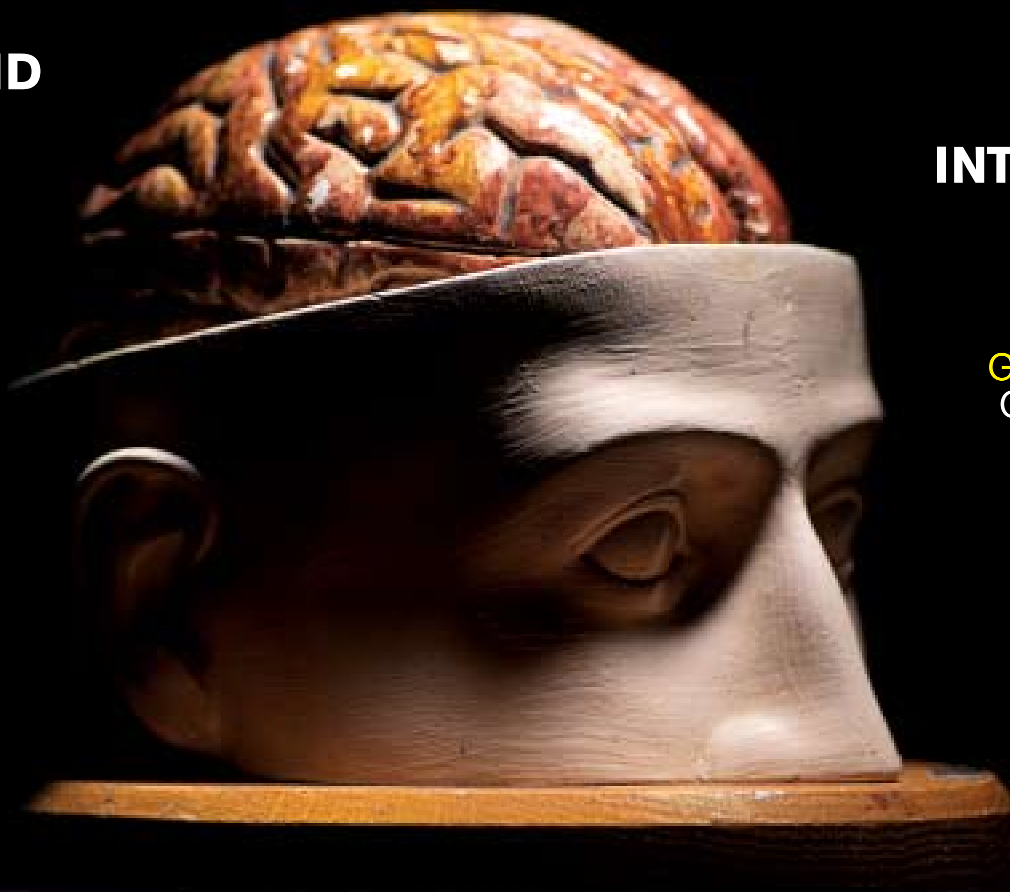
A DISCOVER SPECIAL THE BRAIN

DISCOVER PRESENTS

THE BRAIN

An Owner's Manual



HOW THE MIND CHANGES

From Infancy To Old Age

YOUR BRAIN ON

Sex, Fear, Video Games

WHO'S SMARTER?

His Brain's Bigger, Her Brain's Denser

INTERVIEWS

Kay Jamison On Genius And Insanity

Gerald Edelman On Creating An Artificial Mind

24 HOURS IN THE LIFE OF THE BRAIN

PLUS

8 Head Games To Make You Sharper, The Most Magnificent Neurons, Pinheads Of The Animal Kingdom, When Robots Talk To Each Other

