tactile system. Although the rendering (*above*) is still hypothetical, it reflects the relatively high concentration of receptors for C-tactile afferents in the back, shoulder, scalp and upper arms, as determined experimentally.

TAMI TOLPA; SOURCE: FRANCIS MCGLONE AND SUSANNAH WALKER *Liverpool John Moores University*



Because of a rare disorder, a patient (known as "G.L.") was unable to detect many tactile sensations. Yet her nerve fibers related to gentle touch remained intact. Swedish and Canadian researchers observed her brain activity while brushing her arm. In healthy people, several brain areas are engaged by this touching, including the premotor cortex (PMC), which is associated with movement. G.L.'s brain, however, showed less activity overall. A notable exception was her insular cortex (IC). This area is linked to emotions, suggesting gentle touch relates to feelings.

ence with the nuances of this sensation that she had not been able to identify it at first.

With training, G.L. began to recognize gentle touch and to describe it as pleasant. The same brushing on the skin of the palm, where no CT afferents are present, produced no response. When the team performed the same test on G.L. in a functional MRI machine, they saw that there was no activity in the area of the brain that normally responds to touch, the somatosensory cortex. Instead the response came in the insular cortex, connected to the limbic system and thought to be important for monitoring emotion and a sense of one's own body known as interoception. The latter sense allows people to perceive their internal states, such as hunger and exhaustion, building a necessary inner awareness. A second neuronopathy patient in England confirmed the findings. The activation in the limbic system revealed by the imaging studies was significant evidence in favor of Olausson and Vallbo's original theory that CT afferents had more to do with feelings than simply sensation.

In 2011 Olausson and his colleagues reported on a family in northern Sweden with a hereditary disorder that results in normal myelinated nerve fibers but a substantial loss of unmyelinated C fibers—essentially the opposite of G.L.'s condition. As expected, this group of subjects was capable of sensing touch in terms of discriminating between tactile sensations but did not find a caress at any speed particularly rewarding. (They also had reduced sensitivity to pain and temperature.) "It was almost like a lesion study," Olausson says. "You remove the afferents, and then touch becomes less pleasant."

Most recently, Olausson's lab has turned to looking at affective touch in babies. Touch is the first sense to emerge in utero, and though far from mature, it is the most strongly developed sense at birth. In a study reported at the 2014 Society for Neuroscience meeting in Washington, D.C., Olausson's Gothenburg colleague Emma Jönsson used functional near-infrared spectroscopy (fNIRS), a noninvasive method of brain imaging, to show that newborns can detect the stroking touch that stimulates CT afferents but not a faster brushstroke, indicating that this secondary touch system is indeed already present at birth. The team is extending its investigation to assess touch sensitivities in children six years and older. The researchers believe affective touch could be key to the bond between mother and child. "There must be a system telling newborns that you must be close to caregivers, a system to promote being close to the mother primarily," Olausson says.

Touch Gone Awry

As research into affective touch gains traction, scientists are investigating the question of what might happen if the affective touch system goes awry. After all, if touch does play some fundamental part in our social connectedness, perhaps people who struggle with forming bonds respond differently to the gentle stroking others find so pleasurable.

Autism researcher Kevin A. Pelphrey, director of the Center for Translational Developmental Neuroscience at Yale University, was inspired by McGlone to consider affective touch in his work. "I thought it was pretty clear that it might play a role [in autism] because this system of touch projects to the limbic system," Pelphrey says. "We've long thought that the limbic system was different in autism, so is this another route by which social information is processed? And is that different in autism?"

If touch does play some fundamental part in social connectedness, perhaps people who struggle with forming bonds respond differently to the gentle stroking others find so pleasurable.

FROM "UNMYELINATED TACTILE AFFERENTS SIGNAL TOUCH AND PROJECT TO INSULAR CORTEX," BY H. OLAUSSON ET AL., IN *NATURE NEUROSCIENCE*, VOL. 5, SEPTEMBER 2002

STEPHEN VOSS *Alamy*

Some researchers are investigating whether a negative or subdued response to gentle touch plays a role in disorders characterized by social deficits. For instance, one study has linked autistic traits to a reduced response to a slow brushing stroke on the forearm.

In 2013 Pelphrey and his colleagues published findings from a study in which he put 19 healthy subjects into an fMRI machine and brushed their arms at slow and fast speeds. The researchers saw social areas of the brain, such as the insular cortex, orbitofrontal cortex and superior temporal sulcus, an area of particular interest in autism, react more to the slower, gentler brushstrokes than to the faster ones. Those same 19 subjects—none of whom had autism—also filled out a questionnaire measuring social behaviors. Those with a tendency toward autistic traits showed a moderately muted response to the slow brushing.

Now Pelphrey's group is studying differences between children with and without autism. If the affective touch system turns out to be abnormal in autism, Pelphrey says, it will suggest that autism is happening very early in fetal development. To see if this secondary touch system could serve as a reliable, early biomarker for autism, Pelphrey is using fNIRS to monitor the touch response at birth. "We're using it to study newborns and follow them over time to study the system," he observes. If and when autism develops in some of those babies, Pelphrey's team will refer back to its early testing to see if any signs were apparent.

The link between affective touch and interoception opens up another area of research: addiction. Martin Paulus, a psychiatrist at the Laureate Institute for Brain Research in Tulsa, Okla., is investigating whether he could use CT afferents to probe the neuroanatomy of addicted people or those at risk for addiction. His first results, reported in two studies in 2013, showed that individuals with substance abuse problems showed an overreaction to affective touch in the brain, particularly in the insular cortex. This heightened response to touch might indicate an increased need for other forms of strong stimulation, Paulus says, which might in turn explain the appeal of drugs to this group. On the other hand, a group of drug-addicted individuals a few months into sobriety showed the opposite: a reduced or dulled response to the affective touch. "The whole system gets toned down," Paulus says, perhaps as a consequence of drug use. A study of healthy adolescents, published in 2014, also found increased sensitivity to affective touch in that group compared with adults between the ages of 20 and 55, which may motivate teenagers to seek out experiences that involve pleasurable touch.

Like Pelphrey, Paulus wonders if sensitivity to affective touch could provide a biomarker to predict those at risk of addiction and if it could be altered with treatment. "We're at the very beginning," he says, "but [affective touch] gives us a neuroanatomical scaffold that we can then use to better understand when systems go wrong."

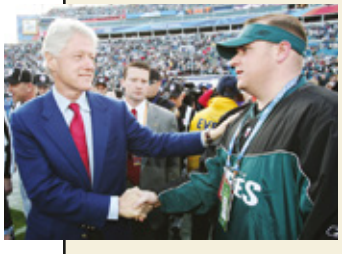
How Touch Makes Friends and Influences People

Touch in all its forms, whether a flirtatious nudge or a cruel pinch, can convey many kinds of social information. In 1984 psychologists Christopher G. Wetzel of Rhodes College and April H. Crusco, then at the University of Mississippi, reported that by briefly touching the hand or shoulder of a patron, a waitress could elicit a bigger tip.

Later studies have further demonstrated that touch can be used to exert influence between strangers, helping salespeople pressure customers or charities seek volunteers. This special touch might even explain why some politicians clap the shoulders of their constituents whenever they meet.

The effect is also at work between intimates. For instance, one 2011 study carried out by a group of psychologists at Central Iowa Psychological Services and Iowa State University found that a woman might touch her spouse more often when discussing a topic of conversation that she brought up than a subject that her partner had raised—as though the extra pressure, physically and metaphorically, might increase her sway. (The study found that men, on the other hand, used touch much less often and without any regard to the person who started the conversation.)

Researchers believe physical interactions that signal warmth and trust can also boost cooperation in groups. In 2010 psychologists at the University of California, Berkeley, found that the amount of time that players on NBA basketball teams spent touching one another early in the season could predict their performance months later. Whether celebratory fist bumps, high fives or half-hugs, the extra contact seemed to reflect a team's united spirit and indicate its ability to play well as individuals and as a unit. —*Daisy Yuhas*



Several studies have found that people use touch to build and reinforce bonds between one another. This could help explain why President Bill Clinton (*left*) was so famously "hands on" while on the campaign trail. Recent research indicates that basketball players in the NBA—such as the Oklahoma City Thunder teammates seen at the right—may perform better when their team engages in more physical contact such as hugs.

The Subtleties of Sensation

The combined evidence, though preliminary, suggests that CT afferents have an important role in our emotional health and that this system is crucial to encouraging human interaction. But not everyone is convinced. David Ginty, a neurophysiologist at Harvard University who is working to delineate the nerve circuits that control all aspects of touch, theorizes that CT afferents are part of an ensemble of fibers (scientists have identified six other fibers in that category) working together like a symphony to convey information about light touch to the brain. In other words, he suspects that CT afferents alone are not as significant as McGlone and Olausson believe they are. In 2012 other neuroscientists, led by Christian Keysers, now at the University of Amsterdam, reported findings suggesting that despite the activity in the insular cortex brought on by affective touch, there are also significant responses in the more traditional brain area for touch, the somatosensory cortex. That could indicate that the affective touch system is not so separate from discriminative touch after all.

Furthermore, it is likely that CT afferent fibers work with other systems in the brain and body that become activated in response to physical contact. The hormone oxytocin, for example, is released by gentle touch and increases our social interest. It is clear that oxytocin must work in some way with CT afferents in contributing to attachment, but we still do not know how. Olausson and his colleague India Morrison, now at Linköping, are embarking on a study designed to try to tease out the relation between oxytocin and CT afferents more clearly.

What we *think* about how we feel also matters. Just because a touch stimulates our CT afferent fibers does not mean it will be enjoyable to everyone in every circumstance. If a stranger caresses your arm on the subway, you are unlikely to interpret the touch as pleasant. One of Olausson's and Wessberg's colleagues, Dan-Mikael Ellingsen, now at Harvard, investigated such effects in a 2014 study. Subjects were told they were going to receive an oxytocin nasal spray that would enhance the pleasantness of touch; in reality, they got a placebo saline spray. Nevertheless, they reported greater pleasantness. But exposing subjects to friendly or angry faces affected their perception of touch. One explanation, Olausson says, may be that competing information from the senses and the brain is reconciled on a case-by-case basis in the same way that we can enjoy the pain of eating spicy foods. If you have CT signaling, he says, there is a good chance you will perceive touch as pleasant, but if there are strong enough conflicting messages (an angry face, a creepy stranger, even a foul odor), the brain can veto the message from the CT afferents and interpret that touch differently.

To really understand the role of affective touch in shaping our brain's social processing, researchers will need to turn to animal models that can provide more precise information. Ginty, for example, studies touch in mice. "It's hard to ask a mouse how something feels," he acknowledges, but the new genetic tools available allow plenty of other tricks you cannot do with humans. Ginty's team is able to visualize and label sub-

GETTY IMAGES

Our system for affective touch most likely works in conjunction with other responses to tactile sensation, such as a rush of the hormone oxytocin, which may heighten the social significance of these interactions.

types of neurons in mice. The researchers can record the activity of those neurons, and perhaps most intriguingly, they can turn off particular sets of neurons to assess the physiological and behavioral responses that result.

Because touch has been so understudied, relative to senses such as vision and hearing, and because work on affective touch is so new, there is a feeling among those in the field of venturing into thrilling, uncharted territory. "This is an incredibly exciting time," Ginty says, "because I think over the next five or 10 years, we're really going to crack open the circuits that underlie the responses to different types of [touch] under different conditions." As we come to understand this sense better, Ginty believes we will be able to identify and develop new treatment solutions based on touch for conditions as diverse as disorders such as Rett syndrome or autism, neuropathic pain and spinal cord damage. And the interoceptive role of gentle touch could have rehabilitative implications. Aikaterini Fotopoulou of University College London has found some evidence to suggest that using affective touch in hands-on therapy might help people with brain lesions regain a sense of ownership over certain body parts.

For the rest of us, a light touch between intimates, as akin to those early caresses I shared with my babies, remains one of the purest signals of mutual comfort and affection. In a society that so often substitutes virtual communication for personal contact, the findings on affective touch remind us to relish every embrace and hold hugs even a few seconds longer. Those moments may be the bedrock of our richest relationships. M

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GETTY IMAGES

How Violent Video Games Really Affect Kids

They are breeding the thugs of tomorrow, or so the conventional wisdom goes. But sometimes a game is just a game

By Greg Toppo

Illustration by **ELEVENDY**

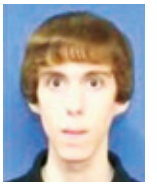
On the morning of August 12, 2013, nearly eight months after 20-year-old Adam Lanza shot his way into Sandy Hook Elementary School in Newtown, Conn., and killed 26 people, Michael Mudry, an investigator with the Connecticut State Police, drove to nearby Danbury to try to solve a little mystery. Police had found a Garmin GPS unit in Lanza's house, and its records showed that the gunman had driven to the same spot nine times in April, May and June 2012, arriving around midnight each time and staying for hours.

The GPS readout took Mudry to the vast parking lot of a suburban shopping center, about 14 miles west of Lanza's home. Workers at a movie theater there immediately recognized Lanza from a photograph. He was at the theater constantly, they told Mudry, but never to see movies. He came to the lobby to play an arcade game, the same one, over and over again, sometimes for eight to 10 hours a night. Witnesses said he would whip himself into a frenzy, and on occasion the theater manager had to unplug the game to get him to leave.

Police had been scouring Lanza's home since the shootings, and on his computer hard drive they found information on weapons magazine capacities, images of Columbine killers Eric Harris and Dylan Klebold, copies of the violent movies *Bloody Wednesday* and *Rampage,* and a list of ingredients for TNT. And like many teenaged boys, Lanza owned the typical first-person shooter, fighting and action games: Call of Duty, Dead or Alive, Grand Theft Auto.

But those weren't the games that possessed Lanza at the movie theater. The title that so consumed the Sandy Hook shooter? Dance Dance Revolution—an arcade staple that has players dance on colored squares to the rhythm of Asian techno-pop. That discovery not only surprised investigators, it also was at odds with overheated speculation in the media and around dinner tables that violent video games had helped turn Lanza into a killer.

Yet no one knows how any of these games—Dance Dance Revolution included—might have affected a kid who was clearly struggling. The truth is that decades of research have turned up no reliable causal link between playing violent video games and perpetrating actual violence. This is not to say that games have no effect. They're built to have an effect. It's just not necessarily the one that most people think.



Adam Lanza, the Sandy Hook shooter, whipped himself into a frenzy playing a video game in the months before his murderous rampage. The title that so possessed him? Surprisingly, it was Dance Dance Revolution.

CORBIS (*Lanza*); MARIO TAMA *Getty Images (playing a video game)*

A Tradition of Worry

The implicit connection between violent media and violent behavior is so old that, like a barnacle clinging to a hull, it's not easily dislodged. The notion dates at least to the Victorian era, when educators, tastemakers and clergymen began criticizing what was then a fairly raucous popular culture. Vi-

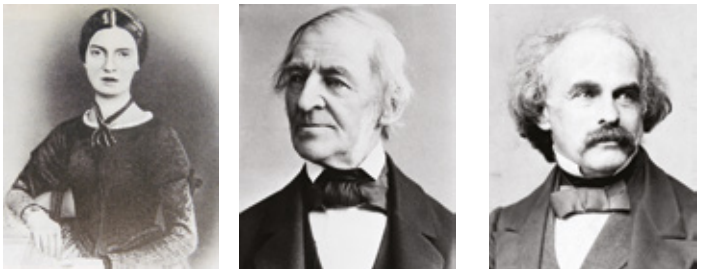
FAST FACTS

FAST BUT NOT SO FURIOUS

1. Children who observe an adult acting violently tend to follow suit when they are frustrated.
2. Violent games appear to be effective teachers of aggressive attitudes.
3. Research has failed to show a causal relation between playing violent games and perpetrating violent acts.
4. The fighting that kids engage in with video games is more akin to play than violence.

