

SPARK!

How exercise
will improve the
performance of
your brain

'Forget fish oil and sudoku – it's exercise
that makes you brainier' *Daily Mail*

Dr John J. Ratey and Eric Hagerman

SPARK!

“Forget fish oil and sudoku – it’s exercise that makes you brainier . . . Regular exercise isn’t just good for your body . . . it can also dramatically improve your brain, boosting learning capabilities, reducing stress, smoothing hormonal fluctuations and reversing the signs of ageing . . . This book is the first time scientific evidence from all over the world has been pulled together to show that the fitter you are, the better your brain works” (Daily Mail)

“Accessible and thought-provoking . . . Dr John Ratey . . . describes a new approach to physical education that builds the link between exercise and the brain . . . He shows that walking, running and strength training not only improve school performance, they also fight stress, anxiety, depression, addiction and even the effects of ageing . . . If exercise came in pill form, it would be plastered across the front page, hailed as the blockbuster drug of the century. So what are you waiting for? Get moving!” (Focus Magazine)

“Want to raise your IQ? Pump up your heart rate! In Spark, Dr. Ratey reveals how cardiovascular exercise can help ward off anxiety, dementia and depression, all while increasing your intelligence. Buy it if you need a little bit of extra motivation to hit the gym” (Self Magazine)

“At a time of year when the prospect of the gym or a bicycle ride seems particularly unappealing just bear in mind that increasing your metabolic rate will do more than simply decrease your waistline, it might literally change the way you think” (Birmingham Life)

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Introduction

Making the Connection

WE ALL KNOW that exercise makes us feel better, but most of us have no idea why. We assume it's because we're burning off stress or reducing muscle tension or boosting endorphins, and we leave it at that. But the real reason we feel so good when we get our blood pumping is that it makes the brain function at its best, and in my view, this benefit of physical activity is far more important—and fascinating—than what it does for the body.

Building muscles and conditioning the heart and lungs are essentially side effects. I often tell my patients that the point of exercise is to build and condition the brain. In today's technology-driven, plasma-screened-in world, it's easy to forget that we are born movers—animals, in fact—because we've engineered movement right out of our lives. Ironically, the human capacity to dream and plan and create the very society that shields us from our biological imperative to move is rooted in the areas of the brain that govern movement. As we adapted to an ever-changing environment over the past half million years, our thinking brain evolved from the need to hone motor skills.

We envision our hunter-gatherer ancestors as brutes who relied primarily on physical prowess, but to survive over the long haul they had to use their smarts to find and store food. The relationship between food, physical activity, and learning is hardwired into the brain's circuitry. But we no longer hunt and gather, and that's a problem. The sedentary character of modern life is a disruption of our nature, and it poses one of the biggest threats to our continued survival. Evidence of this is everywhere: 65 percent of our nation's adults are overweight or obese, and 10 percent of the population has type 2 diabetes, a preventable and ruinous disease that stems from inactivity and poor nutrition.

Once an affliction almost exclusively of the middle-aged, it's now becoming an epidemic among children. We're literally killing ourselves, and it's a problem throughout the developed world, not merely a province of the supersize lifestyle in the United States. What's even more disturbing, and what virtually no one recognizes, is that inactivity is killing our brains too—physically shriveling them. Our culture treats the mind and body as if they are separate entities, and I want to reconnect the two. The mind-body connection has fascinated me for years.

My very first lecture, to fellow medical professionals at Harvard, in 1984, was titled "The Body and Psychiatry." It focused on a novel drug treatment, for aggression, that affected both the body and the brain, which I stumbled on as a resident working in the Massachusetts state hospital system. My

experience working with the most complicated psychiatric patients set me on a path of investigation into the ways in which treating the body can transform the mind. It's been an enthralling journey, and though it continues, it's time to deliver that message to the public.

What neuroscientists have discovered in the past five years alone paints a riveting picture of the biological relationship between the body, the brain, and the mind. To keep our brains at peak performance, our bodies need to work hard. In *Spark*, I'll demonstrate how and why physical activity is crucial to the way we think and feel. I'll explain the science of how exercise cues the building blocks of learning in the brain; how it affects mood, anxiety, and attention; how it guards against stress and reverses some of the effects of aging in the brain; and how in women it can help stave off the sometimes tumultuous effects of hormonal changes.

I'm not talking about the fuzzy notion of runner's high. I'm not talking about a notion at all. These are tangible changes, measured in lab rats and identified in people. It was already known that exercise increases levels of serotonin, norepinephrine, and dopamine—important neurotransmitters that traffic in thoughts and emotions. You've probably heard of serotonin, and maybe you know that a lack of it is associated with depression, but even many psychiatrists I meet don't know the rest. They don't know that toxic levels of stress erode the connections between the billions of nerve cells in the brain or that chronic depression shrinks certain areas of the brain.

And they don't know that, conversely, exercise unleashes a cascade of neurochemicals and growth factors that can reverse this process, physically bolstering the brain's infrastructure. In fact, the brain responds like muscles do, growing with use, withering with inactivity. The neurons in the brain connect to one another through "leaves" on treelike branches, and exercise causes those branches to grow and bloom with new buds, thus enhancing brain function at a fundamental level. Neuroscientists have just begun studying exercise's impact within brain cells—at the genes themselves. Even there, in the roots of our biology, they've found signs of the body's influence on the mind. It turns out that moving our muscles produces proteins that travel through the bloodstream and into the brain, where they play pivotal roles in the mechanisms of our highest thought processes.

They bear names such as insulin-like growth factor (IGF-1) and vascular endothelial growth factor (VEGF), and they provide an unprecedented view of the mind-body connection. It's only in the past few years that neuroscientists have begun to describe these factors and how they work, and each new discovery adds awe-inspiring depth to the picture. There's still much we don't understand about what happens in the microenvironment of the brain, but I think what we do know can change people's lives. And maybe society itself.

Why should you care about how your brain works?

For one thing, it's running the show. Right now the front of your brain is firing signals about what you're reading, and how much of it you soak up has a lot to do with whether there is a proper balance of neurochemicals and growth factors to bind neurons together. Exercise has a documented, dramatic effect on these essential ingredients. It sets the stage, and when you sit down to learn something new, that stimulation strengthens the relevant connections; with practice, the circuit develops definition, as if you're wearing down a path through a forest. The importance of making these connections carries over to all of the issues I deal with in this book.

In order to cope with anxiousness, for instance, you need to let certain well-worn paths grow over while you blaze alternate trails. By understanding such interactions between your body and your brain, you can manage the process, handle problems, and get your mind humming along smoothly. If you had half an hour of exercise this morning, you're in the right frame of mind to sit still and focus on this paragraph, and your brain is far more equipped to remember it. Everything I have written over the past fifteen years has been aimed at educating people about their brains.

