

DEVELOPMENT

SUE WAS DOING IT AGAIN. That young woman who periodically showed up dressed in a Western shirt and kerchief was standing in front of the automatic sliding doors at the Safeway supermarket. She'd look intently straight ahead, take five abrupt steps toward the doors, and try to restrain herself from walking through until they had fully opened. Sometimes she couldn't stop herself and nearly slammed right into the glass. Other times she'd wait long enough and then lunge through. Regardless, she'd back out and do it again. And again. Regular shoppers at the Phoenix, Arizona, store would hesitate beside her, then scurry past, eyeing her while trying not to stare. Once inside they'd shake their heads and make the usual comments: "Must be insane." They didn't know that Temple Grandin would go on to earn a doctorate in animal sciences and become an internationally recognized expert in animal handling. Or that she was autistic.

Temple had a normal birth, but by the time she was six months old she'd stiffen at her mother's touch and claw to free herself from her mother's hug. Soon she could not stand the feeling of other skin touching hers. A ringing telephone and a car driving by her house while a conversation was going on inside caused such severe confusion and hurt in the toddler's ears that she would tantrum, hitting whoever was within reach.

When she was three the doctors said that Temple had "brain damage." Her parents hired a stern governess, who structured the child's day around physical exercise and repetitive play such as "marching band." Occasionally the routine allowed Temple to focus on what she was doing, even speak. She taught herself to escape the stimuli around her, which caused pain in her overly sensitive nervous system, by daydreaming in pictures of places far away. By the time she reached high school she had made great progress. She could handle some of the academic subjects, and sometimes she could control her hypersensitive reactions to the chaos around her, primarily by shutting down to reduce the constant anxiety and fear. This made the other kids regard her as cold and aloof. She grew agonizingly lonely and would often tantrum or engage in pranks to combat her feelings of rejection. The school expelled her.

When she was sixteen Temple's parents sent her to an aunt's cattle ranch in Arizona. The rigid daily schedule of physical work helped her focus. She became fixated on the cattle chute, a large machine with two big metal plates that would squeeze a cow's sides. The high pressure apparently relaxed the animals, calming them enough for a vet to examine them. She visualized a squeeze machine for herself to give her the tactile stimulation she craved but couldn't get from human contact because the stimulation from physical closeness to another person was too intense, like a tidal wave engulfing her.

By this time Temple and her doctors had realized that she had a photographic memory. She was an autistic savant. When she returned to a special school for gifted children with emotional difficulties—the only school option left—her advisors allowed her to build a human squeeze machine. The project got her hooked on learning mechanical engineering and mathematics and on problem-solving, and she excelled at them all. She built a prototype, and would climb into it and use a lever to control the degree and duration of the pressure on her body. Afterward, she would feel relieved, more empathic, and more in touch with feelings of love and caring, even more tolerant of human touch. She started controlled experiments with the device and became skilled in research and lab techniques—which provided the impetus to apply to college.

Temple's state of hyperarousal and her inability to manage environmental stimuli impaired her ability to cope with the normal surroundings of her family or peers. The repetitive exercises as a child, the squeeze machine, and her academic successes gradually gave her the

Source: Ratey, John J. *A User's Guide to the Brain: Perception, Attention, and the Four Theaters of the Brain*. New York, NY: Pantheon, 2001

ability to control her offending behavior. Yet by her late twenties she still had had no success in creating social relationships. She was in a constant state of stage fright. She would get so anxious about approaching someone that she would literally race up and knock the person over, unable to restrain her muscles as she got emotionally energized. If she did manage to stop in time she would stand collar to collar, talking three inches from the person's face, an instant turnoff.

Then Temple put it all together. Walking up to someone in a socially acceptable way was the same as approaching the automatic doors at the supermarket. Both had to be done at the same relaxed pace. So she started showing up at the Safeway. She practiced approaching the doors for hours on end, until the process became automatic. The exercise helped. She found that she could approach people properly if she visualized herself approaching the doors. The doors were like a physical map; they provided a concrete visual picture of an abstract idea about approaching social interactions carefully.

Temple used another rehearsal technique to learn how to negotiate with people, a stressful interaction that usually sent her reeling. She read the *New York Times's* accounts of the Camp David peace talks conducted by President Jimmy Carter with Egypt's Anwar Sadat and Israel's Menachem Begin. She read every word and memorized them at once; being a savant came in handy. She played the conversations over and over again in her brain, like watching an internal videotape, and used them to guide her own conduct when negotiating with real people.

Today Temple Grandin, at fifty-one, leads a fulfilling professional and social life. It is twenty-five years since her training in front of the Safeway doors, and she has learned to pay attention to certain stimuli while ignoring others so that she does not become overly aroused. She also takes low doses of an antidepressant drug that alleviates her pent-up discomfort even better than the squeeze machine.

Temple resorted to a host of unusual practices to rewire her faulty brain circuits in order to control her conduct. She developed the circuits that enabled her to approach the supermarket doors, and then used these newly trained circuits to help position herself with relation to other people. She mastered each technique with practice, made it automatic, and then applied the newly imprinted pattern to other cognitive skills. Temple developed in adulthood the brain circuits her physical childhood development did not provide.

THE BRAIN is not a computer that simply executes genetically predetermined programs. Nor is it a passive gray cabbage, victim to the environmental influences that bear upon it. Genes and environment interact to continually change the brain, from the time we are conceived until the moment we die. And we, the owners—to the extent that our genes allow it—can actively shape the way our brains develop throughout the course of our lives. There is a great ongoing debate between different schools of neuroscientists as to whether the brain is merely a “ready-to-respond-to-environment” machine, an idea championed by a group who identify themselves as “connectionists,” and those who would say that the brain is genetically made up of “ready-to-access” modules that the environment merely stimulates. However, the majority of neuroscientists see a hybrid, where the broad outlines of the brain's development are under genetic control, while the fine-tuning is up to the interaction of brain and environment.

Certainly, much of the course of our brains' development is determined while we are fetuses and young children. But as we will see, there are many other factors that can alter the process—in pregnancy, childhood, adulthood, and old age. A father's smile, exercise before the workday, a game of chess in the retirement home—everything affects development, and development is a lifelong process.

We are not prisoners of our genes or our environment. Poverty, alienation, drugs, hormonal imbalances, and depression don't dictate failure. Wealth, acceptance, vegetables, and exercise don't guarantee success. Our own free will may be the strongest force directing the development of our brains, and therefore our lives. As Temple's experience shows, the adult brain is both plastic and resilient, and always eager to learn. Experiences, thoughts, actions, and emotions actually change the structure of our brains. By viewing the brain as a muscle that can be weakened or strengthened, we can exercise our ability to determine who we become. Indeed, once we understand how the brain develops, we can train our brains for health, vibrancy, and longevity. Barring a physical illness, there's no reason that we can't stay actively engaged into our nineties.

Research on the brain's development has been fast and furious in this decade. The subject has become so popular that in the last few years it has rated a cover story in *Time* (three times), *Newsweek* (twice),

and *Life*, as well as in other major magazines. New imaging technologies and scores of studies are providing enormous insight into ways to help the brain develop in babies, children, and adults, even in fetuses in the womb. Of course, there is also the chance here for misdirection.

The research has even prompted political action at the highest levels of government. In April 1997, Hillary Clinton hosted an all-day White House scientific conference, an unusual event, on new findings indicating that a child's acquiring language, thinking, and emotional skills is an active process that may be largely finished before age three. This premise is in stark contrast to the common wisdom of only a few years ago: that infants are largely passive beings who are somewhat unaware of their surroundings or who simply record everything in the environment without editing it. If infants are in fact editing and processing environmental stimuli, it behooves us to make these stimuli such good ones that they can move through them quickly and on to other learning.

The problem here is that such notoriety can cause sweeping action that may run ahead of sound clinical trials and testing of new hypotheses. Based on research that is not fully confirmed, panelists at the White House conference urged the adoption of federal programs to increase wages and training for day-care workers, improve parenting education, broaden training of pediatricians, and expand prenatal health-care coverage.

The best example of running ahead of research involves the "proof" that exposing infants to classical music enhances their brain development. Several recent studies indicate that this is so, yet others do not, and replication of the positive studies is not yet conclusive. Nonetheless, Georgia governor Zell Miller added \$105,000 to his 1998 state budget proposal so that a cassette or compact disk of classical music could be included with the bag of free goodies that hospitals send home with each of the 100,000 babies born in the state each year. Miller's proposal, and his press conference about it, made national headlines. "No one questions that listening to music at a very early age affects the spatial, temporal reasoning that underlies math and engineering, and even chess," he said. "Having that infant listen to soothing music helps those trillions of brain connections to develop."

While the governor's awareness of brain research was commendable, his action might have been premature. The worry is not that it may waste the state's money. As Sandra Trehaub, a professor of psy-

chology at the University of Toronto who studies infants' perception of music, said in response, "If we really think you can swallow a pill, buy a record or book, or have any one experience that will be the thing that gets you into Harvard or Princeton, then that's an illusion." John Breuer, president of the McDonnell Foundation, a funding organization for biomedical and behavioral research as it affects education, warns that though there may be great advantages to early education programs, neuroscience does not provide reasons for it yet. The link is just beginning to become clear. And as Michael Gazzaniga, a noted neuroscientist at Dartmouth, cautions, we are in danger of being overdone with "politically correct pseudoscience babble" when we allow our enthusiasm to outstrip facts.

Hillary Clinton realized herself that the White House conference could lead to premature and irresponsible decision-making and that the enthusiasm it catalyzed had to be tempered. Appearing on ABC's *Good Morning America* a week later, she admitted that the hyperfocus on properly stimulating babies "does ratchet up the guilt" about what parents ought and ought not to do.

That is why we will take a careful look at research findings throughout this book, and particularly in this chapter. There is much we can learn about how to improve the development of our brains and those of our children. But we have to keep a trained eye out to distinguish research that can be applied to our daily lives from that which is, for now, simply interesting.

A JUNGLE OF NEURONS

THE HUMAN BRAIN is responsible for the painting of Van Gogh, the creation of democracy, the design of the atomic bomb, psychosis, and the memory of one's first vacation and of the way that hot dog tasted. How does this organ encompass such diversity?

The brain is not a neatly organized system. It is often compared to an overgrown jungle of 100 billion nerve cells, or neurons, which begin as round cell bodies that grow processes called axons and dendrites. Each nerve cell has one axon and as many as 100,000 dendrites. Dendrites are the main way by which neurons get information (learn); and axons are the main way by which neurons pass on information to (teach)

other neurons. The neuron and its thousands of neighbors send out roots and branches—the axons and dendrites—in all directions, which intertwine to form an interconnected tangle with 100 trillion constantly changing connections. There are more possible ways to connect the brain's neurons than there are atoms in the universe. The connections guide our bodies and behaviors, even as every thought and action we take physically modifies their patterns.

This description of the developing brain was heresy until recently. For decades scientists maintained that once its physical connections were completed during childhood, the brain was hard-wired. The tiny neurons and their interconnections were fixed; any neuron or link could die, but none could grow stronger, reorganize, or regenerate. Today, these axioms have been amended and enhanced. Thanks to sharp imaging technology and brilliant clinical research, we now have proof that development is a continuous, unending process. Axons and dendrites, and their connections, can be modified up to a point, strengthened, and perhaps even regrown.

Temple Grandin's achievement demonstrates that the brain has great plasticity. But what was actually going on, physically, inside her head? We get a strong clue from Michael Merzenich at the University of California, San Francisco.

Merzenich implanted electrodes in the brains of six adult squirrel monkeys, in the region that coordinates the movement of their fingers. Using computer imaging, he created a map of the neurons that fired when the monkeys manipulated objects with their hands. He then placed four food cups of decreasing diameter outside each of their cages. He put a single banana-flavored food pellet in the widest cup. The monkeys would reach through the bars and work their fingers into the cups until each was able to grasp its pellet and eat it. They practiced dozens of times for several days.

Once they had mastered the widest cup, Merzenich put the food pellets in the next smaller cup. After several days of repetition, the pellets were moved to the third cup, then the fourth. By the end of the experiment the monkeys were extremely skilled with their fingers.

After only one day, the computer images showed that the area of the brain that became active when the monkeys moved their fingers had increased in size. As the animals conquered successively smaller cups, the area got bigger; the number of cells that participated in the task increased. But after the neurons in the cortex mastered the fourth cup,

the area shrank again; as the skill became more automatic, it was delegated to other parts of the brain lower down in the chain of command. The expanded portion of the executive part of the brain, the cerebral cortex, was no longer needed to carry out the skill and guide the hand. This commanding part of the brain, the control center, reverted back to its original size, freeing up neurons to learn other things.