$7.99 CAN. $8.99

DISPLAY UNTIL JUNE 30, 2007

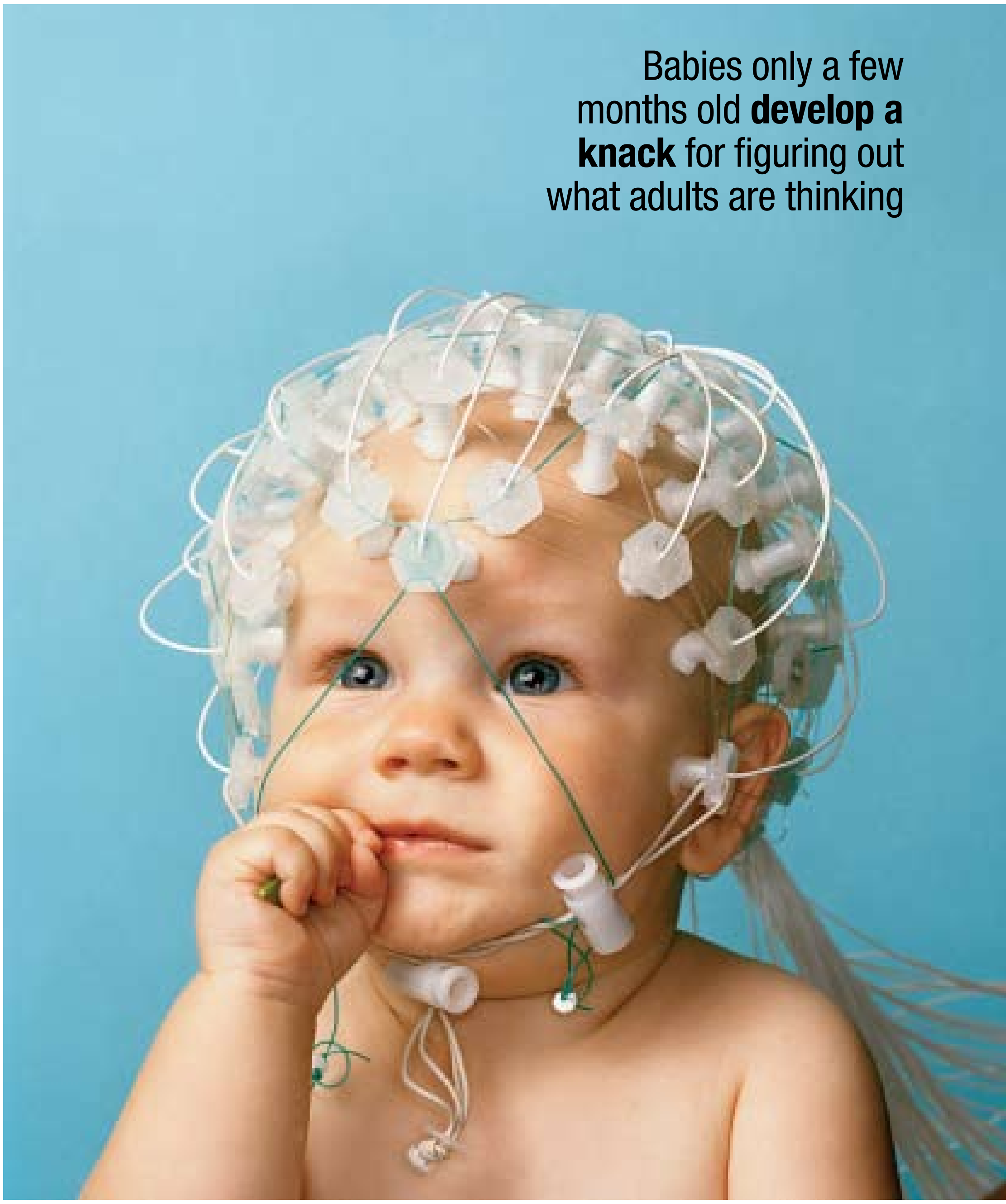
LIFE OF BRAIN

In just a puny three pounds, the adult brain encodes our knowledge and skills, joys and regrets, plans for the future . . . even our sense of self. But this is not the same brain with which we first glimpsed the world. The mental landscape of an infant differs strikingly from that of a teenager or an adult. New discoveries shed light on how these changes happen, unveiling the exotic world of the newborn, explaining why teens are so impulsive, revealing the rewiring that continues well into adulthood and the new neurons that keep popping up even into our seventies. The old image of the brain as essentially static has been replaced by one of flux and transformation: a life story with many chapters.

By **Kathleen McAuliffe** Photographs by **Timothy Archibald**

THE BABY:

LEARNING CURVE



JUST MINUTES after my daughter was born, she surprised me by opening her eyes. I watched them meander aimlessly around the room. "I guess she can't see very well yet," I said to my husband. At that very moment, her gaze wandered in my direction—and stopped. She locked eyes with me. "Whoa!" I exclaimed. "She knows who I am!"

Is it possible a baby only minutes old knows, on some level, who her mother is? "Babies can fool us," says Daphne Maurer, a developmental psychologist at McMaster University in Hamilton, Ontario. "They're both more and less capable than widely assumed." Their greatest talent? Survival: They come into the world with an overwhelming bias toward socially relevant things.

In fact, much learning occurs before birth. "Amniotic fluid is such an excellent conductor of sound that babies are born already attuned to the cadence or rhythm of their mother's voice," says Maurer. A taste for music, it now turns out, can be cultivated in the womb. British psychologist Alexandra Lamont instructed pregnant women in their last trimester to repeatedly play a recording of music they enjoyed. At one year of age, their babies preferred the music they heard as a fetus over other recordings. Similarly, researchers at Monell Chemical Senses Center in Philadelphia have shown that our food preferences are shaped by what our mothers ate at the end of gestation. "Prenatal experience alters our taste for foods, probably through changing the composition of the amniotic fluid, which the fetus drinks," says McMaster's Maurer.

Who would have guessed that a newborn could have a discerning palate, or might prefer Beethoven to the Barney song? Yet the facts are indisputable: Cultural assimilation begins even before we take our first breath.

"The baby's brain is an amazing learning machine in which experience of the world, starting in utero, is helping to tune up neural circuits," says Carla Shatz, professor and chairwoman of the department of neurobiology at Harvard Medical School. Before birth, we are endowed with a luxuriant abundance of brain cells and connections, far more than we will use as adults. Birth sparks another explosive growth spurt in the brain. Neurons respond to a barrage of new sights, sounds, and other sensations by sending out a dense thicket of branches called dendrites, forming a jungle of interconnections.

As the rough outlines of the adult brain take shape, neural pathways are still undifferentiated. "All infants are born in a state of psychedelic splendor similar to an acid trip," says Daniel Levitin, professor of neuroscience and music at McGill University in Montreal. "Sights and sounds and touches are all being activated together, and the infant can't tell what sensory organ they're coming from. It's only through maturation and experience that we learn to distinguish the inputs from different sense organs."

The "maturation and experience" Levitin refers to is the basic process of learning. As new neuronal connections form during early childhood, heavily used pathways become coated in myelin, a fatty insulating sheath that speeds signal transmission. Meanwhile, circuits that are redundant or rarely used wither. Connections leading from our eyes to the auditory cortex or from the ears to the visual cortex, for example, will most likely atrophy, squeezed out by competition from more active pathways.

Eventually the pruning of circuits overtakes production. Half the neural connections we have as toddlers vanish by adulthood. "A 2-year-old has twice as many synaptic connections as does her pediatrician," says Helen Neville, a developmental neurobiologist at the University of Oregon. The pathways that survive are by definition the most useful. In early learning, clearly less can be more.

These changes happen quickly, and there appears to be a range of "sensitive periods" during which the developing brain is most receptive to stimulation. Infants only an hour old are fascinated by anything that even crudely resembles a face, such as a capital *T.* "They preferentially turn their heads toward these kinds of patterns," reports Mark Johnson, an expert on cognitive and brain development at the University of London. He and other researchers have independently demonstrated that newborns are strongly inclined to orient toward human faces that return their gaze. Newborns really don't see very well, especially at a distance. But they can see objects within a yard—not crisply, but in blurry outline, like an out-of-focus photo.

Until about two months of age, tests show, babies use overall face shape and hair contour to distinguish family members. Johnson provides an interesting example: "A mother in one of our studies was all shaken up because her baby was suddenly treating her like a stranger," he says. "It turned out she'd just gotten her hair cut before bringing the baby to the lab."

In infancy, the part of the cortex that recognizes faces is not very particular: It responds to inverted faces and monkey faces. But infants' broadly tuned cortex may give them a unique talent. As measured by distinct changes in brain-wave patterns, 6-month-olds are readily able to distinguish novel monkey faces—something adults can't do. "Even adults who work in a monkey colony lack this ability," says Charles Nelson, a professor of pediatrics at Harvard Medical School. Unless you're raised by a monkey, his research suggests, you lose this ability by 9 months of age. "There seems to be a window of time in infancy during which you must be exposed to faces in order to become an expert at distinguishing one individual from another," says Nelson.

Of course, it's one thing to tell faces apart and quite another to discern the nuanced feelings that flit across them. Yet babies only a few months old develop the knack for figuring out what adults are thinking. Shattering the long-held assumption that babies less than 9 months of age can't recognize emotions, Diane Montague, a developmental psychologist at La Salle University in Philadelphia, videotaped 4-month-old babies responding dynamically to different facial expressions.

To elicit these responses, she played a sneaky form of peekaboo: After a few trials in which she peered out from behind a cloth with a big smile, she'd instead pop out looking angry or frightened or sad. The babies reacted in a markedly different way: When they saw the sad face, they looked away but through subtle facial movements showed intense interest. They would not look back at her even when she peered around the cloth with a happy expression. After an angry face, they did just the opposite: They stared more intently when she subsequently emerged with a smile. "Earlier researchers used photographs to test babies' reactions to expressions," explains Montague. "Babies don't relate to them as well. Photos are static and don't talk to them."

"All infants are born in **a state of psychedelic splendor** similar to an acid trip," says Daniel Levitin, professor of neuroscience and music at McGill University in Montreal

Language is perhaps one of the best-known examples of the way the developing brain is sculpted by experience. More than 20 years ago, trailblazing research by the Canadian psychologist Janet Werker established that infants, unlike adults, can readily perceive virtually all the basic sound units, or phonemes, of the world's languages. She was able to prove this because babies can be conditioned to turn their heads in response to a new sound. Tests of young infants with linguistic backgrounds as varied as German and Kikuyu (spoken in parts of Kenya) have subsequently confirmed this mastery of nonnative phonemes.