Your life changes when you have a working knowledge of your brain. It takes guilt out of the equation when you recognize that there's a biological basis for certain emotional issues. On the other hand, you won't be left feeling helpless when you see how you can influence that biology. This is a point that I keep coming back to with my patients, because people tend to picture the brain as a commander mysteriously issuing orders from an ivory tower, untouchable from the outside. Not at all. Exercise breaks down those barriers. My hope is that if you understand how physical activity improves brain function, you'll be motivated to include it in your life in a positive way, rather than think of it as something you should do.

Of course you should exercise, but I won't be preaching here. (It probably wouldn't help: experiments with lab rats suggest that forced exercise doesn't do the trick quite like voluntary exercise.) If you can get to the point where you're consistently saying to yourself exercise is something you want to do, then you're charting a course to a different future—one that's less about surviving and more about thriving. In October of 2000 researchers from Duke University made the New York Times with a study showing that exercise is better than sertraline (Zoloft) at treating depression.

What great news! Unfortunately, it was buried on page fourteen of the Health and Fitness section. If exercise came in pill form, it would be plastered across the front page, hailed as the blockbuster drug of the century. Other fragments of the story I'm presenting bubble to the surface, only to sink back down. ABC

World News reports that exercise might stave off Alzheimer's disease in rats; CNN flashes stats on the ever-expanding obesity crisis; the New York Times investigates the practice of treating bipolar kids with costly drugs that are only marginally effective yet carry horrendous side effects.

What gets lost is that these seemingly unrelated threads are tied together at a fundamental level of biology. I'll explain how, by exploring volumes of new research that hasn't yet appeared anywhere for the general public. What I aim to do here is to deliver in plain English the inspiring science connecting exercise and the brain and to demonstrate how it plays out in the lives of real people. I want to cement the idea that exercise has a profound impact on cognitive abilities and mental health. It is simply one of the best treatments we have for most psychiatric problems.

I've witnessed this among my patients and my friends, a number of whom have given me permission to tell their stories here. Yet it was far beyond the walls of my office that I discovered the exemplar case study, in a suburban school district outside Chicago. The implications of the most exciting new research merge in this tale of a revolutionary physical education program. In Naperville, Illinois, gym class has transformed the student body of nineteen thousand into perhaps the fittest in the nation. Among one entire class of sophomores, only 3 percent were overweight, versus the national average of 30 percent. What's more surprising—stunning—is that the program has also turned those students into some of the smartest in the nation.

In 1999 Naperville's eighth graders were among some 230,000 students from around the world who took an international standards test called TIMSS (Trends in International Mathematics and Science Study), which evaluates knowledge of math and science. In recent years, students in China, Japan, and Singapore have outpaced American kids in these crucial subjects, but Naperville is the conspicuous exception: when its students took the TIMSS, they finished sixth in math and first in the world in science. As politicians and pundits sound the alarm about faltering education in the United States, and about our students being ill-equipped to succeed in today's technology-driven economy, Naperville stands out as an extraordinary bit of good news. I haven't seen anything as uplifting and inspiring as Naperville's program in decades. At a time when we're bombarded with sad news about overweight, unmotivated, and underachieving adolescents, this example offers real hope. In the first chapter, I'll take you to Naperville. It is the spark that inspired me to write this book.

1- Welcome to the Revolution

A Case Study on Exercise and the Brain

ON A SLIGHT swell of land west of Chicago stands a brick building, Naperville Central High School, which harbors in its basement a low-ceilinged, windowless room crowded with treadmills and stationary bikes. The old cafeteria—its capacity long dwarfed by enrollment numbers—now serves as the school’s “cardio room.” It is 7:10 a.m., and for the small band of newly minted freshmen lounging half asleep on the exercise equipment, that means it’s time for gym. A trim young physical education teacher named Neil Duncan lays out the morning’s assignment: “OK, once you’re done with your warm-up, we’re going to head out to the track and run the mile,” he says, presenting a black satchel full of chest straps and digital watches—heart rate monitors of the type used by avid athletes to gauge their physical exertion.

“Every time you go around the track, hit the red button. What that’s going to do—it’s going to give you a split. It’s going to tell you, this is how fast I did my first lap, second lap, third lap. On the fourth and final lap—which will be just as fast if you do it right —” he says, pausing to survey his sleepy charges, “you hit the blue button, OK? And that’ll stop your watch. Your goal is—well, to try to run your fastest mile. Last but not least, your average heart rate should be above 185.” Filing past Mr. Duncan, the freshmen lumber upstairs, push through a set of heavy metal doors, and in scattered groups they hit the track under the mottled skies of a crisp October morning.

Perfect conditions for a revolution. This is not good old gym class. This is Zero Hour PE, the latest in a long line of educational experiments conducted by a group of maverick physical education teachers who have turned the nineteen thousand students in Naperville District 203 into the fittest in the nation—and also some of the smartest. (The name of the class refers to its scheduled time before first period.) The objective of Zero Hour is to determine whether working out before school gives these kids a boost in reading ability and in the rest of their subjects. The notion that it might is supported by emerging research showing that physical activity sparks biological changes that encourage brain cells to bind to one another.

For the brain to learn, these connections must be made; they reflect the brain’s fundamental ability to adapt to challenges. The more neuroscientists discover about this process, the clearer it becomes that exercise provides an unparalleled stimulus, creating an environment in which the brain is ready, willing, and able to learn. Aerobic activity has a dramatic effect on adaptation, regulating systems that might be out of balance and optimizing those that are not—it’s an indispensable tool for anyone who wants to reach his or her full potential. Out at the track, the freckled and bespectacled Mr. Duncan

supervises as his students run their laps.

“My watch isn’t reading,” says one of the boys as he jogs past. “Red button,” shouts Duncan. “Hit the red button! At the end, hit the blue button.” Two girls named Michelle and Krissy pass by, shuffling along side by side. A kid with unlaced skateboarding shoes finishes his laps and turns in his watch. His time reads eight minutes, thirty seconds. Next comes a husky boy in baggy shorts. “Bring it on in, Doug,” Duncan says. “What’d you get?” “Nine minutes.” “Flat?” “Yeah.” “Nice work.” When Michelle and Krissy finally saunter over, Duncan asks for their times, but Michelle’s watch is still running.

Apparently, she didn’t hit the blue button. Krissy did, though, and their times are the same. She holds up her wrist for Duncan. “Ten twelve,” he says, noting the time on his clipboard. What he doesn’t say is “It looked like you two were really loafing around out there!” The fact is, they weren’t. When Duncan downloads Michelle’s monitor, he’ll find that her average heart rate during her ten-minute mile was 191, a serious workout for even a trained athlete. She gets an A for the day. The kids in Zero Hour, hearty volunteers from a group of freshmen required to take a literacy class to bring their reading comprehension up to par, work out at a higher intensity than Central’s other PE students.

They’re required to stay between 80 and 90 percent of their maximum heart rate. “What we’re really doing is trying to get them prepared to learn, through rigorous exercise,” says Duncan. “Basically, we’re getting them to that state of heightened awareness and then sending them off to class.” How do they feel about being Mr. Duncan’s guinea pigs? “I guess it’s OK,” says Michelle. “Besides getting up early and being all sweaty and gross, I’m more awake during the day. I mean, I was cranky all the time last year.” Beyond improving her mood, it will turn out, Michelle is also doing much better with her reading.