There is evidence that the same thing happens in humans as in Merzenich's monkeys. Alvaro Pascual-Leone of Harvard Medical School, Boston, and Avi Karni of Hadassah University Hospital, Israel, have independently shown, using mapping techniques—for example, magnetic resonance imaging (MRI) and transcranial magnetic stimulation—in living human subjects, that skill acquisition recruits more cortical neurons to master the skill, and that as the skill becomes more automatic, less of the recruited cortex is used.

Thus, the brain has a tremendous ability to compensate and rewire with practice. Temple trained at the Safeway doors for hours each day for several months until the skill became automatic. At first it was incredibly difficult; by the end she did it with little concentration. Once she had mastered the initially higher-order activity, it was probably pushed down into lower regions of the brain, freeing her cortex to learn a new skill. The same would seem to be true about her rehearsing the Sadat-Begin tapes and applying them to her own conversations. Practice counts.

What we learn from Temple's story and Merzenich's monkeys is that our brains are wonderfully plastic throughout adulthood. Brain structure is not predetermined and fixed. We can alter the ongoing development of our brains and thus our capabilities. This is not always beneficial, however, as sometimes in the brain's attempt to adapt, the rewiring can make things worse.

MASSIVE CELL DEATH

THE HUMAN BRAIN HAS EVOLVED, thanks to natural selection, always in the direction of pushing our genes forward. Different sections of the brain expanded and specialized from the less complex swelling at the end of a nerve cord in primitive vertebrates in order to adapt to different environments across evolutionary history. In fish

and amphibians, the visual perception of motion was important to track prey or escape predators, so the parts of the brain responsible for this sense expanded over time in these animals. In monkeys and early humans, color perception was needed in order to tell which fruits were ripe and which were not, and perception of form was needed even in the absence of movement. Thus, a large expansion of cortex evolved to handle these complex visual challenges. Similarly, the need to manipulate these objects in trees and to get from one branch to another led to specialized motor systems not useful in the aquatic environment.

Despite specializations typical only of our species, our brains retain the three basic components found in the simplest vertebrates: the hindbrain at the top of our spinal cord, which controls sensation and movement of the muscles of our face and throat; the midbrain, farther into the center of the head, which deals with some movements of the eyes and some rudimentary hearing and vision; and the forebrain, which achieves its most glorious development in human beings and which contains the cerebral cortex, the white-matter fibers connecting neurons of the cortex with each other and with other neurons, as well as those areas deep in the center of the brain that coordinate automatic sensory and motor functions. The cortex is the layers of neurons lying immediately below the bones of the skull, arching from just behind the forehead and over the top and sides, back to where the back of the head meets the neck. The cortex has evolved and expanded, adding many new functional areas, which participate in activities from playing basketball to designing software. Yet we retain our ancestral past; the seasonal depression many people experience in the dreary darkness of January may stem from animals that survived cold, foodless winters by slowing down their metabolism and hibernating. This ancient pathway remains in our brains despite electric heat and convenience stores.

The human brain has the same organization, the same types of neurons, and the same set of neurotransmitters—the chemical messengers between neurons—as other mammalian brains, which is why rats and monkeys are so widely used to test theories about human brain function. In fact, the basic control mechanisms for developing the brain are shared among all species. Thus we can study worms, fish, and even flies to help us uncover the genetic and chemical processes that guide the development of the human brain.

However, the cortex, which is dwarfed in most species by other brain areas, makes up a whopping 80 percent of the human brain. Compared with other animals, our huge cortex also has many more regions specialized for particular functions, such as associating words with objects or forming relationships and reflecting on them. The cortex is what makes us human.

Human brain development starts soon after the sperm penetrates the egg. The zygote begins to divide—two, four, eight, sixteen—until there are hundreds of cells. By the fourteenth day, the tiny ball of multiplying cells begins to fold in on itself. The process resembles a finger being pressed into the center of a soft balloon; cells from the outer surface begin to move inside the sphere. This movement activates the genes in cells that will form the nervous system. The compressed balloon lengthens and continues folding in on itself to form a tube. One end of the tube will become the spinal cord, and the other will become the brain. Cell division continues, and by the eighth week the brain has developed its three parts. The first weeks and months are a time of furious cell production and overproduction, with 250,000 neuroblasts, or primitive nerve cells, being created every minute.

During and after this period, neurons differentiate to perform distinct functions, first by traveling to a specific site, and then by extending an open hand to neighboring neurons. From the beginning of its being built, the brain is a social brain, the neurons making connections with their neighbors or dying for lack of contact. Little colonies begin developing on their own, and then reach out to other migratory communities. Continually dividing cells on the inside of the neural tube produce incredible numbers of neurons, which migrate out to the various regions of the brain. Most neurons migrate straight out until they reach the developing cortex. However, some go sideways a fair distance away from the original community, or clone, of neurons. Presumably these migrants will set up house in other communities and open the way for communication between the two sites, like an ambassador.

The migration can mean the difference between normal and crippled function. As recently as the early 1980s scientists thought that each cell in the fetal brain had a predetermined function and location in the adult brain. Today we know that the migration itself affects how neurons gain their identity and organize the brain's architecture. For instance, visual neurons become visual neurons not entirely because

they are born visual neurons but because they migrate to a part of the brain where visual information arrives. Proper migration of neurons, therefore, is important for the development of normal brain function. There is a lengthening list of disorders, including autism, dyslexia, epilepsy, and schizophrenia, that may be caused in part by a migration problem. Plenty can go wrong during the journey, as a neuron becomes functional. Other cells it comes into contact with along the way and the specific genes within them that are turned on and off in response to the fetal environment all contribute to the form and function neurons take. Thus hormones, growth factors, cell adhesion molecules that cause neurons to stick together, other signals between cells not as yet well understood, and substances in the mother's blood all have an effect on determining where the neurons will end up and how they will perform. The inner environment guides the genes to make the brain.

During their journey, the neurons are fed and guided by caretaker glial cells, which form a scaffolding along which the neurons migrate—a lattice of support, guidance, protection, and nourishment. After the neurons reach their final places, the glial cells remain, although they change their shape and molecular properties in order to perform different functions. Two types of glia appear: one type controls the metabolism and function of the neurons; the other, which coats the axons with a fatty substance called myelin, controls how fast axons conduct information. The two main types of cells, neurons and glia, make up the brain, which is pretty much complete by the eighth month of pregnancy. At this point there are twice as many neurons as in the adult brain. As the brain ages, neurons that are weak or unused or simply don't fit the job that needs to be done are pruned away, to leave more efficient connections for those that are performing brain work. The principle of "Use it or lose it" begins, with nonworking, "couch-potato" cells dying off while those that are exercised get stronger and develop more connections.

Millions of the neurons travel amazing distances, the equivalent of a hike from New York City to San Francisco. Where they settle helps determine our individual temperament, talents, foibles, and quirks as well as the quality of our thinking processes. If neurons lose their way on their long journeys, developmental disorders may result, which is why it is so important that a pregnant woman not ingest harmful sub-

stances; a particular chemical in the brain at a critical moment will send neurons down the wrong fork in the road, or simply stop the process and cause havoc. Alcohol, nicotine, drugs and toxins, infections such as German measles, and lack of certain nutrients such as folic acid can interrupt the migration.

Once neurons have settled in at their final home—why they stop where they do is still a mystery—they grow dendrites and axons to communicate with other dendrites and axons. The tentacles reach for each other but don't quite touch. Like the outstretched fingers of God and Adam on the ceiling of the Sistine Chapel, they remain separated by a small gap, called a synaptic cleft. The axons and dendrites communicate by sending chemical messengers—neurotransmitters—back and forth across the synapse. A single neuron may be communicating across 100,000 synapses.

Chemical signals, called trophic factors, tell the axons where and how to connect. Whether or not electrical stimulation becomes sustained determines whether a connection between neurons survives or even whether a given neuron lives or dies. Because of the huge overproduction of neurons, there is not enough biochemical juice to support all of the axons searching for connections. Axons battle for limited sites, and those that lose the competition perish. Others that try to connect with the wrong kind of neuron are cut off from nourishment. However, there is no mindless competition of neurons for survival. Instead, forces external to each element in question (receptor, synapse, etc.) determine its degree of use and hence its survival. At first the activity that determines survival is random and spontaneous, but it becomes more organized as the fetus, and then the baby, receives input from its environment.

Two sequential pruning processes then fine-tune the initial neuronal networks that are formed. One causes the loss of entire neurons and the other the loss of branches and synapses. Both seem to involve competition for limited amounts of specific chemical signals released by the target cells. In the first process, neurons that fail to get enough signals from their target cells undergo cell death. This eliminates neurons that have made inappropriate connections and helps match the number of neurons to the number of target cells. In the second process, the connections between surviving neurons are refined by the removal of some dendrites and their synapses and the stabilization of others in a

process that depends on electrical activity along the axons and competition among neighboring target cells. As the brain matures, the synaptic connections are further modified by use.

A period of cell death during the later stages of pregnancy wipes out almost half the neurons in the brain, which are probably phagocytized, or eaten up, by the support cells of the brain and the molecules recycled locally. There is a drop from about 200 billion neurons to 100 billion. This widespread cell death is normal, for it eliminates the wrong and weak connections that could inhibit efficient and proper brain function. This is a classic example of the incredible resourcefulness of evolution, which makes us highly adaptable creatures. It also points to the fact that even at the very beginning of development the brain is a social organ: where there is no connection, there is no life.

When a baby is born, it has millions of good connections waiting for a specific assignment. As the world makes demands, many of the connections are enlisted for specific jobs: seeing, babbling, remembering, throwing a ball. Connections that aren't used are eventually pruned. In the absence of the proper stimulation, a brain cell will die, but offer it a diet of enriched experiences and its neural synapses sprout new branches and connections.

Neurons that survive communicate rapid-fire across the synapses. The more firing that occurs across a specific connection, the stronger that pathway becomes. Billions of these exchanges take place continuously throughout the brain. Some connections transmit and receive signals often, others only occasionally, and the messages change constantly. The exact web of connections among neurons at a particular moment is determined by a combination of genetic makeup, environment, the sum of experiences we've imposed on our brains, and the activity we are bombarding it with now and each second into the future. What we do moment to moment greatly influences how the web continually reweaves itself.

DRUGS, MALNUTRITION, AND STRESS

THOUGH WE SHOULD all heed the lesson to follow, expectant mothers should take it very seriously. The developing brain in the fetus is extremely sensitive to its environment. Most pregnant women are

aware of the dangers they can pose to their unborn babies. But they may not realize just how potent their actions can be. Let's consider a few of the most striking cases of environmental influence.

Smoking

CIGARETTES ARE PROBABLY the "drug" most commonly used during pregnancy. Despite warnings, 20 to 25 percent of pregnant women still smoke. Nicotine can reduce blood flow in the uterus and placenta by causing constriction of the blood vessels. It decreases the fetus's heart rate and breathing movements and exposes it to carbon monoxide.

Smoking raises considerably the risk that a baby will be born premature and underweight. The risk of spontaneous abortion is 1.7 times higher for smoking than for nonsmoking mothers. The risk of congenital abnormalities is 2.3 times higher. Research also shows that there is a 50 percent greater incidence of mental retardation among the children of mothers who smoked during pregnancy and that the more a woman smoked when she was expecting, the greater the chance of retardation. Importantly, the children of mothers who smoke show a threefold increase in attention deficit disorder (ADD), and a well-known reduction in birth weight, which is thought to have a great effect on the development of the brain. The incidence of sudden infant death syndrome is also higher among babies whose mothers smoked during pregnancy. Prenatal use of marijuana has similar effects. A mother's smoking affects her unborn baby because certain substances in her blood are passed to the fetus across the placenta. Research indicates that nicotine actually concentrates in the fetus, exposing it to an even higher level of the drug than the mother experiences.

The leading theory as to how nicotine affects the fetus's brain development is that the drug interferes with the natural migration of neurons, their connections, and their proper pruning during fetal development, although a direct link has not yet been proven. There is also evidence that nicotine can deregulate the dopamine system, undermining the modulating effect dopamine has on the brain's development.

