THE FIRST 20 MINUTES

SURPRISING SCIENCE REVEALS HOW WE CAN

EXERCISE BETTER

TRAIN SMARTER

LIVE LONGER

GRETCHEHN REYNOLDS
The sea squirt is not one of nature's more charismatic creatures, but its life story is instructive to modern humans. Tubular, opaque, and squelchy, it resembles a worm-fish from Mars. But the sea squirt is in reality more closely related to humans than to other fish. It's a member of the chordate family, just as we were long ago, in another evolutionary form. When scientists sequenced the entire genome of the sea squirt a few years ago, they found long sections of DNA identical to our own.

At birth, infant sea squirt larvae have a brain. Not much of one; it consists of a few hundred brain cells and some nerve endings. But it does allow the squirt to think in a rudimentary fashion. Young squirts need to find a home. They can't just float aimlessly for the rest of their lives. So, directed by these few neurons, they begin swimming. The movement seems to strengthen the brain and the nervous system connections. The squirt may even add a few dozen brain cells while wandering. But then it finds an underwater rock, ship hull, or perhaps a lazing walrus and attaches itself. Adult squirts are sessile; they pass the rest of their lives clamped to a single surface, waving with the tides but otherwise never moving from that spot.

So their brains die. The neurons and nervous system connec-
tions shrivel and are absorbed into the squirt's soggy tissues. There is "a strong relationship between activity and brain function in animals," according to Fernando Gomez-Pinilla, Ph.D., a professor of physiological science at the University of California, Los Angeles. When the squirt stops moving, Dr. Gomez-Pinilla says, "it has no further use for a brain."

The moral of the story is that this could happen to anyone.

Sound Body, Sound Mind

Thomas Jefferson, who famously enjoyed farming and other vigorous types of seed sowing, once wrote, "A strong body makes the mind strong." He was half-right. A strong mind also makes the body strong. The connections between movement and thinking are intricate, additive, and multidirectional. Without a brain, you can't move, squirt. But without frequent movement, you have a less healthy, hardy brain.

In fact, today's most exciting research in exercise science involves deciphering the ways in which activity affects the mind, because it affects the mind in almost every way. Recent studies credibly have established that exercise stimulates the creation of new brain cells, pumps up existing ones, improves mood, aids in multitasking, blunts aging-related memory loss, sharpens decision making, dulls stress, enfeebles bullies, and if you happen to be an elementary school student, improves your math grade.

"What exercise does for thinking is remarkable," says Charles Hillman, Ph.D., a professor and director of the Neurocognitive Kinesiology Laboratory, at the University of Illinois at Urbana-Champaign. "It's effective in young people, older people, college students," college professors, and people who write or read books about exercise. "Even a small amount of activity can make an enormous difference" in the functioning of the brain, he says.

There had been hints of that possibility for thousands of years,
of course. Scientists, philosophers, and mystics (who, historically, were occasionally the same person) long have talked of a mind-body connection. The first-century poet Juvenal praised “mens sana in corpore sano” (“a sound mind in a sound body”). But it wasn’t until the past decade or so, with the advent of functional magnetic resonance imaging machines, cellular dye tagging, advanced electron microscopy, and other technologies that can zero in on the activities of individual brain cells that scientists began to understand just how a healthy body makes for a healthier brain at a molecular level.

At the same time, what the brain can do for exercise is substantial, too. The right attitude and thinking can improve athletic confidence, steady your putting, or allow you to lollipop along a tightrope three stories above the floor without falling.

The poor sea squirt has no idea what it’s been missing.

“None of Us Wants to Lose Our Minds”

When Canadian researchers measured the energy expenditure and cognitive functioning of a large group of elderly adults over the course of two to five years, the results were predictable. Most of the volunteers did not exercise, per se, and almost none worked out vigorously. Their activities consisted of “walking around the block, cooking, gardening, cleaning, and that sort of thing,” says Laura Middleton, Ph.D., a professor at the University of Waterloo, who led the study.

But even so, the effects of this modest activity on the brain were remarkable, Dr. Middleton says. While the wholly sedentary volunteers—and there were many of these—scored significantly worse over the years on tests of cognitive function, the most active group showed little decline. About 90 percent of those with the greatest daily energy expenditure could think and remember just about as well, year after year.
"Our results indicate that vigorous exercise isn’t necessary" to protect your mind, Dr. Middleton says. "I think that’s exciting. It might inspire people who would be intimidated about the idea of quote-unquote ‘exercising’ to just get up and move."

Who, after all, wants a memory like a . . . you know . . . thing with holes in it? You use it to drain pasta? But mild cognitive decline is extremely common. This isn’t Alzheimer’s, but the more mundane, creeping memory loss that begins about the time our thirties recede, when car keys and people’s names evaporate. So far medications have shown little promise against this insidious slide in our ability to remember and think.

