Age changes the mind. Even healthy people with no neurodegenerative diseases have a different constellation of cognitive abilities when they’re 80 than when they’re 20. Fortunately, the aging mind doesn’t face a simple, steep decline. Although aspects of memory and other skills decay linearly decade by decade, other abilities age gracefully: Vocabulary, for instance, seems to improve with time. In a new approach to understanding cognitive changes, researchers are recognizing that motivations and emotional values evolve over the life-span—and what people care about helps determine what they remember. The neuroanatomical bases of age-related cognitive changes are poorly understood, but much of the action appears to occur in the frontal lobes, possibly driven by a faltering dopamine system.

Playing Your Mental 45s at 33 rpm

One of the frequently replicated and mightily depressing findings in research on cognitive aging is that performance on a broad range of tasks falls steadily with advancing age. Some of these lab tests require a lot of mental agility. But others tap basic aspects of cerebral function, and some researchers argue that these low-level deficiencies can account for problems with more complex tasks.

Next time you’re stuck behind an elderly driver creeping along in the fast lane, recognize that you’re being held up by a pervasive phenomenon. What psychologists call “speed of processing,” or how quickly the mind works (and directs the body to respond), plummets over time. In one classic test, for instance, a person looks at two columns of several letters each, one on the right and another on the left side of a sheet of paper, and has to say whether they are the same or different. The number of comparisons someone can make in 30 seconds falls linearly with age. The same slowdown is evident in simple response tasks, such as pushing a button as soon as a target flashes on a computer screen. Reduced processing speed appears to hit everyone; no matter how quickly you zip through simple tasks or learn new skills as a youngster, your performance will wane as you age. “If you give older adults enough time, they do learn a given task, but they’re slower,” says Molly Wagster, program director for neuropsychology of aging research at the National Institute on Aging (NIA) in Bethesda, Maryland.

Popular images of how the mind ages present a contradiction. One stereotype depicts elderly folks as slow, distracted, ornery, and plagued by memory lapses. But then there’s the sage, deliberate, serene senior—a taller, if still stooped, version of Yoda. Lab tests of people at various ages lend some support for both scenarios. Certain cognitive skills diminish with age, particularly some types of memory and ways of manipulating information. Many of these declines start at around age 20 and continue at about the same pace throughout life, even in healthy old people who aren’t afflicted by age-related diseases. Other abilities are more resilient. People’s vocabularies peak late in life, for instance, and they get better and better at judging other people’s personalities and motives. And angst-ridden young people have something to look forward to: Mental health improves with age.

Playing Your Mental 45s at 33 rpm

Speed of processing correlates well with a host of other age-related mental declines. “The astonishing thing is that if you use this pretty crude measure, it predicts performance on higher-order tasks like long-term memory or complex reasoning,” says psychologist Denise Park of the University of Illinois, Urbana-Champaign. In a classic 1996 Psychological Review paper, Timothy Salthouse, a psychologist at the University of Virginia, Charlottesville, spells out an argument in which slowed processing goes beyond correlation to cause other mental declines. If the mind is still chugging along trying to interpret low-level stimuli...
When Does Normal Aging Become Abnormal?

Memory lapses can be frustrating and embarrassing, but as one grows older, such stumbles become ever scarier. Lurking in the back of the mind is the specter of Alzheimer’s disease (AD), rattling its ghostly chains perhaps loudest at those people who are aware of the disease’s frightening prevalence and the stealthy attack (see “Detangling Alzheimer’s Disease” and Alzheimer’s Disease Case Study†). This disease is notoriously difficult to diagnose, but it often starts with memory loss.

Once AD starts to take hold, its memory disruptions are subtly but qualitatively different from those of normal aging. As Molly Wagster, program director for neuropsychology of aging research at the National Institute on Aging in Bethesda, Maryland, explains, “one of the most annoying and frightening, but very common and normal,” complaints of the elderly is an inability to remember names. Healthy seniors eventually remember the name of their new neighbor or the movie they saw last week, although it might take a few minutes or hours. In the meantime, the search for the forgotten name “will bug them until they remember,” says Wagster. People with AD, in contrast, “don’t ever pull up the name, and furthermore, they forget they ever wanted to remember it in the first place.”