Alcohol

ALCOHOL CONSUMPTION DURING pregnancy can have devastating consequences. Microscopic studies of fetal brains show that alcohol

causes faulty cell migration. Once they begin to travel, the neurons do not know when to stop, miss their proper destinations, and often die. As a result, the brains of babies whose mothers drink regularly are frequently small, shrunken, and malformed, with a lower density of neurons. These fetal alcohol syndrome (FAS) babies have low IQ scores in childhood and severe reading and math disabilities by the time they reach high school and adulthood, as well as maladaptive behavior, hyperactivity, and depression.

The really unfortunate news is that, as with every other developmental toxin, the most significant effects of alcohol come early in pregnancy: the first six weeks are the most crucial. If a woman is drinking during this period, by the time that she becomes aware that she is pregnant the damage may have been done. Given this, there may be hundreds of thousands of people who have some degree of mental or physical impairment owing to *in utero* exposure to alcohol.

Research also shows that the effects associated with FAS continue and indeed increase as children become adults. There is also a more subtle version of fetal damage known as fetal alcohol effects (FAE). A recent study of 253 people diagnosed with FAS and FAE found that 90 percent had mental health problems; 60 percent experienced disrupted educations; 60 percent had trouble with the law; 50 percent had been accused of inappropriate sexual behavior. This points to a theme that will be repeated time and again in this book: Some types of antisocial and even criminal behavior could be linked to, if not caused by, physical problems in the brain.

Meanwhile, as treatments develop, society can do a great deal to prevent FAS and FAE in the first place, by educating all its citizens about the risks of drinking during pregnancy.

Cocaine

ONLY A FEW studies of cocaine use during pregnancy have been completed. More are needed. But the early results indicate effects similar to those of alcohol. Cocaine interferes with the transfer of nutrients and can shrink the amount of oxygen that travels from the placenta to the fetus, causing impaired growth of the fetus's body and brain. However, most recent studies show that many of the effects of cocaine disappear as the infant matures.

Malnutrition

DURING PREGNANCY, the fetus is more readily harmed by foreign substances than by poor nutrition. Nonetheless, a shortage of certain nutrients in the mother's diet, such as iron, vitamin B₁₂, folic acid, and essential fatty acids, can retard the brain's development. For example, research has shown a clear correlation between an insufficient intake of folic acid and a high incidence of spina bifida. If essential nutrients are not available, neurons stop forming, resulting in smaller brains, less overproduction of neurons in the fetus and subsequently less pruning or fine-tuning, and less cognitive development. Once born, these babies have lower birth weights, slower rates of growth, less coordination, a higher incidence of poor sight, and more learning difficulties. Malnutrition in young children also slows the brain's development, impairing cognition.

However, anxious pregnant mothers must also be careful not to overindulge. The vitamin craze that continues to sweep Western cultures makes it too easy, and seemingly imperative, to take massive doses of vitamins. Consumption of excessive amounts of some vitamins, particularly A and D, can lead to toxicity, which interferes with the brain's neurochemistry. A recent study shows that the consumption of too much vitamin A by pregnant women may cause birth defects. Large quantities of retinol and retinyl esters, the forms of vitamin A commonly used in dietary supplements, cause birth defects in tests on many animals. Pregnant women, with their doctors, should make sure they are getting enough vitamins, but not too many.

Toxins

MOST OF US REMEMBER the frightening warnings we received as children about not eating paint. Toxins such as lead can severely disrupt brain chemistry. During pregnancy, lead, pesticides, anesthesia gases, antibiotics, over-the-counter and prescription medications, and even acne medicine containing large amounts of vitamin A can all act as toxins on the fetus's brain. Ionizing radiation, such as X-rays and drugs used in treating cancer, have the same effect.

Some chemicals may not interfere with the brain's development. A small 1996 study at the University of Toronto of three widely used anti-

depressants—paroxetine, sertraline, and fluvoxamine—showed that these drugs do not appear to cause birth defects, which agrees with research in animals and previous studies of the antidepressant Prozac among pregnant women. However, because the study looked at only 267 expectant mothers, it was far too limited to establish that these drugs are safe during pregnancy. The study also did not explore behavioral differences in the babies born.

A previous study of Prozac found no effects on IQ, language, or behavior among babies exposed to the drug as fetuses. However, other research indicates an increased rate of “minor anomalies” at birth, such as abnormal creases in the palm of the hand. Until more research is done, women who are taking antidepressants or any medication and are considering pregnancy should consult with their doctors about the risks of continuing or stopping medications on the health of mother and fetus.

For their part, would-be fathers would also be wise to avoid exposure to smoking, alcohol, drugs, and toxins for at least three months prior to conception—the life span of the sperm.

NEURAL DARWINISM

IN THE EARLY STAGES of development, neurons travel freely in the brain, though guided in general pathways by genetic instruction. As they float around, some divide into more neurons, some die, and others settle down at permanent sites and make connections with neighbors, building the brain's complex circuitry. Genes provide the basic guidelines that control how the neurons form functioning networks. But the precise chemical environment influences which neurons connect with which.

All of our brains have the same general features that make us human, but each neural connection is unique, reflecting a person's special genetic endowment and life experience. Circuit connections are made stronger or weaker throughout a lifetime according to use. Neurologist and Nobel laureate Gerald Edelman, head of the Neurosciences Institute at the Scripps Clinic in La Jolla, California, calls the process neural Darwinism. Connections that cope well with the sensory inputs they receive, which they can convert into effective actions,

stay intact and become strong. Those that do not, die off in a process that resembles natural selection. Neurons and the circuits they form part of compete with other neurons for survival, and those that are best adapted to the environment survive. The environment around us—what we ingest and inhale, the amount and type of light and sound—actually changes the physical interconnection of synapses within the brain, providing us with more efficient circuitry, and allowing each of us to develop an exclusive brain suited to our particular needs.

Neural Darwinism is the theory that explains why the brain needs to be plastic, that is, able to change as our environment and experiences change. That is why we can learn in the first place, and unlearn too, and why people with brain injuries can recover lost functions. The concept also underlies two of the mantras of this book. “Neurons that fire together wire together” means that the more we repeat the same actions and thoughts—from practicing a tennis serve to memorizing multiplication tables—the more we encourage the formation of certain connections and the more fixed the neural circuits in the brain for that activity become. “Use it or lose it” is the corollary: if you don't exercise brain circuits, the connections will not be adaptive and will slowly weaken and could be lost.

NATURE OR NURTURE

BEING ALTOGETHER HUMAN, which means in part understanding who and what we are, we are curious about the answer to the question of which force plays a stronger developmental role: genes or environment. The debate over “nature or nurture” has raged for two thousand years. At opposite extremes are euthenists, who cite bad parenting and the evils of society as the cause of all mental problems, and the proponents of eugenics, who blame faulty genes for all of society's ills and want to prevent all “bad” people from reproducing.

In reality there is no debate. Most of who we are is a result of the interaction of our genes and our experiences. In some cases, the genes are more important, while in others the environment is more crucial. We tend to oversimplify because we want to identify a single cause of a particular problem, so we can pour our efforts into one “cure.” Some

people hope that programs such as Head Start, which are designed to change a child's environment, will improve intellectual development. Others hope that one drug or one gene alteration will cure all aggressive behavior. Such simplistic approaches will rarely work. The real question is how genes and the environment influence each other; brain structure, and behavior. Untangling each factor's contribution is difficult because we can never fully understand an individual's genes outside an environment, and we can never study the effects of environment on a person while "isolating out" his genes.

Since the 1990s the pendulum has swung toward nature. It seems as though we hear almost daily of a new discovery; genes are now linked to Alzheimer's disease, bedwetting, obesity, and even to overall happiness. Many aspects of development that were previously attributed to learning, bad habits, or environment are now thought to be determined by genes. Many of us are fascinated by the international Genome Project, which is mapping the function of the 100,000 genes in the human genome, some 30,000 to 50,000 of which are designated for the brain. But we must remember that genetics is not destiny. A mere 50,000 genes for the brain are not nearly enough to account for the 100 trillion synaptic connections that are made there. Genes set boundaries for human behavior, but within these boundaries there is immense room for variation determined by experience, personal choice, and even chance.

The point to remember is that genes can be active or inactive and that everything we do affects the activity of our genes. We tend to think of genes as tiny entities that are isolated from the rest of the body, but they reside in every cell and are affected by anything that affects that cell, whether the cell is in the thigh or the cortex. For example, genes activate the exploratory network in a child's brain, and the more enriched the child's environment, the more these genes turn on, and the more the child explores. Adults experience many similar effects: learning increases the activation of genes that turn on the production of proteins in the brain needed to solidify memory.

In a few cases, one gene has complete control over whether you will develop a particular trait; if a man has the gene for color blindness or Huntington's disease, he will suffer these ills. Otherwise, it's rare that a single gene controls anything. In a few other cases, such as heart disease, genes predispose you to possible trouble, but your lifestyle can be the more important determining factor.

Most of our traits are caused by the interaction of many genes as influenced by the environment. That is why it is highly unlikely that specific patterns of behavior, such as stealing or brilliance in math, can be wholly inherited. If sons act like fathers in these cases it is primarily because the son is raised in a criminal environment or is praised for solving math problems and encouraged to play games such as chess that promote spatial thinking. Environment can even negate strong genetic predispositions. For example, Type II diabetes is highly genetic, but if the susceptible person can avoid becoming overweight in midlife there is a good chance that the genes for the disease will not be activated. In another example, it has been found that even though twins carry an identical set of genes, it is not uncommon for one in a pair to exhibit severe Tourette syndrome—a neurological disorder characterized by the presence of tics and streams of nasty language—while the other twin's case is hardly observable. Interaction with the environment accounts for the great difference in severity.

Studies of identical twins separated at birth are often used to test the debate between nature and nurture. While these can be valuable, this test is hamstrung from the start for several reasons, one of which is that differences in the position of each twin in relation to the placenta may bring with them differences in blood supply, hormonal levels, and other factors that are not intrinsic to the genes of the twins. Whether a twin is a "front child" or a "back child," a "spleen child" or a "liver child," makes a difference.

We have much more to learn before we will be able to draw conclusions about which one, nature or nurture, is more important, and for what areas of development. If environment is all-important, it is hard to explain child prodigies—children who seem simply to sit down and play the piano or chess at a very early age, and are able to learn very fast, very well, with little or no instruction. It seems that prodigies must possess an inborn "talent," which means a gene or genes for the intellectual and physical capabilities needed to play the piano or chess.

The remarkable twinning effect directly contradicts the notion that environment is more important than genes. In these cases, twins who are raised apart (with no contact) and are reunited years later find that their lives are very similar. This was the case for a pair of twin brothers separated five weeks after birth and raised eighty miles apart in Ohio. When Jim Lewis and Jim Springer were reunited at the age of thirty-nine, they found they had both married women named Linda,

divorced, and remarried women named Betty. Both chain-smoked Salem cigarettes, drank Miller Lite, loved stock-car racing, hated baseball, and vacationed on the same stretch of beach in Florida. Studies of 7,000 sets of twins by the Minnesota Center for Twin and Adoption Research show that a number of traits may be driven by genes, including alienation, leadership, vulnerability to stress, and even religious conviction and career choice.

But then it turns out that for some twins separated at birth, one twin ends up as a schizophrenic adult and the other does not. How is this possible if they have the same genes? Environment may be the answer. Other twin studies show that environment can mitigate or exaggerate the effect of genes; twin halves raised by parents living in a tough inner city demonstrate more aggressive and violent behavior than the other twin halves raised in suburbs.

The point to remember is that the issue is not nature *versus* nurture. It is the balance between nature *and* nurture. Genes do not make a man gay, or violent, or fat, or a leader. Genes merely make proteins. The chemical effect of these proteins may make the man's brain and body more receptive to certain environmental influences. But the extent of those influences will have as much to do with the outcome as the genes themselves. Furthermore, we humans are not prisoners of our genes or our environment. We have free will. Genes are overruled every time an angry man restrains his temper, a fat man diets, and an alcoholic refuses to take a drink. On the other hand, the environment is overruled every time a genetic effect wins out, as when Lou Gehrig's athletic ability was overruled by his ALS. Genes and the environment work together to shape our brains, and we can manage them both if we want to. It may be harder for people with certain genes or surroundings, but "harder" is a long way from predetermination.

LEARNING TO CHANGE

THE NEURAL PATHWAYS that control the basic functions we need to survive—heartbeat, temperature control, breathing—are already connected at birth, but many more pathways are determined by the greatest environmental factor in our lives: learning. Although the brain's

flexibility may decrease with age, it remains plastic throughout life, restructuring itself according to what it learns.