But activity has a demonstrable benefit. In another recent study, a large group of women, most in their seventies, with vascular disease or multiple risk factors for developing that condition completed cognitive tests and surveys of their activities over a period of five years. Again, the women were not spry. There were no marathon runners among them. The most active walked. But there was “a decreasing rate of cognitive decline” among the active group, the authors wrote. Their ability to remember and think did still diminish, but not as rapidly as among the sedentary.

The benefits of exercise on thinking aren’t limited to older adults, either. Scientists at the University of Illinois have studied school-age children and found that those who have a higher level of aerobic fitness processed information more efficiently; they were quicker on a battery of computerized flash card tests. The researchers also found that higher levels of aerobic fitness corresponded to better standardized test scores among a set of Illinois public school students.

But the impacts on aging are, for those of us in the midst of that process, probably the most beguiling. “If an inactive seventy-year-old is heading toward dementia at fifty miles per hour, by the time she’s seventy-five or seventy-six, she’s speeding there at seventy-five miles per hour,” says Jae H. Kang, Sc.D., a professor of medicine
at Brigham and Women’s Hospital, at Harvard Medical School. “But the active seventy-six-year-olds in our study moved toward dementia at more like fifty miles per hour.” Walking and other light activity had bought them, essentially, five years of better brainpower.

“If we can push out the onset of dementia by five, ten, or more years, that changes the dynamics of aging,” says Eric Larson, Ph.D., a researcher in Seattle who studies exercise and the brain and wrote an editorial about the studies of older women. “This research is a wake-up call,” he adds. “None of us wants to lose our minds,” a sentiment with which I fervently agree.

You Must Remember This

What does happen to our thinking as we age? To better map the landscape of memory loss, researchers at Johns Hopkins University and the Center for the Neurobiology of Learning and Memory, at the University of California, Irvine, had groups of young and older volunteers watch pictures flash onto a screen, while the scientists watched their brains in action at the very moment that they were in the process of trying to create and store certain new memories.

Specifically, the volunteers, wearing head sensors, were shown a series of pictures of everyday objects, like computers, telephones, pineapples, pianos, and tractors, and asked to press a button indicating whether each object typically was found indoors or outside. Later they were shown another set of images and asked whether they remembered seeing that specific photo before or a similar one (a baby grand piano instead of a full grand, for instance), or whether the picture was completely new to them. The researchers tracked brain activity throughout both tasks.

There are many different types of memory processing, but one of the more important for everyday functioning is pattern separation. “Take breakfast,” says Michael Yassa, Ph.D., a professor of
psychological and brain sciences at Johns Hopkins, who led the study. Most of us follow a routine and eat much the same thing at the same time for breakfast most days, he says. But each morning's meal is unique and should produce a unique set of memories. “You need to be able to separate those memories and keep them apart,” he explains. “Otherwise they can override one another and confuse things.”

It turned out that young adults in their twenties were quite good at differentiating the images into the right category, and that activity in an area of their brain called the hippocampus increased as they did so. The hippocampus plays an enormous role in how mammals create and process memories; it also affects cognition, the basic ability to think. If your hippocampus is damaged, you most likely have trouble learning facts and forming new memories. Age is a factor, too. As we get older, our brain tends to shrink in volume, and one of the areas most prone to this shrinkage is the hippocampus. This can start depressingly early, in your thirties. Many neurologists believe that the loss of neurons in the hippocampus may be a primary cause of the normal cognitive decay associated with aging, while also contributing to disease. A number of studies have shown that people with Alzheimer’s disease and other forms of serious dementia tend to have smaller-than-normal hippocampi.

In the Johns Hopkins study, the young people’s hippocampi lit up with activity when they looked and mentally sorted the images. “There would be a lot of activity when young people saw either new or similar objects,” Dr. Yassa says. Their brains, via the hippocampus, were learning and storing the new images as new images, even when they were quite similar to the images they had seen before.

The memories of the older volunteers, ages sixty to eighty, were not as sharp. They usually referred to pictures that were similar but not identical to ones they’d seen earlier as “old” photos. Their brains didn’t create a completely new memory to correspond to the slightly different picture. The baby grand didn’t register as different from the
full grand. Meanwhile, their hippocampi showed far less activation than the young people’s.

At the same time, Dr. Yassa says, in a separate part of his experiment, he used sophisticated MRI scanning technology to examine the interconnections among different parts of the brain. In the process, he found that the hippocampus in many of the older, inactive volunteers was not connected as robustly to the rest of the brain as in young people. Messages stumbled on their way from elsewhere in the brain to the hippocampal memory center, and vice versa.

The older people’s processing miscues weren’t severe. They were small lapses. But they presumably would accumulate, becoming an impasto of forgotten moments, one breakfast fading into another and some small portion of each day being lost.

But there is hope, Dr. Yassa says. “Exercise is one of the few things that might directly change this process.”