The implicit connection between violent media and violent behavior is so old that, like a barnacle clinging to a hull, it's not easily dislodged.

olent, sex-soaked dime novels and penny-dreadful magazines were immensely popular, and upstanding publications such as *Harper's* and the *Atlantic Monthly* took delight in denouncing them. Author and critic Harold Schechter, whose 2005 book *Savage Pastimes* lays out a social history of violent entertainment, notes that the trend divided the literati of the time. Ralph Waldo Emerson complained about his countrymen "reading all day murders & railroad accidents," but Nathaniel Hawthorne loved the scandal sheets so much that he had a friend ship stacks of them to Liverpool, England, while he lived abroad as a U.S. consul. The belle of Amherst herself, Emily Dickinson, relished stories of "those funny accidents where railroads meet each other, and gentlemen in factories get their heads cut off quite informally."



Emily Dickinson (*left*) relished grisly stories of factory decapitations; Ralph Waldo Emerson (*center*) bemoaned the popularity of penny dreadfuls, but Nathaniel Hawthorne (*right*) had his friends send them by the stack when he lived abroad.

The 20th century saw criticism grow more robust. In 1936 Catholic scholar John K. Ryan laid out what he called the "mental food of American children," as seen through the media they consumed. It was a long menu, one that included "sadism, cannibalism, bestiality. Crude eroticism. Torturing, killing, kidnapping." He was talking about daily newspaper comic strips. In 1947 critic and actor John Houseman lodged similar complaints about cartoons on television. They "run red with horrible savagery," he wrote.

Into this fray entered Stanford University psychologist Albert Bandura, now 89, whose experimental studies in the early 1960s established the theoretical basis for limiting kids' access to violent media. In a 1961 study, Bandura and his colleagues gathered 72 preschoolers. Laboratory assistants led the kids, one at a time, into a playroom, where they sat at a small table and received instruction on how to make potato-print pictures. Soon another adult entered the room and settled into the opposite corner with a Tinkertoy set, a mallet and a five-foot, inflated Bobo clown doll, the kind that rights itself if knocked over. The adult then either quietly assembled the Tinkertoys, ignoring Bobo, or turned to the doll and began "aggressing toward it"—punching it, sitting on it, kicking it around the room, all the while saying things such as "Sock him in the nose!" and "Pow!"

After 10 minutes, each child was led into another room and invited to play with some "relatively attractive toys," such as a fire engine, a spinning top and a doll set. But after two minutes, a lab assistant announced that these were "her very best toys" and that she'd decided to reserve them for other children. The kids were swept into a third room that held more toys, both "aggressive and nonaggressive": a tea set, crayons, dart guns, a mallet … and a three-foot Bobo doll. You see where this is going.

Faced with the frustration of having nice new toys suddenly snatched away, the preschoolers who had watched Bobo get mistreated were more likely than the others to take out their aggression on the mini Bobo. Bandura repeated the experiment in 1963, using film and cartoon depictions of Bobo's mistreatment, with similar results. The conclusions

THE AUTHOR

GREG TOPPO is the national education and demographics reporter for *USA Today.*

GETTY IMAGES (*Dickinson*); CORBIS (*Emerson* and *Hawthorne*)

In his seminal work on how children learn to be aggressive, psychologist Albert Bandura found that kids who saw adults kick and punch an inflatable clown doll did the same when some toys were taken away from them.

seemed clear: watching unchecked aggression in real life, on film or in cartoons makes us more aggressive because it provides us with "social scripts" to guide our behavior. Bandura's conclusions opened a floodgate of "media effects" research that continues today.

The problem is that many of the findings, especially when applied to children's media and play, are misleading at best. Critic Gerard Jones, whose 2003 book *Killing Monsters* makes a case for giving kids access to "make-believe violence," writes: "There is no evidence to suggest that punching an inflatable clown has any connection to real-life violence." In many cases, he and others say, researchers mistake natural competitiveness or the effects of discomfort for aggression or mislabel the subjects' temporary aggression as behavior that holds the potential for violence. In an often quoted 1976 study led by Brian Coates at Washington State University, researchers found that preschoolers who watched the famously mild *Mister Rogers' Neighborhood* were three times more aggressive afterward. Jones suggests that the experiment itself may have made kids anxious or even angry by compelling them to "sit in a hard plastic chair in a strange room" and watch TV on cue.

It was the 1999 Columbine High School shootings that got many Americans thinking about violent video games. After the attacks, victims' families sued more than two dozen game makers, saying titles such as Doom, a first-person shooter that the two teen gunmen played, desensitized them to violence. A judge dismissed the lawsuits, but the post-Columbine uproar led more researchers to begin dissecting games, much as Bandura did for TV, in search of the roots of aggression.

Deciphering the Data

A few studies tried to draw distinctions between good and bad games. In a 2010 experiment, Tobias Greitemeyer, then at the University of Sussex in England, and Silvia Osswald of Ludwig Maximilian University in Germany asked subjects to play one of three video games—either a "prosocial" game, an "aggressive" game or the "neutral" game Tetris. After eight minutes, an experimenter reached for a stack of questionnaires but "accidentally" knocked a cup of pencils off the table and onto the floor. Participants who had played the prosocial game were twice as likely to help pick up the pencils as those who played the neutral or aggressive game.

Others have tried to tease out the aftereffects of playing violent games. In a 2012 study, André Melzer of the University of Luxembourg, along with Mario Gollwitzer of Philipps University Marburg in Germany, found that inexperienced players felt a need to "cleanse" themselves after playing a violent video game (the so-called Macbeth effect: "Out, damned spot!"). Researchers asked subjects to play

COURTESY OF ALBERT BANDURA *Stanford University*

Eighth and ninth graders who played violent games more frequently were more vigilant for enemies and got into more arguments with teachers.

either a driving game or the mayhem-heavy Grand Theft Auto for 15 minutes, then pick gifts from an assortment, half "hygienic" (shower gel, deodorant, toothpaste) and half nonhygienic (gummy bears, Post-it notes, a box of tea). Inexperienced players who played Grand Theft Auto were more likely to pick out hygienic products than were experienced players or inexperienced players who had played the driving game.

But neither of those studies make the case that these games lead to real-word violence. Although drawing conclusions about small population subgroups—such as kids at risk of violence—from broad population trends can be dicey, it is still worth noting that as violent video games proliferated in recent years, the number of violent youthful offenders fell—by more than half between 1994 and 2010, according to the U.S. Department of Justice. This trend is not what you would expect if these games had the power to make good boys go bad. Indeed, in a 2011 analysis of game sales from 2004 to 2008, A. Scott Cunningham of Baylor University, Benjamin Engelstätter of the Center for European Economic Research in Mannheim, Germany, and Michael R. Ward of the University of Texas at Arlington found that higher rates of violent game sales actually coincided with a drop in crimes, especially violent crimes. They concluded that any negative behavioral effects playing violent games might have are more than offset because violent people are drawn to such games, and the more they play, the less time they have for crime.

Even if violent video games are not turning people into killers, we might still wonder if they are harming our kids in subtler ways. As psychologist Douglas A. Gentile of Iowa State University puts it, whatever we practice repeatedly affects the brain. If we practice aggressive ways of thinking, feeling and reacting, he writes, "then we will get better at those." In a 2008 survey on the gaming habits of about 2,500 young people, Gentile and his father, psychologist J. Ronald Gentile, found that children and adolescents who played more violent games were likelier to report "aggressive cognitions and behaviors." They concluded that violent video games "appear to be exemplary teachers of aggression." They also found that eighth and ninth graders who played violent games more frequently displayed greater "hostile attribution bias" (being vigilant for enemies) and got into more arguments with teachers.

The greatest worry is the impact on children who are already at risk. "Media is most powerful in our lives when it reinforces our existing values," media scholar Henry Jenkins, now at the University of Southern California, said in a 2003 episode of *Religion & Ethics Newsweekly*. Indeed, Jenkins argued in an essay for PBS, a child who responds to a video game the same way he or she does to a real-world trauma could be showing symptoms of an emotional disturbance. So used in the right setting, a violent game could actually serve as a diagnostic tool.

But beyond such special circumstances, media effects research, with its Bobo dolls as markers of real-world aggression, is problematic. The fighting kids do in physical games and video games alike is just a simulation. In other words, it is play. It looks like fighting, wrote Brian Sutton-Smith, the late renowned play theorist, in his book *The Ambiguity of Play,* "but it is also the opposite of fighting … carried on by those who are not enemies and who do not intend to harm each other."

In a way, we are pointing fingers at the wrong people. When we worry that a violent game is going to turn our kids into killers, aren't we the ones who can't tell fantasy from reality? Kids already know the difference. **M**

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WALKING 2.0

ONE WOMAN'S STORY ILLUSTRATES HOW HOPE, PERSEVERANCE AND EXOSKELETON TECHNOLOGY ARE REVOLUTIONIZING DISABILITY

By Amanda Boxtel

I was 24, and I felt invincible. I taught aerobics. I was a sprinter, a long jumper, the former athletics captain of my school and a ballet dancer. I loved to twirl in space, run on the beach and hike through the wilderness.

All of that changed in a split second. In a freak somersault while downhill skiing, I shattered four vertebrae, along with the illusions of my immortality. An electric current zapped through my legs, and then I lost all movement and sensation below my pelvis. I was paralyzed.

As I lay in a hospital bed, in the winter of 1992, a young doctor strode into my room and spoke words that resonated in every cell of my body: "Amanda, you'll never walk again." As if to soften the blow, he added, "But you can still have children." My unresponsive body lay still in the stark room. My mind was clouded with morphine. The shock left me totally numb.

Thoracic 10, 11 and 12 and the first lumbar vertebra—which the doctors referred to in shorthand as T10, 11 and 12 and L1—were crushed. Like jagged rocks crashing into a river, the shattered bone fragments had smashed into my spinal cord, denying oxygen to the cells and consequently causing them to die.

According to the Christopher & Dana Reeve Foundation, nearly one in 50 people, some six million in all, live with paralysis in the U.S., often as a result of stroke. I represent one of the 1.3 million people in the country who have a spinal cord injury. It is a cruel injury in so many ways beyond not being able to walk. It means grieving the loss of my sexuality and ability to void urine and empty my bowels on my own. It also involves dealing with secondary complications such as intense neuropathic pain.

It took time to turn my wounds into wisdom, to remove any self-imposed limitations, and to live a richer and fuller life. It has taken 23 years of paralysis for me to understand that acceptance and hope must coexist. Adaptive technology has enabled me to ski, kayak and hand cycle. Yet my deepest yearning has always been to learn how to walk again.

Fortunately, we live in an era in which

DAN KITWOOD *Getty Images*

Amanda Boxtel takes a stand at the 2011 London International Technology Show. After 18 years in a wheelchair, Boxtel learned to walk in an exoskeleton. Today, with help from a physical therapist, she regularly uses an exoskeleton for rehabilitation.

technology is augmenting human potential like never before. Science is enabling people to dream big and help one another. For the first time in the history of assisted movement, there is a mobility option beyond standard wheelchairs and unpowered orthotics: the bionic exoskeleton suit. This technology has already transformed my own life, and it holds the promise of restoring dignity and self-reliance to a great many others. We are on the precipice of redefining the word "disabled."

Made for Mobility

When a person sustains a spinal cord injury, not being able to walk brings on a multitude of complications that can be life-threatening. The heart and lungs do not function as well, circulation is impaired, body temperature becomes dysregulated, and bowel and bladder function are significantly disrupted. The longer a person sits, the greater the risk for joint contractures, muscle atrophy, osteoporosis and pressure sores known as decubitus ulcers. Over time limited mobility can be socially isolating. Taken together, these issues lead to a shortened life span.

Can paralysis be reversed? Stem cell therapy certainly holds some promise. So does recent work that combines locomotor training with doses of electrical stimulation to the spine, demonstrating that spinal networks can learn with task-specific practice. The spinal cord, such research suggests, may be as smart and malleable as the brain. And yet the goal of using regenerative techniques to fully restore function remains distant.

After the accident, I knew I had to move my body, or it would essentially begin to die. We are made for mobility. I willed myself through my darkest moments by affirming: *All you have to do is pick up your feet.... Destiny waits for no woman. You are ready. It's up to you and you only.*

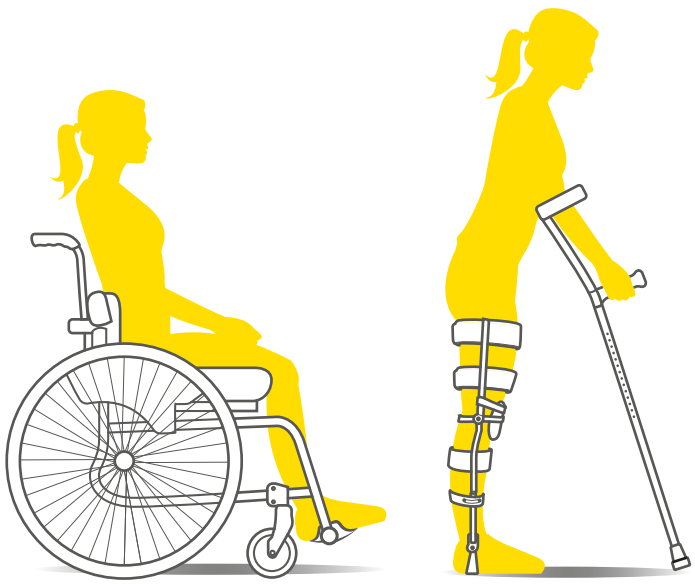
I have learned firsthand how important it is for the neuromuscular system to stay active. In the years after my accident, I maintained range of motion and flexibility in my limbs through intensive therapies such as yoga, Pilates and physical therapy. I trained four to five days a week, combining all kinds of muscular, cardiovascular and balance exercises. I used an antigravity treadmill (which elevated the body so I could engage in cardiovascular exercise without bearing weight on my legs), wore long leg braces while using a walker for balance and vibrated on a side-alternating therapeutic platform to mimic the left-right alternation of walking. A well-rounded exercise regimen helped me maintain fitness and functional independence.

FAST FACTS
MOVEMENT REVOLUTION

1. An estimated six million people in the U.S. suffer from some form of paralysis.
2. Bionic exoskeletons offer a new kind of therapeutic intervention, enabling people to enjoy the physical, emotional and psychosocial benefits of moving upright at a natural gait.
3. Cost and accessibility remain the greatest challenges in connecting people who could benefit from using exoskeleton technology.

I also made myself a guinea pig to test cutting-edge treatments. Sixteen years postinjury, I became a "radical stem cell tourist." I was the first person in the U.S. to undergo controversial human embryonic stem cell treatments in India. The procedure still has not undergone rigorous scientific review, so I cannot recommend its use—but I am nonetheless grateful that it allowed me to regain trace muscle power and sensation. These benefits improved my quality of life, even if they did not enable me to walk.

Through all these experiences, it became clear to me that in any given therapy, at least one of three components of walking was missing. First was the challenge of bearing my full weight on my legs. Second, no treatment enabled me to walk naturally: with joints and bones lined up correctly and a reciprocal gait, which entails moving one arm, then the opposite leg, and being able to bend my knees and strike my heels on the ground with each step. Finally, I could not experience the visual and muscular feedback (called proprioception) that accompanies moving over a certain distance.



These limitations did not discourage my efforts. Instead they served as further motivation. I knew that if I ever hoped to walk again, I would need to prepare my body for the challenge. And in my waking dreams, I began to imagine moving in perfect alignment, encased in an outer shell—a robotic suit that I could strap on, stand up and walk in.

On My Feet

On a Friday afternoon in the summer of 2010, I received a telephone call from Eythor Bender, then CEO of Berkeley Bionics (since rebranded as Ekso Bionics). Bender had heard of me through word of mouth. By that point, I was already giv-

CLINT FORD

ing talks about my story, publicly pursuing new treatments and working with a nonprofit organization that helped people with paralysis enjoy outdoor recreation. Bender had a proposition: he wanted to see if I would test-pilot an exoskeleton prototype for a *National Geographic* television series. I could not possibly refuse.