The brains of children three to ten years old consume twice as much of the blood nutrient glucose as those of adults, in part because their brains are less efficient and are in the business of forming a vast number of connections. Studies also show that children who exercise regularly do better in school. New research indicates that adult exercise juices the brain with more glucose too, which may promote an increase in neural connections.

Because the young brain prunes weak connections, environmental input in a child's early years can have amazing or devastating effects on the brain's wiring, and thus on future behavior. Geraldine Dawson at the University of Washington followed 160 children from infancy until age six. She found that infants raised by depressed mothers—and so not exposed to many smiles or sounds of excitement in response to their actions—showed reduced activity in the left frontal region of the brain, the area responsible for the expression of positive emotions. At three and a half years of age, the children were more likely to exhibit behavioral problems. In cases such as these, intervention by positive fathers or other caregivers and having the mothers undergo treatment could help to strengthen the neural connections before they are eliminated permanently.

Neurons are constantly competing to make connections. Many maps have been drawn that match each region of the brain to the function it controls: one area for speech, another for spatial skills, and so on. However, changes in environmental input continually move the boundaries. An accurate map of the brain would be different for each of us, and would shift over time. Connections that receive input from frequently used body parts will expand and take up more area than those that receive input from infrequently used parts. Magnetic resonance imaging (MRI) shows that the brains of violin players devote much more area to pathways representing the thumb and fifth finger of the left hand—the fingering digits—which are used extensively in hours of training. The younger a child begins practicing, the more area her cortex devotes to these fingers.

The competition to gain more representation in the brain explains why babies born with cataracts that cloud their vision must have them removed by six months or never gain sight. The brain must learn to

see, making connections and stimulating them with inputs from the retina. If these pathways aren't stimulated, they will be eliminated as not useful. Many of us who need glasses have a different prescription for each eye to make the eyes comparably strong. Otherwise, neurons serving the stronger eye will branch out their connections, beating out the neurons serving the weaker eye and making the latter permanently weak. This condition is known as amblyopia. To stimulate the neurons of a weaker eye and prevent its becoming amblyopic, eye doctors will patch the stronger eye. If one eye of a newborn kitten is sewn closed, the eye's neural connections will wither and disappear from lack of use. If the eye is later opened it will never gain sight, because the stronger eye has permanently taken over the available synapses, and, more important, the weaker eye has permanently lost its ability to make connections.

Changing your pattern of thinking also changes the brain's structure. Jeffrey Schwartz at the University of California at Los Angeles School of Medicine found that obsessive-compulsive patients who changed their problematic behavior by repeatedly not giving in to an urge, and deliberately engaging in another activity instead, showed a decrease in brain activity associated with the original, troublesome impulse. It is theorized that neurons contain tiny electromagnetic fields that become misaligned, or "locked," for the duration of a dis-ease or disorder. The neurons get stuck in a rut of abnormal patterns of activity, becoming underactive or overactive or just nonperforming, it being either too easy or too hard for them to fire. A person who forcibly changes his behavior can break the deadlock by requiring neurons to change connections to enact the new behavior. Changing the brain's firing patterns through repeated thought and action is also what is responsible for the initiation of self-choice, freedom, will, and discipline. The drug Prozac can be helpful in breaking these kinds of deadlocks.

We always have the ability to remodel our brains. To change the wiring in one skill, you must engage in some activity that is unfamiliar, novel to you but related to that skill, because simply repeating the same activity only maintains already established connections. To bolster his creative circuitry, Albert Einstein played the violin. Winston Churchill painted landscapes. You can try puzzles to strengthen connections involved with spatial skills, writing to boost the language

area, or debating to help your reasoning networks. Interacting with other intelligent and interesting people is one of the best ways to keep expanding your networks—in the brain and in society.

Some of these activities help owing to a neurological phenomenon called cross-modal influences—cross-training in the sports world. For certain sets of skills, training one part of the brain also benefits another. As we will see in the discussion of language in Chapter 7, dyslexic children who repeatedly listen to elongated sounds generated by a computer can improve their ability to spell and read. A study performed by a team at the University of California showed that college students who listened to 10 minutes of Mozart's piano sonatas just prior to taking spatial reasoning tests scored higher than students who listened to relaxation tapes or the more hypnotic music of Philip Glass. This "Mozart effect" lasted only 15 minutes, though, and other studies have shown weaker improvement or none at all. More research is needed before we all start strapping Sony Walkmans to our heads or sending Mozart tapes home with newborn babies.

There is stronger evidence, however, that children who listen to and play music at ages younger than eight do better on spatial reasoning tests. For example, the California team studied a class of three-year-olds. Half the class attended piano or singing lessons for eight months. Their scores on puzzles, tests of spatial reasoning, and drawing of geometric figures shot up to 80 percent higher than those of their classmates who did not attend music lessons. The musical children gradually became faster and more accurate at spatial reasoning over the school year and boosted their spatial intelligence. The theory is that as music is structured in space and time, practicing it will strengthen circuits that help the brain think and reason in space and time, important for math. If the effect of sustained practice during childhood is permanent, the improved ability will help children in complex math and engineering problems when they grow up. It is theorized that the music triggers neural firing patterns over large regions of the cortex that are also used for spatial reasoning.

Activities that challenge your brain actually expand the number and strength of neural connections devoted to the skill. But as Merzenich's monkeys showed, when complex motor tasks become routine they are pushed down to the subcortical areas, where they reside as more automatic programs. Once a procedure is stored in this lower memory it

becomes hard-wired. That's why we can get on the proverbial bike and pedal away after a decade of not riding. If these skills had stayed in the higher cortex and been unused, the connections would have withered and been lost. Adults who gave up their rock-'n'-roll bands in high school find that when they pick up a guitar years later they can still play, and when their children bring home their first algebra problems, they can still set up an algebraic equation.

The more that higher skills such as bike-riding and cognition are practiced, the more automatic they become. When first established, these routines require mental strain and stretching—the formation of new and different synapses and connections to neural assemblies. But once the routine is mastered, the mental processing becomes easier. Neurons initially recruited for the learning process are freed to go to other assignments. This is the fundamental nature of learning in the brain.

The brain's ability to rewire means that in principle it can recover from damage. Young children who have had an entire brain hemisphere removed because of severe epilepsy manage to compensate with only slight mental or physical disabilities. Intense physical and mental rehabilitation allows circuits in the remaining hemisphere to gradually rewire, taking over many of the functions that the lost hemisphere used to perform. Things won't ever be "normal," as the original well-trained and appropriately placed circuits have been lost, but even complex functions such as language and reasoning are relatively spared after this sudden, massive loss of neurons. We will encounter several examples of such dramatic rewiring throughout this book.

The brain is amazingly plastic. In the past it was commonly accepted that any brain damage was permanent; once a brain region died, the function it controlled was gone forever. More than 500,000 Americans have strokes each year, killing many neurons and cutting many connections, yet in many of them undamaged neurons take over, changing the number, variety, and strength of the messages they send, rerouting traffic around the accident site. Rewiring is possible throughout life.

New connections take time to form and strengthen. They gradually learn what is most useful and adapt. Many stroke victims lose language abilities, but neighboring circuits or neurons in the nondamaged hemisphere try to take over and compensate for the lost function. Of course, these patients are relying on different neural connections

that are probably less efficient for language, so their speech may never be as natural or easy. In cases where brain damage occurs slowly, such as Alzheimer's disease, the brain has more time to compensate, and many deleterious effects can be postponed, though the progressive march of this devastating disease cannot yet be stopped.

The brain reacts differently to injury during different periods of development. Prenatal or early childhood brain damage is often less problematic since many neural circuits are not yet committed to specific skills, knowledge, or memories. The brain can readily rewire on a widespread scale. Although the damage may result in a smaller adult brain or one of lesser overall intellectual abilities, it will seldom cause specific deficits. Most lasting problems are actually due to disconnections from neurons that try to branch out and fill new roles. In later childhood, major damage will be more permanent, although many skills can still be recovered. Plasticity at multiple levels is more active in early life, so that damage at one site produces changes at many other sites, thus changing the brain and its functioning in a more widespread manner. In later life, with less capacity for remodeling at multiple levels, effects at a distance from the site of damage are less likely and specific deficits are more common. From mid-adolescence on, there is less rapid growth of new synapses that allow for flexibility, and by then neurons are completely myelinated, or sheathed. Damage will cause deficits in specific skills with varying degrees of recovery. The more we learn about how the brain restructures itself, the better we will be able to direct other brain areas to take over faulty functions, resulting in greater recovery from trauma and disease.

LIMITS TO PLASTICITY

DESPITE THE BRAIN'S amazing ability to adapt, there are limits to its flexibility. Age does make it harder to reroute and establish new circuits. Music teachers, chess champions, and star athletes all advise parents to start their disciples young. We've all seen how much easier it is for young children to pick up second languages. In an American family that is transferred to Tokyo for a year, the preschool child will learn to converse in Japanese while her mother is still struggling with basic communication.

Children who are exposed to two languages from birth learn to speak both fluently. Linguistic researcher Patricia Kuhl, at the University of Washington in Seattle, likes to say that all babies are born "citizens of the world," meaning that they can learn any language perfectly. She has tested newborn infants with sounds unique to African languages, English, and Japanese. No matter where a baby is being reared, he or she can distinguish the fine auditory cues typical of any non-native language and is presumably ready to learn any language heard.

From about six months on, however, if babies have not heard a particular speech sound, they can no longer distinguish it. Infants whose parents speak English have formed different linguistic connections than infants whose parents speak Japanese, based on the phonemes they hear: the long "ooo" and abrupt "ba" of English, the clipped "toli" and slurred "rr/ll" of Japanese. By its first birthday an infant can no longer process phonemes it hasn't heard; it is functionally deaf to foreign sounds, having learned to ignore sound distinctions not necessary for its native language. In fact its babbling, though not yet words, is confined to sounds that the infant has already heard in its own language. To learn Japanese after childhood, we conjugate long lists of verbs and endlessly repeat dialogue from language tapes, but we can never speak like a native, because our language circuits are unable to form new basic connections.

Brain development in the fetus and baby occurs through a series of critical periods, "windows of opportunity," when the connections for a function are extremely receptive to input. Once the window closes, neural connections are pruned down to the most efficient, according to how much they are used. Then the battle is over: the closed eye and the deciphering of foreign phonemes will never regain space in the brain. It is clear that it is possible for adults to learn to speak a new language with little or no accent, but it is also clear that they do not do this the way a baby does, and instead use altogether different systems to learn. The adult systems are not nearly as good as the baby ones.

These precious windows of opportunity are also times of great vulnerability to irreversible damage. "Closet kids" found by police provide the strongest evidence. These children have been locked in closets or basements for years by psychotic or brutal parents. They grow up without hearing human conversation and are never able to master the sounds and grammatical rules necessary for smooth speech. Through

long instruction after they are found, other pathways compensate to some extent, but tragically, owing to the extreme deprivation, the critical period for natural speech development has been missed.

One girl, Genie, was discovered in 1970 in Los Angeles at age thirteen. She had spent her entire life, from babyhood on, in one room, often chained for hours to a potty chair and beaten if she made a noise. Imprisoned and isolated by her psychotic father, she had effectively grown up without human contact. All she was able to hear was blurred conversation through the walls of her room. After four years of subsequent experiments and training she had learned a vocabulary and sign language, but her syntax remained disrupted. She could produce pidgin-like sentences such as "Applesauce buy store," but was permanently incapable of mastering grammar. She had already passed the limited window of opportunity for language acquisition. (Unfortunately, Genie did not come out of this story well. Funding ran out and Genie regressed after passing through a string of foster homes, where she was beaten and abused.)

In contrast is Isabelle, who was six years old when she and her mute, brain-damaged mother escaped the silent imprisonment of her grandfather's house. With training, a year and a half later she had a 1,500-word vocabulary and could form complex sentences like "What did Miss Mason say when you told her I cleaned my classroom?" She had not yet passed through the window of opportunity for attaining syntax.

University of Chicago psychologist Janelle Huttenlocher has found that the frequency with which normal parents speak to and around their child during the child's second year significantly affects the size of the child's vocabulary for the rest of his or her life. The more words a child hears during this sensitive period, whether it's "cat" or "existentialism," the stronger the basic language connections.