And so are her Zero Hour classmates: at the end of the semester, they’ll show a 17 percent improvement in reading and comprehension, compared with a 10.7 percent improvement among the other literacy students who opted to sleep in and take standard phys ed. The administration is so impressed that it incorporates Zero Hour into the high school curriculum as a first-period literacy class called Learning Readiness PE. And the experiment continues. The literacy students are split into two classes: one second period, when they’re still feeling the effects of the exercise, and one eighth period. As expected, the second-period literacy class performs best. The strategy spreads beyond freshmen who need to boost their reading scores, and guidance counselors begin suggesting that all students schedule their hardest subjects immediately after gym, to capitalize on the beneficial effects of exercise. It’s a truly revolutionary concept from which we can all learn.

FIRST-CLASS PERFORMANCE

Zero Hour grew out of Naperville District 203's unique approach to physical education, which has gained national attention and become the model for a type of gym class that I suspect would be unrecognizable to any adult reading this. No getting nailed in dodgeball, no flunking for not showering, no living in fear of being the last kid picked. The essence of physical education in Naperville 203 is teaching fitness instead of sports.

The underlying philosophy is that if physical education class can be used to instruct kids how to monitor and maintain their own health and fitness, then the lessons they learn will serve them for life. And probably a longer and happier life at that. What's being taught, really, is a lifestyle. The students are developing healthy habits, skills, and a sense of fun, along with a knowledge of how their bodies work. Naperville's gym teachers are opening up new vistas for their students by exposing them to such a wide range of activities that they can't help but find something they enjoy.

They're getting kids hooked on moving instead of sitting in front of the television. This couldn't be more important, particularly since statistics show that children who exercise regularly are likely to do the same as adults. But it's the impact of the fitness-based approach on the kids while they're still in school that initially grabbed my attention. The New PE curriculum has been in place for seventeen years now, and its effects have shown up in some unexpected places—namely, the classroom. It's no coincidence that, academically, the district consistently ranks among the state's top ten, even though the amount of money it spends on each pupil—considered by educators to be a clear predictor of success—is notably lower than other top-tier Illinois public schools.

Naperville 203 includes fourteen elementary schools, five junior highs, and two high schools. For the sake of comparison, let's look at Naperville Central High School, where Zero Hour began. Its per-pupil operating expense in 2005 was \$8,939 versus \$15,403 at Evanston's New Trier High School. New Trier kids scored on average two points higher on their ACT college entrance exams (26.8), but they fared worse than Central's kids on a composite of mandatory state tests, which are taken by every student, not just those applying to college. And Central's composite ACT score for the graduating class of 2005 was 24.8, well above the state average of 20.1. Those exams aren't nearly as telling as the Trends in International Mathematics and Science Study (TIMSS), a test designed to compare students' knowledge levels from different countries in two key subject areas.

This is the exam cited by New York Times editorialist Thomas Friedman, author of *The World Is Flat*, when he laments that students in places like

Singapore are “eating our lunch.” The education gap between the United States and Asia is widening, Friedman points out. Whereas in some Asian countries nearly half of the students score in the top tier, only 7 percent of U.S. students hit that mark. TIMSS has been administered every four years since 1995. The 1999 edition included 230,000 students from thirty-eight countries, 59,000 of whom were from the United States.

While New Trier and eighteen other schools along Chicago’s wealthy North Shore formed a consortium to take the TIMSS (thereby masking individual schools’ performance), Naperville 203 signed up on its own to get an international benchmark of its students’ performance. Some 97 percent of its eighth graders took the test—not merely the best and the brightest. How did they stack up? On the science section of the TIMSS, Naperville’s students finished first, just ahead of Singapore, and then the North Shore consortium. Number one in the world. On the math section, Naperville scored sixth, behind only Singapore, Korea, Taiwan, Hong Kong, and Japan.

As a whole, U.S. students ranked eighteenth in science and nineteenth in math, with districts from Jersey City and Miami scoring dead last in science and math, respectively. “We have huge discrepancies among our school districts in the United States,” says Ina Mullis, who is a codirector of TIMSS. “It’s a good thing that we’ve at least got some Napervilles—it shows that it can be done.” I won’t go so far as to say that Naperville’s kids are brilliant specifically because they participate in an unusual physical education program. There are many factors that inform academic achievement.

To be sure, Naperville 203 is a demographically advantaged school district: 83 percent white, with only 2.6 percent in the low income range, compared with 40 percent in that range for Illinois as a whole. Its two high schools boast a 97 percent graduation rate. And the town’s major employers are science-centric companies such as Argonne, Fermilab, and Lucent Technologies, which suggests that the parents of many Naperville kids are highly educated. The deck—in terms of both environment and genetics—is stacked in Naperville’s favor. On the other hand, when we look at Naperville, two factors really stand out: its unusual brand of physical education and its test scores.

The correlation is simply too intriguing to dismiss, and I couldn’t resist visiting Naperville to see for myself what was happening there. I’ve long been aware of the TIMSS test and how it points to the failings of public education in this country. Yet the Naperville 203 kids aced the test. Why? It’s not as if Naperville is the only wealthy suburb in the country with intelligent, educated parents. And in poor districts where Naperville-style PE has taken root, such as Titusville, Pennsylvania (which I’ll discuss later), test scores have improved measurably. My conviction, and my attraction to Naperville, is that its focus on fitness plays a pivotal role in its students academic

achievements.

THE NEW PE

The Naperville revolution started, as such things often do, with equal parts idealism and self-preservation. A visionary junior high physical education teacher named Phil Lawler got the movement off the ground after he came across a newspaper article in 1990 reporting that the health of U.S. children was declining. “It said the reason they weren’t healthy was that they weren’t very active,” recalls Lawler, a tall man in his fifties, with rimless glasses, who dresses in khakis and white sneakers. “These days everybody knows we have an obesity epidemic,” he continues. “But pick up a paper seventeen years ago and that kind of article was unusual.

We said, We have these kids every day; shouldn’t we be able to affect their health? If this is our business, I thought, we’re going bankrupt.” He already felt like his profession received no respect; schools had started cutting physical education from the curriculum, and now this. A former college baseball pitcher who missed out on the majors, Lawler is a sincere salesman and a natural leader who became a gym teacher to stay close to sports. In addition to teaching PE at District 203’s Madison Junior High, he coached Naperville Central’s baseball team and served as the district coordinator for PE, but even in these respectable posts, sometimes he was embarrassed to admit what he did for a living.

Part of what he saw in that article was an opportunity—a chance to make his job matter. When Lawler and his staff at Madison took a close look at what was happening in gym, they saw a lot of inactivity. It’s the nature of team sports: waiting for a turn at bat, waiting for the center’s snap, waiting for the soccer ball to come your way. Most of the time, most of the players just stood around. So Lawler decided to shift the focus to cardiovascular fitness, and he instituted a radical new feature to the curriculum. Once a week in gym class, the kids would run the mile. Every single week! His decision met with groans from students, complaints from parents, and notes from doctors.