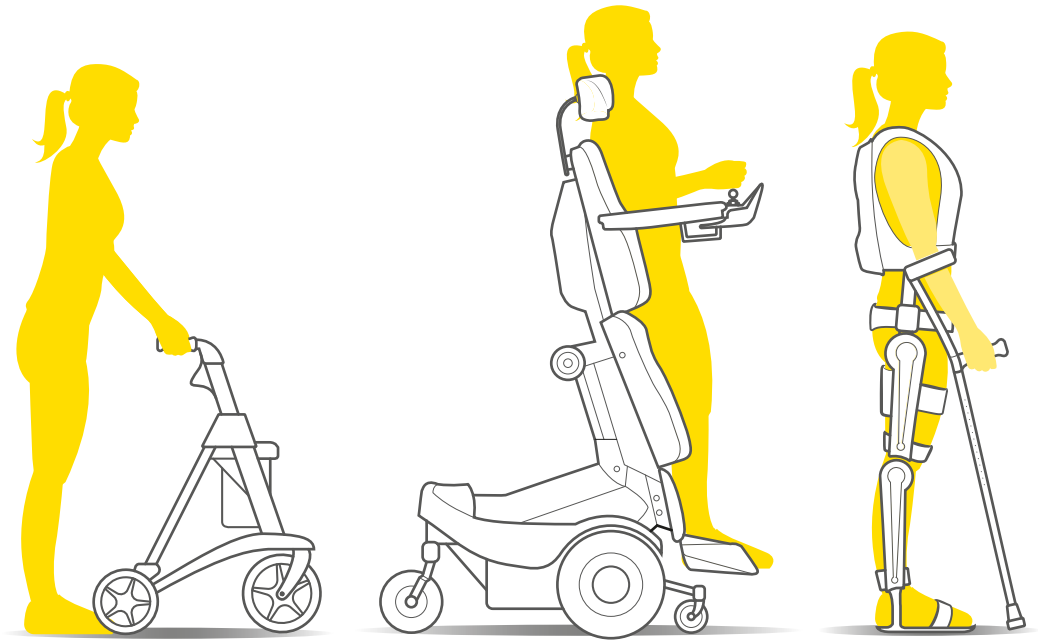
Eight days later I flew to the company's location in Berkeley, Calif., where the film crew had allotted me just four days to demonstrate that I could walk in the exoskeleton. The prototype was primitive by today's standards, but the basic idea, which remains at the core of exoskeleton design, was based on the human body. The metal frame served as a skeleton, motors gave me power much like my muscles, and sensors sent signals to a central computer, located on a backpack, just as nerves communicate with the brain. Together these pieces made up a wearable robot that could be manipulated by remote control.

To use the device, engineers strapped me into the exoskeletal frame that encompassed my legs and feet. They connected me to a pulley-and-tether system rigged to the ceiling for extra safety as the robot powered me upright and onto my feet in a natural sit-to-stand motion. The engineers controlled all the robot's motions with a remote. My job was to maintain my center of gravity and shift my weight as appropriate to keep my balance. I tipped and stumbled while the engineers watched and guided me. Had it not been for my rigorous training, I might not have managed to stay upright, but I was walking independently (with a spotter) by day four.

Those moments were profound. I had to unlearn the double-handed pushing habits that had become ingrained during 18 years of using long-legged braces with a walker and propelling a hand cycle and a wheelchair. I had to relearn the natural motions of walking, such as moving limbs cross-laterally (right arm, then left leg, and so on). I stared straight ahead into space, nervous and tentative, concentrating on my positioning. The experience was exhausting, exhilarating and incredibly emotional. Imagine wanting something intensely for nearly two decades and suddenly receiving it in one powerful, upright moment.

My first steps in an exoskeleton would be followed by many more. I became an ambassador for Ekso Bionics and continued practicing with newer models as the technology improved. In 2012 the company's Ekso suit became commercially available for rehabilitation centers for an average cost of $110,000 plus service and warranty fees. A year later, after a massive community fund-raising effort, I acquired my own personal suit. I named it "Tucker" in memory of my beloved late golden retriever so that we could still, in a sense, go for walks together.

My suit is more sophisticated than the prototype I tested in 2010. Tucker is equipped with smart crutches, for example, which enable me to initiate walking and standing modes and let me trigger my first step. Another assistive feature enables me to engage the trace muscles in my legs to contribute maximum effort to my step while the robot's artificial intelligence powers me through to finish the step in a normal gait. Although I own Tucker, all of my walking is done in a rehabilitative context, with a



For the first time in the history of assisted movement, there is a mobility option beyond standard wheelchairs and unpowered orthotics: the bionic exoskeleton suit.

THE AUTHOR

AMANDA BOXTEL is a professional speaker and serves as executive director for the Bridging Bionics Foundation, which aims to bridge mobility with bionic technology. She lives near Aspen in Basalt, Colo., with a golden retriever named Benson.

Boxtel visits the Maroon Bells scenic area in Colorado with her dog, Benson.

physical therapist spotting, to ensure that I am safe and everything is working properly. (The Ekso is for clinical use only and not designed for daily living. The U.S. Food and Drug Administration is currently revisiting this technology's safety and efficacy in light of new regulatory classifications.)

To date, I have walked more than 130,000 steps with Tucker. The health benefits have been numerous. Walking causes my digestive system to become more efficient, with increased bladder and bowel regularity. I have better circulation in my legs: they are warm to the touch and pink rather than cold and splotched with purple. Swelling is reduced in my legs and ankles. My legs actually tingle through to my tippy-toes when I stand up and walk. My heart pumps more blood through my body. I have relearned proper gait patterns and the best way to align my joints and bones.

I have also regained an awareness of where my body is in space, finding my center of gravity with weight shifts as though the exoskeleton has become a part of my own body map. My sleep has improved with high-dosage walking. I have increased mental acuity, as if a veil has been lifted from my head. My neuropathic pain dissipates almost completely, and I enjoy a better quality of life. I firmly believe that exoskeleton technology can reduce the risk of secondary complications and become a preventive health care measure.

My sleep has improved with high-dosage walking. I have increased mental acuity, as if a veil has been lifted from my head. My neuropathic pain dissipates almost completely.

I am not alone in that belief. Researchers at leading rehabilitation hospitals around the globe, including the U.S. Department of Veterans Affairs and the Kessler Foundation, a New Jersey–based nonprofit, are investigating how exoskeletons could modulate the secondary consequences of being unable to walk. Gail Forrest, an expert in human movement at Kessler, found preliminary evidence in 2012 that in 13 patients with spinal cord injury, using the Ekso suit could improve heart, lung and circulatory health.

When I don the exoskeleton, stand up and walk, I feel the tallness of my body—something I never imagined was possible in my lifetime. Each time I stand, a moment of euphoria sweeps through my body as I feel my five-foot, seven-inch frame. I look across a room and at the tops of things. My greatest joy is standing at eye level and feeling a heart-to-heart hug. In my 23 years of paralysis, my mother has grieved my loss and hoped to see me walk again. Every step I make is for her. And I feel like I am walking for every brother, sister, friend, neighbor or colleague who shares that same dream for a loved one.

Beyond Disability

Exoskeletons carry important symbolic significance beyond their practical uses. For 1,500 years, the wheelchair has been the only mobility option for millions of people. And although it may enable someone like me to live a full life, it is also the universal symbol for disability, which can be disempowering. For some users, the wheelchair becomes their entire identity. Today, for the first time, we are encountering an alternative with radically different connotations. Exoskeletons are science fiction's great equalizers: helping Ellen Ripley defeat the extraterrestrial queen in *Aliens* and transforming Tony Stark into Iron Man. They represent human enhancement and imagination.

In the past decade we have begun to see exoskeletons take their place in society for industrial and military uses as well as for physical rehabilitation. In 2008, with support from the

CHARLES ENGELBERT

U.S. Department of Defense, Berkeley Bionics developed an exoskeleton called HULC (for human universal load carrier) that allows soldiers to squat, march and leap over rough terrain while carrying 200 pounds of gear. Multiple manufacturers are looking to exploit a more general market by taking exoskeletons into industrial applications, such as helping warehouse workers lift very large boxes or firefighters climb multistory buildings.

Companies in at least five countries now manufacture and sell medical exoskeletons. All must be used with a physical therapist, with the exception of the ReWalk system from ReWalk Robotics. Last year the FDA approved the $70,000 device for at-home use with a friend or family member serving as a spotter. What I have learned from my own research and experience testing a variety of exoskeletons is that all of them provide similar psychological and basic physical therapeutic benefits. The challenges to more widespread use are weight, cost, accessibility, minimizing fall risk, improving functionality and individual customization. Most of today's suits weigh between 22 and 50 pounds and cost more than $70,000.

In 2013 Boxtel participated in a research and development project led by engineers at 3D Systems. In the photograph at the right, the team scans Boxtel to design 3-D-printed components for a form-fitting and highly personalized exoskeleton.

COURTESY OF 3D SYSTEMS

Future exoskeleton technology will not only produce lighter and cheaper models, it could fuse robotics, 3-D printing, smart materials, nanotechnology, neural interfaces and design to morph flawlessly into the human body. That would bring us closer to the true definition of the singularity—that is, the merging of human with machine [see "Melding Mind and Machine," on page 52]. But we must keep individuality and humanity at the forefront; the goal is to humanize machines, not mechanize humans.

I have had a glimpse of this future. In 2013 design engineers at 3D Systems invited me to participate in a research and development project to create the first hybrid partially 3-D-printed exoskeleton. The design team scanned my body to tailor the suit exactly to it and tapped my ideas for the device's appearance. The 3-D-printed parts—designed to resemble my muscles—were lightweight, ventilated, flexible and strong. The resulting suit was easily doffed and donned, and it provided support without pinching any pressure points. I felt, for the first time, as if the outer casing of the suit was one with me. Because I helped to create it, it matched my personality.

With 3-D printing, we can showcase the human body and stunning design, along with functionality. I was a co-creator of the design process, bringing the human experience into the equation. I can envision suits that are sleek, sexy, streamlined and feminine or rugged and practical for the no-makeup, adventuresome athlete that I am. As exoskeleton manufacturers engineer more functional suits for daily living, we can look forward to creating designs that enable individuality and self-expression—the ultimate personal fashion statement.

Making Strides

My experiences have convinced me that walking should be seen as a human right. By supporting research and development, we can usher in the next generation of exoskeletons and increase their access and affordability around the world. Two years ago I founded the Bridging Bionics Foundation, which educates the public about bionic advances and raises money for further study and helps communities gain access to bionic equipment. Although there are potentially millions of Americans with limited mobility who could benefit from an exoskeleton, manufacturers currently estimate that fewer than 1,000 devices have been sold in the U.S. The challenges are many, but chief among them are access and price. Not only are the devices costly, but training and annual maintenance fees can also be prohibitively expensive. Most of these costs are not covered by insurance.

This year I donated Tucker to my community so that others could share in this tremendous gift. (I will still visit and use my exoskeleton at the rehabilitation center.) In addition, I led a fund-raising effort to raise tens of thousands of dollars for training other individuals who are paralyzed and meet the inclusion criteria to walk in this device.

For individuals who are paralyzed or have some form of lower-extremity muscle weakness, the exoskeleton has come to represent a fusion of biology and technology, the most complicated neuroprosthesis ever imagined. It is a fantastic example of the power of combining science, engineering and the human spirit. I foresee a day when people will no longer hear the words: "You'll never walk again." Instead they will hear: "Yes, you can. It'll just be different. Let's show you how." M

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MELDING MIND & MACHINE

Instead of using remotes or crutches, future generations of bionic exoskeletons could communicate directly with the nervous system

By Ariel Bleicher

ILLUSTRATIONS BY CLINT FORD

Imagine yourself as a child, standing on the tops of your dad's loafers as he shuffles across the living room. It is exhilarating—being maneuvered like a marionette, his feet moving your feet, his hips swinging your hips. But here is the upshot of walking on someone else's shoes: eventually you would rather do it on your own.

For people who have lost some or all control of their legs, robotic exoskeletons are engineering marvels. In rehabilitation clinics and users' homes, they are getting patients who have lost mobility to spinal cord injury or stroke out of their wheelchairs and moving upright again for short periods. And this renewed locomotion has physical benefits, such as better blood circulation and lower risk of infection.

But for all their virtues, the medical exoskeletons on the market today have some clear limitations. Most models, for example, require patients to use crutches and allow only a limited range of motion. Engineers expect basic features such as agility and balance will improve with more sensors and more sophisticated control algorithms. The biggest advances, though, may come from making better use of patients' own abilities.

Several research groups are now working on a next generation of exoskeletons that electrically stimulate patients' muscles to par-

CHAD BAKER *Getty Images*

tially power the robotic brace. Further in the future, new devices that decode brain activity, known as brain-machine interfaces, or BMIs, could let patients control their cyborg legs with their mind. Tomorrow's exoskeleton may do more than move a pair of limbs. By creating a dialogue with the nervous system, it could become an integral part of the person who uses it.

The Body Electric

In the 1960s doctors began working with engineers to outfit mechanical braces with wearable electrodes, known as functional electrical stimulation (FES) systems, to aid in walking. The first of these contraptions, called hybrids, sent a gentle jolt through the calf to the peroneal nerve, which flexed the ankle, preventing patients from dragging their toes, a common symptom of stroke and multiple sclerosis. By the 1980s volunteers with spinal cord injuries were testing hybridized leg orthotics. These specialized braces used finger switches wired to strategically placed electrodes to contract the quadriceps and hamstrings, facilitating steps.

These early hybrids, however, had one big shortcoming. After a spinal cord injury, muscles shrink and weaken. Slow-twitch fibers, which enable sustained movements such as walking, morph into fast-twitch fibers, which provide instant force but become fatigued quickly. Patients could not power such a device very long before their muscles needed a rest. "Gravity always wins," says Ronald Triolo, executive director of the Advanced Platform Technology Center at the U.S. Department of Veterans Affairs.

Robotic exoskeletons could offer a solution. Triolo and other researchers are now incorporating FES into exoskeletons in hopes that they can coordinate with patients' muscles to share some of the burden. For example, Triolo's team is developing a prototype hybrid that requires implanting electrodes in the body to more precisely activate individual muscles by accessing deep nerves such as those that control the hip flexors. The scientists have found that contracting these muscles can lift the knee high enough for patients to climb stairs, but they can mount only a few steps before tiring. With a little extra push from the robot, they can ascend an entire staircase.

And there are unique advantages to exoskeletons with this hybrid design. Compared with traditional exoskeletons, these new devices require a user's body to do more work. "If you use a muscle instead of a motor for some movements, you can get away with much smaller motors and potentially have a smaller, lighter apparatus," Triolo says, which would make exoskeletons easier to transport and extend their battery life.

Exercise is another perk. Putting deconditioned muscles back to work builds strength and tone and increases metabolism, improving overall health. Many experts believe hybrid exoskeletons could help regenerate neural connections that were damaged or weakened by an injury or stroke. "For the neural system to recover, you need neurons firing," says Michael Goldfarb, an engineering professor at Vanderbilt University whose laboratory developed the technology behind the exoskeleton Indego, which U.S. manufacturing giant Parker Hannifin plans to release later this year. The company is also developing models with FES capability and expects to test these hybrids in clinics in 2016.

For some paraplegics, no amount of stimulation will get the muscles pumping again. But for the thousands of wheelchair-bound people who might benefit, hybrid exoskeletons could provide a safe way of learning to walk more independently. Goldfarb envisions these machines teaching locomotion like a coach spotting a gymnast. "As the muscles do more and more, the robot does less and less," he says. Some stroke patients, he predicts, may even recover well enough to "give the device back."

The Mind in Motion

The next frontier is the brain. Because exoskeletons today are operated physically, via manual controls or body positions, they demand a great deal of focused attention. Users cannot sip a cup of coffee, for example, or hold a lover's hand as they stroll down the street. A BMI could free the hands for multitasking while allowing more dexterous movements.

In a pioneering experiment with monkeys in 1969, physiologist Eberhard Fetz of the University of Washington showed it was possible to use electrical signals in the brain to control something outside the body. By implanting electrodes in monkeys' motor cortex, the brain region that governs voluntary movement, Fetz was able to record the activity of individual neurons. When these cells randomly fired at a certain rate, a monitor pinged, and the animals, which were strapped to a chair, got a treat. In just minutes, the monkeys learned to tweak their brain activity to ping the monitor whenever they pleased, essentially producing the sound—and a snack—with their mind alone.