“We Knew the Brain Controls Behavior, Not That Behavior Controls the Brain”

The Morris water maze is the rodent equivalent of an IQ test: Mice are placed in a tank filled with water dyed an opaque color. Beneath a small area of the surface is a platform, which the mice can’t see. Despite what you’ve heard about rodents and sinking ships, mice hate water; those that blunder upon the platform climb onto it immediately. Scientists have long agreed that a mouse’s spatial memory can be inferred by how quickly the animal finds its way in subsequent dunkings. A “smart” mouse remembers the platform and swims right to it.

In the late 1990s, one group of mice at the Salk Institute for Biological Studies, near San Diego, blew away the others in the Morris maze. The only difference between the smart mice and those
that floundered was exercise. The brainy mice had running wheels in their cages, and the others didn't.

At the time, mainstream scientists believed that the mammalian brain was a relatively rigid, inflexible organ, isolated from the physiological operations of the rest of the body behind the skull and the blood-brain barrier, which prevents the passage of large molecules into the brain. It was believed that the brain did not change much structurally over a person's life span. It couldn't. It supposedly had no ability to make new cells. In high school biology classes, most of us were taught that we had been born with a certain number of brain cells and would have only those and no other neurons for the rest of our lives. When some of this limited supply of cells died due to age or a regrettable overindulgence in beer, mental function would decline. The damage couldn't be stayed off or repaired.

But under the direction of Fred "Rusty" Gage, Ph.D., a world-renowned professor in the Department of Genetics, and his colleagues, these mice proved otherwise. Before being euthanized, the animals had been injected with a chemical compound that incorporates itself into actively dividing cells. During autopsy, those cells could be identified by using a special dye. Gage and his team presumed they wouldn't find such cells in the mice's brain tissue, but to their astonishment, they did. Up until the point of death, the mice had been creating fresh neurons. Their brains were regenerating themselves.

All of the mice showed this vivid proof of what's known as neurogenesis, or the creation of new neurons. But the brains of the athletic mice showed much more. These mice, the ones that had scampered on running wheels, were producing two to three times as many new neurons as the mice that hadn't exercised.

But does neurogenesis also happen in the human brain? To find out, Dr. Gage and his colleagues obtained brain tissue from deceased cancer patients who had donated their bodies to research. While still living, these people had been injected with the same type
of compound used on Dr. Gage’s mice. (Pathologists were hoping to learn more about how quickly the patients’ tumor cells were growing.) When Gage dyed their brain samples, he again saw new neurons. Like the mice, the humans showed evidence of neurogenesis, and this neurogenesis was centered almost exclusively in the hippocampus.

Dr. Gage’s discovery hit the world of neurological research like a thunderclap. Since then, scientists have been finding more evidence that the human brain is not only capable of renewing itself but that exercise speeds the process. “We’ve always known that our brains control our behavior,” Dr. Gage told me, “but not that our behavior could control and change the structure of our brains.”

The human brain is extremely difficult to study, however, especially when a person is still alive. Without euthanizing their subjects, the closest that researchers can get to seeing what goes on in the skull is through a functional MRI machine, which measures the size and shape of the brain and, unlike a standard MRI machine, tracks blood flow and electrical activity.

Not long after Dr. Gage and his colleagues published their seminal studies of neurogenesis in mice and humans, neuroscientists at Columbia University, in New York City, set out to determine if something similar was happening in living humans. They gathered a group of men and women ranging in age from twenty-one to forty-five and asked them to begin working out for one hour four times a week. After twelve weeks, the test subjects, predictably, were more fit. Their VO2 max had risen significantly.

But something else happened as a result of all those workouts: Blood flowed at a much higher volume to the hippocampus, a part of the brain where neurogenesis occurs. Functional MRIs showed that a portion of each person’s hippocampus now received almost twice the blood volume it had before. Scientists suspect that the blood pumping into that part of the brain was helping to produce fresh neurons there.
The Columbia study suggests that shrinkage of the hippocampus, so common as we age, could be slowed via exercise. The volunteers in this study showed significant improvements in their memory, as measured by a word-recall test, after they’d been working out for three months. And moreover, those with the biggest increases in VO2 max had the best scores on the test of all the participants.

“It’s reasonable to infer that neurogenesis was happening in the people’s hippocampi,” says the leader of the study, Scott A. Small, M.D., a professor of neurology at Columbia, “and that working out was driving the neurogenesis.”

Fighting Back the Shadows

Mice, like people, tend to lose their grasp on memory and clear thinking as they age. They are not intellectual giants to begin with. Young mice devote most of their brain capacity to finding food or sex. But there is a poignant downslope over time in their ability to figure out how to get the chow or the girl. They become confused and distracted. Their memories slip away like shadows.

Unless they run.

In experiments that reinforced and expanded our understanding of how moving affects thinking, scientists with the Laboratory of Neuroscience at the National Institute on Aging separated young lab mice and a similar group of elderly rodents into two groups. Half of the young and the old mice were given running wheels in their cages. The other half remained sedentary. Most mice enjoy running, and the youngsters given running wheels scampered on theirs for hours at a time. Even the elderly mice managed at least an hour a day.