Constraints on plasticity for many sensory and motor functions also depend on critical time periods. Most humans move all their body parts during the first two years of life. By age two the motor circuits become hard-wired. If for some reason a child never moved his arms these circuits would be lost and he would never be able to move his arms in a natural way. Regions for basic vision are complete by six months. Acquisition of other functions, however, such as academic learning, takes place over a lifetime, unconstrained by windows of development.

Understanding when the brain's circuits are most receptive to learning a particular skill can help create the optimum environment for a child's development. Psychiatrist Dan Stern at the University of Geneva believes that the critical period for developing emotions occurs from ten to eighteen months. Stern was one of the first and most long-term baby watchers, and has looked for evidence of emotional and social critical periods. His work indicates that if parents regularly respond to their baby with delight, the child's circuits for positive emotions are reinforced. If parents repeatedly respond with horror, the child will shut down those circuits and instead reinforce the fear circuits; the research shows that early fright conditions the baby's brain for more fright. Prolonged depression in the mother conditions the baby for depression, too. The key words here are "repeatedly" and "prolonged." An occasional scowl won't set the child up for a miserable life.

Stress management is also learned during a critical period early in life, according to research on newborn rats, which have neurons very similar to humans. The studies reveal that the more the rats are gently handled, the more they produce serotonin, a brain chemical that controls aggressive behavior. As adults, the rats who had received gentle handling were better able to cope with stress, had stronger immune systems, and actually lived longer than rats who had not been treated gently.

Many cognitive functions share pathways in our brain's complex tangle of neural connections. The development of one skill can therefore profoundly influence another that is seemingly unrelated. As the Mozart effect shows, music and spatial reasoning appear to be linked. Listening to words and reading share some of the same circuits, too.

THE NUNS OF MANKATO

THE BRAIN'S PLASTICITY not only helps with recovery but may actually play a role in preventing brain disease. For evidence, just visit the School Sisters of Notre Dame nunnery in remote Mankato, Minnesota. Many are older than ninety, and a surprising number reach one hundred; on average they live much longer than the general public. They

also suffer far fewer, and milder, cases of dementia, Alzheimer's, and other brain diseases. David Snowdon, the University of Kentucky professor who has been studying them for years, thinks he knows why.

Spurred on by their belief that "an idle mind is the devil's plaything," the nuns doggedly challenge themselves with vocabulary quizzes, puzzles, and debates about health care. They hold current-events seminars every week, and write often in their journals. Sister Marcella Zachman, featured in *Life* magazine in 1994, didn't stop teaching at the nunnery until she was ninety-seven. Sister Mary Esther Boor, also pictured in *Life*, still worked the front desk at ninety-nine. Snowdon, who has examined more than 100 brains donated at death by nuns in Mankato and other School Sisters locations across the nation, maintains that the axons and dendrites that usually shrink with age branch out and make new connections if there is enough intellectual stimulation, providing a bigger backup system if some pathways fail.

Snowdon has found that the nuns who earned college degrees, taught school, and constantly challenged their minds into old age lived longer and resisted Alzheimer's disease better than the nuns who had lower levels of formal education and spent most of their time cleaning rooms and preparing food. Snowdon's conclusion, and that of other scientists who have studied aging and the brain, is that any intellectually challenging activity stimulates dendritic growth, which adds to the neural connections in the brain. The more mentally challenged sisters have more neural connections, which allows them to reroute messages when the brain is damaged by stroke or disease, counteracting the debilitating effects on the brain and thus keeping them healthier and more active for more years. Given that the sisters have led otherwise similar lives in the same environment for decades minimizes the influence of any other factor.

The hypothesis that more academic challenge leads to a more flexible brain in old age is supported by gerontologist Denis Evans, who studied elderly residents in the working-class community of East Boston, Massachusetts. He gave them a series of memory and mental status tests, and repeated the testing three years later. Residents who had fewer years of formal education consistently showed a greater decline in test scores, independent of age, birthplace, occupation, income, or native language.

REGENERATION

HOPE IS NOW GROWING that brain damage can be treated by inducing neurons to regenerate; recent discoveries indicate that regeneration might be possible. If so, brains damaged by stroke, Parkinson's disease, and Alzheimer's disease could actually produce new brain cells to fill the roles of the cells that have died. It is true that most neurons can't be regrown when they die; our brains would have a hard time holding on to memories and skills if cells were easy to replace. However, in a few specific regions, such as the hippocampus, the birth and differentiation of neurons continues through old age.

In studies with adult rats, Alan Lewis of Signal Pharmaceuticals found that new, undifferentiated neurons taken from brain areas that are still growing and moved to another part of the brain can learn to perform the local function there. Lewis grafted immature nerve cells from memory areas into smell areas; the cells used cues from the local environment to develop into mature olfactory neurons. Since neurons aren't totally preprogrammed to perform specific functions, neurons moved from one area may be able to take over functions lost to brain damage in another.

Genetic manipulation may also help. Evan Snyder at Harvard Medical School removed newly formed brain cells from newborn mice. He injected them with a gene that would cause them to divide and then inserted them into different areas of brains of adult mice in which stroke had been induced. The implanted neurons migrated to the damaged areas, divided, and took on local specialized functions. One theory is that the cells responded to chemical signals released by dying neurons or by ordinary brain cells that no other cells were responding to. Because actively dividing cells have not yet specialized their function, if they are directed to the right location they may be able to fill in for neurons lost to stroke, disease, or accidents.

Implanting dividing cells that could renew brain function could be a key to fighting Parkinson's, the disease that has ravaged boxer Muhammad Ali and that affects 500,000 to 1 million Americans a year, most over age fifty-five. Parkinson's results from cell death in the substantia nigra, which produces dopamine and sends it to a second

brain structure called the striatum, which coordinates movement. No dopamine means no muscular coordination.

One way of restoring the dopamine supply would be to replace the faltering substantia nigra neurons with ones that work. The question is where to get the immature neurons. Until recently the only source was brain tissue from aborted human fetuses. The first fetal transplants a decade ago were promising but prompted isolated instances of public outcry, reported in the media with persistent Frankenstein clichés. President Bush promised to ban the technique, just as President Clinton would later vow to do for human cloning. However, research continued in Europe and in privately funded ventures in America. In 1993 the U.S. presidential disapproval was lifted. No conclusive clinical trial of the process has yet been completed. Only 200 transplants have been carried out at the universities of Lund, in Sweden, and Colorado, at Denver, so the real value of the treatment is only just being discerned.

The anecdotal evidence is somewhat encouraging. Curt Freed at the University of Colorado says that roughly two-thirds of the patients have improved. Half can abandon their medication altogether while keeping up normal appearance. A study by Olle Lindvall at Lund suggests that remission can last for up to six years.

However, the results remain open to debate, since techniques for doing the transplants have not been standardized. Researchers do not agree on how much fetal tissue to implant, and they do not know how best to scatter the cells in the patient's brain. None of the researchers has much idea what is happening in the third of the patients who do not improve.

Another recent breakthrough has been the parallel work of teams at Johns Hopkins and at the University of Wisconsin who have successfully cultured embryonic stem cells in the laboratory. These cells may someday be able to be harvested for successful transplantation into the brain. We are coming into an age when mature nerve cells can be changed into undifferentiated young neurons in a Petri dish by manipulating the function of their genes, which will allow more rapid progress of this line of research and will get around the ethical issues that have marred its progress thus far.

Meanwhile, researchers are trying the same approach in patients with Huntington's disease, the hereditary disorder that killed Woody

Guthrie, which also involves the striatum. Unlike the symptoms of Parkinson's, which can often be checked with a drug called L-dopa (making transplants a treatment of last resort), the symptoms of Huntington's disease cannot be counteracted, and the disease affects intellectual function as well as movement, leading to severe dementia and death.

More positive results are needed before transplantation of fetal nerve cells can be said to be effective. The ethical objections to the use of cells from aborted fetuses persist, too; up to eight fetuses are used for some Parkinson's patients. Legislators have tried to pass laws to ensure that a woman's decision to have an abortion is not influenced by the idea that her fetus's tissue may help a Parkinson's victim, and many states still prohibit fetal-tissue transplants. Clearly, we need new ways for getting immature brain cells that do not involve fetal tissue. Another way around the problem would be to find an animal source of nerve cells.

Fetal pigs are one possibility. One of the problems is that the brain may reject any cells that are not its own, more so if they are not even human. Like pig insulin, which is rejected by diabetic humans much less than beef insulin, pig's brain cells are less likely to be rejected. When transplanted into rats with Parkinson-like traits, pig donor cells can accurately rewire damaged portions of the striatum.

Undifferentiated fetal pig cells have already been implanted in the brains of some Parkinson's patients at the Lahey Hitchcock Medical Center in Burlington, Massachusetts, in hopes that the cells will take on local functions, such as the production of dopamine. The first person to receive such cells was Tony Johnson, a fifty-seven-year-old civil engineer who had endured Parkinson's for twenty-seven years. Six months after a tiny drop of cells was injected into his brain, Johnson's wife told the *Boston Globe* that her husband's speech and walking were better, though he still needed drugs to control his symptoms.

Researchers at Harvard Medical School have shown that nerve cells from fetal pigs can mature in the human brain, but so far the number of trials has been small. About a dozen Parkinson's and a dozen Huntington's patients have had fetal-pig-cell transplants. Their recovery rate is comparable to that of patients receiving human fetal tissue; over half have regained some of their motor control six months after surgery.

While using pig cells overcomes the ethical questions raised in connection with the use of human fetal tissue, it brings problems of its

own, as it carries the risk of transplanting pig diseases. Therefore, a third possibility is being pursued: regenerating replacement cells taken from a patient's own brain.

Recent research has overturned the old neurological dogma that adult brains cannot renew themselves. It used to be thought that neural stem cells (neuroblasts)—which divide to produce nerve cells in the fetal and child brain—shut down in adulthood. But Brent Reynolds and Sam Weiss at Neurospheres, a Canadian biotechnology company, have shown that stem cells may be inactive in adults but are still alive, and might be prompted to create new neurons. They have coerced stem cells in a test tube to churn out new cells by adding "growth factors," molecules that stimulate tissue growth. If this were sustained, cells already in the patient's brain could be triggered, or moved and triggered, to create new neurons to replace the lost brain function.

Scientists at Ontogeny, a company in Cambridge, Massachusetts, are trying to leapfrog this procedure by working with a potent growth-factor protein that, in a Petri dish, can transform stem cells into mature dopamine producers. They have named the protein "sonic hedgehog," after a fast-moving children's video-game character. They are currently implanting it into the brains of mice to see what happens. One of the oldest biotech companies, Amgen, is experimenting with growth factors derived from glial cells, which has been effective in slowing the onslaught of Parkinson-like symptoms in monkeys. Amgen's and Ontogeny's approaches would require regular injections of growth factors into the brain, which means a patient would have to have a hole drilled in his skull and be fitted with a catheter.

It will be some time before efforts to regenerate brain cells become part of established medicine. Meanwhile, for the vast majority of us, who are not debilitated but are coping with everyday problems and with aging, the lesson about brain development is that we have the power to influence our brain's ability to renew itself. The human brain's amazing plasticity enables it to continually rewire and learn—not just through academic study, but through experience, thought, action, and emotion. As with our muscles, we can strengthen our neural pathways with brain exercise. Or we can let them wither. The principle is the same: Use it or lose it!

10

CARE AND FEEDING

IT HAS BECOME OBVIOUS that we can actually change our brains. By altering the external environment of our surroundings or the internal environment of our bodies, we can take better advantage of our strengths and amend our weaknesses. The possibilities for change are bounded only by our imagination, our willingness to assess our brains accurately through self-reflection, and our commitment to do some hard work.

If you've read every chapter in this book, you've learned about dozens of specific actions that might be taken at specific times in people's lives to train their brains—from exposing infants to music and lots of talking to challenging the elderly with crossword puzzles and debates on current events. But many of the fundamental tools for the care and feeding of the brain are everyday matters. Physical and mental exercise, proper nutrition, and adequate sleep will help anyone gain cognitive clarity and emotional stability. Other important practices come from the realms of spirituality, meditation, even the pursuit of one's passions. In all these we take advantage of the brain's great plasticity—our power to reconfigure our brains.

One necessary precursor to change, though, is often a change in attitude. The spectrum of mental disorders, from everyday anxiety to chronic schizophrenia, are not moral failings or the result of bad

upbringing or a failed personality. Mental problems, from hot temper to laziness, from chronic worry to excessive drinking, all have roots in the biology of the brain. That doesn't excuse the behavior. But it shifts the focus of responsibility: we and our care-givers have to examine our biological lives as well as our social and emotional lives.