FAST FACTS

THE ROBOTIC WALKING COACH

1. Existing exoskeleton technology can help people with impaired mobility, but it has significant limitations.
2. Functional electrical stimulation systems, which use gentle current to coax muscles into action, could enable lighter and more restorative bionic aids.
3. In the future, exoskeletons could communicate directly with the brain via implants or a sophisticated net of electrodes on the scalp.

CURRENT TECHNOLOGY

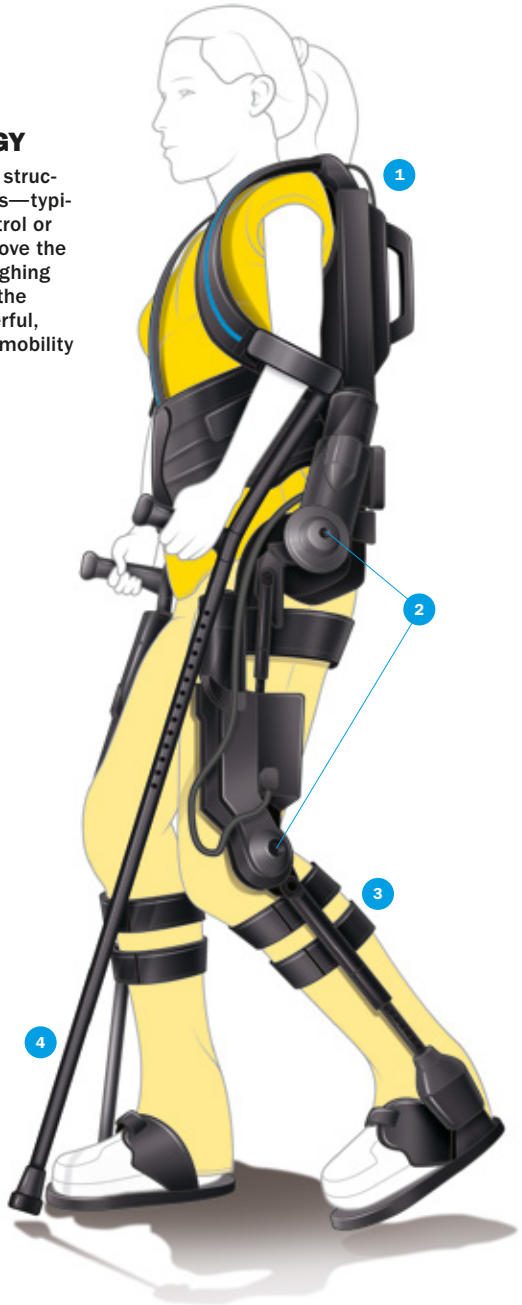
Today's exoskeletons provide structural support and use robotics—typically guided by a remote control or shifts in body position—to move the device and user forward. Weighing between 22 and 50 pounds, the equipment is heavy but powerful, enabling people with limited mobility to stand upright and walk.

1 A backpack contains a battery and computer, which controls the robot.

2 Electric motors at the hips and knees move the upper and lower legs.

3 Leg braces support the user and house sensors that provide feedback on joint position.

4 Crutches help with balance and in some cases include buttons to direct the exoskeleton.



By creating a dialogue with the nervous system, tomorrow's exoskeleton could be an intimate part of the person who uses it.

Using implants in rodents, monkeys and humans, researchers have since built more sophisticated BMIs to operate a cursor on a screen or a robotic limb. In a 2012 study, scientists led by Leigh R. Hochberg of Brown University taught two quadriplegic individuals to reach for and grasp objects with a robot arm by using only their thoughts. In each patient's motor cortex, a 96-electrode array the size of a baby aspirin recorded the chattering of hundreds of neurons. Using a mathematical model called a decoder, the researchers then translated these signals into machine commands, such as force, velocity and position—in much the same way that the spinal cord transforms the brain's output into a flutter of muscle contractions.

There are, however, problems with this BMI scheme. Although an implanted array gives the most fine-grained account of one's state of mind, it can invite infections and rarely lasts for more than a couple of years. That is because the brain attacks the device as a foreign invader, enveloping it in proteins that dampen the neural signals.

These drawbacks have led some researchers to investigate BMIs that use electroencephalography (EEG) systems, which record rhythmic activity across the entire brain through a net of electrodes on the scalp. Until recently, scientists believed EEG signals were too weak and noisy to use for controlling an exoskeleton. But a series of studies in 2010 suggested that, in fact, an EEG-based BMI might be able to decipher intended hand and leg motions with surprising accuracy. "We're still figuring out the limits of EEG," says José L. Contreras-Vidal, a neuroengineer at the University of Houston who led the studies. He is currently testing an early prototype called NeuroRex, an EEG-equipped exoskeleton that allows patients to initiate steps just by thinking about walking.

At Duke University, Miguel A. L. Nicolelis has undertaken a similar endeavor called Walk Again. The project made

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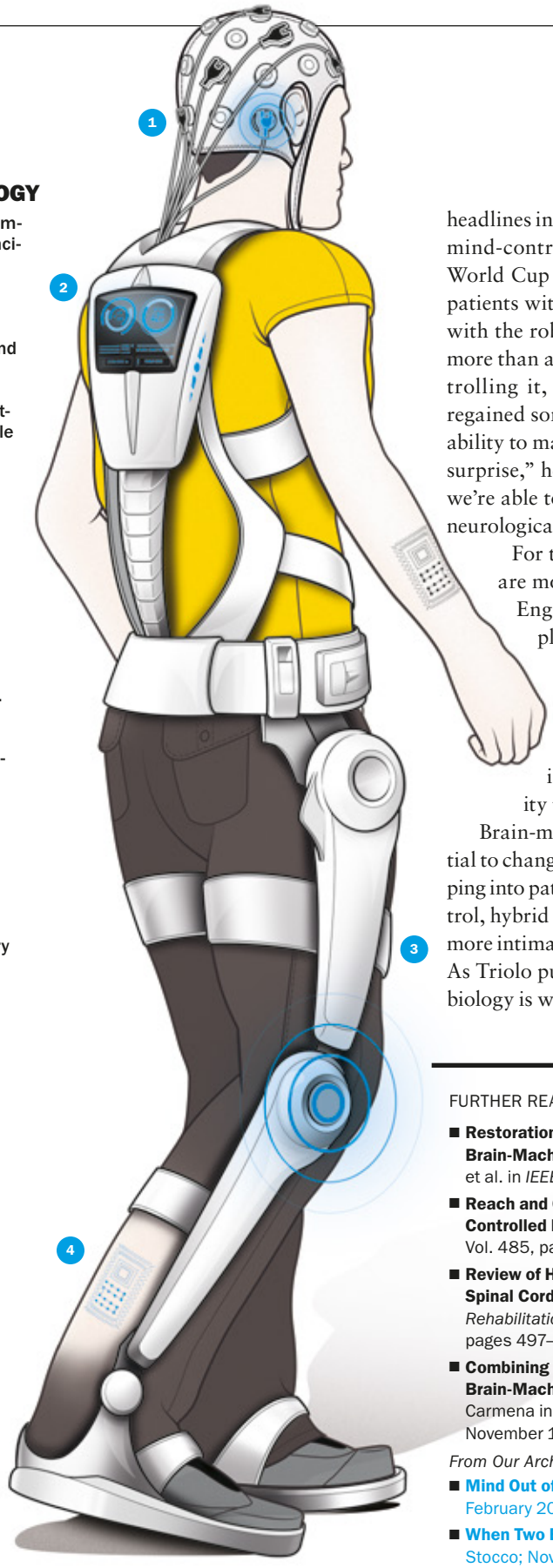
ARIEL BLEICHER is a freelance science journalist in New York City. She has written for *Scientific American* and *IEEE Spectrum,* among other publications.

FUTURE TECHNOLOGY

This artist's rendering combines the same core principles of current exoskeleton devices with a few critical innovations. The lighter design removes cumbersome crutches and remotes, relying on the user's brain to direct the equipment. Electronic tattoos could deliver a gentle vibration to the forearm or leg—depending on an individual's existing sensitivities—offering additional feedback as a person walks.



1 An electrode cap records brain activity, allowing the user's mind to directly issue commands to the machinery.

2 A computer converts brain signals into instructions for movement.

3 Motorized leg braces electrically stimulate muscles and assist in walking.

4 Electronic tattoos vibrate to provide sensory feedback, enabling people who lack other cues as the result of injury to still "feel" their movement through space and even the texture of the terrains they travel over.

headlines in 2014, when a 29-year-old paraplegic used a mind-controlled exoskeleton to literally kick off the World Cup in Brazil. Since then, Nicolelis says, eight patients with spinal cord injuries have been practicing with the robot in his lab two to three days a week for more than a year. They have gotten much better at controlling it, he reports. Remarkably, they have also regained some sense of touch and, in several cases, the ability to make small leg movements. "This was a great surprise," he says. "It seems we're at a threshold where we're able to not only restore mobility but also induce neurological recovery."

For the moment, brain-controlled exoskeletons are most likely decades away from common use. Engineers must first show they can make implants safe and durable or else use EEG signals from the scalp to direct more diverse skills, such as turning and ascending stairs. They must also ensure that real-world distractions, such as talking or eating, will not interfere with the decoder's ability to interpret a user's intentions.

Brain-machine interfaces ultimately have the potential to change how an exoskeleton serves its user. By tapping into patients' natural systems of movement and control, hybrid and brain-directed assistants could become more intimately bound to the minds and bodies of users. As Triolo puts it, "working with biology instead of for biology is where the future is going." M

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BEFORE THE TRAUMA

New insights are making it possible to predict—and maybe one day prevent—cases of post-traumatic stress disorder

By Moises Velasquez-Manoff

Illustration by **DANIEL STOLLÉ**

Travis Adams, shown during his service with the U.S. Marines in Iraq, was successfully treated for PTSD and now helps other veterans.

The bomb that shattered Travis Adams's peace of mind never actually exploded. Its timer went off, but the bomb malfunctioned. Still, the 25-year-old U.S. marine remained haunted by the memory of an explosive device diabolically concealed beneath a tempting array of cookies and candies. Whoever had set it that day in Iraq must have planned to blow up children. "People are evil if they're willing to do that," he recalls thinking.

Adams had his share of close calls during his nine years of active duty, including a mortar that landed 50 yards from his bed one night. But he could not shake off his horror of the candy bomber, which soon metastasized into a broader distrust of his superiors and even himself. By the time Adams returned home to San Diego four years later in 2012, he was drinking heavily, irritable and prone to fits of anger. He spent most of his time alone, playing video games. People told him he had changed. He ignored them. It was not until later that same year, when his older brother, also a former marine, pressed him to get help that he visited the local Department of Veterans Affairs center. There he received a diagnosis of post-traumatic stress disorder (PTSD).

Adams's story is all too familiar. After two protracted military conflicts in Iraq and Afghanistan, American mental health experts are seeing an epidemic of PTSD among returning soldiers. Between 10 and 20 percent develop symptoms of the disorder, which include agitation, irritability, disturbing and intrusive imagery, and difficulty sleeping. This poses a tremendous burden on the soldiers themselves and on society at large, costing billions of dollars in treatment and lost productivity. In 2012, 500,000 veterans sought medical attention for PTSD, nearly three times the number requesting help a decade earlier.

Given such proportions, there is considerable urgency to discover the sequence of biological events that causes PTSD and to learn why some soldiers succumb and yet others do not. Such an understanding may yield better interventions in the form of new medicines and therapies and even allow for prevention. Finding ways to forestall the damage done by extreme stress would benefit not just service members: nearly one in 15 Americans acquire symptoms of PTSD following a traumatic life experience.

To that end, the overseas deployment of 2.7 million Americans since 2001 has afforded scientists a unique research opportunity. Clues are starting to emerge from a number of studies looking at soldiers before and after their exposure to war zones. Investigators have, for example, uncovered measurable differences in brain structure and function that appear to predict vulnerability to the disorder. Perhaps most intriguing, heightened immune reactivity seems to both increase the likelihood of developing PTSD and mark its onset. What is more, changes in the brain and in the immune system may reinforce one another.

Studies show that experiencing trauma early in life seems to increase the chance of suffering from PTSD years later—perhaps because these early traumas alter the expression of genes involved in how the body responds to stress, threats, injury and infection. Although the finding is contested, some researchers argue that American soldiers are more likely to have experienced childhood abuse and adversity than the general population, and some recruits may enlist just to escape harrowing environments. Thus, the military may count in its ranks a greater than average ratio of people prone to PTSD—upping the imperative to understand how the disorder unfolds and how it might be prevented.

Renegade Inflammation

Terror in any form involves an immediate physical reaction: your stress hormones rise; adrenaline floods your body; your heart rate accelerates; and blood shunts away from nonessential functions, such as digestion, to more essential ones, such as

FAST FACTS

SPOTTING THOSE AT RISK

1. Some soldiers may be especially susceptible to post-traumatic stress disorder (PTSD) because of changes in the brain and immune system caused by childhood trauma.
2. These alterations may reinforce one another, setting up heightened inflammation and exaggerated fear responses that can engender psychological distress.
3. Understanding these biological modifications may help scientists to devise more targeted therapies to treat PTSD and possibly even prevent it.

COURTESY OF TRAVIS ADAMS

BETWEEN 10 AND 20 PERCENT OF SOLDIERS RETURNING FROM AFGHANISTAN AND IRAQ WILL DEVELOP SYMPTOMS OF PTSD.

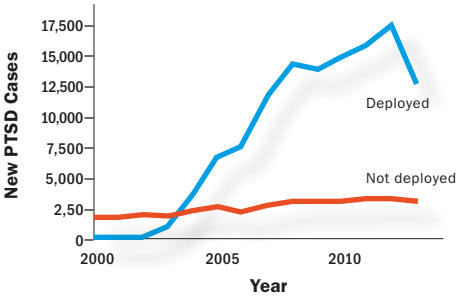
powering the muscles needed to move. For years scientists suspected that this fight-or-flight response somehow got stuck in the "on" position in PTSD—a theory supported by studies showing that patients with PTSD have disturbed cycles of stress-related hormones such as cortisol and altered expression of genes involved in the fight-or-flight response. But scientists had also noted odd signs of inflammation in the blood serum of PTSD patients. And animal studies suggested that chronic stress could activate the immune system, inducing low-grade but persistent inflammation. So one outstanding question that arose in PTSD research was: Is inflammation an unimportant sideshow, or does it somehow contribute to psychiatric symptoms?

Results corroborating the latter idea are beginning to surface from the Marine Resiliency Study at the VA's San Diego facility, among other places. This investigation took a variety of measurements from some 2,600 marines before and after deployment. In 2013 Stephen J. Glatt, a neuroscientist at SUNY Upstate Medical University in Syracuse, and his colleagues examined the data and found that just by looking at the expression of certain genes, many involved in inflammation, they could predict with 70 percent accuracy who would develop PTSD after exposure to battlefield trauma. The more these genes cranked out inflammatory signals before combat, the greater the risk of PTSD later. A subsequent study on the same cohort, conducted by Satish Eraly of the University of California, San Diego, and his colleagues, reported that troops showing the highest levels of C-reactive protein, a marker of systemic inflammation, before deployment were also those most susceptible to PTSD afterward.

Both findings imply that a tendency toward inflammation can predispose someone to PTSD and that the immune system may be causally involved in the disorder. This observation aligns with parallel research showing that people with PTSD have an elevated risk of other diseases associated with inflammation, including cardiovascular disease, metabolic syndrome, diabetes, autoimmune diseases, preterm birth in women and dementia in old age. To date, it remains unclear whether they have an underlying propensity to become inflamed or whether trauma-induced inflammation increases the risk of these other conditions.