We lose this linguistic facility between 6 and 12 months of age, as circuits that are rarely activated presumably shrivel from disuse. In fact, waiting until adulthood to begin learning a second language greatly slows down the process: English-speaking adults studying Hindi for the first time needed more than a year of training to learn certain phonetic distinctions that any newborn can make, Werker has shown.

When her findings reached the public, parents eager to raise multilingual children rushed out to buy foreign language tapes for their babies' nurseries. But recent research by Patricia Kuhl, a cognitive neuroscientist at the University of Washington, suggests they're probably wasting their money. Kuhl exposed 9-month-old American infants to native Mandarin Chinese under a variety of conditions: Some of the babies were played recordings of a speaker, others heard and saw the speaker on videotape, and still others interacted with a live speaker over 12 sessions. Only in the last group was the typical decline in phonetic discrimination for Chinese reversed.

There's simply no substitute for watching another live person speak, Kuhl found. Infants are more alert in social situations and discern meaning by following eye gaze. If no one engages them directly, says Kuhl, infants treat language as if it were background noise and tune it out.

Still more recently, Kuhl uncovered another clue to how we master language. Using a new technique called magnetoencephalography, which allows neuronal activity to be monitored with millisecond precision even as a baby moves, she tracked infants as they progressed during the first year of life from cooing to babbling to uttering that first word. As that happens, she discovered, the parts of the brain that understand and produce speech are actually beginning to link up. This new pathway allows babies to map the relationship between sounds with precise movements of their lips and tongue. This promotes speech mimicry, says Kuhl, and it's also why kids from Brooklyn speak "Brooklynese."

Babies appear to master all this learning without relying on conscious memory, at least not in the way we experience it as adults. Put a handful of marbles in a cup, shake them around and then spill them out and a 9-month-old watching you may remember this sequence of events for about three weeks, says Harvard's Nelson. By 16 months, he'll do better. Even so, generally adults have little or no recollection of this period of their lives. For most of us, our first memory dates from the age of 3 or 4. What happened to all that lost time?

"Babies don't have a very sophisticated filing system," as Nelson puts it. Consider the challenge that confronts a baby who learns to grasp an object for the first time. During the first years of life, sensory systems for seeing, processing tactile information, hearing, and so on are being fine-tuned but don't yet communicate very well. The part of the baby's brain that distinguishes different objects, for example, isn't properly linked up with the area that oversees how to manipulate them. Consequently, a baby may recognize a rattle yet struggle to grip it and shake it.

In the toddler years, with increased chatter between the brain's specialized centers and further gains in language, children begin to associate objects with their names, functions, and how they feel, taste, and smell. In this way, memory gradually begins to crystallize.

If all goes well, by the end of early childhood, we learn how to talk, walk, read faces, grasp objects, and more. But what if we don't get the right sensory inputs early, as happens to people born deaf or blind? Or what if the developmental process goes awry, as occurs in autism?

"The result can be a very funky wiring system," reports the University of Oregon's Neville. In blind people, for example, the visual cortex may take over auditory processing, and visual processing can happen in the auditory cortex of the deaf. Autistic individuals may process faces in parts of the brain normally reserved for inanimate objects. Or if a baby has an inward-turning eye that is not corrected by around age 3, the unaffected eye may monopolize the visual cortex, resulting in partial blindness even if the crooked eye is later surgically straightened.

Neuroscientists believe that even neglect probably takes a toll, causing fewer neuronal connections to be retained by adulthood. Kids who are ignored may grow up to be both intellectually and emotionally stunted. "The malleability of the young brain is clearly a double-edged sword," says Neville. "It allows for learning at a breathtaking pace, but it can be a liability if something goes wrong or the input isn't optimal."

For better or worse, parents are the main sculptors of their baby's brain. But that doesn't require bombarding the crib with flash cards, *Baby Einstein* videos, or other products of the mushrooming "brainy baby" industry. Babies learn best through social interactions. For fostering learning, experts say, nothing beats hugs, kisses, and lots of fun together. Young minds thrive on TLC.

THE TEENAGER:

RISKY BUSINESS

IT WAS the last day of school, so 17-year-old Carla Wagner and some friends decided to celebrate. The Miami-based teens smoked some marijuana, and each downed several shots of tequila. Then they all piled into Wagner's car to go for a drive. As Wagner bantered with her buddies, she reached for her cell phone and lost control of the car. It swerved across a bicycle path and hit a tree. Wagner and her friends survived—but a 16-year-old girl rollerblading on the path was instantly killed.

Few who have weathered the tumultuous teen years could deny suffering major lapses of judgment during this rite of passage. And while adolescents may look like adults, and occasionally behave like adults, a glimpse inside their brains tells a radically different story. "Not long ago, it was assumed that the brain was grown-up—'fully cooked'—by the end of childhood," says Jay N. Giedd, chief of brain imaging at the child psychiatry branch of the National Institutes of Health in Bethesda, Maryland. "We now know better."

A flurry of research over the last decade has revealed that the cerebral cortex is undergoing riotous changes at this time of life. Neurotransmitters radically transform in number and type, fomenting a lust for experimentation and risk taking. New connections are being forged between centers of higher conceptual thinking. Myelination—the insulation of circuits to speed signal transmission—jumps precipitously. "In a second flowering, akin to early childhood, the wiring scheme of the cerebral cortex is becoming richer, more complex, and efficient," Giedd says.

At the tail end of this roller-coaster ride, connections then diminish through a "use it or lose it" pruning, culminating in a leaner but keener brain. And nowhere is this change more profound than in the frontal cortex—especially the so-called prefrontal cortex, the portion just behind the forehead that is widely credited for being the seat of higher judgment, wisdom, and forethought. The very last part of the brain to develop, the prefrontal cortex is what allows adults to weigh actions—like drinking before driving—against their consequences. It is this part of the brain that helps us resist peer pressure and stops us from doing stupid things we may later regret. Functioning as the brain's CEO, it also enables adults to prioritize their actions and gives them a leg up at multitasking—for example, yakking on a cell phone while driving. "The very late blossoming of the prefrontal cortex," says Giedd, "goes a long way toward explaining why teens and cars are such a deadly combination."

This anatomical fact may also shed light on why teens can be model citizens of the world one moment and impetuous children the next. "Under ideal conditions, teens function very much like adults," says Beatriz Luna, director of the Laboratory of Neurocognitive Development at the University of Pittsburgh. "But when the going gets tough, they may become quickly overwhelmed." Adolescents, Luna has found, exert a great deal more mental effort to do what's relatively easy for adults. A simple experiment she designed vividly illustrates this point. Teens and adults were instructed to avoid looking at lights that popped up on a computer screen as an MRI scanner recorded their brain's activity. "Since it's natural to look toward lights," says Luna, "the challenge is to suppress this impulse."