Weeks passed. The mice ran or, for those without running wheels, lounged. Then each of the mice was placed in an individual Plexiglas box that included a mouse-sized light-up touch screen. Im-
ages could be flashed on the screen, which, thanks to infrared sensors, recognized the lightest of nose pokes from the mice.

They were taught with a food reward to nose flashing squares. Eventually the mice had to remember and differentiate between several squares appearing on the screen, sometimes touching and sometimes widely spaced. This tests pattern separation and other elements of mouse learning and memory.

The young running mice proved masterful. They processed the information faster and with fewer errors than the young sedentary mice. Upon examination of their brain tissues, they also turned out to have more than twice as many new brain cells in their hippocampi as the unmoving animals.

Improvements took longer and were less striking among the older exercising mice and, in fact, did not occur at all among the elderly sedentary mice. None of them ever managed to understand what they were supposed to do. But doggedly, the ancient runners started differentiating one well-separated and lit-up square from the others, earning their kibble. Unlike the inactive old mice, they were able to remember and learn.

Their brains showed little evidence of neurogenesis, though, suggesting that other processes within the brain may also be at play when we exercise.

Use Your Noggin

Different scientists have varying pet theories about how exercise prompts the brain to remodel itself, each of them involving an alphabet soup of interrelated biochemical processes. One popular hypothesis points to insulin-like growth factor 1, a protein that circulates in the blood and is produced in greater amounts in response to exercise. IGF1 has trouble entering the brain—it usually stops at the blood-brain barrier—but exercise is thought to help it to pass
through the barrier, sparking neurogenesis and other changes in the brain’s tissues.

Other researchers credit BDNF, or brain-derived neurotrophic factor, for many of the beneficial mental impacts of exercise. BDNF is a protein produced in the brain and elsewhere in the body. Pumped out in greater profusion during and after exercise, it’s known to help neurons develop and thrive. It also allows the brain to consolidate short-term memories into long-term ones.

And then there’s BMP, bone morphogenetic protein. At Northwestern University’s Feinberg School of Medicine, scientists have been manipulating the levels of this protein in the brains of laboratory mice. BMP, which is found in tissues throughout the body, affects cellular development in various ways, some of them undesirable.

In the brain, BMP has been found to contribute to the control of stem cell divisions. Your brain, you will be pleased to learn, is packed with adult stem cells, which, given the right impetus, divide and differentiate into either additional stem cells or young neurons. As we age, these stem cells tend to become less responsive. They don’t divide as readily and can slump into a kind of cellular sleep. It’s BMP that acts as the sleep aid, says Dr. John A. Kessler, the chairman of neurology at Northwestern and an author of many studies about the substance. The more active BMP and its various signals are in your brain, the more inactive your stem cells become and the less neurogenesis your brain undergoes. Your brain grows slower, less nimble, and, no matter what your chronological age, physiologically older.

But exercise countermands some of the numbing effects of BMP, Dr. Kessler says. In work at his lab, mice given access to running wheels had about 50 percent less BMP-related brain activity than sedentary controls within a week. They also showed a notable increase in Noggin, a beautifully named brain protein that acts as a BMP antagonist. The more Noggin in your brain, the less BMP
activity and the more stem cell divisions and neurogenesis in your brain. Mice at Northwestern whose brains were infused directly with large doses of Noggin became, Dr. Kessler says, "little mouse geniuses, if there is such a thing." They aced the mazes and other tests.

Whether exercise directly reduces BMP activity or increases production of Noggin isn't yet known and may not matter. The results speak for themselves. Through a complex interplay with Noggin and BMP, physical activity helps to ensure that neuronal stem cells stay lively and new brain cells are born. "If ever exercise enthusiasts wanted a rationale for what they're doing, this should be it," Dr. Kessler says.

But wait, there's more. Exercise also shapes up individual brain cells, just as it strengthens muscles. Muscles of course grow fitter if we work out, a process due in part to an increase in the number of muscle mitochondria, those tiny organelles that float around a cell's nucleus and help to create energy. The greater the mitochondrial density in a cell, the greater its vitality.

Like muscles, the brain gets a physiological workout during exercise. "The brain has to work hard to keep the muscles moving" and all of the bodily systems in sync, says J. Mark Davis, Ph.D., a professor of exercise science at the Arnold School of Public Health, at the University of South Carolina. Scans have shown that metabolic activity in many parts of the brain surges during workouts, but it was unclear whether those straining brain cells were adapting and changing as muscle cells do.

Then Dr. Davis and his colleagues let some mice run for eight weeks, while others stayed inactive. At the end of the two months, the researchers had both groups run to exhaustion on treadmills. The running mice were in better shape, lasting on the treadmills almost twice as long as the unexercised animals. Their brain cells were in better shape, too. When the scientists examined tissue samples from the exercised animals' brains, they found markers in-
indicating substantial new mitochondrial development in their brain cells. There was nothing comparable going on in the brains of the sedentary mice.