The link between PTSD and immune activation fits with a growing body of research connecting inflammation and psychiatric illnesses—especially depression. Psychiatrist Andrew H. Miller of Emory University was among the first to explore this relation more than a dozen years ago. He studied cancer patients receiving infusions of a protein called interferon-alpha to activate their immune systems. These patients often reported feeling

Annual New PTSD Diagnoses, All U.S. Military Services, 2000–2014*



*As of September 2014

down, and about 30 to 45 percent of them fell into a deep depression that usually lifted when treatment ceased. Inflammation, Miller had observed, could trigger profound feelings of despair and even suicidal thoughts.

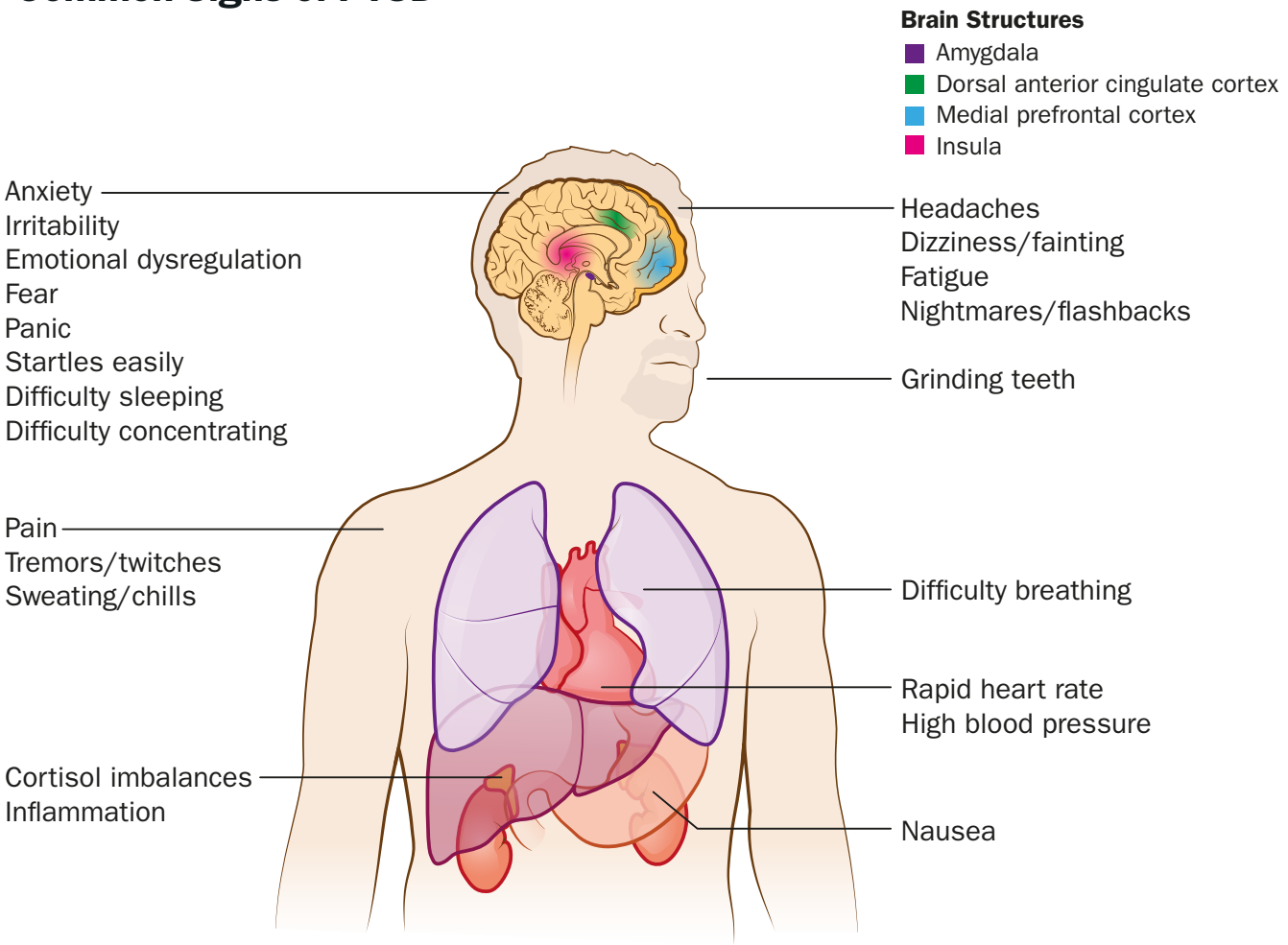
A flurry of animal research, meanwhile, began to unveil how the brain and immune system interact. Historically, scientists viewed the two as entirely separate, assuming that the blood-brain barrier shielded the brain from any potential damage caused by an immune response to infection or injury. What they discovered is that neurons themselves actually secrete and respond to immune system signaling proteins and that white blood cells—the warriors of the immune system—can cross from brain to body and back. A T cell in your intestine today might be in your brain tomorrow. Moreover, roughly half of the

SOURCE: *A GUIDE TO U.S. MILITARY CASUALTY STATISTICS: OPERATION INHERENT RESOLVE, OPERATION NEW DAWN, OPERATION IRAQI FREEDOM, AND OPERATION ENDURING FREEDOM,* BY HANNAH FISCHER. CONGRESSIONAL RESEARCH SERVICE, NOVEMBER 20, 2014

THE AUTHOR

MOISES VELASQUEZ-MANOFF has written for *Mother Jones,* the *New York Times Magazine* and the *Atlantic,* among other publications. He is author of *An Epidemic of Absence: A New Way of Understanding Allergies and Autoimmune Diseases* (Scribner, 2012).

Common Signs of PTSD



Trauma can produce a range of physical symptoms and may also wreck the balance between brain and immune system, contributing to feelings of anxiety, irritability and emotional upset, as seen in PTSD. When we are afraid, the amygdala initiates fight or flight. As part of that response, the pituitary and adrenal glands act to boost levels of the stress hormone, cortisol, possibly suppressing immunity in the short term. But chronic stress leads to reduced cortisol, greater activation of immune cells and increased inflammation, causing further reactivity in the amygdala. Chronic or extreme stress may also reduce volume and possibly function in the dorsal anterior cingulate cortex, the insula and the prefrontal cortex, brain areas involved in self-control and keeping emotions in check.

volume of the brain consists not of neurons but of glial cells, which help to maintain synaptic connections and prune unneeded ones. Glial cells act very much like white blood cells, and they are exquisitely sensitive to inflammation elsewhere in the body.

Thus, one way inflammation may influence our mental state is by modifying the activity of glial cells, disturbing how they maintain neuroplasticity and prompting a decline in their production of proteins, such as brain-derived neurotrophic factor, necessary for learning and memory formation. Both these functions are thought to go awry in PTSD and depression. More recently, Miller and his colleagues have observed another way in which inflammation may impact the brain and adversely affect mood. They took functional MRI scans of patients treated with interferon-alpha for hepatitis C infection and found reduced activity in a brain region called the basal ganglia. This reduction correlated with an inability to feel pleasure after a re-

TAMI TOLPA

warding activity—in this case, winning a simulated card game, played inside the scanner and rigged in their favor. Additional positron-emission tomography scans revealed that the subjects' brains were producing lower than normal levels of dopamine, the neurotransmitter that, among other things, makes us feel good.

Considering these results together, Miller proposes that immune activation mutes the neural circuitry responsible for pleasure and motivation, and he offers an evolutionary explanation: if you are genuinely fighting some pathogen, inflammation signals to your brain that it is time to hunker down, rest and take it easy to aid recovery. Clinical depression, he thinks, occurs when this signal starts blaring in the absence of ongoing infection or injury—say, in response to extreme stress of the kind that provokes PTSD. Indeed, those suffering from PTSD often report profound feelings of depression, suggesting shared biological underpinnings. Maybe more pertinent, some patients receiving interferon-alpha infusions also display hostility and aggression akin to that seen in PTSD.

Miller sees all these behaviors as a kind of survival instinct, conserved across many species. "If you ever see a dog hit by a car on the street, everyone knows that the last thing you should do is go poke the dog," he says. It is liable to take your finger off.

Hair-Trigger Fear

A few years before Glatt found that inflammation levels before deployment could predict which soldiers might later succumb to PTSD, Roee Admon, a neuroscientist now at Harvard University, was looking at another way to detect who was vulnerable. The amygdala—two almond-shaped regions deep in the brain—coordinates the fear response, considered central to PTSD. Admon began examining these areas in Israeli soldiers and military paramedics using fMRI. He found that the recruits whose amygdala reacted most forcefully, meaning with the greatest blood flow, to images of potentially threatening soldiers before service were the most vulnerable to PTSD after combat stresses.

Later studies revealed that hyperactivity in both the amygdala and the immune system might be related. In 2012 neuroscientist Naomi Eisenberger and her colleagues at the University of California, Los Angeles, began exploring this connection by provoking inflammation in healthy volunteers with infusions of a bacterial by-product called endotoxin. Then, using fMRI, the researchers observed amygdala activity when participants were shown pictures of frightening faces. Sure enough, individuals inflamed by the endotoxin showed significantly more blood flow in the amygdala than control subjects did.

In a subsequent experiment, the same group tested the effects of stress on the immune system. They first recorded interviews with 31 healthy female volunteers. During fMRI scans, the women then watched what they were told was a real-time evaluation of their personality made by another study participant (in actuality, a researcher). The assessments included words such as "annoying," "arrogant" and "boring." Women who became the most stressed, reflected by greater activity in the amygdala, also became the most inflamed, as measured by blood tests.

PATTERNS OF GENE EXPRESSION CAN PREDICT WITH 70 PERCENT ACCURACY WHICH INDIVIDUALS WILL DEVELOP PTSD.

The research raises the classic chicken-or-egg question: Do differences in neural architecture—such as having a hyperreactive amygdala—dictate your immunological response to upsetting stimuli, or do tendencies in immune function increase the risk of brain dysfunction after trauma? The answer may be all of the above; there may be several paths to what we consider to be a single disorder. That does not mean we should throw our hands up in despair, says Dewleen Baker, lead scientist for the Marine Resiliency Study. To the contrary, it could imply that multiple intervention points exist. "Anywhere you can break into this disordered system and make it right—that would be a good way to go," she says.

Preemptive Therapeutic Strikes

The best time to intervene in PTSD may be years—perhaps decades—before the trauma that precipitates it actually takes place. A consistent finding is that early-life adversity increases the risk of PTSD many years later. In the Marine Resiliency Study cohort, the relationship was dose-dependent. The soldiers who reported having the greatest number of childhood hardships—such as physical or emotional abuse or neglect—have triple the risk

Using Virtual Worlds to Heal Real Wounds

Breakthroughs may one day emerge from recent discoveries about the roots of post-traumatic stress disorder. But for now most patients get talk-based treatments such as cognitive-behavior therapy and drugs such as serotonin reuptake inhibitors, originally developed to treat depression. That does not mean that there is nothing new under the sun for PTSD. Increasingly, therapists are working with innovative technologies, including virtual reality, to augment treatment.

By vividly re-creating the sensations of war, virtual-reality programs can help PTSD sufferers come to terms with harsh memories.

One long-standing treatment, often called exposure therapy, involves asking the afflicted to mentally revisit the trauma. The idea is to help them gradually reprocess it so that lingering symptoms—agitation, avoidance and panic—subside. This approach does not work for everyone, but it helps about half of the patients who try it, which is roughly the same success rate as cognitive-behavior therapy.

Albert Rizzo, director for medical virtual reality at the Institute for Creative Technologies at the University of Southern California, thinks that virtual reality can improve results. As computer-processing power has grown, he and his colleagues have designed ever more intricate war zone experiences, replete with sights, sounds, vibrations and smells—diesel fuel, sweat, burning plastic—that can boost the reexposure process. "Instead of watching *Band of Brothers,* they're in a *Band of Brothers* episode," Rizzo says.

These episodes have been tested at more than 50 hospitals and clinics around the U.S. They usually feature some catastrophe—an improvised explosive device (IED) detonating or a squad leader getting killed. But unlike real life, the soldier can hit pause and, aided by a therapist, talk about what is happening. When asked about traumatic events, soldiers with PTSD cannot always recall their feelings. They appear stricken by an emotional numbness. Rizzo thinks his scenarios can accelerate the deconditioning process that is at the heart of exposure therapy because they appeal directly to sensory memory and may trigger memories that are otherwise inaccessible.

Other researchers are testing tech-enhanced versions of an older technique called biofeedback, which gives patients real-time readouts of heart rate and other physiological functions. Instructors demonstrate breathing methods and, in some cases, visualization practices for regulating these functions. The theory is that, armed with such tools, patients can learn to calm themselves when the panicky sensations of fight or flight kick in.

Carmen Russoniello, a professor at East Carolina University and a former marine himself, is teaching biofeedback techniques to soldiers suffering from PTSD by way of video games. Participants directly control avatars in games such as Pac-Man using their physiological responses. The calmer they are, the better they fare. "How do you turn yourself into a meditator in a couple of hours?" he asks. "This is one way to do it." —*M.V.-M.*

of developing PTSD compared with those with the least distressing upbringings, even when controlling for alcohol and tobacco use.

This may be because childhood adversity seems to modify the same immunological pathways implicated in PTSD. An ongoing prospective study of more than 14,500 families in the Avon region in England showcases this link. Epidemiologist Natalie Slopen, now at the University of Maryland, and her colleagues examined these data and reported that youths who faced difficult circumstances before age eight had higher levels of the inflammatory proteins interleukin-6 (IL-6) and C-reactive protein at age 10 and of C-reactive protein at age 15. Psychiatrist Golam Khandaker of the University of Cambridge and his colleagues found that elevated levels of IL-6 and C-reactive protein at age nine predicted psychiatric disorders, such as depression and psychosis, at age 18. Chronic stress may rev up immune function, and that modification may increase the risk of psychiatric problems.

Early life struggles may also alter the amygdala and other brain areas associated with PTSD. Studies indicate that children reared in orphanages and otherwise deprived of affection from caretakers—an extreme stress—display an enlarged, overactive amygdala that responds more readily to threatening images. Making matters worse, maltreatment also seems to reduce volume, and presumably functionality, in regions of the prefrontal cortex, such as the insula and dorsal anterior cingulate cortex, involved in self-control, self-awareness and executive function. These structures may help put the breaks on runaway reactions and emotions. Amit Etkin, a neuropsychiatrist at Stanford University, speculates that when they go offline, as they appear to do in PTSD, other areas are left unchecked, possibly accounting for the disorder's hallmark tendency to obsessively ruminate. "If we're right, resisting inner voices and not being too much in your own head is important for recovering from trauma," he says.

These twin modifications to the nervous and immune systems may augment each other. Extreme early life stress may change immune function, producing a permanently elevated immunological "idle speed" and a tendency to become rapidly inflamed. And a brain modified by childhood trauma may mount a stronger and faster fear response, more likely to trigger a proinflammatory cascade in the face of some stressor. "It's like an orchestra," Baker says. "If it isn't playing quite right, it's easier to flip into a chronic condition like PTSD."

Sandro Galea, dean of Boston University's

COURTESY OF INSTITUTE FOR CREATIVE TECHNOLOGIES, UNIVERSITY OF SOUTHERN CALIFORNIA

RESEARCHERS HOPING TO PREVENT PTSD ARE TESTING DRUGS, DIET AND APPROACHES THAT TARGET INFLAMMATION.

School of Public Health and one of the first to note immunological abnormalities in PTSD, argues that more comprehensive social welfare policies aimed at improving the health and well-being of vulnerable groups, such as poor children, might serve to reduce the overall incidence of stress-induced psychiatric disorders. Barring that, he says, the next best fix is to ensure robust social support for returning soldiers and others exposed to trauma. Research by him and others suggests that social support, including group therapy–like models and assistance to manage military personnel's affairs during deployment, can help stave off PTSD even after trauma has occurred. The idea is to prevent an already battle-strained soldier from coming home to more stress—for example, back rent or a repossessed car. "I am convinced that that's the best approach to help as many people as possible as much of the time," he says. It is worth noting that strong social networks also help ward off other disorders associated with chronic inflammation, such as heart disease and dementia.