But well before this stage of forgetting, AD has a long presymptomatic phase in which physical abnormalities accumulate in the brain and the mind starts to decay. Researchers such as psychologist Marilyn Albert of Johns Hopkins University in Baltimore have identified a subtle state called mild cognitive impairment (MCI) that predicts who is most at risk of developing full-blown AD. A diagnosis of MCI requires a complaint about noticeable memory loss, which must be corroborated by someone close to the patient; no signs of confusion or other markers of dementia; and a “questionable” degree of impairment in daily life. In general, Albert says, MCI means that someone’s memory is below par for his or her age. Over 5 years, Albert finds, about 50% of people who fit the criteria for a diagnosis of MCI convert to probable AD.

Additional measures improve the accuracy with which Albert and her colleagues can predict who will develop AD. Patients who have MCI and an impairment in so-called executive functions—skills such as problem solving and working memory that require planning and repeated monitoring by the brain—are at high risk for AD. A typical diagnostic test is called “Trail B,” a connect-the-dots game for grown-ups. Subjects are shown a field of dots in which each dot is labeled with a letter or a number. They must start with dot number 1 and go to the spot labeled A, then number 2, then B, always switching between numbers and letters while remembering their place in both sequences.

A seesawing memory deficit can also indicate impending AD, says psychologist Denise Park of the University of Illinois, Urbana-Champaign. In longitudinal studies, people who score poorly on a memory test time after time are less at risk than those who perform fairly well some days but bomb the test on other days.

Imaging techniques that depict the physical structure of the brain can help strengthen a diagnosis of AD. Gerontologist Naftali Raz of Wayne State University in Detroit finds that the hippocampus shrinks steadily even in healthy oldsters, but a nearby area of the brain called the entorhinal cortex shrivels dramatically in those with AD. When combined with tests of memory and executive function, Albert says, structural imaging can improve her research group’s ability to predict who will develop AD.

The high incidence of AD in the elderly population—by some estimates, 50% of people older than 85 suffer its symptoms—might be skewing some studies of supposedly normal aging, points out cognitive neuroscientist John Gabrieli of Stanford University. Impairments that ultimately add up to AD can disrupt someone’s thinking for years before diagnosis. “I suspect [that] these people are contributing to a lot of the effects” seen in cognitive aging studies, he says.

Gabrieli suggests that many cognitive and brain changes that accompany aging fall into two categories. One is an Alzheimer’s-like decline, which might not progress all the way to AD in some people, that hits the entorhinal cortex and surrounding brain areas and causes severe memory disruptions. The other resembles the declines characteristic of Parkinson’s disease (PD) but shows up even in healthy brains. As in PD, the brain loses dopamine function over the years, and the frontal lobes get creaky (see Andersen Review‡ and Parkinson’s Disease Case Study§). This conceptual framework, he says, might help researchers pick apart which cognitive changes are truly normal and which are symptoms of incipient AD.

---L.H.

The Impersistence of Memory

Some of the most annoying age-related cognitive changes are memory lapses (see sidebar). Psychologists have teased apart many types of memory; for the most part, they’re buffeted by age.

Short-term memory involves keeping items in mind temporarily. When you look up a number in a phone book and walk across the room to the telephone, short-term memory is what allows you to dial the correct number. But you probably won’t remember the number 5 minutes later. Classic tests of short-term memory include digit span, in which an experimenter reads a list of numbers and the subject recites as many as possible, and Corsi Blocks, in which an experimenter points, one at a time, to a series of blocks on a table, and the subject repeats the pointing pattern. Older people can hold fewer numbers or positions in

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† sageke.sciencemag.org/cgi/content/full/sageke;2001/1/oa2
‡ sageke.sciencemag.org/cgi/content/full/sageke;2001/1/re1
§ sageke.sciencemag.org/cgi/content/full/sageke;2001/7/dn4
mind than younger subjects can.