As she discovered, both age groups are equally adept at diverting their gaze from the lights. But teens rely much more heavily on the frontal cortex. In contrast, adults use that part of the brain to a much lesser degree during the task and instead distribute the workload among different specialized centers. The adult's more mature frontal cortex is a better manager: It's delegating chores rather than doing the whole job itself. "What this tells us is that teens are using up their most valuable resource—the frontal cortex—to do a relatively simple

Because their brains are not yet "fully cooked," teens are more sensitive to stress and more attuned to thrills.

▷

task," says Luna. "So if they're under emotional stress from peer pressure or in a situation that requires them to multitask, their performance is likely to deteriorate." Translation: They're liable to fall apart or throw a tantrum if too many demands are placed on them.

To add to the many strains on teenagers, some are much less accurate at reading faces than adults. Teens were shown pictures of faces portraying emotions from happiness and sadness to anger and fear at the laboratory of Deborah Yurgelun-Todd, director of cognitive neuroimaging at McLean Hospital outside of Boston. In a video clip of the experiment, Yurgelun-Todd asks a teenage boy, "What were those faces feeling?" "A lot of them are shocked or angry," he replies, reflecting the less discriminating ability he and other teens have when asked to identify expressions of anger, sadness, and fear. By contrast, the adults were 100 percent accurate in making such discriminations.

"I assumed our response to emotion would be hardwired very early in life, but I was wrong," says Yurgelun-Todd. Even more intriguing is the reason why: The limbic system, predominantly a part of the lower brain involved in primal responses to frightening or threatening situations, reigns supreme in teens when they are processing negative emotions. But in adults, the more developed prefrontal cortex exerts a moderating influence on this response, amplified by the sobering effects of life experience. It's as if the higher brain is telling the lower brain, "Now, now—settle down! There you go, overreacting again." By listening to this "voice of reason," adults are able to make more nuanced discriminations of expressions than teens.

"The take-home message from all this is that the teen years are a time when we are still refining our ability to distinguish emotions and accurately assess people's motives," says Yurgelun-Todd. "A teen looking at his teacher's face, parent's face, or the expressions of his peers may be assuming people are reacting to him one way when that's not the way the other party perceived the interaction. That can lead to a lot of miscommunication."

As if that weren't enough reason for teenage angst, a sudden abundance of the neurotransmitter dopamine in the prefrontal cortex at puberty triggers further upheavals. A significant function of dopamine is to focus the adolescent's attention on reward-associated cues in the environment, explains Susan Andersen, an expert on the teen brain at Harvard Medical School. By evolution's design, it seems, teenagers are suddenly scanning the horizon for sexual partners and the skills, tools, and provisions needed to strike out on their own. "That's a good thing," says Andersen, "but with that shift in focus also comes a heightened sensitivity to stress and a new passion to seek out novel or thrilling sensations." Worse, it makes drug experimentation more exciting—and at least in the case of stimulants—more addictive.

Andersen studies addiction to cocaine in rats by training them to associate different environments with either a placebo or the drug—a procedure called place conditioning. When juvenile rats are given the option of entering the habitat where a moderate dose of cocaine is readily available, they shun that space. "They don't like how cocaine makes them feel," says Andersen, "and children are the same. They don't like stimulants." Similarly, older rats and people aren't attracted to cocaine. But adolescents are a different story. At the outset of puberty animals suddenly find

> "A brain in flux," says Duke's Scott Swartzwelder, "is **open to new experiences** and to exploring the world—all of which enhance survival."

the cocaine environment immensely attractive. And they will seek the drug more even as they mature into adulthood. Research on human teens exactly parallels this finding. "If you look at stimulant abuse according to age, there's very little risk until you hit puberty," says Andersen. "But between 11 and 14, the risk jumps four times."

That may also be true of nicotine, the stimulant in tobacco. At the University of California at Irvine, researchers are now reporting very similar results in place-conditioning studies of rats addicted to nicotine. And paralleling this finding, humans who make it to their late teens without succumbing to its seductive clutches are much less likely to take up smoking later.

What happens at the threshold to adulthood that makes stimulants less appealing? "After dopamine comes online," says Andersen, "the prefrontal cortex gradually matures." Eventually the higher seat of judgment prevails, muting our thrill-seeking ways.

Alcohol similarly appeals to teens eager to experiment. But unlike stimulants, it poses a significant risk of addiction beyond a narrow sensitive period—possibly because alcohol's action on the brain is more diffuse. Among other things, its depressant properties dampen feelings of social awkwardness—a powerful lure to teens and young adults.

At the start of her freshman year at the University of California at Berkeley, 18-year-old Esther Hwang recalls having her first piña colada ever. And then another. And another. And another. "I was surprised by the change in myself," she writes in an award-winning essay on teens and alcohol. "I hugged without hesitation and called people 'sweetheart.' More boys approached me. It became easy to be lovable and loving when drinking."

After getting caught in a vortex of partying and drinking, Hwang stopped turning to alcohol as a social crutch. But binge drinking remains one of American youth's most popular forms of recreation: An estimated 7 million youngsters 12 to 20 years of age binge drink at least once a month, according to the government's National Household Survey on Drug Abuse. And while it may take years of heavy boozing before they fall prey to cirrhosis of the liver, it's a myth that teens are more resilient to alcohol's toxic effects than adults, warns Scott Swartzwelder, a neuropsychologist at Duke University and at the U.S. Department of Veterans Affairs. "The developing brain is more vulnerable to chemical insults," he says.

A decade ago, Swartzwelder surprised the scientific community by showing that alcohol disrupts the hippocampus, the brain's memory center, more severely in adolescent rats than in older rats. More recently, he and others have extended that finding to humans. Alcohol also damages the prefrontal cortex, regardless of age. Since this part of the brain is changing rapidly in adolescence, teens who regularly abuse alcohol are particularly susceptible to its harmful action. Alcohol's one-two punch to the hippocampus and the prefrontal cortex can translate into long-lasting, and possibly even permanent, cognitive deficits. Even three weeks after abstaining from alcohol, teens who were former binge drinkers scored more poorly on tests of verbal and nonverbal recall than their nondrinking peers.

