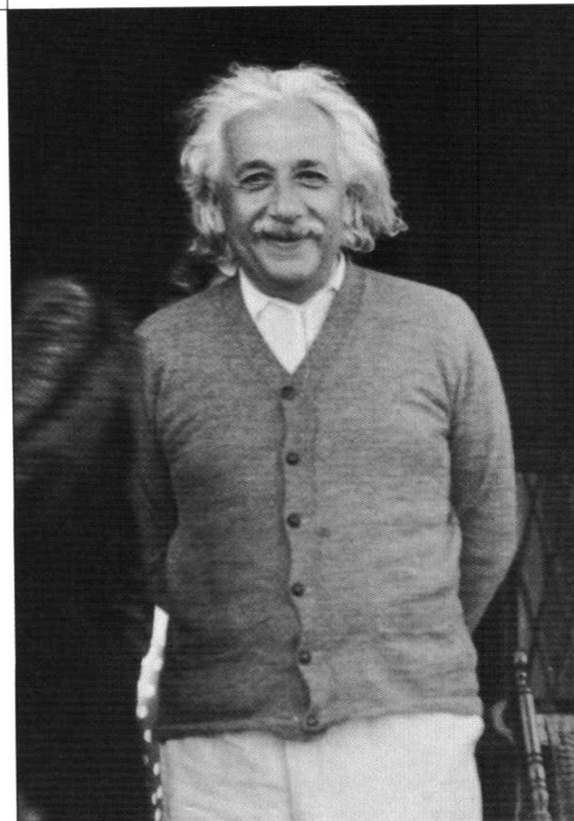
High-Aptitude Minds

Brain researchers are finding clues to the biological basis of (**brilliance**)

By Christian Hoppe and Jelena Stojanovic



Within hours of his demise in 1955, Albert Einstein's brain was salvaged, sliced into 240 pieces and stored in jars for safekeeping. Since then, researchers have weighed, measured and otherwise inspected these biological specimens of genius in hopes of uncovering clues to Einstein's spectacular intellect.

Their cerebral explorations are part of a century-long effort to uncover the neural basis of high intelligence or, in children, giftedness. Traditionally, 2 to 5 percent of kids qualify as gifted, with the top 2 percent scoring above 130 on an intelligence quotient (IQ) test. (The statistical average is 100. See the box on the opposite page.) A high IQ increases the probability of success in various academic areas. Children who are good at reading, writing or math also tend to be facile at the other two areas and to grow into adults who are skilled at diverse intellectual tasks [see "Solving the IQ Puzzle," by James R. Flynn; SCIENTIFIC AMERICAN MIND, October/November 2007].

Most studies show that smarter brains are typically bigger—at least in certain locations. Part of Einstein's parietal lobe (at the top of the head, behind the ears) was 15 percent wider than the same region was in 35 men of normal cognitive ability, according to a 1999 study by researchers at McMaster University in Ontario. This area is thought to be critical for visual and mathematical thinking. It is also within the constellation of brain regions fingered as important for superior cognition. These neural territories include parts of the parietal and frontal lobes as well as a structure called the anterior cingulate.

But the functional consequences of such enlargement are controversial. In 1883 English anthropologist and polymath Sir Francis Galton dubbed intelligence an inherited feature of an efficiently functioning central nervous system. Since then, neuroscientists have garnered support for this efficiency hypothesis using modern neuroimaging techniques. They found that the brains of brighter people use less energy to solve certain problems than those of people with lower aptitudes do.

In other cases, scientists have observed higher neuronal power consumption in individuals with superior mental capacities. Musical prodigies may also sport an unusually energetic brain [*see box on page 67*]. That flurry of activity may occur when a task is unusually challenging, some researchers speculate, whereas a gifted mind might be more efficient only when it is pondering a relatively painless puzzle.

Despite the quest to unravel the roots of high IQ, researchers say that people often overestimate the significance of intellectual ability [see "Coaching the Gifted Child," by Christian Fischer, on page 68]. Studies show that practice and perseverance contribute more to accomplishment than being smart does.

FAST FACTS

All in the Head

1>> Smarter brains tend to be bigger—at least in certain locations. Researchers have fingered parts of the parietal and frontal lobes as well as a structure called the anterior cingulate as important for superior cognition.

2>> Some studies suggest that the brains of brighter people use less energy to solve certain problems than those of people with lower aptitudes do. But under certain circumstances, scientists have also observed higher neuronal power consumption in individuals with superior mental capacities.