He was undeterred, yet he quickly recognized that the grading scale discouraged the slowest runners. To offer nonathletes a shot at good marks, the department bought a couple of Schwinn Airdyne bikes and allowed students to earn extra credit. They could come in on their own time and ride five miles to raise their grades. “So any kid who wanted to get an A could get an A if he worked for it,” Lawler explains. “Somewhere in this process, we got into personal bests. Anytime you got a personal best, no matter what it was, you moved up a letter grade.” And this led to the founding principle of the approach he dubbed the New PE: Students would be assessed on effort rather than skill. You didn’t have to be a natural athlete to do well in gym.

But how does one judge the individual effort of forty kids at a time? Lawler found his answer at a physical education conference he organized every spring. He worked hard to turn the event into an exchange of fresh ideas and technologies, and to encourage attendance he talked the vendors into donating door prizes. Each year at the beginning of the conference, he would push a towel cart through the aisles, collecting bats and balls and other sporting goods. Cast in among the bounty one year was a newfangled heart rate monitor, which at the time was worth hundreds of dollars.

He couldn't help himself; he stole it for the revolution. "I saw that son of a buck," he freely admits, "and I said, That's a door prize for Madison Junior High!" During the weekly mile, he tested the device on a sixth-grade girl who was thin but not the least bit athletic. When Lawler downloaded her stats, he couldn't believe what he found. "Her average heart rate was 187!" he exclaims. As an eleven-year-old, her maximum heart rate would have been roughly 209, meaning she was plugging away pretty close to full tilt. "When she crossed the finish line, she went up to 207," Lawler continues. "Ding, ding, ding! I said, You gotta be kidding me! Normally, I would have gone to that girl and said, You need to get your ass in gear, little lady!"

It was really that moment that caused dramatic changes in our overall program. The heart rate monitors were a springboard for everything. I started thinking back to all the kids we must have turned off to exercise because we weren't able to give them credit. I didn't have an athlete in class who knew how to work as hard as that little girl." He realized that being fast didn't necessarily have anything to do with being fit. One of Lawler's favorite statistics is that less than 3 percent of adults over the age of twenty-four stay in shape through playing team sports, and this underscores the failings of traditional gym class. But he knew he couldn't have the students run the mile every day, so he set up a program of what they have termed "small-sided sports"—three-on-three basketball or four-on-four soccer—where the students are constantly moving.

"We still play sports," Lawler says. "We just do them within a fitness model." Instead of being tested on such trivia as the dimensions of a regulation volleyball court, Naperville's gym students are graded on how much time they spend in their target heart rate zones during any given activity. "We developed the program not knowing what we were doing," Lawler says. And yet, the New PE has managed to put into practice principles consistent with all the new research about exercise and the brain.

CARRYING THE TORCH

Every revolutionary leader needs a lieutenant, and Lawler couldn't have chosen a more able agitator than Paul Zientarski, Naperville Central High School's physical education coordinator and former football coach. To students and colleagues, Zientarski is Mr. Z, a gray-haired furnace of a man with steady eyes and a facts-is-facts delivery. He has the presence of Mike Ditka and Bill Parcells rolled into one formidable figure of authority. "It took me the longest time to convince him of this stuff," says Lawler of his friend and ally. "But once he buys into it, get out of his way.

Because he's going to shove it down your throat if he has to." As their movement grew, Lawler would take the lead in proselytizing the outside world with the fitness-not-sports message, talking to Newsweek and testifying before the U.S. Senate, and Zientarski would become the unwavering enforcer of the mission back home, transforming the phys ed program at Naperville Central into a well-oiled working model of the New PE. Lawler retired from teaching in 2004 after being diagnosed with colon cancer, but he has continued to lobby for daily physical education even during his back-and-forth battle with the disease. They've both become grassroots experts on the subject of exercise and the brain.

They learned by grilling speakers from the conferences Lawler organized, attending sports physiology seminars, reading neuroscience research papers, and constantly e-mailing their findings to each other. And they've taken it upon themselves to educate their colleagues as well. It's not uncommon for Zientarski to buttonhole an English teacher in the hallway and hand her a stack of the latest brain research—homework from the gym teacher. It's because of their relentless spirit of investigation that I got to know these two men. Lawler heard me interviewed on the National Public Radio program *The Infinite Mind*, during which I referred to a protein that's elevated during exercise as "Miracle-Gro for the brain."

Unbeknownst to me, Lawler began repeating the phrase in interviews of his own, including one with the director of a documentary film about obesity in America, *Super Size Me* (2004). I had been looking for a concrete way to illustrate the effects of exercise on learning for this book, and focusing on a school district was a natural way to do that. But I also think the sheer size of the Naperville experiment gives it a broader resonance. The story is about students, but the lessons apply to adults too. What Naperville provides is a powerful case study on how aerobic activity can transform not only the body but also the mind. It also happens to be a wonderful template for reshaping our society. So I made the journey to Illinois, and as I sat with Lawler and Zientarski in the atrium of the Naperville Holiday Inn, I listened to them say things I never expected to hear from a couple of coaches. "In our department,

we create the brain cells,” Zientarski says. “It’s up to the other teachers to fill them.”

A NEW STEREOTYPE: THE SMART JOCK

Lawler’s tack runs opposite the trend in American public schools of cutting physical education in favor of increasing study time in math, science, and English—an effort to help students pass tests dictated by the No Child Left Behind Act. Only 6 percent of U.S. high schools offer a daily physical education class. At the same time, kids are spending an average of 5.5 hours a day in front of a screen of some sort—television, computer, or handheld device. It’s not surprising that American children are less active than they’ve ever been. That is why I was so inspired by what’s going on in Naperville.

The first time I visited, it was just before school let out for the summer, but you wouldn’t have known that by watching gym class at Madison Junior High. There must have been thirty kids jumping around with the sort of energy and enthusiasm you would only expect to see at the beginning of the school year: lining up to get on the climbing wall, arguing about who was going to get to use a new exercise bike attached to a video-game monitor, running wildly on treadmills, playing a video game called Dance Dance Revolution, where you dance on a control pad.

They were all wearing heart rate monitors, and—most important—they were all engaged. Some 30 percent of U.S. schoolchildren are overweight—six times more than in 1980—and another 30 percent are on the cusp. In Lawler’s district, an astonishing 97 percent of freshmen in 2001, and again in 2002, were at a healthy weight according to body mass index guidelines from the Centers for Disease Control (CDC). In the spring of 2005, an independent assessment of Naperville 203 students’ fitness showed even better results. A sports physiologist named Craig Broeder and a team of his graduate students from Benedictine University came in and tested a random sampling of 270 students, from sixth graders through high school seniors.