Understanding that biology lies at the root of mental disorders can be extremely liberating. We don't blame ourselves or feel ashamed if we have a bad back or a physical illness, so why should we impose blame and shame on ourselves when the problem is mental? If our back is bad we may alter our external environment by getting a new chair, and strengthen our internal environment by doing back exercises each day. The same view should be extended to mental problems—those we have, and those other people have. Simply lifting the burden of blame and shame can be a major first step toward a cure—for the patients, their families, and their care-givers.

TIPPING THE BALANCE

CRITICS SOMETIMES CLAIM that a focus on "ordinary" measures like exercise and diet is too simplistic to affect extraordinary behavior. Not so. The brilliantly simple evidence from exciting new areas of physical and social science—complexity theory and tipping points—shows how powerful such universal factors can be in affecting the brain-body system.

Complexity theory finds meaningful patterns in what looks like chaos. The idea has been applied primarily to large physical systems, such as weather patterns. Each water droplet, each puff of air has an influence, and together the billions of influences compound into a grand, additive result. Edward Lorenz, a scientist at MIT, calls this the butterfly effect: even the tiny flap of a butterfly's wing on one side of the world could potentially build to a hurricane on the other. And yet, even though there are virtually an infinite number of inputs into this complex system, there are fairly predictable outputs: a clear day, clouds, rain, hot or cool temperatures, and an occasional hurricane.

Scientists are applying one aspect of complexity theory to explain human phenomena. They call the small change that can precipitate a large effect a "tipping point." At some critical juncture, an isolated

PHYSICAL EXERCISE

EVERYONE KNOWS THAT EXERCISE is "good" for you. However, not only is it hard to start, but everyone has different recommendations to follow: Is three times a week for 30 minutes enough? At what intensity? Aerobic or anaerobic? Weight-bearing or not?

The first step in starting an exercise program that will help your body and brain is to do something active—anything. Research shows that just a brisk walk will bring health benefits, from reducing the risk of heart attack, hip fractures, diabetes, and colon cancer to lowering weight and blood pressure. Exercise, especially swimming, has also been found to help make arthritis less painful.

Obviously, exercise improves the body, but some of the most exciting new findings point to the positive effect exercise can have on mental health. First of all, it increases the amount of blood that gets to the brain. And it has been shown that it can augment the number and density of blood vessels in the areas that need them most: the motor cortex and cerebellum. Thus, in addition to its well-known effect of increasing blood vessels and improving circulation in the heart, it seems that exercise or activity has a similar effect on the brain. The more we use it, the more we stress it, the better our circulation is, and the more fit that part of the brain becomes.

Better self-esteem is also a known effect of exercise. Women who regularly participate in sports and exercise have a more positive self-perception than those who do not, according to a 1996 survey done for the Coors Brewing Company. Telephone interviews of 505 women age eighteen and older found that 80 percent of them believed an active fitness regimen heightened their sense of well-being, and 52 percent said it improved their social life.

Different types of exercise seem to have different effects on mental health. There have been over 1,000 studies on the effect of exercise on depression. Short sessions of vigorous aerobic exercise, usually in a program that lasts for several weeks, seem to be the most helpful for mild to moderate depression. A 1994 Harvard study found that men who burned more than 2,500 calories a day in aerobic activity were 28 percent less likely to develop clinical depression than less active men. It is hypothesized that prolonged, strenuous exercise raises the brain

change tips the whole system in a different direction. Take a jar of water, cool it and cool it, and it remains water down to 35 degrees, then 34, then 33. But reduce the temperature by one degree more and suddenly the water turns to ice. The temperature was consistently reduced, but at one point the whole system suddenly changed. This way of analyzing systems is now being used in many fields, from economics to ecology. What causes a safe middle-class neighborhood to slip over the edge and become a dangerous slum? What turns a city district with a high rate of crime and teenage pregnancy into a stable neighborhood? In the latter case, perhaps new citizen activities such as neighborhood watches, the DARE program, and a zero tolerance for crime build upon each other until one day the neighborhood reemerges as safe.

Arguably, the most complex system known to science is the human brain. Given a hundred billion neurons, each with possibly thousands of synaptic connections bathed in multiple chemical transmitters, it is difficult to imagine the sheer volume of interactions that go on. It may be hard to determine what small factor could have been in the wrong place at the wrong time to contribute to a mental health problem—like the tiny pebble kicked off a path that creates an avalanche farther down the mountain.

The beauty of tipping points is that a complex system can just as easily tip up as down. A small and seemingly inconsequential action can lead to successful treatment of a disorder. Perhaps a lonely, depressed young man decides one day to go for a walk. Then he starts walking a few times a week. On one occasion he tries running for a while. Then he begins to run more often. Each time he can go a little farther. He soon notices that he is sleeping and eating better, that he has more energy and looks better in the mirror. Like the movement of the butterfly's wing, that isolated first walk may have started a sustained chain of events that are now building toward improving the man's self-esteem and increasing his energy, affecting his entire brain-body system. One day, feeling physically and mentally stronger, the man finds a new job. He begins to make friends, starts to laugh—and turns his life around.

This man's extraordinary metamorphosis began with an ordinary walk. There are many tools right at our fingertips for changing our mental health, both in correcting our problems and simply in becoming the kind of person we want to be.

levels of endorphins, the naturally occurring opiate-like substances that decrease pain and enhance feelings of comfort and well-being. However, with our advancing understanding, we now see that the three major neurotransmitters—norepinephrine, dopamine, and serotonin—that have preoccupied researchers concerned with mood, cognition, behavior, and personality are all increased by exercise and are strongly implicated in its mood-elevating effects. Dopamine, the key neurotransmitter involved in the feelings of reward, motivation, and attention, is increased both in the intensive phase of exercise and in prolonged exercise (at least in rats). Similarly, serotonin, the neurotransmitter of the '90s made so famous by the Prozac craze, is also elevated by both intensive and regular exercise programs. Thus one could say, using all the poetic license one can muster, that exercise increases the neurotransmitters, which help with mood regulation, anxiety control, and the abilities to handle stress and aggression and to become more attentive and social.

Exercise that involves learning complex movements can impact our brains in other ways. Modern dance, basketball, and the martial arts involve a host of coordinated movements, and practicing them causes more connections to grow between neurons. Exercise that forces us to improve balance and coordination may not only help overcome clumsiness but also reduce shyness and even enhance the ability to make friends; these kinds of exercises strengthen neural networks in the cerebellum, which is the area responsible not only for balance and physical coordination but also for coordinating our social interactions. There is also the psychic benefit; a dance instructor involved in one of the studies observed that as adult students gained control over their bodies, they also gained control over their lives.

New research indicates that these kinds of exercise also affect the basal ganglia and corpus callosum, sharpening memory and increasing the capacity to master new information. While some deterioration of these areas can occur with age, it is not inevitable. Maintaining memory and repairing weakened brain connections depend on stimulation. As most of us approach our fifties, our minds slow down. This generalized slowing affects almost everything we do, from our reaction time to how quickly we learn or recall. Part of the reason is that the body has become less efficient at delivering nutrients to the brain. The antidote: exercise, to get more nutrients up into the brain. Several studies show that older men who have stayed in shape do better on mental

tests than those who have not; indeed, they do just as well as men thirty to forty years younger. Aging brains may also decline in function owing to lower levels of dopamine crossing the synapses. Physical exercise elevates these dopamine levels.

MOVEMENT

PHYSICAL EXERCISE is a special case of a larger activity: movement. As we have seen, motor function is crucial to all the other brain functions. The many connections we are finding between motor and cognitive functions suggest that any sort of physical activity can improve our motor function and therefore our cognition. For example, we often experience anxiety because we have no possible motor schemata to solve a problem, no movement we can make to cope with the perceived situation we face. Outwardly we "freeze" with anxiety, while inwardly we "churn." Without a motor response, there can be a buildup of these physiological changes that can cause additional anxiety. Movement provides the physiological release that we need to bring our bodies back into balance. As human beings, we are meant to be moving.

Stagnation is a problem for many people in today's society. Computers and television have further contributed to our already sedentary lifestyle. Inactivity can hasten the decline of our mental abilities. We don't have to run a marathon to benefit; simply moving is good for our bodies and our brains. When we combine movement with a learning activity such as dance, we get extra benefits because new connections form in the brain as a result of learning a new task. As new routines and dance steps are introduced, the brain produces a greater number of connections between its neurons, which creates a brain that is better able to process more information.

Patients with Parkinson's disease who practice tai chi on a regular basis have seen improvement in their physical and mental symptoms. Coordinated movements as in tai chi and dance increase concentration, will power, and balance, and also enhance the ability to cope with physical and emotional stress. Hatha-yoga, an ancient Indian technique used to develop physiological, psychological, and spiritual potentials, has lately become popular in Western countries as a method for coun-

tracting stress. It consists of active exercises, postures, and regulation of breathing, combined with relaxation and meditation. Hatha-yoga has been found to decrease excitability, aggressiveness, and somatic complaints and to enhance emotional and life satisfaction.

Routine physical activity may also help us solve problems we're stuck on. When we start moving, we activate the brain, which can help us in many undefined ways. For many people, the act of pacing helps them think; for them the old adage is true: "I think better on my feet." Since the health-conscious '90s, more and more people have been walking several miles a day, finding that this motor activity not only makes them feel more fit and invigorated, but allows them to sort out things that are on their minds or solve vexing problems. Many people claim they do their best thinking or come up with their most creative ideas while performing some fundamental physical activity like walking or jogging.

The reason is that the primary motor cortex, basal ganglia, and cerebellum, which coordinate physical movement, also coordinate the movement of thought. Just as they order the physical movements needed for moving, they order the sequence of thoughts needed for thinking. Fundamental motions like walking and running trigger the most deeply ingrained neural firing patterns in these brain regions. It may be that as this happens, it causes the brain to establish fundamental firing patterns among complex thoughts, helping us to find a solution or generate a creative idea.

One offshoot of movement and exercise is massage, or more fundamentally touch. Modern medicine has lost touch with the benefits of touching. However, clinical studies have shown that full-body massage has a positive effect on medical conditions such as hyperactivity and diabetes. Massaging the temporal artery can ease migraines. Massage can help asthmatics breathe easier, boost the immune function in HIV-positive patients, improve autistic children's ability to concentrate, reduce anxiety in depressed adolescents, limit agitation in Alzheimer's patients, and even lessen apprehension in burn victims about to undergo the extremely painful procedure of debridement, in which all of the dead or infected tissue is removed.

It doesn't matter what style of massage is used. Whether it's Swedish massage, reflexology, or shiatsu, it's all rubbing, and that's what matters. It works in part by stimulating nerve pathways that tell the brain to lower the levels of the stress hormones cortisol and epineph-

rine. It may also affect the brain directly; Tiffany Field at the Touch Research Institute, University of Miami School of Medicine, has reported that tactile stimulation appears to increase the activity of the vagus, one of twelve cranial nerves that influence heart rate, speech, and the absorption of food. Studies show that touch helps babies born prematurely to grow faster, helps ADD kids pay more attention, increases attentiveness and responsiveness in autistic children, raises feelings of calmness and well-being in adolescents with ADHD, and reduces anxiety and pain in children with juvenile rheumatoid arthritis.

Touch may even help couples rekindle their sex life. When you were a teenager, the mere touch of a girlfriend's or boyfriend's hand on yours in a movie theater could send you reeling. When couples consult with Mark Schwartz, a psychologist at the Masters and Johnson Institute in St. Louis, on how to improve their sex life, he tells them to go home and caress each other all over, but not on the genitals or breasts. And intercourse is not allowed. As they tease each other in this way, they drive each other wild—just like the teens in the movie theater—and reignite their desire for actual sexual contact.

Touch, movement, exercise—these physical aspects of our lives—are extremely important to our mental health. Our brains originally evolved to direct complex motions, such as are needed in the constant competition for food and mates. Much of what the brain does is still quite similar; we should learn to view all brain functions as descendants of motion. Motion is involved in almost every aspect of human experience: thoughts move from one topic to another, emotions stir us deeply. Language is essentially a complex semantic dance by the mind and the tongue, a sophisticated form of motion that allows us to manipulate the contents of the world without laying a hand on them. To improve our brains we have to move our bodies, take action, get going.