The implications of that finding are exciting. Reenergized brain cells should be resistant to fatigue, Dr. Davis says. Since bodily fatigue is partially mediated by signals from the brain, exercising your body could be training your brain to allow you to exercise more, amplifying the benefits, which is nice of it. Revitalized brain cells also could reduce mental fatigue and sharpen your thinking, “even when you’re not exercising,” Dr. Davis says.

Perhaps most important, the additional mitochondrial density could, at least in theory, protect against some neurological diseases. “There is evidence [from other studies] that mitochondrial deficits in the brain may play a role in the development of neurodegenerative diseases,” including Alzheimer’s or Parkinson’s, Dr. Davis says. “Having a larger reservoir of mitochondria” in your brain cells could provide some buffer against those conditions, he says.

“There is no medicine or other intervention that appears to be nearly as effective as exercise” in maintaining or even bumping up a person’s cognitive capabilities, Dr. Hillman says.

The impacts extend even beyond the ability to think and remember. Exercise also dramatically alters how you feel.

Buddha Brain

Researchers at Princeton University recently made the remarkable discovery that the brain cells that sprout as a result of exercise seem to be preternaturally calm. In the experiment, scientists allowed one group of rats to run. Another set of rodents didn’t exercise. Then all of the rats swam in cold water, which, you’ll remember, they dislike. It causes stress, similar to our work deadlines or marital strife.

Afterward, the scientists examined the animals’ brains. They
used cellular markers to determine which of the neurons were the youngest, suggesting that they had been created in the weeks since the experiment began. They also looked for gene activity indicating that individual brain cells had responded to the stress by firing.

They found that the stress of the swimming had activated neurons in all of the animals' brains, whether they'd exercised or not. But the newborn brain cells in the running rats (which were the cells scientists assumed had been created by the running) were much less likely to express the genes indicating that they'd been active. They remained quiet. The "cells born from running," the researchers concluded, appeared to have been "specifically buffered from exposure to a stressful experience." The rats had created, through running, a brain that was biochemically and molecularly calm.

For those of us now worried about the state of our memories, word that exercise also improves mood and lessens anxiety could hardly be more opportune. And the impacts on emotion and mood are wide-ranging. In an experiment at Yale University, researchers found that prolonged exercise altered the expression of almost three dozen genes associated with mood in the brains of laboratory mice, and a study from Germany concluded that light-duty activity such as walking or gardening made participants "happy," in the estimation of the scientists. Similarly, an extremely similar experiment by scientists from Oklahoma State University found that female rats allowed to run at a moderate pace for ten to sixty minutes several times a week—my exercise regimen, in fact—behaved with robust mental health in stress tests. My husband would be surprised by that finding.

Even anger seems to yield to or moderate with exercise. In a study presented at a recent American College of Sports Medicine conference, hundreds of undergraduates at the University of Georgia filled out questionnaires about their moods. From that group, researchers chose sixteen young men with "high trait anger" or, in less technical terms, a short fuse. They were, their questionnaires indicated, habitually touchy.
The researchers invited the men to a lab and had them fill out a survey about their moods at that moment. During the two days of the study, the men were each fitted with high-tech hairnets containing multiple sensors that could read electrical activity in the brain. Next, researchers flashed a series of slides across viewing screens set up in front of each young man. The slides were intended to induce anger. They depicted upsetting events such as Ku Klux Klan rallies and children under fire from soldiers, interspersed with more pleasant images. Electrical activity in the men’s brains indicated that they were growing angry during the display. For confirmation, they described to researchers how angry they felt, using a numerical scale from 0 to 9.

On alternate days, the men either sat quietly or rode a stationary bike for thirty minutes at a moderate pace while their brain patterns and verbal estimations of anger were recorded. Then they watched the slide show again.

The results showed that when the volunteers hadn’t exercised, their second viewing of the slides aroused significantly more anger than the first. After exercise, however, the men’s anger plateaued. They still became upset—exercise didn’t inure them to the slides—but it helped them to hold their anger in check.

“Exercise, even a single bout of it, can have a robust prophylactic effect” against the buildup of anger, says Nathaniel Thom, Ph.D., a stress physiologist who conducted the study. “So if you know that you’re going to be entering into a situation that is likely to make you angry, go for a run first.”

Don’t Let the Bullies Get You Down

Exercise also provides an emotional shield if you’re heading into a situation in which the other guy has not gotten his run in and has, um, “issues,” as researchers at the National Institute of Mental
Health learned when they turned mouse bullies loose on their cage mates.

In a disturbingly accurate simulacrum of many modern human office situations, researchers at the institute gathered two types of mice. Some were strong and aggressive; the others, less so. All were male. The alpha mice got private cages. Male mice in the wild are territorial loners. So when the punier mice were later slipped into the same cages as the aggressive rodents, separated only by a clear partition, the big mice acted like thugs. They employed every animal intimidation technique, and during daily five-minute periods when the partition was removed, they had to be restrained from harming the smaller mice. In the face of such treatment, the smaller animals became predictably twitchy and submissive.