“I can tell you that the Naperville school system is miles ahead of the national norm in terms of fitness,” says Broeder, a former regional president of the American College of Sports Medicine. “It’s not even close. They had one male out of a hundred thirty something who was obese. It’s amazing. Their percentages of body fat were way below national norms using the CDC’s height and weight standards. On other fitness variables, something like ninety-eight percent of the students passed.” Broeder is perfectly aware of Naperville’s demographics, yet he’s still impressed. “The numbers are too high for it to just be that,” he says. “The PE program itself has to have had an additive impact on what that population would achieve otherwise. Let me put it this way: you can’t say for sure that the PE program does it, but their fitness

is so far off the scale that it can't be just because it's Naperville."

But what, exactly, do we know about the effect of gym on GPA? Few researchers have tackled the question, although one study from Virginia Tech showed that cutting gym class and allocating more time to math, science, and reading did not improve test scores, as so many school administrators assume it will. Because gym class can mean so many things, research in this area has focused on the correlation between physical fitness and academic achievement. The most telling studies come from the California Department of Education (CDE).

Over the past five years, the CDE has consistently shown that students with higher fitness scores also have higher test scores. The CDE correlated scores from standard achievement tests with scores from the FitnessGram, the state-mandated physical assessment, for more than one million students. The FitnessGram measures six areas: aerobic capacity, percentage of body fat, abdominal strength and endurance, trunk strength and flexibility, upper body strength, and overall flexibility. Students earn one point for each area if they pass the minimum requirements, so the top score on the FitnessGram is six. It's worth noting that this test doesn't measure how fit a student is, just whether he or she is acceptably fit in each area. In other words, it's pass-fail.

In 2001 fit kids scored twice as well on academic tests as their unfit peers. Among California's 279,000 ninth graders, for instance, those who scored a six on the FitnessGram ranked, on average, in the sixty-seventh percentile in math and the forty-fifth percentile in reading on the Stanford Achievement Test. If these scores seem less than stellar, consider those of the students who passed only one of the six areas: they ranked in the thirty-fifth and twenty-first percentiles, respectively. When the CDE repeated the study in 2002, it factored in socioeconomic status.

As expected, students with a higher standard of living scored better on the academic tests, but the results also showed that within the lower-income students, fitter kids scored better than unfit kids. This is a powerful statistic in itself. It suggests that although parents may not have immediate control over their financial situations, they can improve their kids' chances of performing well by encouraging them to get in shape. Exercise could break the cycle. The California studies don't stand alone. In 2004 a panel of thirteen noted researchers in fields ranging from kinesiology to pediatrics conducted a massive review of more than 850 studies about the effects of physical activity on school-age children. Most of the studies measured the effects of thirty to forty-five minutes of moderate to vigorous physical activity three to five days a week.

They covered a wide range of issues, such as obesity, cardiovascular fitness,

blood pressure, depression, anxiety, self-concept, bone density, and academic performance. Based on strong evidence in a number of these categories, the panel issued a recommendation that schoolchildren should participate in one hour (or more) of moderate to vigorous physical activity a day. Looking specifically at academic performance, the panel found enough evidence to support the findings of the California studies, and it also reported that physical activity has a positive influence on memory, concentration, and classroom behavior. It didn't specify gym class, but you can see how the students in Naperville are getting a healthy jump start.

A WHOLE NEW BALLGAME

"I'm not a researcher; I'm a PE teacher," says Zientarski to a dozen educators packed into his cinderblock office at Naperville Central, as he hands them copies of the CDE studies. The educators come from a neighboring suburb, a school in South Side Chicago, as well as a rural district in Tulsa, Oklahoma, and they're here because Naperville 203 serves as a training academy for a nonprofit agency called PE4life, which has adopted the New PE philosophy. Illinois is the only state that requires daily physical education, and PE4life is lobbying to change that—as well as the way it's taught.

Zientarski stands up and announces, "Now, we're going to take a tour." He leads the way, moving through the hallways with the deliberate stride of a seasoned U-boat commander. At the first stop, three student helpers are administering computerized health diagnostics to a group of sophomores with a computer system called TriFit. Giving the kids targets for heart rate, blood pressure, body fat, and the rest, he announces, is a proven method of motivating people to stay fit. Indeed, studies suggest that simply getting on the scale every morning improves the likelihood that someone who's overweight will shed pounds.

But Lawler and Zientarski's ambitions extend far beyond concerns about their students' body mass index. "I tell people it's not my job as a PE teacher to make kids fit," Zientarski says. "My job is to make them know all of the things they need to know to keep themselves fit. Exercise in itself is not fun. It's work. So if you can make them understand it, show them the benefits—that's a radical transformation. Especially for us coaches. We're control freaks. I can get sixty-five kids to stand on a white line if I say Hut!, and for years that's what we did." Students in Naperville 203 had heart rate monitors before they had the Internet. When you walk into the gym at any of the district's schools today, it feels like you're in a state-of-the-art adult health club. Each has a TriFit assessment machine and weight machines, which in the junior highs are custom-made to accommodate students at that age.

There are climbing walls and video-game-based aerobic machines. (Through

Lawler's lobbying and Zientarski's browbeating, most of the equipment has been donated.) The curriculum is designed to teach kids the principles, practice, and importance of fitness. When they reach high school, they're given a broad menu of options—from kayaking to dancing to rock climbing to typical team sports like volleyball and basketball—and shown how to draw up their own fitness plans. It's all centered around TriFit assessments students complete each year starting in fifth grade.

They design their plans as freshmen and track their improvement until they graduate, at which time they get a fourteen-page health assessment. It combines fitness scores with factors like blood pressure and cholesterol levels, along with lifestyle and family history surveys, to predict risk of disease and suggest preventive measures. It is an astonishingly comprehensive document by any professional health standard, let alone one that an eighteen-year-old can carry in his hand as he steps into adult life. If only the rest of us could be so lucky.

Sports physiologist Craig Broeder, who conducted the fitness study in Naperville, remarks that students can choose from eighteen activities for gym. "One of the things that too many people forget is that you have to find something that allows a student to feel comfortable at excelling," he says. "So that it feels like them when they're doing it. When you only give a kid a limited option, like playing basketball, and you make it seem like punishment or boot camp, there's no way he's going to continue doing it.

At Naperville, they give kids lots of options by which to excel; they design lifetime fitness activities." It's important for adults to remember this when considering how to get in shape. Zientarski leads his group into the old girl's gym to show off the jewel of Central's physical education program: a twenty-four-foot-high, ninety-foot-long climbing wall and a high-ropes course they recently started using in a new leadership class. He gives an example of a drill he uses to teach trust and communication: the climber is blindfolded and has to rely on commands from his partner to reach the next hold on the wall.

The newest part of the wall is set at an easier pitch for PE students with physical and mental disabilities. Answering the obvious concerns about liability, Zientarski says they have very few injuries in here because the kids are cooperating, not competing, and this is one of the most important lessons he and his staff teach. "If you ask people, What is it you want our graduates to be able to know and do when they leave high school?" Zientarski explains, "They'll say, We want them to be able to communicate. We want them to be able to work in small groups. We want them to be able to problem solve. We want them to be risk takers. Where does that happen?" he asks, eyeballing his guests. "Science class? I don't think so."