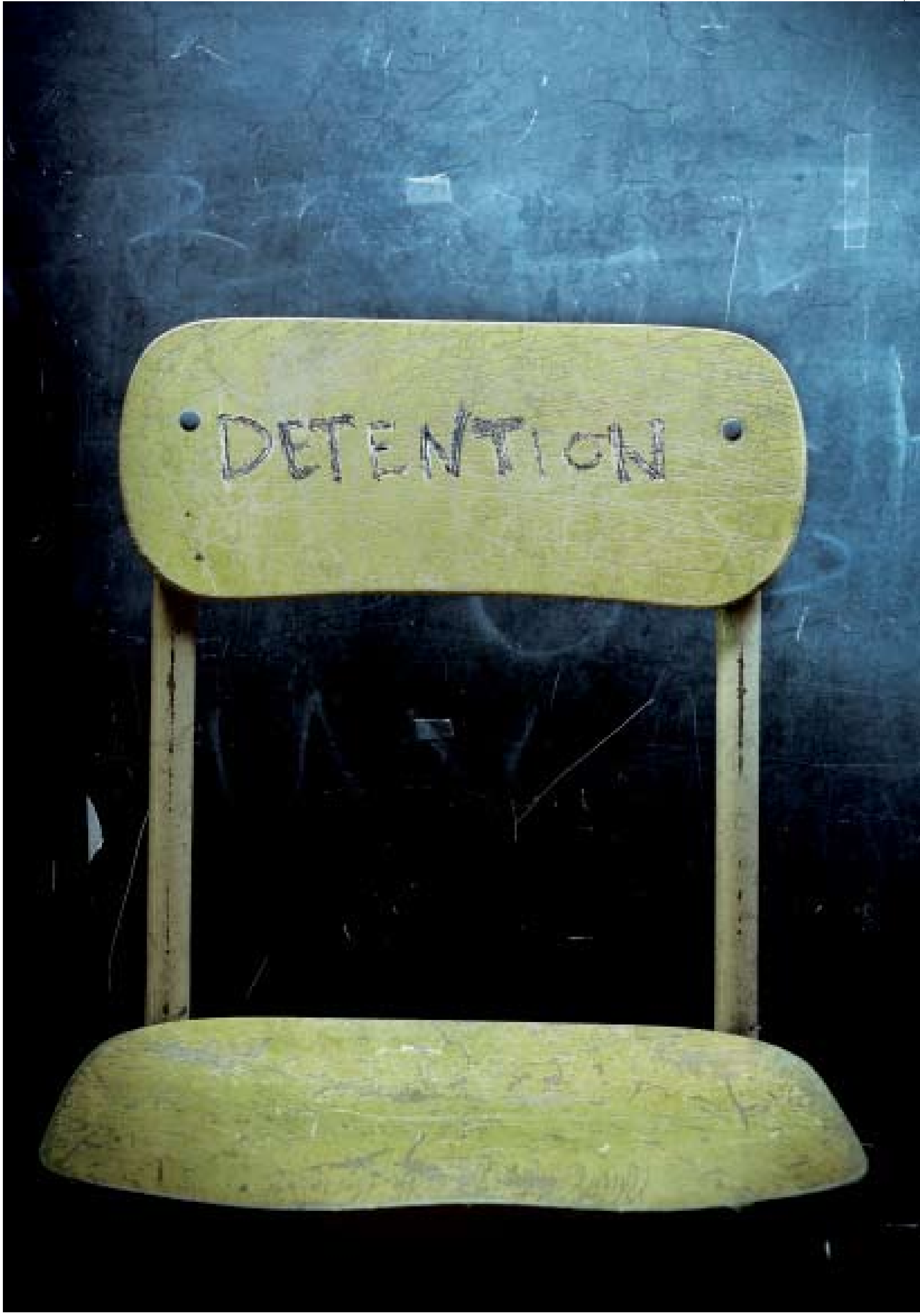
Adolescents who only occasionally drink still face unique hazards. Research shows that the same amount of alcohol impairs memory and learning performance more in both younger animals and humans relative to their older counterparts. Yet, paradoxically, teens are actually less sedated by alcohol than adults. That spells big trouble, says Swartzwelder. “While an adult who drinks heavily might literally conk out, a teen who consumes the same amount is still alert,” he says. “So the teenager may pick a fight in a bar or get behind the wheel of a car or engage in any number of perilous activities.”

In addition to all the pressures and temptations facing adolescents, the typical teenager is sleep deprived—the key to why they suddenly become hard-to-revive morning slackers. Melatonin, the brain chemical that promotes sleep, is released an hour later at puberty, turning teens into night owls. Yet many high schools start at 7 a.m. The resulting fatigue, says Mary Carskadon, an adolescent-sleep expert at Brown University, may contribute to adolescents’ famous penchant for moodiness and could interfere with learning. “Sleep deprivation,” says Carskadon, “could mean the difference of a grade or two, or affect agility at learning a new piano piece or any number of other skills.”

But not all the news about the teen brain is negative. In primitive societies, scientists speculate, there may be advantages to having healthy, strong adolescents stay up late in front of the campfire to guard against predators or invaders from other tribes. “Old people, who wake up early, can cover the morning shift,” points out Carskadon. In that way, she and others theorize, each age group fills a different “temporal niche,” offering communities round-the-clock protection.

The dynamic brain of the teen is also less set in its ways. “Teens are more inclined to think outside the box and be more experimental and creative,” Swartzwelder says. Consider the invention of the steel drums, one of the few genuinely novel acoustic instruments of the 20th century. That innovation is commonly traced to young teens in Trinidad—often on the fringes of society—banging on empty oil drums and the lids of garbage cans. We also have teens to thank for break dancing, rap, hip-hop, bold new fashions, and even great works of literature. A love of science fiction and dragon lore inspired Christopher Paolini at age 15 to begin to write *Eragon*, a best-selling novel in which he even invents his own languages.

Risk taking and thrill seeking are often viewed as destructive. But, as Swartzwelder points out, they can also be wonderful assets for prompting us to leave our families, find a mate, and develop independence. “A brain in flux,” he says, “is more open to new experiences and to exploring the world—all of which enhance survival.”



Alcohol hits adolescents’ memory hard; teens who binge drink score worse on tests even weeks afterward.

The University of Pittsburgh’s Luna agrees. “Adolescent rats become big risk takers the moment they hit puberty too,” she says. “And yes—occasionally they die in the process. But guess what? If they don’t start exploring and taking risks at this stage, their chances of survival are actually worse. It’s the less adventurous rats that are the least likely to make it to adulthood, because they don’t learn what they need to know for the long haul.”

Whether two-legged or four-legged, teens learn to survive by pushing the envelope. Whoever coined the adage “What doesn’t kill you will make you stronger” must have been the parent of a teenager. ▷

ADULT BEHAVIORS

THE pitcher lets loose a 95-mile-per-hour fastball. Derek Jeter starts tracking it even before it takes flight. Within milliseconds, a nerve signal has traveled from his eyes clear across his brain to the visual cortex at the back of his head. As the New York Yankees' slugger bends into the ball, his nervous system rushes a message to his hands for a last-second correction in the tilt of his bat. Wham! He nails it for a base hit down the middle.

Sometimes, younger simply means better. In our early twenties, our reaction times are nimblest—a huge asset on the sports field or dance stage. Our memory is sharpest, allowing us to assimilate vast quantities of information as we cram for tests or learn a new profession. Analytic reasoning—our ability to juggle novel information to solve a problem—also peaks in young adulthood. Imaging studies of the brain appear to back this up, showing a slow, steady decline in the volume of our gray matter from our twenties on.

Nonetheless, most of us in the decades between our thirties and sixties don't feel that our mental powers are fading. We may miss the sharpness and speed of youth (Jeter's skills being the exception rather than the norm), but that loss is accompanied by a new capacity for broader thinking and a better ability to focus on what's important. Call it wisdom, for lack of a better word. "Sure, I could think faster when I was young, but I didn't think as efficiently," says Guy Morris, a 52-year-old real estate executive from Westchester County, New York. "Today I'm much better at gauging the return on the amount of time, energy, and money invested in a project. I can cut through great swaths of information to get straight to the filet mignon."