MENTAL EXERCISE

WE SHOULD ALSO purposely exercise our minds. The value of pursuing mental fitness has come up repeatedly in the preceding chapters. Young children who study piano in addition to routine academics end up doing better on standardized tests. The nuns of Mankato, who keep

on doing crossword puzzles and debating politics into their eighties and nineties, live far longer and have far fewer and milder cases of dementia such as Alzheimer's than the general public. And even within their own ranks, the nuns who have attained higher levels of formal education and who constantly challenge their minds in old age live longer and resist brain disease better than those who are less well educated and spend less time pursuing cognitive activities.

Mental exercise strengthens and even renews neural connections, keeping the brain flexible and resilient. For years scientists believed that the irreversible loss of neurons was inevitable in old age. However, actual evidence indicates that there is not a great deal of loss. PET scans show that the frontal lobes of a twenty-five-year-old and a seventy-five-year-old glow equally bright after the same memory test. Decline in old age is caused primarily by the lack of mental exercise.

New mental tasks increase neural connections and help the brain become more adaptive to future events, whether these include coping with the death of a family member or mastering a new computer language. You have the best chance of growing connections between your axons and dendrites by tackling activities that are unfamiliar to you. Learn to play the piano, to tap-dance, to repair small engines. Study philosophy, converse with provocative people. Like the nuns of Mankato, if you constantly challenge your brain to learn new things, you may develop more neural connections that help you delay the onset of Alzheimer's disease, recover from a stroke, and live a longer life. And your life will be more interesting. It's never too late to start; studies show that the adult cortex retains its basic plasticity. You can indeed teach an old dog new tricks.

The lesson here is that we have the power to change our brains. The human brain's amazing plasticity enables it to continually rewire and learn, not just through academic study but through experience, thought, action, and emotion. As with our muscles, we can strengthen our neural pathways with exercise. Or we can let them wither. It is wise to remember once again one of the brain's most basic principles: Use it or lose it.

Every time we choose to solve a problem creatively, or think about something in a new way, we reshape the physical connections in our brains. The brain has to be challenged in order to stay fit, just as the muscles, heart, and lungs must be deliberately exercised to become more resilient. Some stress makes us tougher in the face of future

adversity. There is even research that shows that exposure to reasonable challenges during childhood alters the balance of brain chemicals so that children are able to respond better to stress later in life. Houston psychologist Emmy Werner found evidence for this when she went looking for trouble in Hawaii. For years she studied the offspring of chronically poor, alcoholic, and abusive parents to understand how failure was passed from one generation to the next. To her surprise, one-third of the children ended up leading more productive lives than their parents. Many social scientists now suggest that while we must continue to study children who fail, there may be much more to learn from children who succeed despite adversity. Such children, researchers find, are not simply born that way. The presence of a variety of positive influences in their lives often makes the difference between a child who fails and one who thrives. The implications are profound; parents, teachers, volunteers, peers, and all those who are in contact with children can create a pathway to resiliency. Werner later studied women who overcame adversity in their adult lives. She found that several factors made the difference: at least one person who gave them unconditional love and acceptance; a sense of faith in themselves; the willingness to seek support; and finally, hope.

For children, cognitive cross-training may be a creative way to harness the brain's plasticity. While music lessons have value of their own, they may also help children develop stronger math and spatial skills. Talking to babies often, and exposing them to foreign languages in their early years, aids their cognitive development. If you are socially or politically inclined, you can fight for arts programs in schools and communities. Budget-cutters often see the arts as "frills," but research shows that these programs are more than just an adjunct course of study; they are an important part of intellectual development.

As noted before in this book, we must nonetheless be careful not to place too much emphasis on a single fix. Several years ago, when research showed that babies might be able to discern spoken language while still in the womb, many pregnant women began talking incessantly to their bellies. They played foreign-language instructional tapes on their stereos and strapped the headphones to their abdomens. Obstetrician René Van de Carr opened Prenatal University in California, for women from their fifth month of pregnancy on. He led mothers in exercises in which they counted and spoke loudly to their fetuses,

accompanied by coordinated pats on the abdomen to make the fetus pay attention. The intent was to foster the child's future intellectual growth. When asked on an ABC news show whether he believed that parents who didn't follow the program were somehow letting their fetal babies' brains lie fallow, Van de Carr said, "I wouldn't want anybody to feel guilty. I think they may be missing an advantage."

Perhaps, or perhaps not. While studies do show that some fetuses respond to the sound of their mother's voice, they may not hear much more than a distant, muffled sound, blurred by the aqueous womb, the whooshing of blood through the placenta, and the beating of the mother's and baby's hearts. Some scientists on the ABC program maintained that the expectant mothers at Prenatal U. were wasting their time and money, since no research has shown that a fetus's brain benefits from this kind of treatment. One scientist went further: "The fetus has so much work to do in maturing and getting its brain developed, that it doesn't need this other type of stimulation that may interfere." Another said, "The stimulation might be interfering with the fetus's need for rest. The fetus spends about 90 percent of its time sleeping, when it is growing, recharging its batteries, and conserving its metabolic energy."

The theory of mental exercise can be applied to several of the brain's functions, notably memory. By challenging yourself to remember, you keep synaptic pathways alive. Constantly challenging yourself to learn will also maintain an efficient process of long-term potential in your brain, so that your working memory remains spry in old age. As you age you can use these kinds of mental activities to counteract some of the degradation of the frontal lobes, which are responsible for working memory. Remembering your memories is a wonderfully beneficial cognitive exercise. Perhaps that is why so many older folks regularly recount stories of the past—to keep them alive not just for others, but for themselves.

Memory changes due to advancing age are largely the result of lesser efficiency in processing, not of some pathological breakdown in the brain. Aging is unavoidable; severe memory loss is not. Several factors may slow the onset of memory problems encountered in Alzheimer's disease and other forms of dementia. The intake of antioxidants such as vitamin E and selegiline may help the brain fend off cellular attacks on the neurons. The use of nonsteroidal anti-inflammatory drugs (NSAIDs) such as aspirin and ibuprofen may be

helpful too, since inflammation is thought to be a cause of the plaques and tangles found in the brains of Alzheimer's patients. Corroboration comes from a review of numerous epidemiological studies on people with arthritis; early indications are that those who have taken anti-inflammatory agents for years to reduce the symptoms of arthritis may have a decreased risk of Alzheimer's. But researchers have issued a strong warning against using these studies as a mandate to start downing aspirin or ibuprofen daily. None of the anti-inflammatory drugs was ever designed for long-term use, and there could be serious side effects such as damage to the stomach lining, internal bleeding, and interference with kidney function—conditions that could be much more life-threatening than Alzheimer's.

Can drugs reverse loss of memory? Our decade of the brain has certainly renewed the pursuit of pharmaceuticals intended to do so. For example, Gregory Gray at the University of Southern California found that vitamin B₁₂ supplements miraculously initiated the full recovery of 8 out of 13 senile subjects in his study. In Italy, another study concluded that Alzheimer's patients who took 2 grams of carnitine daily for a year showed a significant improvement in long-term memory and verbal ability.

John Morley, chief of geriatric medicine at the St. Louis University School of Medicine, discovered that beta amyloid, a component of the nerve-cell membrane, will actually damage other neurons. In a leap of intuition, Morley tested and found that beta amyloids were overabundant in the brains of Alzheimer's patients. Consequently, he suggests that beta amyloid blockers may be a good future treatment for that condition.

Whether drugs can actually enhance a healthy memory is another matter. The notion of a pill that can help a synaptically challenged fifty-something remember where he left his keys is quite a temptation for hustlers, con artists, and quacks. In early 1997, for example, ginkgo biloba became all the rage. An extract from the tree of the same name, it was being widely sold in health-food stores as a herbal supplement. Research showed that it improved blood flow to the brain. Salespeople therefore insisted that it would bring more oxygen to the brain, which "of course" would improve memory. Well, oxygen plays no special role in coding memories. Besides, our brains get all the oxygen they need naturally. If a person had enough oxygen debt in his brain to actually impair his memory, he'd have a much bigger problem,

namely, being on the verge of a stroke. There are some studies that show that test subjects who took ginkgo biloba did better in certain brain tests, but other studies show no improvement. In short: we don't know enough about this substance to recommend its use, much less make sweeping claims about its benefits.

Just the same, recent research indicates that one class of chemical compounds called ampakines may enhance some processes involved in forming memories. Gary Lynch at the University of California at Irvine injected ampakines into the brains of laboratory rats, and observed that they remembered their way through mazes much better than untreated rats. In very preliminary tests, young men with normal memories who took ampakines performed up to 20 percent better on some standard short-term memory tests, and men in their sixties and seventies as much as doubled their scores.

Only extensive trials will tell if ampakines and other memory drugs are really effective for humans. Time and again "cognition enhancers" that worked wonders on lab rats and even on small human test groups have fizzled in controlled clinical trials. Many turn out to be no more effective in stimulating the brain than a nice cup of espresso.

The clear message you should derive from the benefits of mental and physical exercise is that the worst thing you can do to your brain is to be content living a passive life. The habit of passivity is pervasive in our culture, from longing for miracle cures to watching television for hours to being politically apathetic. Physical and mental action is fundamental to maintaining mental health.

ROOTS AND SHOOTS

WHAT WE INGEST is also fundamental to how we think and feel. The brain is an incredibly active furnace, consuming 25 percent of the glucose and oxygen we take in. It burns glucose as its sole fuel, and yet it has no storage site for it. What little glucose is present in the brain at any time can be depleted within 5 to 10 minutes if replenishment is not available. The brain also needs a range of other nutrients. Researchers are making great strides in discovering how different foods can help us stay younger, get smarter, and feel better.

The relationships between what we ingest and what goes on in our brains are at times straightforward and at other times complex. Poor diet is common in people who suffer from depression and other mental disorders. Even minor nutritional deficiencies can be associated with changes in mood. Memory loss, confusion, depression, and other mental disorders in the elderly, once attributed simply to aging, can also be consequences of a poor diet.

One significant relationship is that food intake affects the formation and activity of neurotransmitters. It is no coincidence that people turn to pasta, desserts, and other carbohydrate-rich foods when they feel down in the dumps. Carbohydrates increase brain concentrations of an amino acid called tryptophan, which is the building block for the neurotransmitter serotonin. Consequently, increased tryptophan means a higher level of serotonin in the brain, which in turn relieves depression, insomnia, and irritability by promoting feelings of calmness and serenity. This finding was illustrated in a study conducted by Katy Smith at Littlemore Hospital, Oxford, U.K. She gave half of a group of women with a history of clinical depression a drink containing tryptophan and half of them a drink without it. The women rested for several hours and were then assessed for mood changes. The group without tryptophan had significantly lower moods.

Even cholesterol is getting some play in mood regulation. Although we have put the hex on cholesterol, we still need it, at least in moderate amounts, because it is necessary to make brain stuff such as the myelin that surrounds and protects nerve fibers. In recent studies, rapidly lowered cholesterol levels have been associated with depression, anxiety, panic disorder, violence, and suicide. When we go wild in altering food intake, in this case absurdly lowering cholesterol levels, we risk upsetting the equilibrium we need.

Central nervous system stimulants such as caffeine can also affect mood. One to two cups of coffee may combat fatigue, increase alertness, and improve work performance, but higher doses often result in agitation, headaches, nervousness, or decreased ability to concentrate.

Deficiencies in vitamins B₁, B₂, B₆, and B₁₂, niacin, folic acid, and vitamin C are often found in psychiatric patients and are thought to contribute to a cycle of depression, lack of interest in food, progressive malnutrition, and increasing mental or emotional disorders. Vitamin deficiencies seldom occur singly and are almost always accompanied

by inadequate intake of other vitamins, protein, iron, and minerals. Even small deficiencies in normal people can promote personality and mood changes, insomnia, aggressiveness, and impaired reasoning and judgment. Clearly, a better diet rich in vitamins and minerals, with supplements if necessary, is the road to reversing many ailments of the brain. This may sound as old as the ages, but a balanced diet is the best brain medicine.

Eating foods rich in certain nutrients at the right time of life may also increase intelligence. For example, a lack of iodine in the mother's diet during pregnancy may lead to hypothyroid conditions that can cause severe brain damage in the unborn baby. The teen years are vulnerable to iron deficiency because of increased growth, and the onset of menstruation in women. A Johns Hopkins University study of teenage girls showed how important iron is to proper brain function. Half of a group of girls who had a slight iron deficiency were given supplements, while the other half were not. The group with supplements improved their performance on tests of memory and learning.