Long-term memory is more than just glorified short-term memory. It requires encoding information; maintaining it over hours, days, or longer; and then retrieving it out of cold storage when needed. Age can obstruct any of these stages. A real-world example that has been studied in the lab is the “tip of the tongue” phenomenon: the inability, which grows more pronounced with age, to retrieve a word that you know you know. Lab tests of long-term memory often involve asking someone to copy a complex line drawing and then having the person wait 30 minutes or more and sketch the figure again from memory.

Elderly people often repeat themselves, telling the same old story to the same bored audience. Even worse, occasionally an olderster tells a story to the person he or she heard it from in the first place. Failures of so-called source memory—the ability to recall where you learned something—increase with age. Researchers often gauge this type of memory by asking a person to listen to a tape-recorded list of words, some spoken by a man and others by a woman. Later, the subject must look at a written list containing some of the same words and recall which voice spoke them.

But the flavor of memory hardest hit by age is what’s known as working memory. Park calls it “mental horsepower: the raw mental energy to take in and manipulate information.” Working-memory tasks are very demanding, usually requiring someone to store a certain amount of information as well as process it in a complex way, and older people find this type of chore more challenging than younger ones do. Typical lab tests include asking someone to store a certain amount of information as well as process it in a complex way, and older people find this type of chore more challenging than younger ones do. Typical lab tests include asking someone to store a certain amount of information as well as process it in a complex way, and older people find this type of chore more challenging than younger ones do. Typical lab tests include asking someone to recite a string of letters, as in a short-term memory task, but to alphabetize them at the same time.

Attention, Attention

Old folks are not only prone to forget things, but also their minds tend to drift. Like working memory, paying attention is one of the mind’s primary executive functions. These higher level skills, such as the ability to solve a logic problem, require planning and organization. Researchers think that these mental acrobatics are performed by the frontal lobes. One such task that proves relatively difficult for older subjects is attention switching. For example, a computer screen flashes a series of colored shapes. At first, subjects push a button whenever a red object appears, but then, as they were instructed before the test began, they have to switch to looking for a square.

Divided-attention tasks are somewhat similar; as the name implies, they require someone to attend to two or more ongoing events. They seek to mimic real-life situations such as driving, in which someone has to stay within the lane lines, watch for an exit, and maintain a decent speed—all while talking on the cell phone.

Attending to the appropriate computer target or highway sign requires another related skill: the ability to screen out irrelevant information that constantly bombards the senses. Older people have more trouble suppressing such distractions. It’s a more subtle phenomenon than working memory and is a little harder to study in the lab, but as Park points out, this problem is one of the reasons that older people are “more likely to get off the goal path in a discussion”—that is, they sometimes ramble in conversations. The prototypical inhibition test is the Stroop task. A list of color names is printed in mismatched ink colors—for instance, the word “brown” in blue type. Subjects have to name the color of the ink, a surprisingly difficult task that requires inhibiting the urge to pronounce the printed word.

The sad news is that these cognitive skills—speed of processing, working memory, attention switching, etc.—are inversely related to age, and their declines spare no one. As Carstensen points out, cognitive slowing has no regard for race, sex, or level of education. She finds that the rate of deterioration is fairly steady: The difference between a 20-year-old and a 30-year-old is about the same as that between an 80-year-old and 90-year-old.

Brain Traces

Mapping all of these cognitive changes onto the brain has been almost tough enough to warm the hearts of those mind-body dualists who are philosophically opposed to studying the mind as an output of the brain. Although no overarching theory reconciles the various results, some researchers have made a few sturdy connections between the aging brain and the aging mind (see Gazzaley Perspective*). Still, the widespread changes in the aging brain make it unlikely that researchers will be able to map particular mental declines to particular coordinate...
sion comes from work by neuroimager Naftali Raz of Wayne State University in Detroit and colleagues, published in Cerebral Cortex in 1997 and other journals. The prefrontal cortex is the brain region that does the heavy lifting when it comes to working memory or other executive-function tasks. The frontal lobes take up a big chunk of the human brain—most of the brain in front of the ears.

But the frontal lobes don’t grow old alone. Other so-called association areas (those concerned with integrating information from other brain regions) such as the temporal-occipital cortex, which is above and slightly behind the ears, wither with age. The hippocampus, a region deep within the brain that forms memories, seems to shrink gradually until middle age, when its volume loss accelerates, Raz finds in longitudinal studies.