New research suggests that when faced with complex information or ambiguity, the middle-aged brain may trump the cognitive prowess of youth. Perhaps related to that finding is the fact that the majority of Nobel Prizes have been awarded for work accomplished when the laureates were between 30 and 50 years of age. The march of decades also brings huge gains in knowledge and skills—which is why, for the most part, 20-year-olds are not CEOs or the leaders of nations. As for that missing gray matter, it's possible that we're better off without it—a controversial claim that is gaining support in some neuroscientific circles.

"Older adults are much faster to grasp the high concept or the essence of the matter at hand," says Gene Cohen, director of the Center on Aging, Health, and Humanities at George Washington University Medical Center in Washington, D.C. "They're not always so good on the details, but they see the big picture." That mastery of complexity, in turn, often translates into enhanced creativity and a new willingness to take intellectual risks.

Cohen speaks from both personal and professional experience. In his midforties, after two decades as a gerontologist, he began pursuing a new passion for inventing games; his first was a cross between chess and Scrabble called Word-War III. Around the same time Cohen also began writing popular books. It's small surprise that his latest, *The Mature Mind* (2005), is a frontal assault on negative stereotypes about the aging brain. "I don't deny the young adult has some mental advantages—like being faster on the draw," says Cohen. "What bothers me is that others deny many of the advantages of the mature brain."

If there are divergent views of our intellectual potential at midlife, it is because neuroscientists are just beginning to map out the changes that happen during this phase. Moreover, what little they do know is often surprising, making findings difficult to interpret.

A case in point: It's well known that children have an advantage in acquiring new languages, in part because the young brain is more adaptable and flexible. Yet language acquisition research by Stanford University psychologist Jay McClelland hints that adults may be able to reawaken this flexibility.

Learning a new language is difficult in part because foreign speech sounds, according to McClelland, can have the paradoxical effect of reinforcing the circuits involved in native language processing. He makes the analogy to color: If your only cognitive categories were for red and blue, how would your brain interpret purple? Perhaps circuits for both red and blue would be activated, strengthening those interpretations. Similarly, when we hear foreign sounds that straddle phonetic categories, we may inadvertently collapse them into the sounds we know best.

Yankee shortstop Derek Jeter (age 32), here about to bunt, embodies the best of adult performance: speed matched with skill and experience.

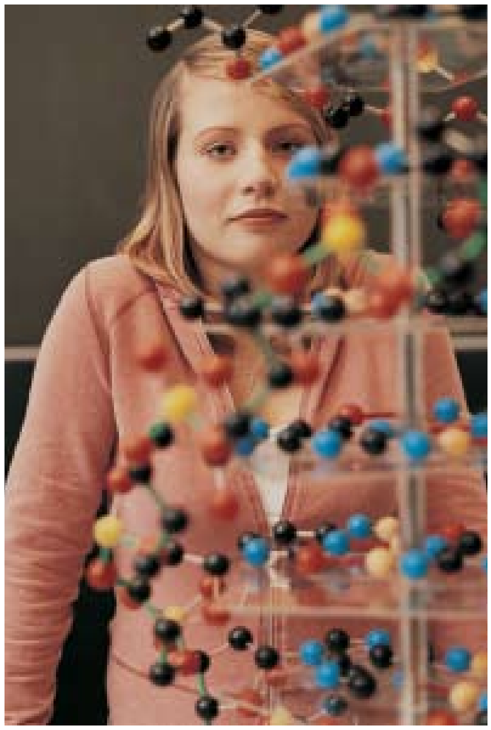
To counter that effect, McClelland, working with Japanese adults learning English after newly arriving in the United States, used a computer to exaggerate the phonetic distinctions that often confuse Japanese speakers when they hear English. He accentuated certain frequencies to interrupt the assimilation of these words into sounds familiar to the Japanese speakers. Virtually overnight, the adult learners turned into prodigies. After just an hour of training, they were able to make tricky phonetic distinctions that would normally require five years of living in an English-speaking environment.

What jolted these adults out of their habitual hearing patterns? As we get older, McClelland's research suggests, what we've learned becomes more entrenched. It's as if repeated experience with the same information wears a groove in our neural networks, which is why many things become easier with practice. McClelland theorizes that he was able to tweak the wiring scheme of those circuits, disturbing them enough to allow learning to etch a new groove in the old pattern. Perhaps, he speculates, learning conditions could be structured to rewire other circuits, like those that underlie unconscious racial prejudices or sexual stereotypes.

McClelland's findings are part of a new surge of research into plasticity in the adult brain, which turns out to be much more flexible far longer than expected, especially in the frontal and temporal lobes, which govern abstract conceptual thinking and planning. The organizational tumult in the frontal lobes that begins at puberty persists well into the midtwenties, MRI scans now reveal. And white matter—the connective fibers coated in signal-speeding myelin that allow neurons to communicate—continues to infiltrate the frontal and temporal lobes for decades to come.

These slow-to-mature sectors of the brain show a simultaneous shrinkage in the nerve-cell body, or gray matter, an observation that has led some researchers to the grim conclusion that we begin losing the brain's most precious real estate in our twenties. Yet MRI experts disagree about how to interpret this erosion of gray matter. It may signal a decline in intellect—or it may be a sign of improved neural functioning. "I doubt we're losing brain cells in the cortex," says Naftali Raz, who studies MRI scans of young and old adults at the Institute of Gerontology at Wayne State University in Detroit. "More likely the shrinkage of gray matter reflects the loss of branches between brain cells, as less-used circuits are being trimmed back."

The pattern of change reflects the pruning and fine-tuning of circuits, agrees George Bartzokis, who is a professor of neurology and director of the Memory Disorders and Dementia Clinic at UCLA. "Autopsies of people who died in their fifties and sixties show no loss of neurons in the frontal and temporal lobes," he insists. "It only looks that way on MRI scans because white matter is invading these areas," an indication that more existing circuits are becoming myelinated. And that, he says, is further evidence of growth and development.



The adult brain is more flexible than previously thought.

Myelin boosts signal transmission more than 13-fold—a jump in speed analogous to switching your Internet connection from dial-up to broadband. Myelinated circuits also transmit 30 times more information per second, giving them greater bandwidth. Some circuits, like those controlling motor activity, have already begun to demyelinate by the thirties, which is one reason major-league baseball players and tennis pros are heading for retirement by this age. But other areas, especially those that govern higher reasoning, have only just hit full speed. "The reason we make much better decisions in middle age than when we were 21 is because all the brain is finally online," says Bartzokis. "Young adults are still stuck with the slow speed and narrow bandwidth of dial-up in many circuits. Fifty is when we're fully myelinated and our intellectual potential soars."