When Adams sought help at the San Diego VA center, he was put on antidepressant medication. Then he began cognitive-behavior therapy—a kind of mental training that taught him to question and assess his own thoughts and beliefs and, ultimately, to change them. The incremental improvements he saw motivated him to work harder. And he recovered, he says, after just a few months. Now he works for the San Diego VA center, helping other veterans with PTSD.

Adams's treatment regimen is among the best currently available for PTSD [*see box on opposite page*]. But the emerging biomarkers of PTSD—the differences observed in brain and immune function—may one day yield therapies that complement, or even supplant, talk therapy–based approaches. Last year Miller and his colleagues published a small randomized, placebo-controlled trial in which he gave infusions of a drug called infliximab to depressed subjects, some of whom showed signs of inflammation. The medication, normally used to treat autoimmune disorders, blocks a proinflammatory protein: tumor necrosis factor–alpha. Miller found that among patients with higher baseline levels of inflammation, those who took infliximab responded more readily to treatment, suggesting that calming the immune system can sometimes improve mood. Now he aims to test the drug on subjects with PTSD.

Other researchers are considering less conventional ways to curb inflammation and possibly prevent PTSD. These range from dietary interventions to developing drugs based on curcumin, a nutrient derived from turmeric that has neuroprotective and anti-inflammatory properties, to inoculating subjects with what some call a "dirt vaccine." The concoction, derived from soil-dwelling bacteria—*Mycobacterium vaccae*—stimulates an arm of the immune system that counteracts inflammation, says neuroendocrinologist Christopher A. Lowry of the University of Colorado Boulder. If it works in people as well as it works in mice, he can imagine immunizing soldiers before they head to the battlefield. "You should be able to prevent PTSD," he says, by strengthening soldiers' own ability to regulate inflammation.

Our understanding of PTSD has advanced dramatically since World War I, when physicians first described it as shell shock. Because the condition occurred without obvious wounds, some thought that afflicted soldiers had weak dispositions or that they faked their problems to avoid fighting. "It was blaming the victim," says Irina Komarovskaya, a psychiatrist at New York University. Views have changed, but many of those struggling with the disorder still feel stigmatized. For them, the emergence of biological markers for PTSD may be important for reasons beyond the hope for better therapies. Understanding the disorder in solidly biological terms may finally erase the lingering shadow of shame. M

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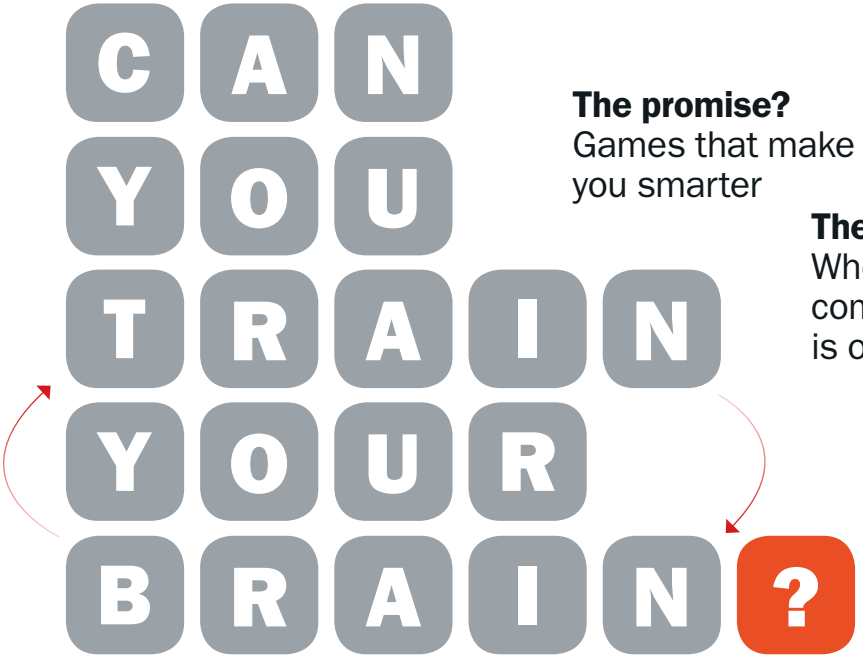


The promise?
Games that make you smarter

The reality?
When science meets commerce, objectivity is often the loser

By Simon Makin

I'm tapping away at my laptop as colored shapes appear on-screen. I'm supposed to hit the right arrow key—and fast—if the new shape matches the previous one and the left arrow key if it doesn't. Next, in a test of attention, I'm throwing switches on virtual tracks to direct colored trains into appropriately colored stations. It's a little trickier but not much more interesting; I get bored, and my mind wanders. Suddenly, I have two trains about to roll into the wrong stations, with more emerging all the time. It does not end well. I am determined to redeem myself, and I start the next game with clenched teeth. Grids of squares appear, some of which briefly change their shade, and I have to remember their positions. The grids get larger and harder to take in as I play, but I rack up a big score anyway. Final verdict: I'm in the 92nd percentile for memory, the 80th percentile for speed—and the 13th for attention. I suppose the problem *was* lack of attention, but it didn't help that I am color-blind.

I have just taken Lumosity's Fit Test, a free online assessment and lure for new customers. Lumos Labs, which created the Lumosity program, is one of the biggest players in the rapidly growing "brain-training" industry, alongside outfits with such enticing monikers as CogniFit, MindSparke, Cogmed, HAPPYneuron, Posit Science and Jungle Memory. Market research firm SharpBrains estimates global spending on brain health technology, including both software and "biometrics" such as electroencephalogram headsets, was around $1.3 billion in 2013, up from $210 million in 2005. It predicts that the figure will hit $6 billion by 2020.

Most early clients were schools and health care providers buying programs such as those offered by Cogmed (which claims to treat attention-deficit/hyperactivity disorder, or ADHD, and other learning problems), but private consumers now make up the largest, fastest-growing segment, led by baby boomers. They are drawn by ads that promise boosts to mental performance and fitter brains, with companies claiming that training can help customers maintain mental function into old age or can even prevent dementia. Such appeals are bound to have a big impact when, according to an AARP survey, "staying mentally sharp" is a greater concern than physical health for people age 50 and older. The ads usually also boast that products are "designed by leading neuroscientists" and are "scientifically tested."

But no sooner had brain training hit the market, roughly a decade ago, when the clamor began. Skeptics pointed

Illustration by **MARK ALLEN MILLER**

out that many studies suffered from serious flaws and raised questions about the evidence of benefits. Media reports soon began denouncing the industry—"Brain Games Are Bogus," proclaimed the *New Yorker* in a 2013 article. And last October a group of more than 70 neuroscientists working under the auspices of the Center on Longevity at Stanford University and the Max Planck Institute for Human Development in Berlin issued a report stating: "We object to the claim that brain games offer consumers a scientifically grounded avenue to reduce or reverse cognitive decline when there is no compelling scientific evidence to date that they do."

Research into cognitive training is now a sea of conflicting studies and contradictory claims. A variety of reasons exist for the divergence of opinion, but the root of the problem is the complexity of learning and intelligence—and hence of attempts to measure aspects of cognition. And in a field where even the most talented, earnest and diligent researchers regularly fail to exclude all possible sources of bias or error, research studies with industry ties will draw special scrutiny because when science and commerce intersect, truth can be a casualty.

Yet two conclusions do emerge from the murk: Training the brain in any meaningful way, especially as we age, is very difficult. Making it look like you have succeeded, however, is surprisingly easy.

TRAINING MAY BE LESS USEFUL FOR THOSE WHO NEED IT MOST: **OLDER ADULTS.**

Make Yourself Smarter!

Research into cognitive training goes back at least three decades, and then, as now, the holy grail of training was "far transfer." The science-fiction-esque term refers to an improvement in mental skills significantly beyond the focus of the training activity, including, researchers hope, skills that are broadly useful in real-life tasks.

Early studies succeeded in showing gains only in tasks very similar to the training itself. In 1982, for instance, psychologist Karlene Ball, now at the University of Alabama at Birmingham, and neuroscientist Robert Sekuler, now at Brandeis University, conducted a study in which they trained people to detect slight differences in the direction of moving dots on a screen. The participants got better at discerning ever smaller differences, but the improvements were specific to the direction the dots were moving in the experiment. If the average pathway was rotated more than 45 degrees, the improvements vanished, and presumably the training had little relevance to actual visual acuity tasks such as driving.

Around this time, though, tantalizing clues began to emerge that the brain can change even in old age. Researchers once thought this property, called plasticity, was restricted to critical periods during development. But progress on various medical frontiers, most obviously in the capacity of stroke victims to recover, has provided new evidence of plasticity throughout life.

More relevant for the cognition entrepreneurs are signs that healthy adult brains can change, too. The most famous example is a 2000 MRI study by Eleanor Maguire and her colleagues at University College London, which showed that London taxi drivers, who must master detailed knowledge of the city, had marked differences in the shape of their hippocampus (the region used to store navigational information) compared with noncabbies. The longer the cabbies had been driving, the greater some of those differences were.

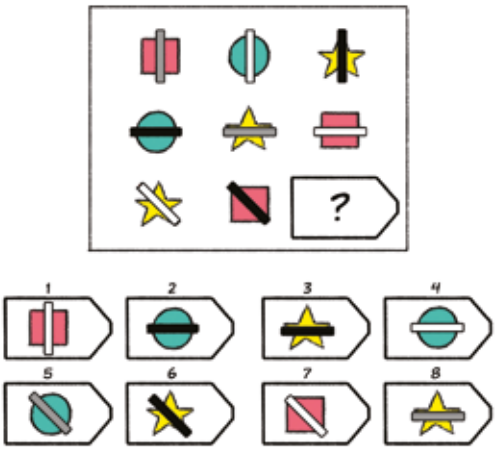
But these changes appeared in people who had acquired tremendous amounts of complex, real-world experience. The typical age-related decline in plasticity may actually occur for a reason: it is not an unqualified good. Later in life, neural plasticity is likely less important than neural stability, which lets us hold on to learning and habits we need. Moreover, plasticity is metabolically costly—requiring a lot of energy—so major change in adults does not come easily.

A handful of findings in the early 2000s finally showed that the effects of cognitive training might not be as limited as many had assumed. In 2002 a group led by Torkel Klingberg at the Karolinska Institute in Stockholm trained children with ADHD using "adaptive" memory tasks—those whose difficulty changes with the subject's performance. Adaptive training is based on the widely accepted principle that people learn best when pushed to the edge of their ability, so they get neither too bored nor too frustrated. The kids improved on tests of reasoning and attention compared with a group trained with nonadaptive programs. The team also found some evidence for reductions in ADHD symptoms, noting that the kids were less likely to look away from a task they were performing.

An ideal target for cognitive training is working memory, a measure of our ability to hold and manipulate information in the face of interference. Working memory acts as a kind of mental work space. It is involved in reading and problem solving and correlates with measures of IQ. The link with intelligence in particular inspired psychologists Susanne M. Jaeggi and

FAST FACTS
THE BRAIN GAME

1. Despite widespread claims, there is little evidence that brain-training games provide easy boosts to cognitive function.
2. Making brain training look effective is easy because performance on the games inevitably gets better with practice.
3. Industry claims that games are scientifically "proved" are misleading at best.
4. For healthier cognitive aging, time and effort are better spent on other activities, such as physical exercise and social engagement.



Cognitive measures are inevitably imperfect, as one common tool used to validate brain training reveals. Raven's Progressive Matrices is a test featuring arrays of shapes that vary in systematic ways, with a final element missing. Participants must select one of several options that logically completes the sequence. (The answer is number 5.) Researchers estimate that 64 percent of the variation in scores is related to fluid intelligence, making it one of the best measures of reasoning around. But these tests also tax players' visuospatial memory and processing speed, muddying any conclusions about reasoning alone.

GEORGE DOUTSIOPOULOS (*Raven's Progressive Matrices*); FROM "THE DYNAMICS OF CHANGE IN STRIATAL ACTIVITY FOLLOWING UPDATING TRAINING," BY SIMONE KÜHN ET AL., IN *HUMAN BRAIN MAPPING*, VOL. 34, NO. 7; JULY 2013 (*fMRI*)

Martin Buschkuehl, both then at the University of Bern in Switzerland, and their colleagues to develop a task to give working memory a workout. Their "dual *n*-back" training presents people with two simultaneous streams of information: shapes that appear on a screen and an audio sequence of spoken letters. Participants must indicate whenever a shape or a sound is the same as one presented *n* items ago. The task adapts to the subject's ability level by changing the value of *n*.

In a 2008 study, Jaeggi's group divided 34 healthy young adults into four groups that trained for different lengths of time. Psychologists differentiate between "crystallized" intelligence, which involves acquired knowledge, and "fluid" intelligence, which is the ability to reason with new material. Jaeggi and her colleagues evaluated the effects of training with tests of fluid intelligence that asked participants to figure out the relations between abstract shapes [*see illustration above*]. The conclusion: training increased fluid intelligence, and the more people trained, the smarter they became. It seemed that subjects could boost their fluid intelligence with nothing more than hours of practice on a laboratory task. Researchers previously had thought intelligence was pretty much fixed, so this finding made a big splash. The promise of far transfer had materialized.

Jaeggi has never sought to commercialize dual *n*-back training, but versions of it now crop up in most companies' arsenal of games (MindSparke in particular focuses mainly on *n*-back training). And a number of game makers have cited the 2008 study as evidence that their brain games are effective—even though Jaeggi distances herself from such claims and was a signatory of the recent consensus statement.

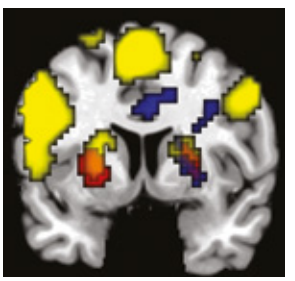
Problems with Motivation

No sooner had far transfer appeared to be within reach than critics threw it into doubt again. One of the main concerns involves a central problem in psychology: human beings react in a variety of complex ways when others are studying them. In a recent series of research reviews, psychologists at the Georgia Institute of Technology pointed out that people often change their behavior, usually by improving performance, when they know they are being watched.

And as I discovered myself, motivation can have a big effect on cognitive tasks. Many of the studies, including Jaeggi's, used so-called no-contact control groups, who took the tests at the beginning and end of the study period and had no contact with the researchers in between those times. The approach saves money, but it is inherently problematic because less interaction with the researchers can mean less motivation to perform.

The remedy is to use active control groups, who have the same degree of contact with researchers as the test subjects. And when some researchers did so, the far-transfer effect vanished. In 2013 psychologists Monica Melby-Lervåg of the University of Oslo and Charles Hulme of University College London conducted a meta-analysis that combined data from 23 studies of working memory training. They found a small increase in far-transfer measures of nonverbal reasoning but none at all when considering only studies using active control groups. (Jaeggi and her colleagues argued in a 2014 study that the latter studies failed to reproduce their findings because the test subjects did not fully engage with the training and so did not reap its benefits.)

At the same time that psychologists were looking for behavioral evidence of far transfer, neuroscientists were exploring whether training might induce changes in neural activity, thus demonstrating the biological plasticity believed to underlie benefits. Researchers trying to discern changes in activity typically ask participants to perform a task in a functional MRI scanner, both before and after training. Interpreting these results, however, can be difficult. At issue is whether differences in brain activity reflect genuine changes in cognitive ability or just changes in mental strategy arising from practice. Plus, scientists cannot predict whether a trained brain will show an increase in activity, implying more processing, or a decrease in activity, implying greater efficiency [*see illustration below*].



Increased brain activity is not the same as better brain function. In this image of average neural activity of participants in a training regime to build working memory, activity grew in early sessions (*red*), showing an increase in processing, and then declined (*blue*), possibly reflecting greater neural efficiency.

BRAIN-TRAINING FACTS AND FANCIES

Game makers are bold in their claims about the good things their products can do for your head. But is there any truth to the boasts?

CLAIM: Brain games are designed by neuroscientists and scientifically tested

VALIDITY: *True*

Some brain-training outfits—Cogmed and Posit Science among them—were indeed founded by scientists, and they have conducted a slew of studies on their products, as have independent researchers. Most companies at least base their games on cognitive tasks devised by scientists and so can point to research into those tasks as evidence that their games work.