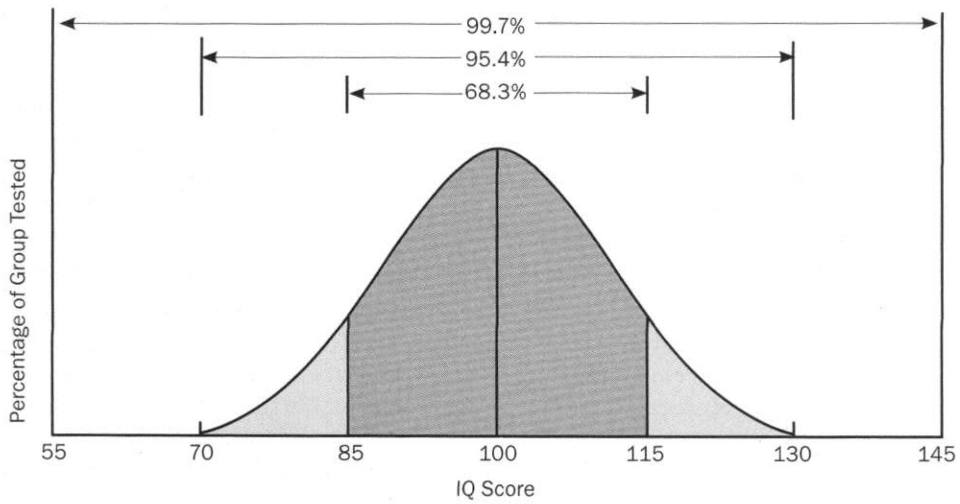
3>> People often overestimate the importance of intellectual ability. Practice and perseverance contribute more to accomplishment than being smart does.

All else equal, **bigger brains** are smarter: brain volume accounts for about 16 percent of the variance in IQ.

Flavors of Smart

Objective intelligence tests are the best way to identify high intelligence. The bell curve below represents the distribution of scores on such exams. In addition to revealing how bright a child is, IQ tests generate an individual aptitude profile, which identifies a child's particular strengths and weaknesses. Educators can use those profiles to tailor gifted programs or projects to each child.

—Christian Fischer



Bright: 115+, or one in six (84th percentile)

Gifted: 130+, or 1 in 50 (98th percentile)

Highly gifted: 145+, or 1 in 1,000 (99.9th percentile)

Size Matters

In humans, brain size correlates, albeit somewhat weakly, with intelligence, at least when researchers control for a person's sex (male brains are bigger) and age (older brains are smaller). Many modern studies have linked a larger brain, as measured by magnetic resonance imaging, to higher intellect, with total brain volume accounting for about 16 percent of the variance in IQ. But, as Einstein's brain illustrates, the size of some brain areas may matter for intelligence much more than that of others does.

In 2004 psychologist Richard J. Haier of the University of California, Irvine, and his colleagues reported evidence to support the notion that discrete brain regions mediate scholarly aptitude. Studying the brains of 47 adults, Haier's team found an association between the amount of gray matter (tissue containing the cell bodies of neurons) and higher IQ in 10 discrete regions, including three in the frontal lobe and two in the parietal lobe just behind it. Other scientists have also seen more white matter, which is made up of nerve axons (or fibers), in these same regions among people with higher IQs. The results point to a widely distributed—but discrete—neural basis of intelligence.

The neural hubs of general intelligence may change with age. Among the younger adults in Haier's study—his subjects ranged in age from 18 to 84—IQ correlated with the size of brain regions near a central structure called the cingulate, which participates in various cognitive and emotional tasks. That result jibed with the findings, published a year earlier, of pediatric neurologist Marko Wilke, then at Cincinnati Children's Hospital Medical Center, and his colleagues. In its survey of 146 children ages five to 18 with a range of IQs, the Cincinnati group discovered a strong connection between IQ and gray matter volume in the cingulate but not in any other brain structure the researchers examined.

Scientists have identified other shifting neural patterns that could signal high IQ. In a 2006 study child psychiatrist Philip Shaw of the National Institute of Mental Health and his colleagues scanned the brains of 307 children of varying intelligence multiple times to determine the thickness of their cerebral cortex, the brain's exterior part. They discovered that academic prodigies younger than eight had an unusually thin cerebral cortex, which then thickened rapidly so that by late childhood it was chunkier than that of less clever kids. Consistent with other studies, that pattern was particularly pronounced in the frontal brain regions that govern rational thought processes.

The brain structures responsible for high IQ may vary by sex as well as by age. A recent study by Haier, for example, suggests that men and women achieve similar results on IQ tests with the aid of different brain regions. Thus, more than one type of brain architecture may underlie high aptitude.

Low Effort Required

Meanwhile researchers are debating the functional consequences of these structural findings. Over the years brain scientists have garnered evidence supporting the idea that high intelligence stems from faster information processing in the brain. Underlying such speed, some psychologists argue, is unusually efficient neural circuitry in the brains of gifted individuals.

Experimental psychologist Werner Krause, formerly at the University of Jena in Germany, for example, has proposed that the highly gifted solve puzzles more elegantly than other people do: they rapidly identify the key information in them and the best way to solve them. Such people thereby make optimal use of the brain's limited working memory, the short-term buffer that holds items just long enough for the mind to process them.