In contrast, brain regions that process incoming sensory signals, such as those from the eyes or ears, are largely spared. As Park points out, this observation is a bit of a problem for the hypothesis that age-related mental changes are driven by the same types of neural decay as reduced sensory acuity.

A novel technique that gives a slightly different view of the brain confirms the notion that certain brain areas are more vulnerable to age-related decay than others are. A high-resolution magnetic resonance imaging technique highlights the brain’s gray matter—consisting mainly of neuron cell bodies rather than neural connections, which are concentrated in the white matter—and is a more precise measure of a discrete region’s health than is overall volume. Elizabeth Sowell of the University of California, Los Angeles, and colleagues report in the January 2003 issue of Nature Neuroscience that gray matter in frontal and association areas shrinks over the life-span, as do the hippocampus and nearby regions.

The breadth of brain changes means “things are looking bad for brain localization studies,” says cognitive neuroscientist John Gabrieli of Stanford University. Traditionally, such studies have sought to link one cognitive problem with one well-defined region of the brain. But now it seems as though researchers will have to look for interactions among many brain regions—something that’s more difficult to do than isolating one particular region whose malfunction leads to a specific deficit. However, comparing the changes associated with normal aging with those seen in neurodegenerative disease might provide some insights.

Researchers who study cognitive aging carefully screen subjects to make sure they’re assessing the effects of healthy aging and not age-related diseases. People with diabetes or those who have suffered strokes, for instance, wouldn’t make the cut. But as Gabrieli points out, Alzheimer’s disease has a long prediagnosis phase in which subtle memory deficits begin to appear. The odds are that many people with this malady are included in supposedly healthy population samples, probably exaggerating the effects of age on memory and other functions. Other age-related conditions might also contribute to apparent age-related memory deficits. For instance, many elderly people develop a condition called reduced glucose tolerance, in which they can’t use blood sugar well but don’t meet the criteria for full-blown diabetes. A study published online several weeks ago in the Proceedings of the National Academy of Sciences by psychiatrist Antonio Convit and colleagues at the New York University School of Medicine showed that, compared with people without reduced glucose tolerance, those with the condition—who would not be excluded from standard cognitive-aging studies—have poorer memories and smaller hippocampi.

Even in healthy seniors, one chemical change in the brain that might contribute to the frontal lobes’ steady decline is a loss of the neurotransmitter dopamine. This chemical messenger is one of the main means of communication to and within the frontal lobes, and dopamine transmitters and receptors become sparser with age, reported Nora Volkow, the new head of the National Institute on Drug Abuse, in the American Journal of Psychiatry in 2000. Declines in dopamine function parallel loss of speed of processing and certain aspects of long-term memory, according to work by Lars Bäckman of Uppsala University in Sweden, published in the same journal issue.

At the cellular level, age-related disruptions in calcium regulation might play a role in cognitive decay (see “This Is Your Brain ... And This Is Your Brain on Calcium†”). Such disruptions cause aged neurons, particularly those in part of the hippocampus, to have a longer refractory period between firings—which might promote overall slowing of cognitive processing, NIA’s Wagster points out.

Functional-imaging studies show, in a rainbow of colors, which parts of the brain are active during a given mental chore. Some studies have picked up age-related differences that appear to relate to cognitive changes. For instance, compared with young subjects, older people show less activity in their prefrontal cortex during memory encoding. This phenomenon was first noted by cognitive neuroscientist Cheryl Grady, currently of the Rotman Institute in North York, Ontario, and colleagues at the U.S. National Institutes of Health in a 1995 study reported in Science. And if information doesn’t make a big impression at the beginning of a memory task, no wonder older subjects have a hard time recalling it later.

Two wide-ranging differences in brain activity have repeat-

† sageke.sciencemag.org/cgi/content/full/sageke;2002/15/ns4
New Synthesis

Suddenly appeared in functional imaging studies. As people age, brain activity during simple visual tests—such as determining whether two faces match—shifts from the back to the front. Roughly speaking, the back of the brain is responsible for simple visual processing; the frontal lobes do the more challenging jobs that require more concentration and cogitation. As cognitive neuroscientist Roberto Cabeza of Duke University points out, this shift is probably an attempt to compensate for inefficient neural processing in the brain’s visual system. If it isn’t working well, people call upon the frontal lobes to help with what would otherwise be a fairly straightforward task. The time and effort involved in recruiting extra brainpower might contribute to the slowdown in performance.