After two weeks of cohabitation, many of these weaker mice were nervous wrecks. Tested in a series of stressful situations away from the cages, the mice responded with, as the scientists call it, “anxiety-like behavior.” They froze or ran for dark corners. Everything upset them. “We don’t use words like ‘depressed’ to describe the animals’ condition,” says Michael L. Lehmann, Ph.D., a fellow at the institute who led the study. But in effect, those mice had responded to the repeated hectoring and abuse by becoming depressed.

However, that condition didn’t crop up in a separate subgroup of mice that had been allowed access to running wheels for several weeks before they were housed with the aggressive mice. These mice, although wisely submissive when confronted by the bullies, rallied nicely when away from them. They didn’t freeze or cling to dark spaces in unfamiliar situations. They explored. They appeared to be, Dr. Lehmann says, “stress resistant.”

“In people, we know that repeated applications of stress can lead to anxiety disorders and depression,” says Dr. Lehmann. “But one of the mysteries” of mental illness “is why some people respond pathologically to stress and some seem to be stress resistant.”

The answer, at least in part, may be workouts. “It looks more
and more like the positive stress of exercise prepares cells and structures and pathways within the brain so that they’re more equipped to handle stress in other forms," says Michael Hopkins, Ph.D., a researcher affiliated with the Neurobiology of Learning and Memory Laboratory, at Dartmouth University, who has been studying how exercise differently affects thinking and emotion. “It’s pretty amazing, really, that you can get this translation from the realm of purely physical stresses to the realm of psychological stressors.”

Of course, as we all know, mice are not people. But the scientists believe that this particular experiment is a fair representation of human interpersonal relations. Hierarchies, marked by bullying and resulting stress, are found among people all the time, Dr. Lehmann says. Just think of your own most dysfunctional office job. (It’s also worth noting that the same experiment cannot be conducted on female mice, who like being housed together, Dr. Lehmann says, so he and his colleagues are planning to test a female-centric version, in which “cage mates are swapped out continuously,” to the consternation and grief of the female mice left behind.)

And perhaps best of all, Dr. Lehmann does not believe that hours of daily exercise are needed or desirable to achieve emotional resilience. The mice in his lab ran only when and for as long as they wished. For his own part, Dr. Lehmann doesn’t run. But he has no car and walks everywhere, and although he lives in Washington, DC, a cauldron of stress induction, he describes himself as a “pretty calm guy.”

Will Any Workout Work?

Whether any one type of exercise is better than another for spurring changes in the brain remains uncertain. Most researchers are proponents of endurance workouts, such as walking, running, cycling, swimming, and so on. In one of the few experiments to directly
compare the effects of different types of regimens on mental functioning, twenty-one students at the University of Illinois were asked to memorize a string of letters and then pick them out from a list flashed at them. Then they were asked to do one of three things for thirty minutes—sit quietly, run on a treadmill, or lift weights—before performing the letter test again. After an additional thirty-minute cooldown, they were tested once more. On subsequent days, the students returned to try the other two options. They were noticeably quicker and more accurate on the retest after they ran compared with the other two options, and they continued to perform better when tested after the cooldown.

"There seems to be something about aerobic exercise," says Dr. Hillman, who conducted the study. "It sparks changes in the brain structure and function. It's not clear if other types of exercise can do that."

Henriette van Praag, Ph.D., an investigator in the Laboratory of Neuroscience at the National Institute on Aging, agrees. "It appears that various growth factors must be carried from the periphery of the body into the brain to start or intensify a molecular cascade there," she says. For that to happen, you may need "a fairly dramatic change in blood flow," like the one that occurs when you run or cycle or swim.

But there is some limited evidence that weight training can have beneficial impacts, as well. Recently scientists in Brazil developed the first plausible animal version of weight training. It's been difficult to study the molecular effects of resistance-style exercise on the mind because animals can't lift weights. Lab rats, mice, and other animals usually love to run and can be made to swim, so it's been easy to use animals to study aerobic exercise and the brain. (Cycling is difficult.) But lab animals can't heft barbells very well, and they don't fit on Nautilus machines.

So the Brazilian researchers had the clever notion to attach weights to the tails of a group of lab rats and have them clamber
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slowly up a ladder five times a week. A separate control group of rats did not exercise. After eight weeks, the tail-weighted animals had developed the bulky muscles of human gym rats, an indication that the exercise regimen was focusing on muscle. They’d also become smart, performing better than the sedentary animals on tests of memory and learning. And when the scientists compared brain tissue from both groups of animals, they found that the weight-trained rats’ brains contained far more growth factors associated with neurogenesis than the sedentary animals.

The few applicable studies in humans have been encouraging, too. In one, a group of women age sixty-five or older completed twelve months of light-duty weight training twice a week. They did not do any endurance training, such as walking. At the end of the year, they performed significantly better on tests of mental processing ability than a control group of women. Functional MRI scans of both groups showed that portions of the brain that control decision making and other types of thinking were more active in the weight trainers.