CLAIM: Brain training will improve your performance on cognitive tasks

VALIDITY: *True but usually meaningless*

The real surprise would be if training did not lead to higher scores for a given task. But such improvement does not indicate a boost in cognitive function. To be compelling, companies must show that the benefits transfer to tasks other than the one at the center of the training regime.

CLAIM: Brain training can treat ADHD

VALIDITY: *Possible*

Researchers have reported positive results, primarily for Cogmed's working memory training, in kids and adults with ADHD or other problems with attention. But findings overall tend to be mixed, and many of the positive results have been contested. Problems include the use of subjective measures such as parent or teacher ratings and disagreements about appropriate control groups.

CLAIM: Brain games can prevent cognitive decline

VALIDITY: *Maybe but probably not*

Some studies suggest that certain kinds of training lead to better performance on tasks different from the focus of the regimen, regardless of the participant's age, but others have found that gains are not shared by older adults. Completely missing: compelling evidence of impact on real-life functioning.

CLAIM: Brain games can prevent, or delay progression of, Alzheimer's disease

VALIDITY: *False*

Most companies are actually pretty careful not to make explicit claims of efficacy in treating Alzheimer's, choosing instead to merely strongly imply that their products work to prevent or treat the condition. But studies show no real evidence that cognitive training can forestall Alzheimer's or dementia in general.

CLAIM: Brain training can make you safer on the road

VALIDITY: *True*

Eureka! Evidence is strong that increased performance on speed-of-processing tasks—which train people to process their full field of view as quickly as possible—leads to improvements in driving performance, including reduction in the number of dangerous maneuvers committed in actual driving tests.

Practice Makes Perfect

With far transfer hard to achieve and demonstrate, much of brain training focuses on "near transfer": exercises that confer benefits on tasks that use similar skills. Near transfer is less ambitious but also less controversial. Many studies show that training a particular cognitive ability, such as memory, can improve performance in other tasks using that skill even if it does not lead to gains in, say, reasoning tasks.

As it happens, though, showing why performance has improved is not a simple matter. People can get better at any task simply by practicing, so researchers must demonstrate that gains from training involve more than repetition by using tests that differ from the training task. Yet devising a task that taxes one and only one cognitive ability is nigh impossible. Everything we do involves multiple cognitive processes, so the effects of practicing one task can influence performance on others [*see box at left*]. The only way researchers can be reasonably confident that improvements reflect real changes in a cognitive ability, rather than improvements in test-taking skills from practice, is to measure each outcome using multiple tests that tax the ability in different ways.

Even better than multiple tests is a set of sophisticated statistical techniques called latent factor measures, so named because they reveal changes in underlying abilities. These methods require both large batteries of tests and big samples. For instance, in 2010 psychologist Florian Schmiedek of the German Institute for International Educational Research and neuroscientists Martin Lövdén, now at the Karolinska Institute, and Ulman Lindenberger of the Max Planck Institute for Human Development used latent factor analysis in one of the most intensive training studies to date. Their regime involved 101 younger and 103 older adults, who performed six tests of perceptual speed, three working memory tests and three episodic memory tests, administered in an average of 101 hour-long sessions over six months. The researchers used 14 measures for outcomes, covering near and far transfer. They did find far-transfer effects to episodic memory and reasoning that were still present two years later. But the effects were very small, and older adults did not show these gains, presumably because of declining plasticity, which suggests that training may be less useful for those who need it most.

Although such studies represent a gold standard, they are rare because the resources required make them both cumbersome and expensive. In a 2014 review of studies of transfer, Schmiedek and his colleagues found that only 7 percent of studies used latent factor measures, and less than a quarter even used multiple measures.

Ironically, solid evidence that brain-training techniques can have measurable real-world benefits would finally emerge in an unconventional setting. Speed-of-processing training is based on a measure referred to as useful field of view—the breadth of

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Complex activities such as sports and music making may be more effective than brain training in preventing cognitive decline. Social engagement helps, too.

space you can take in at a glance—developed almost 30 years ago by Ball of the University of Alabama and psychologist Daniel L. Roenker of Western Kentucky University. The task involves fixating on a central object while noting as rapidly as possible where in the visual periphery other objects appear.

And the measure of performance that verified efficacy? The risk of having a traffic accident. In a 2003 study, Roenker and his colleagues found that training resulted in a drop of about a third in the very real-world measure of dangerous maneuvers in driving tests. Not yet clear is whether the training enhances cognitive capacity or simply hones a skill useful in some actual circumstances, but such a theoretical consideration is of little concern to anyone sitting behind the wheel in rush hour. "There are a slew of studies that say people who practice these games improve their game playing," says psychologist Laura Carstensen, director of the Stanford Center on Longevity. "The real question is, Does this transfer outside of a lab into improved functioning?" In this case, it seems to do so.

Buyer Beware

Despite the occasional glint of sunlight on the horizon, uncontested evidence that brain training results in far transfer of cognitive skills, whether measured by increased IQ or impact on real-life functioning, remains rare, and researchers still debate the significance of near transfer. Thus, industry claims of quick and easy boosts to intelligence, grades or even mental functioning are looking increasingly hollow.

Just as worrisome for companies and customers alike is the possibility that the way brain games target single cognitive abilities might be eliminating the variety that helps to make learning effective. For instance, in a 1978 study, Robert Kerr and Bernard Booth, both then at the University of Ottawa, found that children who were trained to throw beanbags at targets two and four feet away later performed with greater accuracy when throwing at targets three feet away—a distance they never practiced—than did kids who trained only at the three-foot distance, suggesting that learning to modulate relations was more important than specific experience.

So makers of brain games might be taking exactly the wrong approach. They break cognitive activity down into simple components and target them using highly repetitive procedures. This schema probably leads to faster improvement in the games, but it might also produce less transfer. When Lumosity promises on its Web site that "just 10–15 minutes of Lumosity training per day can lead to improvements in Lumosity over time," the claim might be true, but it is also almost meaningless. Practicing any task will inevitably help you do it better without necessarily improving your performance at anything else. In other words, routing colored trains on a screen will not improve your lot in the world.

Yet the games that are most likely to be effective are not an easy sell, because they are so challenging. Dual *n*-back training, for instance, is a fiendishly tough and unpleasant experience—a big problem for the industry if engagement turns out to be key for achieving benefits.

People might be better off, in any case, engaging in pursuits known to have a payoff: naturally complex activities such as learning a language, taking up a musical instrument, or playing sports or even some video games. All engage multiple cognitive functions simultaneously and in constantly changing circumstances, a varied menu more likely to produce enhancements in abilities. Physical and social engagement have been repeatedly linked to healthier cognitive aging. So if the 30 minutes a day you spend training your brain means you're missing a walk with your dog, you're trading in known benefits for a gamble.

It's still early days for cognitive training. The problem, as ever, is that business has raced ahead of the science, with most companies paying little heed to the real state of the evidence when they put their marketing material together. Someday research could produce techniques that are at least modestly helpful for some people and in certain circumstances.

In the meantime, I'm going to lace up my sneakers and head out for a run. **M**

FURTHER READING

- **Exercising Your Brain: A Review of Human Brain Plasticity and Training-Induced Learning.** C. S. Green and D. Bavelier in *Psychology and Aging,* Vol. 23, No. 4, pages 692–701; December 2008.
- **Hundred Days of Cognitive Training Enhance Broad Cognitive Abilities in Adulthood: Findings from the COGITO Study.** Florian Schmiedek, Martin Lövdén and Ulman Lindenberger in *Frontiers in Aging Neuroscience,* Vol. 2, Article No. 27; July 13, 2010.
- **Is Working Memory Training Effective?** A Meta-analytic Review. Monica Melby-Lervåg and Charles Hulme in *Developmental Psychology,* Vol. 49, No. 2, pages 270–291; February 2013.
- **On the Validity and Generality of Transfer Effects in Cognitive Training Research.** Hannes Noack, Martin Lövdén and Florian Schmiedek in *Psychological Research,* Vol. 78, No. 6, pages 773–789; November 2014.

From Our Archives

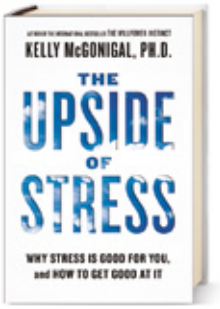
- **Calisthenics for a Child's Mind.** Ingrid Wickelgren; May/June 2013.

ISTOCKPHOTO (*archer*); CORBIS (*guitarist*); GETTY IMAGES (*teacher*)

DON'T STRESS ABOUT STRESS

The Upside of Stress: Why Stress Is Good for You, and How to Get Good at It

by Kelly McGonigal. Avery, 2015 ($26.95; 304 pages)



Correlation does not imply causation. This is a fundamental lesson psychology professors like me teach in introductory courses. Violating this principle can lead to serious misconceptions, even dangerous practices.

McGonigal, a psychology instructor at Stanford University, probably teaches that principle, but in *The Upside of Stress* she seems to have ignored it. The book is a follow-up to a powerful TED talk she gave in 2013, which has had more than 10 million views online. Her message: I have been wrong in counseling people to avoid stress; new research shows that stress can hurt you only if you believe it can.

McGonigal credits a 2012 study by Whitney P. Witt, then at the University of Wisconsin–Madison, and her colleagues for her epiphany, but that study showed only that believing one's stressful experiences are harmful was *correlated* with illness and early mortality. That does not mean beliefs caused illness. There is a simpler, less mysterious way of accounting for the results: people who experience stress but who suffer minimal ill effects from it come to believe that stress cannot hurt them, whereas people who *do* suffer ill effects come to believe that stress is harmful. Voilà, we now have the correlation those researchers found but with belief as an *outcome* rather than a cause. McGonigal continues to make this type of error throughout her book.

On the plus side, she describes a variety of recent experiments that indicate that telling people about the positive aspects of stress can indeed cause some to feel and function better. Even here, though, she often exaggerates the significance of the studies' results by using language suggesting that all the subjects in the study—mothers, students, women—were helped. That never happens in real research; only some people are helped—enough to get the study published.

Based in part on studies with soldiers and police, McGonigal also tells us that avoiding stress can hurt you, whereas high stress can be good for you. She never mentions the many professions in which one must be relaxed to perform optimally: acting, writing and public speaking, to name a few. It makes you wonder: if optimal performance can be achieved when one is in a relaxed state (think martial arts), wouldn't that be the happiest and healthiest way to go through life?

As early as the 1950s, therapists such as the late Albert Ellis showed that teaching people how to reinterpret challenging events in positive ways could help them reduce or eliminate stress, and therapists worldwide now teach people to "reframe" in this way. McGonigal is saying that when you *do* feel stress, don't make matters worse by stressing about *that*. Reframe the stress as "excitement" and make it work for you.

Although this strategy might work for some, there are still thousands of studies showing the ill effects of stress on the immune system, mood, the brain, sleep, sexual functioning, you name it. If some people feel and function better when we tell them stress is good, I'm all for it. But stress is still a killer.

—Robert Epstein

NATURE CONNECTION

How to Raise a Wild Child: The Art and Science of Falling in Love with Nature

by Scott D. Sampson. Houghton Mifflin Harcourt, 2015 ($25; 352 pages)

Many preschoolers and their parents know paleontologist Sampson as "Dr. Scott" on the television program *Dinosaur Train,* where he adds science commentary to the show's animated dino tales and closes each episode with this exhortation: "Get outside, get into nature and make your own discoveries."

In *How to Raise a Wild Child,* Sampson provides a persuasive book-length exposition of that tagline. He makes a cogent case for the importance of cultivating a "nature connection" in children and offers thoughtful guidance on how to do so amid today's pressures of hectic, high-tech, increasingly urbanized life.

Sampson cites various studies indicating the benefits of exposure to nature, including reduced stress, stronger immunity and better concentration. Some doctors have even begun writing "park prescriptions" to encourage patients to go outdoors. "On the whole, nature is good for us, both as children and adults," he writes, adding that we need to cultivate an emotional bond with natural settings if we are to protect them. As evolutionary biologist Stephen Jay Gould once noted: "We will not fight to save what we do not love."

Troublingly, in recent decades kids more and more have been sequestered indoors, as fearful parents discourage unsupervised roaming and schools cut back on recess to make more time for test prep. Today American children spend more than seven hours a day, on average, in front of electronic screens, doing homework, playing games, watching TV and interacting with friends via social media.

To heal this growing rift with nature, Sampson touches on three broad themes: experience, mentoring and understanding. Experience, he emphasizes, should be frequent and hands-on; nature documentaries can only do so much, and regular forays into local green spaces are no less important than grand Yosemite adventures: "A meaningful connection with nature is forged first and foremost through firsthand, multisensory experiences, from abundant unstructured time in the backyard to weekends in the park and occasional visits to wilderness." Mentoring, in Sampson's conception, centers on adopting the playful attitudes of children, not simply relaying information. "Being an effective mentor means becoming a coconspirator, a fellow explorer, a chaser of clues," he writes. To promote understanding, Sampson favors focusing on big ideas, such as evolution and cosmology, showing kids that everything in nature is connected—including them. Although technology often separates kids from nature, it can also be used to build appreciation, such as with apps for bird-watching, plant identification and geocaching (using GPS for outdoor treasure hunts).

Sampson proposes making cities more nature-friendly by creating more green school yards, reintroducing native species and linking parks through networks of trails. *How to Raise a Wild Child* is stocked with valuable ideas and deserves attention from policy makers, educators and activists, as well as the parents of 21st-century kids. *—Kenneth Silber*

BOOK SMART

Whispersync for Voice

Amazon (free with Kindle and Audible apps)

I am an avid reader. But proclaiming as much in the past few years has made me feel a little dishonest—I can so rarely find time to read for pleasure. What kind of "avid reader" finishes only two books a year? A few months ago, however, I discovered a delightful way to fit books back into my busy life: a technology from Amazon called Whispersync for Voice, which is automatically included with the free Kindle and Audible apps. This ingenious bit of cross-platform magic, originally released in 2012 and recently updated, allows a reader to switch between reading an e-book purchased through Amazon and listening to the book's audio narration seamlessly in these apps on any device.

My typical reading schedule now starts in the morning, as I listen to an audiobook on my smartphone while I hike with my dog. Whenever I find myself waiting in a line, I switch to reading the book in the Kindle app on my phone. When I'm doing chores around the house, I listen to the narration on our home stereo system, via my computer. Before bed, I read a little more on my iPad. Throughout all those transitions, Whispersync for Voice is behind the scenes, marking my place so I never have to search for where I left off. And as with most apps, the features keep getting better. This past April the Kindle app was updated so that switching between reading and listening happens with only one click.

Another small but real benefit: Whispersync for Voice relieves a minor concern I have about using electronic screens at night. Recent studies have hinted that e-reading might disrupt sleep patterns—although most research finds the effect only after several *hours* of screen time before bed. Still, I am on my computer most of the day for work, and when I add e-reading or a movie to the mix, I might be approaching that threshold. So now, on days when I am sick of staring at a glowing screen, I can simply switch over to listening to my book while I rest my eyes.

All these little chunks of reading and listening time add up. I have completed 14 novels since I discovered Whispersync for Voice three months ago—and I am thrilled that books are back in my life in a major way. As an editor for *Scientific American Mind,* I see many studies about the benefits of reading or listening to stories—fiction may hone your social skills, for instance, and a well-drawn character can evoke empathy for people unlike yourself. Even more, though, I simply missed getting lost in an imagined world, which happens for me more intensely with books than it does with movies or TV. Don't get me wrong—I love my favorite shows, and I make time to watch them. But the other night, when I tried turning on the TV while cooking dinner, I found myself wondering what the characters were up to in the book I am currently immersed in. I turned off the TV and dove back into my novel. —*Karen Schrock Simring*

ROUNDUP

WIRED TO BE KIND

Three books explore the science of altruism

Is altruism learned or innate? In **The Altruistic Brain: How We Are Naturally Good** (Oxford University Press, 2015; 312 pages), neuroscientist Donald W. Pfaff argues that the human brain is wired for selflessness. To make his case, Pfaff postulates that our development and survival have hinged on the care we receive from loved ones, a relationship that has primed us to help others. Pfaff then proposes the altruistic brain theory, which, he writes, "explains exactly how altruistic behavior happens when it happens." He lays out a five-step process by which our brain unconsciously drives us to act altruistically. To his credit, Pfaff tries to unravel an immensely complex topic, but the book may fall short for the same reason: his attempt to explain altruism in a single theory leads him to make logical leaps and to oversimplify his case.