As we grow older, we're also more inclined to involve both sides of the brain in cognitive efforts—a finding so new that its meaning is still being debated. Young adults tend to favor one hemisphere or the other depending on the mental task, explains Roberto Cabeza, an expert on brain imaging at the Center for Cognitive Neuroscience at Duke University in Durham, North Carolina. People in their twenties, for example, rely almost exclusively on the left hemisphere during language processing. During visual-spatial reasoning, however, the right hemisphere dominates. By middle age, this strict division of labor starts to break down, and both hemispheres engage during the same tasks—a trend that becomes pronounced in people who stay lucid with advanced age.

Cabeza, who coined the term HAROLD (for "*h*emispheric *a*symmetry *r*eduction in *ol*der a*d*ults") to describe this shift, believes that the older brain is compensating for loss of function. "As our mental powers dwindle, we need to draw on more diverse centers of the brain to accomplish the same thing," he says. Cabeza likens the situation to an older person lifting with two hands what a younger person can hoist with one.

Cohen, by contrast, puts a more positive spin on the finding. "If you're using both sides of the brain," he says, "you might be getting added value." He points to the work of Jean Piaget and other scholars of developmental psychology who have found that young adults tend to focus on the answer, the solution. But older adults, research shows, can tolerate considering more than one idea and can mull over competing or even contradictory solutions. Cohen believes this broader vision reflects the better integration of the left and right hemispheres that occurs with age. In addition, he suspects that the tendency to process information across both halves of the brain contributes to creativity.

Miami resident Ruth Vander Zee would agree. In her thirties and forties, she conducted choirs, gave piano lessons, and taught English to middle school students. "All of those activities taught me about life and people and how to find the emotional heart of music and great literature," she says. She now integrates these skills in a new occupation: Almost a decade ago, at age 51, Vander Zee launched a career as an author of children's books. "What I'm doing now feels like a synthesis of everything that came before," she says.

Like Vander Zee, many adults engaged in creative and intellectual work feel that all the pieces finally come together in their fourth or fifth decade—one of the rewards of maturity. Even if Cabeza is largely right, and the brain runs downhill throughout adulthood, the benefits in thinking and creativity might outweigh that loss. The poet William Carlos Williams spoke of "age that adds as it takes away": A modern neuroscientist just might agree.

ELDERLY:

SILVER STARS

RETIRE?" Jay Cohn raises one bushy gray brow in disdain. "I'm too busy."

At 76, the Minneapolis cardiologist keeps a grueling schedule that would exhaust many 20-year-olds. Cohn oversees half a dozen clinical trials and directs an institute devoted to the prevention of heart disease. He's also involved in launching two high-tech companies. "I feel that I'm being creative and productive and making a difference," he says.

So much for old folks shuffling off into the sunset. Older adults today are still highly engaged with their jobs and their passions. On average, they experience cognitive decline a full decade later than did the previous generation, says K. Warner Schaie, a professor of human development and psychology at Pennsylvania State University. For this scientist, who is himself still active in research at the age of 78, that's proof that healthier lifestyles, increased education, and better medical care are keeping us nimble-minded.

Aging may soon be easier on all of us. The great discovery of the last decade in neuroscience—that even adult brains grow and change—is now being exploited to understand how mental functioning can be maintained in advanced age. Some of these remedies are surprisingly simple. Regular mental workouts, for example, are important, as is keeping physically fit. Research has also revealed a few upsides to getting older: Better judgment and a more positive attitude turn out to be normal parts of the aging process.

Aging takes a physical toll on the brain. Between our teen years and early adulthood, as our intellectual power surges, gray matter shrinks and white matter expands. But in the aged brain, the loss of gray matter may signify atrophy rather than mental development. Even more ominous, by about age 60 white matter begins to erode at an accelerated pace. Primate studies have shown that with advanced age, the myelin insulating the brain's wiring literally unravels. In people with vascular disease, this process can start as early as the forties. Damage, especially in the frontal and temporal lobes and the hippocampus, a key memory ▷

Research has revealed a few **upsides to getting older:** Better judgment and a more positive attitude turn out to be normal parts of the aging process

PAGE 12: JEFF LEWIS. OPPOSITE PAGE: RAYMAN/GETTY IMAGES. THIS PAGE: TIMOTHY ARCHIBALD.

Researcher David Bennett seeks the causes of dementia.

center, becomes plainly visible in brain scans. This suggests that signal transmission is becoming sluggish and erratic, says Naftali Raz of Wayne State University in Detroit, which may in turn explain why the mind slows down and is more prone to bouts of forgetfulness.

Pat Abujaber of Pompano Beach, Florida, knows those exasperating "senior moments" all too well. "First there was the stolen car that wasn't stolen after all," says the 69-year-old retired teacher. "I just forgot where I'd parked it. Then there was the time I didn't pack my overnight bag: 'My, this is light,' my daughter said when she picked it up. It was empty! I thought I'd packed, but I hadn't. I'd left my clothes and toiletries back in the hotel room."

Abujaber recalls that being in a foreign country at the time was distracting. "Difficulty dealing with distraction is very common in older adults," says Denise Head, assistant professor in the department of psychology at Washington University in St. Louis. Not only does the memory center of the brain start to shrivel with age, but the frontal lobes aren't doing as good a job keeping us on task.

However, the relationship between physical changes in the brain and cognitive problems is not straightforward. Gray matter may begin to dwindle in our twenties, but for most of us, crystallized intelligence—reasoning based on a lifetime of knowledge, skills, and experience—remains robust into our early sixties. Further insights into the connection between physical and cognitive aging have come from a large collection of brains under the stewardship of David Bennett, director of the Alzheimer's Disease Center at Rush University Medical Center in Chicago. He directs a unique study in which 1,000 cognitively normal subjects over the age of 65 have volunteered to undergo regular mental tests and, after death, donate their brains.

To Bennett's surprise, many subjects who perform very well on cognitive tests reveal, after their deaths, brains gummed up with amyloid plaques and tangles of tau protein—the signatures of Alzheimer's disease. What tipped the balance toward dementia in many cases, he found, were additional insults: the burst vessels in the brain that are the hallmarks of strokes, protein deposits associated with Parkinson's disease, and the death of nerve cells, most likely due to highly toxic stress hormones. These findings give Bennett hope that reining in the ravages of disease and stress could mean an end to many forms of senility.

Education builds a **"neural reserve" to draw on** in old age; additional years of education correspond to a lower risk of Alzheimer's

There's other good news: Barring severe disease, we are capable of learning and forging new nerve connections throughout life. Some areas of the brain continue to produce new neurons into our eighth decade and probably beyond. Designed with a redundancy of neurons and connections, the brain can rebound from damage and compensate for the loss of circuits with age. One example of its adaptability: The older brain uses both hemispheres to tackle tasks that, in younger brains, are processed using predominantly one side.

What are our best options for fending off mental decay? For those lucky enough to live beyond age 85, the risk of developing Alzheimer's eventually climbs to about 50 percent. The 20 to 25 percent of the population who carry one particular variant of the apolipoprotein E gene are prone to developing dementia much earlier, frequently before age 80.