In another massive reorganization of activity, elderly subjects use both halves of the brain to accomplish tasks that younger people perform with just one hemisphere. The right half of the brain generally specializes in spatial knowledge, and the left half controls verbal communication. But that division of labor changes with age, as cognitive neuroscientist Patricia Reuter-Lorenz of the University of Michigan, Ann Arbor, reported in a 2000 study published in the Journal of Cognitive Neuroscience. During a typical verbal working-memory task, such as recalling arbitrarily paired sets of words, young people use the left prefrontal cortex, but older people use both cortices; in spatial working memory tasks, youngsters use the right hemisphere, but older adults use both halves of the brain.

A debate is bubbling about whether this loss of specialization helps or hinders older people’s mental performance (see “A Generation Gap in Brain Activity”). Randy Buckner, a cognitive neuroscientist at Washington University in St. Louis, Missouri, is one of the main proponents of the pessimistic view. He suggests that the two hemispheres normally compete for activation, and the one most skilled at a given task takes over. As the connections between the two hemispheres decay with age, he says, this competition might dampen, in which case both hemispheres would try to take on every chore—an outcome that would be inefficient and perhaps add noise to the system. Cabeza counters that activity in areas not recruited by younger brains compensates for age-related problems and improves performance. He grouped elderly subjects by how well they scored on a battery of memory tests. The people with the best memory, he found, showed the most activation in the “wrong” hemisphere; those with more memory deficits lit up just one hemisphere, as young subjects do, his team reported in Neuroimage in 2002. Cabeza adds that “very little is known” about the neuroanatomical basis for how this double activation comes about.

Older But Wiser

Although elderly people usually perform poorly on a host of lab tests, their apparent mental declines rarely cause serious difficulties in their everyday lives. “There’s a big gap,” says Carstensen. “Even though you do have systematic negative changes, something must be moderating the effects” (see Helmhuth Science article). One such moderator, Park suggests, is ever-increasing expertise about the world. One of the most lab-friendly measures of knowledge is a vocabulary test—and scores improve with age. In a massive study gauging performance on standard lab tests by people of different ages, Park’s team reported in Psychology and Aging in 2002 that speed of processing, working memory, and other types of memory and executive functions decline fairly linearly over time. But knowledge-based tests showed a perky upward trend that should warm the aging heart. For people who care about words, this is great news. As Wagster says, older people are “more facile; they use more words and use them more appropriately.” Other standardized general knowledge tests also show improvements in scores over the years.

One way in which older people might compensate for cognitive deficits is through automatic, repeated processing. When a task is fairly new, it takes a lot of intensive, frontal-lobe-esque processing. But “the more practiced you are in a task, the less you invest,” says Park. Even highly complex activities can become automatic—including, she says, giving a talk. Experienced academics already know how to work the slide projector; they’re also used to having a roomful of drowsy faces turn their way. By taking such things in stride, they have more attention to devote to the presentation, many parts of which have probably been practiced in past talks. “Even though speed of processing and working memory are down, you may give a better talk,” says Park. In contrast, “a junior scientist may have resources drained off by things that are automatic for a senior person.”

Expertise can preserve even tasks that require speed. For instance, young and old master pianists showed the usual differences in lab tests of processing speed, such as tapping a key as quickly as possible. But the older musicians moved their fingers just as fast as the youngsters when playing the piano, according to a 1996 study in the Journal of Experimental Psychology by psychologists Ralf Krampe of the University of Potsdam in Germany and Karl Anders Ericsson of Florida State University in Tallahassee.