“We’re not trying to show that lifting weights is better than aerobic-style activity” for staving off cognitive decline, says the University of British Columbia’s Dr. Teresa Liu-Ambrose, the study leader. “But it does appear to be a viable option.”

Lucky

Meanwhile, the mental effects of exercise flow both ways. If exercising has an impact on thinking, thinking also greatly influences exercise performance, although the impacts can be shifty and fickle. Look at confidence. Some studies have found a correlation between robust self-confidence and improved performance, but others have found that athletes who are too internally assured can ignore external cues about any given day’s needs; they don’t pay enough
attention to their opponents, the weather, their equipment, or warnings from their own tired body, which can cause failure as well.

Confidence is especially tricky when it comes to injury risk. Athletes identified by researchers as supremely confident are believed to be at higher risk for injury, because a bulletproof ego can lead to risk taking. On the other hand, low athletic self-confidence doesn’t help much, either. A recent survey of high school athletes found that those who reported in the preseason that they weren’t confident about how they would perform in the games and meets ahead tended to wind up hurt, especially if they were female.

But confidence is most problematic when it’s yoked to self-deception, as a fascinating study of clowns and tumblers makes clear. In the study, forty-seven athletes who were hoping to land a spot in a Cirque du Soleil show filled out questionnaires about their health and attitudes at the start of a training camp. Each of the athletes previously had been an elite competitor in gymnastics, trampoline, swimming, or diving. They were used to knowing what their bodies could do.

But they were being thrust into an entirely new discipline. The training camp regimen was strenuous and mentally trying, says Madeleine Hallé, Ph.D., a senior performance psychologist with Cirque du Soleil. The athletes were beginners again after years of being among the best in the world.

More than half of them wound up injured during the four-month camp. Some hurt themselves multiple times.

Injuries were most common among those who, according to their questionnaires, possessed low “self-efficacy,” a kind of enhanced self-confidence, or the feeling that you are easily capable of performing the task ahead. But not all athletes with low self-efficacy got hurt. Some considered themselves incapable of the demands of Cirque, but they were wrong. And some who scored high on self-efficacy sustained multiple injuries. They demonstrably were not physically ready, but they thought they were.
That distinction between lacking self-confidence when you should have it and having it when you perhaps shouldn't is likely to make a big difference in performance and injury risk, says Ian Shrier, M.D., a professor in the department of family medicine at McGill University, who studied the Cirque performers. It also will affect the proper response. If you're correct that you're not physically ready to perform a task, the best intervention is going to be augmented coaching and physical training. But if you have the ability but simply don't believe that you do, intercessions should probably focus on building psychological coping skills, rather than physical technique.

Which carries us, inextricably, to the issue of lucky underwear. If you lack confidence despite having fine technique and training, science suggests that you might want to look to luck. An astonishing number of the world’s top athletes are deeply superstitious. For years, Michael Jordan wore the shorts from his national-championship-winning University of North Carolina days under his Chicago Bulls uniform. Serena Williams supposedly wouldn’t change her socks at tournaments she was winning. Other professional athletes carry lucky charms or perform rituals, like bouncing a basketball in elaborate sequences before a free throw or kissing the golf ball before a putt. Baseball first baseman Jason Giambi has said that he would slip on a pair of “lucky” thong underwear when his batting average fell. (And during Giambi’s career the thong’s reputation became so potent that slumping teammates reportedly begged to borrow it.)

But does lucky underwear work? Unfortunately for those of us who really despise thongs, researchers at the University of Cologne, in Germany, found that the answer is a qualified yes.

In a series of experiments, the scientists asked college students to make as many golf puts as possible on a putting green. Before his or her first attempt, each participant was handed a golf ball. Some were told, “Here is your ball; so far it has turned out to be a lucky
ball.” The rest were told, more blandly, “This is the ball everyone has used so far.” Each student putted ten times.

The students using the “lucky” balls sank significantly more putts than those who didn’t.

Next the researchers had a different group of students complete a dexterity test. The students were given a plastic cube containing thirty-six balls and a shelf dimpled with thirty-six holes. They were told to dip and twist the box until the balls rested in the holes. First, though, they were given instruction from a moderator, who told some of the volunteers, “I press the thumbs for you,” a German idiom that loosely translates to, “I’m keeping my fingers crossed for you; good luck.” The rest received neutral directions. By a fairly significant margin, the volunteers who had been offered the thumb pressing maneuvered the balls into position fastest.

“Activating a good-luck superstition,” the authors concluded, “leads to improved performance by boosting people’s belief in their ability to master a task.” More precisely, they added, “the present findings suggest that it may have been the well-balanced combination of existing talent, hard training and good-luck underwear that made Michael Jordan perform as well as he did.”

Interestingly, superstitions flourish most in situations in which talent is being pushed to its limits and any edge might be decisive, even if it’s fantastical. In a nifty experiment at Colorado College, in Colorado Springs, a group of students putted. Their first round of putts was easy, measuring only three feet to the cup. The second round consisted of nine-foot putts. Each volunteer putted twenty times at each distance. Students could choose their balls from a basket containing four different colors. During the easy round, the best putters pulled balls out at random; they weren’t interested in the colors. But the less able students, those who weren’t good at putting, tended to pick the same-color ball after any successful putt; it had become their “lucky” ball.