GOOD FOR THE BODY, GOOD FOR THE BRAIN

About 135 miles south of Naperville, at the University of Illinois at Urbana-Champaign, a psychophysicologist named Charles Hillman conducted his own version of the CDE study with a group of 216 third and fifth graders and found the same correlation between fitness and academics. He and his coauthor, Darla Castelli, noticed something interesting. Of the six areas that the FitnessGram measures, two seem to be particularly important in relation to academic performance. “Body mass index and aerobic fitness really stuck out in our regression equation,” Castelli says.

“They were the most significant contributors. I was really surprised it was that clear-cut.” Hillman went beyond correlating data, though. He wanted to dig into the neuroscience of these findings, so he took a group of forty kids—half fit, half unfit—and measured their attention, working memory, and processing speed. During the cognitive testing, the kids wore something like a swim cap embedded with electrodes that measured electrical activity in the brain. The electroencephalogram (EEG) showed more activity in fit kids’ brains, indicating that more neurons involved in attention were being recruited for a given task. “We see better integrity there,” Hillman explains. In other words, better fitness equals better attention and, thus, better results.

Hillman also found something telling in how his subjects responded to making a mistake. While measuring their brain activity, he used what’s called a flanker test, in which a series of five capital letters (Hs and Ss) are flashed on a screen. The only letter of interest is the one in the middle; the subject hits one button when it’s an H and another button when it’s an S. When something like HSHH shows up, at the rate of once a second, it’s easy to make a mistake, and you know as soon as you’ve done so. What Hillman found, he says, is that “fit kids slow down and make sure they get that next one right.”

The ability to stop and consider a response, to use the experience of a wrong choice as a guide in making the next decision, relates to executive function, which is controlled by an area of the brain called the prefrontal cortex. (I’ll explore executive function in subsequent chapters, especially when we get to attention-deficit/hyperactivity disorder, which is partly caused by a lapse in the prefrontal cortex. If a child with ADHD took the flanker test, she would hit the wrong button before being able to stop herself, or hesitate too long to hit the right button. But you can imagine how much all of us rely on executive function.) Learning from our mistakes is profoundly important in everyday life, and Hillman’s study shows that exercise—or at least the resulting fitness levels—can have a powerful impact on that fundamental skill.

FOLLOW THE LEADERS

There may be no better embodiment of Naperville's faith in the transformative power of exercise than Jessie Wolfrum. A self-described nerd and a straight-A student while at Central, she graduated in 2003 and enrolled at Embry-Riddle Aeronautical University in Daytona Beach, Florida, where she is now majoring in engineering physics. As a twin who tended to rely on her relationship with her sister rather than engage with other kids, Jessie had been shy all her life. "In third grade, my mom gave me the option of piano or soccer," Jessie recalls, laughing about it now.

"I was so scared of the idea of hanging out with a bunch of girls at something I probably wasn't going to be good at that I picked something I didn't even like. I played piano for eight years!" Of course, Phil Lawler didn't give her the piano option when she arrived as a student at Madison Junior High. Jessie had to participate, just like everyone else, and although she didn't much care for gym, it wasn't too terrible—certainly not traumatizing. And she learned lessons about her body that would serve her for years to come.

When she and her sister, Becky, moved on to Central, their divergent class schedules meant they weren't able to constantly lean on each other, so Jessie was forced to talk to other kids more often than she felt comfortable doing. She signed up for speech class to deal with her social anxiety, but she says what really helped her blossom was enrolling in kayaking. Jessie took to this skill-intensive sport immediately, and discovering she was good at something outside the academic realm helped transform her.

"If somebody notices that you're doing something that they can't do, you get some attention," Jessie says. "In kayaking, people started to notice me, and then I wasn't the person who faded into the wallpaper. It made me more adventurous. Even if you're shy, if somebody is like, How do you do that? you forget that you're shy, and you just explain it: you have to turn your head this way or do that with your paddle." The swimming pool leveled the playing field in other ways too. "Once everybody changes into their swimsuits, you can't tell who's in the popular group," she says.

"The class totally jumped those boundaries of social standings. I had a lot of problems with that until I took kayaking." Emboldened by her experience in kayaking class, Jessie signed up for the leadership course being taught by Mr. Zientarski. The first thing he did was separate Jessie and her twin—and all of the other inseparable cliques. The leadership students learn to rock climb, and it's this sport in particular that captured Jessie's attention. She joined the Adventure Club, a sort of ad hoc Zero Hour for kids who wanted to come in at 6:30 in the morning to get extra time on the climbing wall or use the pool for kayaking.

Jessie and her sister actually decided to go paddling the morning of the Prairie State Achievement Examination, the Illinois version of the Scholastic Aptitude Test (SAT). They were so confident in their preparation, and so attuned to how exercise helped them focus, that they were comfortable splashing around a cold pool right before an important exam. How many high school kids do you know who would do that? How many adults do you know who would do that? “When we showed up for the test, we were cold and wet,” recalls Jessie. “We walked into the classroom, and we were the only ones who were awake. We ended up doing pretty well.”

They both scored 1400 out of a possible 1600—top-notch results. When she got to college, Jessie continued pushing herself both academically and socially. She is an A/B student and, most surprisingly, she became a resident adviser, watching over a group of underclassmen on her hall, providing them with comfort, discipline, and counsel. She is no longer a wallflower. It’s tough to keep up with exercise in the transition from high school to college, but Jessie never strayed too far from her regimen. During her freshman year at Embry-Riddle, whenever anything stressful would come up, she and her roommate would run laps on the stairs in her dorm.

That’s something she learned back in Naperville—how to manage her brain with exercise. And that’s the message I hope to deliver in this book. “These days, every hour is sucked up with something—watching over residents, classes . . .” Jessie says. “When I don’t have time to work out, I wish I did. Every time I know that a whole bunch of tests are coming up—when I’m really stressed out—I think, OK, you know how to handle this. It’s definitely a relief to know that I have something to fall back on. If I didn’t have that, I’d probably just go eat or something. But I know that exercise will spike up my brain activity, and so I think, Just go do it. I wouldn’t know that if it weren’t for my gym class.”

BEYOND FITNESS

Like many people, I grew up thinking that gym was a joke. We had some fun, but, to my recollection, phys ed wasn’t especially educational. As an adult, when I began lecturing to teachers and doctors about the positive impact of physical activity on mood, attention, self-esteem, and social skills, I certainly wasn’t thinking of gym as the antidote. In my experience, PE wasn’t really about exercise. Quite the opposite—it discouraged exercise. The cruel irony was that the shy, the clumsy, the out of shape—some of the kids who could most benefit from exercise—were pushed aside to sit on the bleachers. Someone like Jessie Wolfrum would have been marginalized and left to stew in her shame. Over the years, I’ve listened to a number of patients recount tales of humiliation in PE. The sidelines are fertile ground for developing the

very sorts of issues that exercise ameliorates. Part of the Naperville magic is that Lawler and Zientarski are exquisitely tuned in to this dynamic.