Emotional Rescue

Most standard lab tests of cognition are cold, neutral affairs, devoid of emotional significance. They test memory for nonsense words, say, or meaningless strings of digits. But in the past few years, some researchers have demonstrated that emotions mediate cognitive changes of aging. “It’s possible our approaches to studying cognition in isolation may obscure how much cognitive function relies on—is fundamentally integrated with—emotion and motivation,” says Wagster. In some cases, emotions apparently interfere with constructing solid memories.
possibly exaggerating the memory loss measured in elderly subjects. In other cases, emotions strengthen memory.

Challenging the idea that memory tests are neutral, psychologist Thomas Hess of North Carolina State University in Raleigh finds that the expectations older subjects bring to the lab greatly influence their performance. The inspiration for his study came from work with African-American students showing that they perform worse in school than what their abilities predict. Claude Steele, a sociologist at Stanford, proposed that the pervasive expectation of academic failure inhibits the students, perhaps by increasing anxiety levels. Given what an experimenter called an IQ test, African-American students performed much worse than if given the same test without the loaded title. Hess suspected that elderly subjects experience some of the same performance anxiety.

Typical labs that study cognitive aging, Hess’s included, recruit subjects with fliers announcing a “study of aging and memory.” Most people know that cognition is supposed to decline with age, he points out, and they probably expect to perform poorly if they’re old. To test the effect of this expectation, his team gave some subjects a short newspaper-like article describing cognitive declines with age. Another group saw an article emphasizing a more positive viewpoint, and a third read no article beforehand. The impact was powerful. Compared with people who had read a positive article, those exposed to the negative one scored about 20% to 30% less on a simple memory test, a difference almost as large as that usually attributed to age in such studies, Hess’s team reported in the Journal of Gerontology in 2003. In this case, at least, memory problems were all in the mind.

In addition to boasting improved vocabularies, older people generally outperform youngsters in interpersonal tasks. They “are experts in the social domain,” says Hess. His team reported in a 2001 Psychology and Aging study that older subjects are better than younger ones at judging the character of a fictitious stranger. These wise seniors saw through irrelevant behaviors to peg whether the stranger is honest, for instance.

Aside from apparently having performance anxiety about memory tests, older people are generally more emotionally balanced than their younger peers are. Carstensen had people carry pagers and, when buzzed, record whether they were experiencing an emotion and, if so, whether it was positive or negative. Bad juju decreased steadily across the ages.

Carstensen teamed up with Gabrieli’s group to determine how the brain thinks about different emotional signals. They showed old and young subjects a frequently used set of photos depicting positive, negative, or neutral scenes—such as a dog with puppies, a burn victim, or a book on a table, respectively. As in previous studies of college-age volunteers, when young people looked at negative images, they showed more activation in a part of the brain called the amygdala, which processes emotional stimuli. They also remembered negative stimuli better than positive or neutral ones. Older people showed the opposite effect, according to the researchers’ new work, which Carstensen described at a New York Academy of Sciences meeting in November 2002. Their brains responded more strongly to positive pictures, and afterward the older subjects remembered the positive images best. Carstensen says that, for years now, when people have come to her lab for experiments, she has frequently asked them whether they regulate their emotions better than when they were younger. If they said that they do, she would ask them how they manage it.

“The most common response is: ‘Oh, I just don’t think about it,’” says Carstensen. “If you look at these brain images, you see that they were right all along!”

Older people also care more about emotionally meaningful things than younger people do, Carstensen finds. Younger subjects are more interested in preparing for the future and gaining new experiences, whereas older subjects savor the here and now. For instance, in work that’s in press, she showed old and young subjects mock ads that were identical except for their slogans. One pair showed a collage of photos and advertised a camera with either the caption “Capture the unexplored world” or “Capture those special moments.” Young folks wanted the world; old folks were most interested in interpersonal relationships.

Finding factors, such as emotional appeal, that improve memory in the elderly might help them compensate for age-related declines, Carstensen says. But older people aren’t the only ones who stand to benefit. Because seniors seem to have a more positive outlook on life, says Carstensen, “we may do very well to study older people to see how to help younger people.”

Laura Helmuth is an associate news editor at Science. She’s frozen in indecision over whether to capture those special moments or the unexplored world.

Further Reading


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Denise C. Park and Norbert Schwarz (Eds.), Cognitive Aging: A Primer (Taylor & Francis, Philadelphia, PA, 2000).


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