An important subset of the roots and shoots we ingest is the medications and drugs we take. Doctors and drug companies typically concern themselves with how a psychoactive drug affects a patient's body and brain. But instead of just asking, "What does this drug do?" the physician should ask, "What does this drug mean to the patient?" The issue that is overlooked is the patient's attitude toward the medication he is taking. What is his impression of this particular drug's therapeutic value? What is his desire and expectation concerning side effects and treatment outcome? The complexity of any pharmacological intervention is compounded by the thoughts, moods, and attitudes of the patient. As drug therapy strives to become more accurate, it will become even more dependent on understanding psychology. Matching pharmacological treatments to symptoms, therefore, must be recognized as an essential component in the treatment of almost any brain disorder.

Direct application of neurotransmitters to the brain might one day be part of the chemical arsenal. Why do children who suffer from brain damage often recover fully, while adults with the same damage are permanently incapacitated? The University of Wisconsin's Ronald Kalil found that the brains of young cats are bathed in neurotrophic factors, which help the brain reorganize or rebuild damaged networks. Adult cats' brains have far less of these chemicals. When Kalil soaked

tiny sponges in neurotrophic-factor solution and placed them in the brains of adult, brain-damaged cats, the adult brains began to repair themselves.

Using drugs or even natural substances to enhance the performance of our brains brings us smack up against our puritan roots, and we feel that we are cheating. Yet we daily use other environmental tools to help us function better. As more options become available, the debate will continue as to what we should or should not use and whether it ought to be the goal of our lives to become more efficient and more content through such means.

TECHNOLOGY

DRUGS ARE JUST ONE WEAPON in the larger technological arsenal society has to combat mental illnesses and otherwise improve the brain. When the cell phone is ringing, the microwave is beeping, the computer has crashed, and the fax modem is on the fritz, modern technology can seem more like a curse than a convenience. Scientists and engineers, however, are developing many ways to use technology in healing.

For example, the body's own electrical signals are being harnessed to help paralyzed people communicate. Scientists at Emory University have successfully implanted an electrode in the motor cortex of two such patients. Over several weeks, neurons grew onto the electrode, creating a connection between its circuits and the brain's circuits. Now when the neurons fire, the signals are captured by the electrode and transmitted through the skin to a receiver on the surface of the scalp. Once the patients are trained, they can control the pattern of the impulses, which can be used to drive a cursor on a computer screen. The two patients thus far have been able to conduct basic communications in this way. In the future, it might be possible to use this kind of signaling to command a wheelchair, a prosthetic limb, or even the actual muscles in a paralyzed limb.

Technology is also being used in brain-training—from children with learning disorders to soldiers in the military. Anyone who has seen a video game can imagine how a virtual-reality simulator could be an effective tool for training pilots or tank drivers. Some of the really

exciting research, however, is in using computer games to help children with dyslexia. As described in Chapter 7, Paula Tallal at Rutgers University and Michael Merzenich at the University of California at San Francisco have developed software for children who have problems processing certain combinations of letter sounds, which makes it difficult for them to read.

The hit interactive toy from Japan, Tamagotchi, is showing the possible power that interactive technology may have on our psychology. Tamagotchi is a cyberspace pet, a little figure on a key-chain screen that needs to be loved, played with, and fed over days and weeks or it will die. Children watch the pet hatch from an egg on the screen and then care for it as it signals its needs, as often as every ten minutes during peak times. If the child is neglectful, the pet dies. The toy can be reset, but keeping the pet alive is still an incredible emotional experience for many children. Could this type of technology be used to teach social skills or behavior?

Computers are also being used to simulate talk therapy and assist in relaxation and meditation. A software program called the Therapeutic Learning Program, recently developed at UCLA, operates like an interactive self-help book to assist patients in grappling with their depression and anxiety. Sessions last 30 minutes once a week for 10 weeks. Patients tell the computer their problems, and the computer develops a strategy to help them cope with those problems. This type of program should be used only with the supervision of a mental health professional, but it allows patients a degree of self-control and independence to proceed at their own pace without interruption.

There are also many Internet sites and computer programs that are devoted to teaching relaxation, meditation, and even hypnosis. These programs vary in their degree of interactivity and also in their effectiveness. Other sites provide straight educational material on medical information of all types, not to mention lists of support groups, doctors, and organizations that address every kind of disorder. Accurate, timely access to information can be the patient's best means to a swift recovery.

Another application of new technology may help the 2 million Americans who have "essential tremor," a little-understood disease that causes persistent shaking but no other symptoms, and the 500,000 who have Parkinson's disease. A tiny electrode is implanted in the thalamus. From there a wire runs under the scalp down to the collar-

bone, where a pacemaker-sized "pulse generator" is implanted. The generator sends electrical waves to the electrode, which blocks tremors by emitting constant, tiny electrical pulses. In studies of 120 patients who received the implant, about half of those with essential tremor saw their shaking disappear. Others showed different ranges of improvement. The implant did not help the Parkinson's patients as much, but it may still hold promise.

One recent advance that seems straight out of science fiction is transcranial magnetic stimulation (TMS). This new technique for affecting the brain does not seem to have the sometimes harmful side effects of drugs or surgery. A small coil of magnets, shaped in a figure 8, is placed against the scalp beside the area of the brain that is to be affected. This device delivers repetitive bursts of magnetic fields for perhaps 20 minutes at a time, which can excite or inhibit synaptic activity in localized regions of the brain. Researchers at the National Institute of Mental Health have used this technique to treat the frontal-lobe hyperactivity found in obsessive-compulsive disorder. Twelve patients diagnosed with OCD were given the stimulation at several different points on their skulls. The patients found that stimulation to the frontal lobe on the right side of the head resulted in a reduction in compulsions and an improved mood. More research needs to be completed before we truly understand the possibilities of this new technology. Researchers are most excited about the possibility of using magnetic stimulation to vault people out of serious depression, a replacement for effective but damaging shock therapy. Tests have succeeded in arousing neurons in the left prefrontal cortex (behind the forehead), where electrical activity is often abnormal in depressed people.

As the magic of our machines increases and as we gain more and more understanding of how the brain works, we will be better able to use technological devices to help direct our lives, not just as the wretched slaves that we now employ in the external world, but as intelligent helpers that will guide us to a better use of what we have in the "black box."

Years ago I proposed that *The Sharper Image* would soon be advertising the complete "Home Brain Gym." My personal gymnasium of the future would be a machine individually designed to maximize every day. It would probably be something like a Stairmaster, or a treadmill with all sorts of gadgets attached, and there would be a built-in com-

puter monitoring and asking questions of whoever steps into the machine. Yesterday's activities and achievements would be reviewed, and a game would be played to assess current brain activity. All of the relevant history of the gym-user would be known by the computer, and, after performing a range of neurological evaluations of physical and mental alertness, mood, and so forth, as well as inquiring into the coming day's activities, it would design a comprehensive body-brain workout to tune up the user for whatever might lie ahead. If a particular system was functioning below par, the machine would center the workout around getting things back in balance. Accompanying the physical exercise, the right kind of light and the proper harmonies, rhythms, and scents would be projected to get the brain in tune. Puzzles, video games, and mental drills would be involved as well, in order to raise or lower the level of one system or another. The net result would be that a person could step out of the gymnasium not only physically but mentally primed for the day ahead.

SPIRITUALITY AND MEDITATION

AN OFTEN OVERLOOKED ASPECT of the treatment of mental disorders is the connection between the mind and the body. The mind, or free will, can impact on the physical manifestations of illness. The famous case of Broadway actor Yul Brynner, who long starred in *The King and I* and who seemed to put his cancer into remission for a decade using only his will to counteract it, made many people aware of the strong powers the mind can have over the body. Religious people, practitioners of yoga or meditation, and disciples of Eastern cultures are familiar with the powers the mind can exert on mental illnesses and their effects on the body—powers that are rarely examined by Western medical science.

Herbert Benson at Harvard Medical School is one medical researcher who has championed the mind's power in using the "relaxation response," the physical reaction of the body to relaxation by the mind. This is usually accomplished by the practice of meditation or progressive relaxation. Now Benson is looking into the effects of prayer. In his new book, *Timeless Healing: The Prayer and Biology of Belief*,

he cites a study of 92,000 people in Washington County, Maryland, who went to church once or more per week. This group of people had 50 percent fewer deaths from coronary heart disease and 53 percent fewer suicides than the general public.

In 1998 there were several major media reports that looked into the possible links between spirituality and mental health. We are far from drawing any conclusions. As with medications, any efficacy of spirituality would be affected by a person's attitude toward it. Here the brain's structure may make clarity even harder to find. The two brain hemispheres provide two ways of looking at and understanding the world. The right attempts to see the whole, the left orders specific experiences. This leads to very different ways of approaching abstract concepts such as the divine.

The left hemisphere would favor a god of the Word. People with dominant left hemispheres would hold the Word as sacred—the Bible is the truth and the guide and its order rules. As Jerry Falwell tells it, "The writ is the writ" and the narrative carries the day. God is about victory, and heaven is a reward that is full of happiness. There is a point and an endpoint to it all.

Right-brainers hold experience to be most dear; they would want to insert themselves into the gestalt of God, and see and accept everyone and everything as part of the whole of God's creation. To them, God is simply oneness, and that is a continual mystery. The right-brainer's heaven is just a part of the oneness.

Unfortunately, proponents of these two views often clash with each other over which is the "truth." In trying to reign supreme, however, each side misses a fundamental point. Both would agree that God is something of which nothing greater can be conceived. However, for humans, all conception is limited by the language, context, and meaning capabilities of the brain—a limit that falls far short of being able to define something that is beyond all conception. Instead of arguing about and in some cases killing each other over our different conceptions of God, we might try bringing both deities—both hemispheres—together. Then we might at least find a better way to think about the Almighty, and about the universe and our place in it.

Powerful as the brain may be to conceive of such complex thought, it also deserves an occasional break. Our muscle analogy again: when overworked, the brain too becomes fatigued. Unfortunately for the

brain, going to sleep doesn't provide absolute rest. The brain continues to receive stimuli from the environment and the body even during sleep, as well as generating a steady supply of dreams.

To promote health and well-being, we must help the brain rest. One way to accomplish that is through meditation. Meditation is a focused awareness, achieved by sitting quietly and turning one's attention inward. Thoughts, feelings, and perceptions are observed and then put aside. Judgment is suspended and attention is paid only to the object of the meditation. Some people choose a word or phrase to say aloud or to themselves. Others concentrate on looking at an object such as a candle or a picture. Logic and language are cast aside. Distractions are ignored. Gradually, the mind becomes quiet and deeper levels of awareness are reached.

The body has a physical reaction to this altered state of consciousness. Sympathetic nervous system activity decreases and metabolism slows down. Heart rate, blood pressure, and breathing rates fall, and electrical skin conductance and blood flow decrease. These reactions in the body have been found to help reduce high blood pressure, relieve chronic pain and migraine headaches, and soothe depression and anxiety. The brain's own electrical activity changes, too. Instead of supporting a decentralized storm of signals, large numbers of its neurons fire in a pleasing synchrony.

PASSION

FINDING OUR INDIVIDUAL synchrony in life is equally important to a healthy brain. It is crucial to letting our talents blossom, and important for getting us away from the addictive behaviors that abound in life.

Any activity that gives us a sense of purpose and accomplishment, that makes us feel glad to be alive, can help us care for and feed our brain. Many people put off doing what they love, or what they know they need to do for themselves, until later in life, trying to get the world's demands out of the way first. What a grave mistake! It is far better to make sure that part of our lives is consumed with activities that we can put all our hearts, minds, energies, and joys into at once.

Find a mission in your life. A commitment to a calling, a career, even a hobby focuses the mind and the soul. Psychotic patients report that

they don't hear "the voices" while they are busy working. Surely we ordinary people can calm our own internal voices with some intent activities. Almost any form of work or concentrated effort can quiet the noisy brain. Work you love is more powerful still because it brings with it a sense of accomplishment, pleasure, and well-being. Passion heals.

Remember one important point: In pursuing your passion, the actual doing is what matters, not any measure of success. A diet of constant, stimulating activity is the best prescription for our troubles. It keeps the brain in a state of constant change, flow, confirmation, and anticipation, thereby reducing the noise, fragility, self-doubt, and stagnation with which we all have to contend.