“We used to do chin-ups,” recalls Zientarski, with a tone bordering on disgust. “I would say about sixty-five percent of our boys couldn’t do one chin-up. Come on down to PE class and be a failure!” What strikes me about Zientarski’s transformation from drill sergeant to sculptor of bodies, brains, and minds is how far he has been willing to go in redefining gym. For example, one of the most innovative changes he made at Central was to add a mandatory square-dancing class for freshman. It may not sound cutting edge, but the class is set up to use movement as a framework for teaching social skills—a wonderful idea on many levels.

In the first few weeks of the class, all the students receive scripts to use as conversation starters with their partners, and everyone switches partners after each dance. As the course progresses, the students are given time to interact without the scripts, first for thirty seconds and building up from there. The final exam is based on how accurately the students remember ten facts about a partner after spending fifteen minutes chatting. Some kids who are socially timid never get a chance to learn how to talk to people and make friends, so they retreat, especially from the opposite sex.

By not being singled out or relegated to a special social skills class, Zientarski’s square-dance students get to practice how to talk and interact in a nontoxic setting. The activity serves both as a distraction and as a confidence builder. Some master the drill, and others merely break through their fears, but because everybody’s doing it, it’s less embarrassing. When I talk to colleagues about the Naperville revolution and tell them that kids are learning these kinds of social skills in gym class, the reaction I get is stunned silence—they are in awe, just as I was.

Throughout my work, I have spent a lot of time trying to identify and address the problems of what I call the social brain, and Zientarski has found the perfect prescription to help overcome the growing isolation and solitary nature of our lives today. In gym class! By having the structure, opportunity, and expectation, socially anxious students log in positive memories about the way to approach someone, how close to stand, and when to let the other person speak. Exercise serves as the social lubricant, and it’s crucial to this kind of learning because it reduces anxiousness. Their brains are primed by the movement, and they lay down circuits that record the experience, which at first may be painful but which becomes less so in the context of an experience shared by the entire class. It’s an intuitively brilliant way to bring kids out of their shells, at a poignant age when everyone feels self-conscious. Zientarski puts them all in the same boat and gives them the tools and encouragement to build up their self-confidence.

The dancing makes the whole lesson work. It's offerings like this, I believe, that explain why so many parents in Naperville report that gym is their kids' favorite class. A mother named Olfat El-Mallak has two daughters who went to Madison and then Central. "It's not just physical exercise; it's something else that happens inside of them," she says. "This is almost like a motivational program. My girls believe in themselves. They are both very confident about themselves, and they didn't start this way. This is because of the PE program at District 203."

SPREADING THE GOSPEL

There are fifty-two million children, from kindergarten through twelfth grade, who attend public and private schools in the United States. If all of them had the benefit of Naperville-style physical education, our next generation of adults would be healthier, happier, and smarter. That is the ultimate goal of PE4life, the group that has hired Lawler to teach other educators the fitness-not-sports philosophy and methodology. About one thousand educators from 350 schools have been through the training, and many have since implemented their own versions of the program.

One such graduate is a man named Tim McCord. He is the physical education coordinator for the school district in Titusville, Pennsylvania, a defunct industrial town of six thousand that's been left for dead in a stretch of hill country between Pittsburgh and Lake Erie. This is where, back in 1859, the world's first successful oil well was drilled, but oil has come and gone, right along with the economy: The median income is now \$25,000; 16 percent of the town is below the poverty line; and a few years back, about 75 percent of the kindergartners received government assistance for school lunches. Which is to say, this is not a wealthy suburb.

In 1999 McCord visited Naperville, came home, and transformed physical education in Titusville almost overnight. The district has twenty-six hundred students in one high school, one middle school, four elementary schools, and one early learning center. Titusville installed fitness centers in the secondary schools, bought heart rate monitors, and got the local hospital to help fund the TriFit diagnostics. Titusville even restructured the school day, adding ten minutes to the schedule and shaving time from academic classes to carve out time for daily gym. "It did not cost us a cent to do that," McCord says, noting that it was an administrator's suggestion. "And it's a huge move with No Child Left Behind—everybody else is going in the other direction." Now Titusville's secondary schools have climbing walls, and the fitness centers are brimming with the latest training technology, most of it donated.

The Cybex Trazer, for instance, is a brand-new device that looks like an

upright computer station where students chase flashing lights. There are also cycling trainers, which allow kids to race one another on video screens or cue up routes from the Tour de France and compete with virtual Lance Armstrongs. McCord has also reached out to the community, opening the schools' fitness centers to members of the senior center. Within the schools, he's invited teachers in other subjects to get involved: English students use the heart rate monitors during public speaking, and math students use the data to learn how to graph.

Since the program started in 2000, the standardized test scores of Titusville's students have risen from below the state average to 17 percent above it in reading and 18 percent above it in math. Equally important are the psychosocial effects McCord has noticed: not a single fist fight among the 550 junior high kids since 2000. The district's bootstrap story has prompted visits from state representatives and even the president of the CDC. During one such show-and-tell, as McCord led a group past the junior high's climbing wall, he noticed a girl named Stephanie stuck about halfway up. Bookish and a little heavysset, she was on display for everyone to see her fail.

But as her classmates noticed her struggling, they began cheering, "Go, Stephanie!" She made it to the top, and McCord spoke to her later. "She started to cry and couldn't believe the other kids were cheering her on," McCord recalls. "She said it helped her pull herself up." The buzz about the broad effect of exercise on students is spreading among other government officials. Iowa Senator Tom Harkin recently held hearings about reestablishing physical education in schools based on news that one PE4life school in the inner city reduced its disciplinary problems by 67 percent. At Woodland Elementary School in Kansas City, Missouri, nearly all of the students have subsidized meal programs.

In 2005 the physical education staff expanded gym from one class a week to forty-five minutes a day, focused almost entirely on cardiovascular activity. In the span of one school year, the students' fitness levels improved dramatically, and counselors reported that the number of incidents involving violence at Woodland decreased from 228 to 95 for the year. For an inner-city school to go through such a rapid transformation, and for such a depressed town as Titusville to come alive as it has, is remarkable. McCord's community rallies around the Stephanies of the world rather than just the football team, and as the schoolchildren grow up, a larger percentage will continue to move and be active. They'll grab their kayak or bike instead of their Game Boy, and their minds and moods will be sharper for it.

Revolutions rely on youth, but as we've seen with Lawler, Zientarski, and McCord, even adults can make a major shift and recognize how physical activity influences the brain. If Titusville can find the spark, so can the rest of

us. My hope is that we can use these examples as a new cultural model and, ultimately, reconnect the body and the brain. As you'll see, they belong together.

2- Learning

Grow Your Brain Cells

WHEN THE STUDENTS in Titusville or in Naperville go for a mile run in gym, they are more prepared to learn in their other classes: their senses are heightened; their focus and mood are improved; they're less fidgety and tense; and they feel more motivated and invigorated. The same goes for adults, in the classroom of life. What allows us to absorb the material is where the revolutionary new science comes into play. In addition to priming our state of mind, exercise influences learning directly, at the cellular level, improving the brain's potential to log in and process new information.