Perhaps, in trying to understand altruism, we need to look beyond brain function. In **Does Altruism Exist? Culture, Genes, and the Welfare of Others** (Yale University Press, 2015; 192 pages), evolutionary biologist David Sloan Wilson explores altruism through an evolutionary lens and makes a compelling case that true examples of altruistic behavior can be found in a number of social animals and, especially, in humans. Wilson argues that natural selection extends beyond traits that are shaped by genes; it also applies to traits influenced by culture. "Unrestrained self-interest is far more likely to *undermine* the common good," he writes. Consequently, "altruistic groups beat selfish groups." Wilson concludes by making a sweeping statement that to benefit, or perhaps save, humanity, people must prioritize their altruistic tendencies. In other words, we should spread the love.

But altruism may not be the key to understanding human virtue. In **The Moral Arc: How Science and Reason Lead Humanity toward Truth, Justice, and Freedom** (Henry Holt,* 2015; 560 pages), skeptic and *Scientific American* columnist Michael Shermer proposes that our reliance on scientific and rational thinking is actually what has driven people and society to become more moral. Shermer defines moral progress as an "improvement in the survival and flourishing of sentient beings." He cites studies tracking the historical decline in war-related deaths and (despite some recent lapses) government-sanctioned torture, progress in our views of human rights with the abolition of slavery, and more. He appears to overstate, however, the degree to which science has inspired this moral progress.

Relying heavily on anecdotes to depict how we have replaced magical thinking with scientific prowess, Shermer fails to fully recognize the role science has played in morally questionable ventures (the atomic bomb, for one). Despite such flaws, his work does offer an intriguing, fresh take on how we have advanced as moral beings.

—*Victoria Stern*

COURTESY OF AUDIBLE, INC. (*Whispersync for Voice icon*); ISTOCKPHOTO (*heads icon*); *SCIENTIFIC AMERICAN MIND* AND HENRY HOLT ARE AFFILIATES

Why do some people believe in conspiracy theories?

—Thea Buckley, India

Christopher French, a professor of psychology at Goldsmiths, University of London, explains:

Although conspiracy beliefs can occasionally be based on a rational analysis of the evidence, most of the time they are not. As a species, one of our greatest strengths is our ability to find meaningful patterns in the world around us and to make causal inferences. We sometimes, however, see patterns and causal connections that are not there, especially when we feel that events are beyond our control.

The attractiveness of conspiracy theories may arise from a number of cognitive biases that characterize the way we process information. "Confirmation bias" is the most pervasive cognitive bias and a powerful driver of belief in conspiracies. We all have a natural inclination to give more weight to evidence that supports what we already believe and ignore evidence that contradicts our beliefs. The real-world events that often become the subject of conspiracy theories tend to be intrinsically complex and unclear. Early reports may contain errors, contradictions and ambiguities, and those wishing to find evidence of a cover-up will focus on such inconsistencies to bolster their claims.

"Proportionality bias," our innate tendency to assume that big events have big causes, may also explain our tendency to accept conspiracies. This is one reason many people were uncomfortable with the idea that President John F. Kennedy was the victim of a deranged lone gunman and found it easier to accept the theory that he was the victim of a large-scale conspiracy.

Another relevant cognitive bias is "projection." People who endorse conspiracy theories may be more likely to engage in conspiratorial behaviors themselves, such as spreading rumors or tending to be suspicious of others' motives. If you would engage in such behavior, it may seem natural that other people would as well, making conspiracies appear more plausible and widespread. Furthermore, people who are strongly inclined toward conspiratorial thinking will be more likely to endorse mutually contradictory theories. For example, if you believe that Osama bin Laden was killed many years before the American government officially announced his death, you are also more likely to believe that he is still alive.

None of the above should indicate that all conspiracy theories are false. Some may indeed turn out to be true. The point is that some individuals may have a tendency to find such theories attractive. The crux of the matter is that conspiracists are not really sure what the true explanation of an event is—they are simply certain that the "official story" is a cover-up.

What are the best and worst ways to prepare for an exam?

—Lola Irele, London

Daniel Willingham, a professor of psychology at the University of Virginia and author of *Raising Kids Who Read: What Parents and Teachers Can Do,* responds:

So glad you asked! Scientists have a lot of practical information on this topic, but most students do not know about it. Research investigating how students learn was first conducted at highly competitive institutions such as the University of California, Los Angeles. Even students at these top schools used terrible strategies.

For example, students commonly highlight what they read, but research shows that it does not help memory. Most students highlight as they are reading text for the first time, when they do not know what is important enough to highlight.

Another ineffective comprehension method is rereading. Doing so makes the student *feel* he or she is getting to know the material better and better. Rereading is like someone explaining the same thing repeatedly. It all makes sense, so you say, "Yes, yes, got it." But reviewing an explanation is not the same as being able to explain something yourself.

The flaw in rereading—failing to know if you have learned the material—points to our first good study technique: self-testing. Self-testing may involve flash cards, it may mean answering questions at the back of a book chapter or it may be fielding questions lobbed by a study buddy.

There are two main benefits to self-testing. First, in contrast to rereading, self-testing offers an accurate assessment of what has been learned and whether one needs to keep studying. Second, scores of studies show that self-testing is a great way to cement material into memory. It is even better than equivalent time spent perusing the material.

Another useful technique is to periodically pause when reading to ask why a statement in the text is true. We have all had the experience of passing our eyes over words but not really thinking about what we have read. Pausing every few paragraphs to ask, "Why does that make sense?" prompts thinking and learning.

A third technique is to spread out study sessions instead of cramming. Much research shows that memory is more enduring when material is reviewed days or even weeks apart. This is a practice that teachers can promote by giving more frequent assignments and quizzes that require a review of material covered earlier in the course. Even brief memory refreshers can result in big returns in learning. **M**

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1 MEET YOUR MATCH

Rearrange these six matchsticks to make "nothing." No matchsticks may be bent, broken or placed over another.

2 SENTENCE SNAKE

The coiled sentence below will complete a rhyme with the first line "Murphy's law is very fine." Figure out the correct starting letter, then move in any direction, letter by letter. Each letter will be used once and only once.

T K K O E
I E C F N
P E E F I
S Y N T L
O U R H E

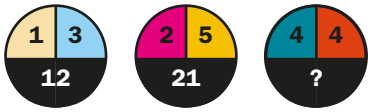
3 MADDENING MATRIX

Supply the missing number.

X	Z	Y	A	30
Y	Z	Y	Z	34
Y	Y	Y	Z	33
A	A	Z	X	28
29	32	33	?	

4 NUMBER SENSE

Following the logic used in the first two circles below, find the missing number in the third circle.

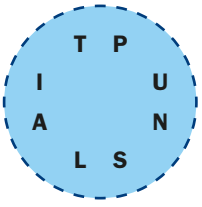


5 THEY GROW SO FAST

Jessica is half Justin's age. In six more years, she will be four-fifths of Justin's age. In 10 years, she will be six-sevenths of Justin's age. How old are Jessica and Justin now?

6 WORD WHEEL

What word is coiled inside the circle?



7 ONE OF THESE THINGS ...

Which of the numbers below is least like the others? (The fact that 10 is a two-digit number is irrelevant.)

1 2 6 5 10

8 BACK WHERE YOU STARTED

Each of the words below begins and ends with the same letters. Fill in the blanks to complete the words.

R E _ _ _ _ _ _ R E
D E _ _ _ D E
A L _ _ _ _ _ _ _ A L

9 PUZZLING PATTERN

Which pair of letters would logically come next in the sequence below?

A Y D V G S J P M M P J ? ?

a) R K
b) S G
c) R S
d) S I

10 DISTRIBUTION PROBLEM

Place the letters in the word HOPE in the empty boxes of the square below so that each horizontal, vertical and long diagonal contains one of the letters but so that no two of the same letters are next to each other (short diagonals do not matter).

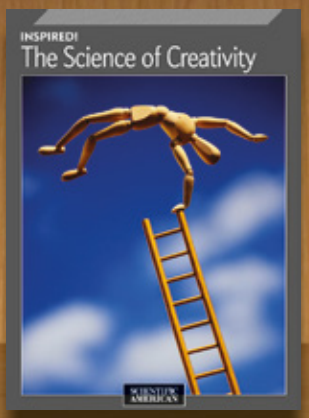
H			
	O		
		P	
			E

Answers

1.

2. IT KEEPS YOUR NECK OFF THE LINE.
3. 31 (A = 6, X = 7, Y = 8, Z = 9).
4. 24. Add the top two numbers and multiply the sum by 3.
5. Jessica is two, and Justin is four.
6. NUPTIALS.
7. 5. It is not a three-letter word.
8. REPERTOIRE, DEGRADE, ALLEGORICAL.
9. Answer b) S G. The two interlwined series are the alphabet forward from A, skipping two letters, and the alphabet backward from Y, skipping two letters.
10. One possible answer:

H	E	O	P
P	O	E	H
E	H	P	O
O	P	H	E



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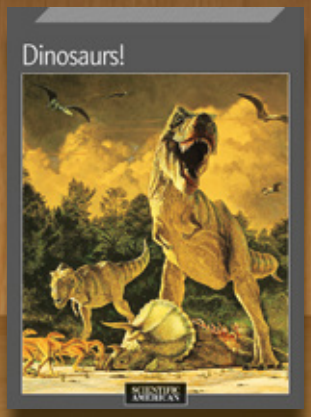

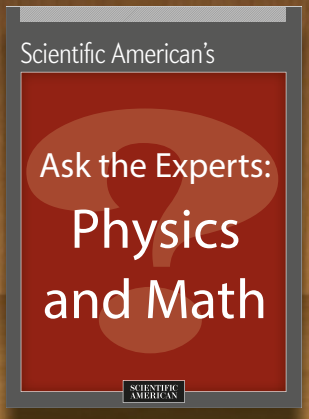

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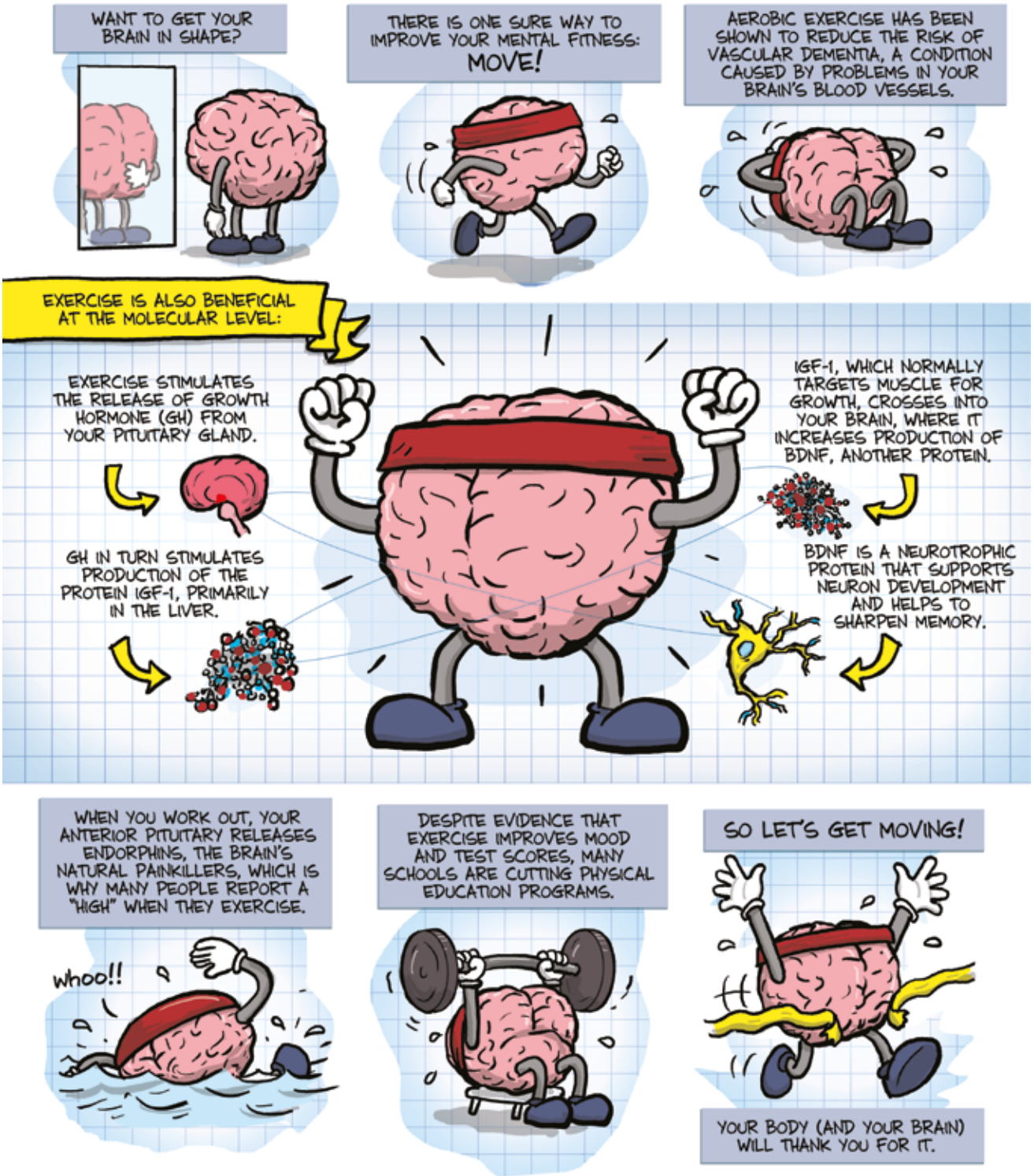
MIND IN MOTION

BY DWAYNE GODWIN & JORGE CHAM



Dwayne Godwin is a neuroscientist at the Wake Forest University School of Medicine.
Jorge Cham draws the comic strip *Piled Higher and Deeper* at www.phdcomics.com.

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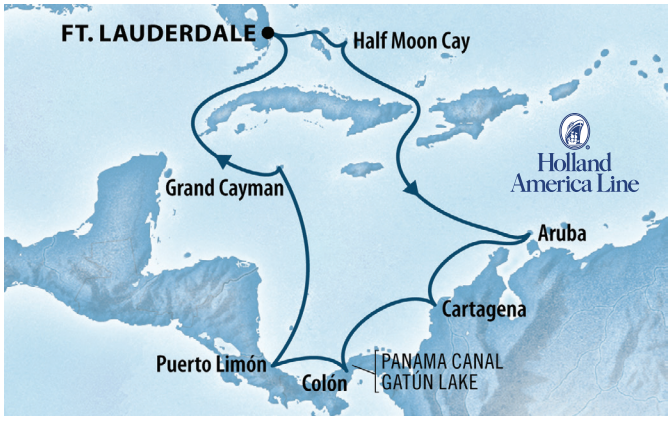
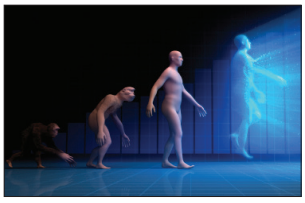


MATHEMATICS

- The Five Elements of Effective Thinking
- To Infinity … and Beyond
- The Fourth Dimension
- Expect the Unexpected



ANTHROPOLOGY

- Human Evolution: the Big Picture
- The First Humans
- The Neanderthals: Another Kind of Human
- The Rise of Homo Sapiens

PSYCHOLOGY

- Your Memories Are Not Your Own
- Rationality Needs Feelings
- Personality Matters
- Moral Reasoning and Moral Identity
- Achieving the Good Life

ASTROPHYSICS

- The State of the Universe Report
- In the Beginning
- Oh Dear, What Could Dark Matter Be?
- Dissonance in the Cosmic Symphony

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