Evidence is accumulating that even the impact of bad genes can usually be blunted by lifestyle changes. The brain thrives on mental stimulation, exercise, and good nutrition—all of which can significantly delay cognitive decline. In a nutshell, what's good for the heart is good for the brain. Because neurons and the cells that maintain myelin are gluttons for oxygen and nutrients, unimpeded blood flow is crucial. Keeping cholesterol low and avoiding high blood pressure and diabetes contribute to cardiovascular health, which in turn fosters cognitive staying power.

Exercise is potent therapy for older brains. The hippocampus, which "bar codes" memories for later retrieval, is one of two main sources of new neurons in the adult brain (the olfactory bulb is the other). Physical activity increases the rate at which these cells divide and survive, reports Fred H. Gage, a neuroscientist at the Salk Institute in La Jolla, California.

In the latest finding from this promising line of research, exercise has been shown to change the very brain regions that are most likely to degenerate first—the frontal lobes and the hippocampus. People between 60 and 79 who adopt a regular walking regimen can actually bulk up their brains, boosting the volume of both white and gray matter in these areas, finds Arthur Kramer, professor of neuroscience and psychology at the University of Illinois at Urbana-Champaign. The increase may be due to the production of neurons, he says, but more likely the brain swells in size because of an influx of capillaries and a surge in new neuronal connections. As older people become more fit, they show big improvements in executive function, multitasking, and filtering out distracting stimuli. "On average," Kramer says, "regular exercisers look about three to five years younger on a variety of cognitive tests."

A diet rich in fish fat may benefit both heart and brain. About a half dozen studies show that fish consumption is associated with reduced risk of cognitive impairment and Alzheimer's disease, reports Martha Clare Morris, associate professor in internal medicine at Rush University Medical Center. In her research, at least one meal per week of any type of fish—not just the fatty kind recommended for heart health—was associated with a 60 percent reduction in the risk of Alzheimer's disease.

And don't bother cutting out coffee if you're a java drinker. It contains potent antioxidants—substances that deactivate the disease-causing by-products of metabolism. In animal studies, the beverage has been shown to inhibit the brain-cell destruction that occurs in Parkinson's disease. People who drink coffee regularly are much less likely to develop the illness. More recently, a small human study hints that older men who drink three cups a day suffer less memory loss and fewer thinking problems than those who abstain.

Keeping an aging brain healthy requires cognitive as well as physical exercise. Education builds what neuroscientists call "neural reserve," a profusion of connections you can draw on in old age. Several studies find that additional years of education correspond to a lower risk of Alzheimer's. Similarly, intellectually stimulating leisure activities—board games, crossword puzzles, playing a musical instrument, and reading—protect against this form of dementia.

In recent years, neuroscientists have developed mental calisthenics programs to forestall cognitive decline in aging adults. These approaches typically feature simple mental calculations, memorization of words or pictures, rapid counting or reading, and recognition of ascending or descending scales of notes.

Madelon Hanson, an 85-year-old resident of Wyndemere Senior Living Campus in Wheaton, Illinois, is halfway through one such program, and she's impressed. "It was exhausting at first," she says, "but now I'm really loving it because I'm noticing a difference." Her retirement community recently adopted a brain fitness software program developed by the San Francisco–based company Posit Science. "I can rattle off the names of my 15 neighbors on our two hallways, whereas before I wouldn't have been able to recall many of them. And I don't have to grope so often for words in midsentence." Dozens of studies are under way to see if these exercises actually can turn back the clock on cognitive aging, but Hanson needs no convincing. "I wish I could go on learning forever," Hanson says. "I'm still so excited and curious about the world."

Hanson's good attitude about aging is more common than many younger people suspect. The process of getting older actually predisposes us to take a rosier view of life, finds Laura Carstensen, a professor of psychology at Stanford University. "The stereotype of the crotchety older person is a myth," she says. As people get older, "they have fewer negative emotions, so their overall day-to-day emotional experience is more positive."

This shift seems to be a normal part of aging. Young people are more attuned to negative stimuli. Older people, by contrast, pay attention to the things that make them feel good. In a laboratory setting they are faster to react to and remember a smiling face than a picture of the same person looking sad or distressed. In an fMRI study, Carstensen and her collaborator John Gabrieli of MIT found that in elderly people, the amygdala—a part of the brain that reacts to powerful or threatening emotions—activates in response to pictures of puppies or children playing. Frightening or violent images quiet the amygdala down. Younger people, in contrast, respond equally to positive and negative pictures.

Young people are more attuned to negative stimuli; **old people, by contrast, pay attention** to the things that make them feel good

This improved skill in mood regulation requires heavy lifting by the prefrontal cortex, which is remarkable considering that this region of the brain is already under duress with advanced age. An Australian team led by Lea Williams at the University of Sydney has recently found that the prefrontal cortex in older adults actively squelches negative inputs from the lower brain, where responses are more automatic. At the same time, it throws open the gates to emotionally positive information. "This shift, which happens around 50 years of age, predicts emotional well-being," Williams says. "You get better at 'braking' in response to upsetting information and 'releasing' for happiness as you get older."

The accumulation of life experience, both Carstensen and Williams agree, probably spurs this developmental change. "A younger person can't afford to ignore negative information," says Carstensen, "so learning it takes a high priority even if it makes them feel bad." Since older people have already survived adversity and danger, they have the luxury of overlooking the unpleasant side of life, she theorizes. Aged adults may also have more skill at avoiding bad experiences, as well as the learned ability to regulate their responses when difficulties can't be avoided.

Since a healthy body and a healthy mind often go hand in hand, people who live exceptionally long lives may remain productive and creative even into their triple digits. It's worth noting that the French chemist Michel-Eugène Chevreul pioneered the field of gerontology in his nineties and continued making scientific contributions until a year before his death at 103. Grandma Moses finished 25 pictures after age 100—and she didn't even start painting until age 76.

And then there's George Dawson, an illiterate African American laborer who never went to school—instead, picking cotton, laying railroad ties, and doing other hard work most of his life. At age 98, after almost a century of signing his name with an *X,* he entered a literacy program and learned to read. At 102, a year before his death in 2001, Dawson published his memoirs—an astonishing testament to the brain's resiliency and lifelong capacity for growth. The book's title? *Life Is So Good.* Ω

Keeping An Old Brain Young

Aging brains continue to restore themselves. However, they need the right ingredients—good blood flow, healthy fats, and mental stimulation. For best brain health:

Exercise. Above and beyond the other benefits, regular workouts cultivate new neurons and keep the brain sharp.

Keep the pipes open. If necessary, take medication to control high cholesterol, high blood pressure, or diabetes.

Choose smart fats. Make sure they're the right kind: Polyunsaturated and monounsaturated fats found in olive oil, nuts, and seafood are rich in the fatty acids that are a key constituent of every cell membrane in the brain.

Focus on friends. Social networks are mentally stimulating and encourage well-being, which may protect the brain from the damage wrought by amyloid plaques and other signs of neurodegeneration, reports David Bennett, director of the Rush Alzheimer's Disease Center in Chicago.

—Kathleen McAuliffe