Darwin taught us that learning is the survival mechanism we use to adapt to constantly changing environments. Inside the microenvironment of the brain, that means forging new connections between cells to relay information. When we learn something, whether it's a French word or a salsa step, cells morph in order to encode that information; the memory physically becomes part of the brain. As a theory, this idea has been around for more than a century, but only recently has it been borne out in the lab. What we now know is that the brain is flexible, or plastic in the parlance of neuroscientists—more Play-Doh than porcelain. It is an adaptable organ that can be molded by input in much the same way as a muscle can be sculpted by lifting barbells.

The more you use it, the stronger and more flexible it becomes. The concept of plasticity is fundamental to understanding how the brain works and how exercise optimizes brain function by fostering that quality. Everything we do and think and feel is governed by how our brain cells, or neurons, connect to one another. What most people think of as psychological makeup is rooted in the biology of these connections. Likewise, our thoughts and behavior and environment reflect back on our neurons, influencing the pattern of connections. Far from being hardwired, as scientists once envisioned it, the brain is constantly being rewired. I'm here to teach you how to be your own electrician.

THE MEDIUM IS THE MESSENGER

It's all about communication. The brain is made up of one hundred billion neurons of various types that chat with one another by way of hundreds of different chemicals, to govern our every thought and action. Each brain cell might receive input from a hundred thousand others before firing off its own

signal. The junction between cell branches is the synapse, and this is where the rubber meets the road.

Synapses don't actually touch, which is a little confusing because neuroscientists talk about synapses "wiring together" when they establish a connection. The way it works is that an electrical signal shoots down the axon, the outgoing branch, until it reaches the synapse, where a neurotransmitter carries the message across the synaptic gap in chemical form. On the other side, at the dendrite, or the receiving branch, the neurotransmitter plugs into a receptor—like a key into a lock—and this opens ion channels in the cell membrane to turn the signal back into electricity.

If the electrical charge at the receiving neuron builds up beyond a certain threshold, that nerve cell fires a signal along its own axon, and the entire process repeats. About 80 percent of the signaling in the brain is carried out by two neurotransmitters that balance each other's effect: glutamate stirs up activity to begin the signaling cascade, and gamma-aminobutyric acid (GABA) clamps down on activity. When glutamate delivers a signal between two neurons that haven't spoken before, the activity primes the pump. The more often the connection is activated, the stronger the attraction becomes, which is what neuroscientists mean when they talk about binding.

As the saying goes, neurons that fire together wire together. Which makes glutamate a crucial ingredient in learning. Glutamate is a workhorse, but psychiatry focuses more on a group of neurotransmitters that act as regulators—of the signaling process and of everything else the brain does. These are serotonin, norepinephrine, and dopamine. And although the neurons that produce them account for only 1 percent of the brain's hundred billion cells, these neurotransmitters wield powerful influence. They might instruct a neuron to make more glutamate, or they might make the neuron more efficient or alter the sensitivity of its receptors. They can override other signals coming into the synapse, thus lowering the "noise" in the brain, or, conversely, amplify those signals.

They can deliver signals directly, like glutamate and GABA, but their primary role is in adjusting the flow of information in order to fine-tune the overall balance of neurochemicals. Serotonin, which you'll hear a lot more about in later chapters, is often called the policeman of the brain because it helps keep brain activity under control. It influences mood, impulsivity, anger, and aggressiveness. We use serotonin drugs such as fluoxetine (Prozac), for instance, because they help modify runaway brain activity that can lead to depression, anxiety, and obsessive-compulsiveness. Norepinephrine, which was the first neurotransmitter scientists studied to understand mood, often amplifies signals that influence attention, perception, motivation, and arousal. Dopamine, which is thought of as the learning, reward (satisfaction),

attention, and movement neurotransmitter, takes on sometimes contradictory roles in different parts of the brain. Methylphenidate (Ritalin) eases attention-deficit/hyperactivity disorder (ADHD) by raising dopamine, thus calming the mind. Most of the drugs we use to improve mental health target one or more of these three neurotransmitters.

But as I hope to make abundantly clear, simply raising or lowering the level of a neurotransmitter doesn't elicit a crisp one-to-one result because the system is so complex. Manipulating just one neurotransmitter creates a ripple effect that takes different paths in different brains. I tell people that going for a run is like taking a little bit of Prozac and a little bit of Ritalin because, like the drugs, exercise elevates these neurotransmitters. It's a handy metaphor to get the point across, but the deeper explanation is that exercise balances neurotransmitters—along with the rest of the neurochemicals in the brain. And as you'll see, keeping your brain in balance can change your life.

TO LEARN IS TO GROW

As fundamental as the neurotransmitters are, there's another class of master molecules that over the past fifteen years or so has dramatically changed our understanding of connections in the brain, specifically, how they develop and grow. I'm talking about a family of proteins loosely termed factors, the most prominent of which is brain-derived neurotrophic factor (BDNF). Whereas neurotransmitters carry out signaling, neurotrophins such as BDNF build and maintain the cell circuitry—the infrastructure itself.

During the 1990s, as neuroscientists began to pin down the cellular mechanism of memory, BDNF became the focus of a whole new field of research. About a dozen papers on BDNF were published before 1990, the year scientists discovered that it exists in the brain and nourishes neurons like fertilizer. Then, “a tsunami of labs and pharma companies” joined the fray, says Eero Castrén, a neuroscientist involved in the early work on BDNF at Sweden's Karolinska Institute. Today the research literature shows more than fifty-four hundred papers on BDNF.

Once it became clear that BDNF was present in the hippocampus, an area of the brain related to memory and learning, researchers set out to test whether it's a necessary ingredient in the process. Learning requires strengthening the affinity between neurons through a dynamic mechanism called long-term potentiation (LTP). When the brain is called on to take in information, the demand naturally causes activity between neurons. The more activity, the stronger the attraction becomes, and the easier it is for the signal to fire and make the connection. The initial activity marshals existing stores of glutamate in the axon to be sent across the synapse and reconfigures receptors on the receiving side to accept the signal.

The voltage on the receiving side of the synapse becomes stronger in its resting state, thereby attracting the glutamate signal like a magnet. If the firing continues, genes inside the neuron's cell nucleus are turned on to produce more building material for the synapses, and it is this bolstering of the infrastructure that allows the new information to stick as a memory. Say you're learning a French word. The first time you hear it, nerve cells recruited for a new circuit fire a glutamate signal between each other.

If you never practice the word again, the attraction between the synapses involved naturally diminishes, weakening the signal. You forget. The discovery that astonished memory researchers—and earned Columbia University neuroscientist Eric Kandel a share of the 2000 Nobel Prize—is that repeated activation, or practice, causes the synapses themselves to swell and make stronger connections. A neuron is like a tree that instead of leaves has synapses along its dendritic branches; eventually new branches sprout, providing more synapses to further solidify the connections. These changes are a form of cellular adaptation called synaptic plasticity, which is where BDNF takes center stage.