When the testing moved to the longer putts, the better golfers
started picking the same-color ball after successful putts. As their skills were being challenged, they began turning to luck to increase their chances. Meanwhile, the less talented putters, who missed almost all of the longer putts anyway, no longer seemed to care which ball they used. Luck couldn’t help them now.

The lesson from this and the other experiments is, at its most basic, that being superstitious is a sign not of weakness but “of hope,” says Kristi Erdal, Ph.D., a professor of psychology at Colorado College and an author of the putting study. You may be turning to an external, intangible force, but you haven’t given up.

And that, in a broader sense, is the message of all of the science related to exercise and the brain: Just keep going. Every researcher I spoke with on this topic exercises. Some run. Some walk. There are a few bike racers. Tennis is popular, too. But none are sedentary. They know too much. Beneficently, they’ll share.

“As a neurologist,” Columbia University’s Dr. Small says, “I constantly get asked at cocktail parties what someone can do to protect their mental functioning. I tell them, ‘Put down that glass and go for a run.’”

How to Sharpen Your Mind and Mood

1. Bulk Up Your Brain.

In one study, elderly sedentary people who began a walking program showed significant growth in several areas of the brain after six months. Scientists believe that the workouts prompted the creation of new neurons, as well as new blood vessels and connections between the neurons. The walkers’ brains were bigger, faster, and younger, and they consequently performed better on tests of memory and decision making than people who’d remained sedentary.
2. A Little May Be Enough.
In mice, a fairly short period of exercise and a short distance seems to produce results in terms of improved cognition. "Walking around the block, cooking, gardening, cleaning, and that sort of thing" significantly improved cognitive function in a group of older people, says Dr. Middleton, who studied the group.

3. Run Away from Serious Memory Loss.
"Epidemiological studies show that long-term runners have a lower risk of neurological disease," including Alzheimer's and Parkinson's, says Dr. Mark Tarnopolsky, a professor of medicine at McMaster Children's Hospital, who has studied exercise and the brain for decades and himself runs almost every day.

4. Get the Kids Out, Too, for Your Own Sake.
Studies from the University of Illinois have found that "just twenty minutes of walking" before a test raises kids' scores, even if the children are otherwise unfit or overweight, says Dr. Hillman, who has studied exercise and kids' brains. Other work from his lab has shown that aerobically fit children score higher on tests of complex memory than less fit youngsters. But perhaps most compelling from a parental standpoint, a years-long Swedish study found that among more than a million eighteen-year-old boys who joined the army, better fitness consistently correlated with higher IQ, even among identical twins. The fittest young Swedes also were significantly more likely to go on to lucrative careers than the least fit, rendering them less prone, one hopes, to taking up residence in their parents' basements.

5. Quit with the Dumb Jock Jokes.
Japanese researchers recently loaded rats' running wheels, similar to cranking up a stationary bicycle's resistance. The load
on the wheels equaled 30 percent of the rats' body weight. They could barely push themselves along, straining as if against a hurricane-level headwind. After eight weeks, the animals had packed on muscle mass in their legs, while a group of rats jogging easily on unloaded wheels had not. The buff rats also displayed increased levels of gene activity in the brain associated with improved brain functioning—more, in fact, than in the animals that hadn't added muscle. The stronger the animals became, the better their brains worked.

6. Take a Step. Lift a Mood.

Exercise speeds the brain's production of serotonin. Abnormally low levels of serotonin have been associated with anxiety and depression. In some studies, exercise has been as or even more effective than antidepressant medications at making people feel better.

7. Be Patient.

The stress-reducing changes in the brain wrought by exercise don't happen overnight. In experiments at the University of Colorado, rats that ran for only three weeks did not show much reduction in stress-induced anxiety, but those that ran for at least six weeks did. "Something happened between three and six weeks," says Dr. Benjamin Greenwood, who helped conduct the experiments. The lesson, he continues, is "don't quit." You may not feel a magical reduction of stress after your first jog or swim. But the molecular biochemical changes will begin, Dr. Greenwood says. And eventually, he says, they become profound.

8. Find a Training Partner.

A rather touching experiment with a species of sociable, gregarious rats found that when these animals were housed alone, their brains did not benefit from exercise as much as
when they were in shared cages. Loneliness increased the levels of stress hormones in the animals’ brains. Exercise added more stress, apparently blunting the positive effects of the workouts. Socially housed rats produced copious amounts of new brain cells when they exercised; the lonely animals did not.


Sex can spur neurogenesis. It is a moderate workout, after all, if you do it right. When male rats at the Princeton Neuroscience Institute were given access to “sexually receptive” females, they responded as nature intended and vigorously engaged with the girl rats. The resultant activity led to an increase in neurogenesis in their brains. Sex improved their ability to think, obvious jokes notwithstanding.