Starting in the late 1980s, Haier and his colleagues have gathered data that buttress this so-called efficiency hypothesis. The researchers used positron-emission tomography, which measures glucose metabolism of cells, to scan the brains of eight young men while they performed a nonverbal abstract reasoning task for half an hour. They found that the better an individual's performance

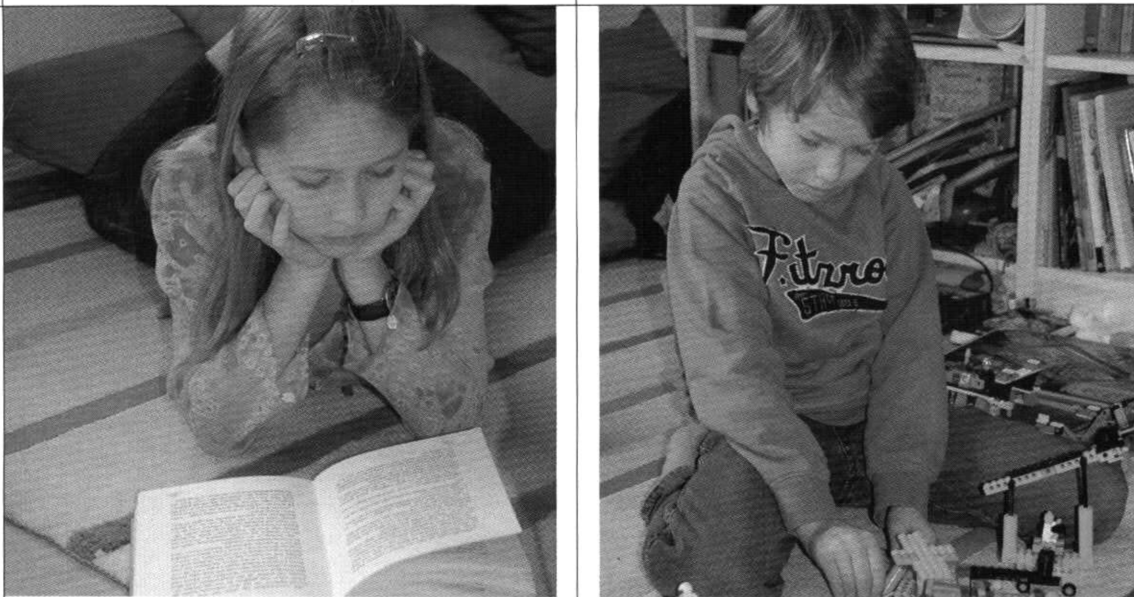
> In one theory, **high intelligence** stems from efficient neural machinery and rapid data processing in the brain.

Right over Left

Genius in areas such as math, music and art is accompanied by extensive use of the right hemisphere of the brain over the left. In the 1980s Harvard University neurologists Norman Geschwind and Albert Galaburda were intrigued by the fact that many such mathematically, musically and artistically gifted people are also left-handed or ambidextrous and are more likely to have left-hemisphere deficits, such as stuttering or dyslexia. Geschwind and Galaburda suggested that such a right-hemisphere preeminence could result from higher-than-average testosterone levels in the womb: some studies indicate that testosterone can impede the development of the brain's left hemisphere and thus, to compensate, might facilitate that of the right.

Of course, male fetuses are typically exposed to higher testosterone doses than female ones are, providing a possible explanation for the preponderance of male math prodigies and of males with language disorders. This hormonal account of the origins of genius—and pathology—remains controversial, however. *—C.H. and J.S.*

MOHAMED SADATH *iStockphoto*



SMART SIBLINGS: Lea Schlierfstein (*left*), 10, is a self-described bookworm. She is also a member of a Chinese Club. Nico Schlierfstein (*right*), eight, has already skipped a grade. His favorite pursuits are math, religion and sports.

COURTESY OF MARKUS SCHLIERFSTEIN

on the task, the lower the metabolic rate in widespread areas of the brain, supporting the notion that efficient neural processing may underlie brilliance. And in the 1990s the same group observed the flip side of this phenomenon: higher glucose metabolism in the brains of a small group of subjects who had below-average IQs, suggesting that slower minds operate less economically.

More recently, in 2004 psychologist Aljoscha Neubauer of the University of Graz in Austria and his colleagues linked aptitude to diminished cortical activity after learning. The researchers used electroencephalography (EEG), a technique that detects electrical brain activity at precise time points using an array of electrodes affixed to the scalp, to monitor the brains of 27 individuals while they took two reasoning tests, one of them given before test-related training and the other after it. During the second test, frontal brain regions—many of which are involved in higher-order cognitive skills—were less active in the more intelligent individuals than in the less astute subjects. In fact, the higher a subject's mental ability, the bigger the dip in cortical activation between the pretraining and posttraining tests, suggesting that the brains of brighter individuals streamline the processing of new information faster than those of their less intelligent counterparts do.

The cerebrums of smart kids may also be more efficient at rest, according to a 2006 study by psychologist Joel Alexander of Western Oregon University and his colleagues. Using EEG, Alexander's team found that resting eight- to 12-hertz alpha brain waves were significantly more powerful in 30 adolescents of average ability than they were in 30 gifted adolescents, whose alpha-wave signal resembled those of older, college-age students. The results suggest that gifted kids' brains use relatively little energy while idle and in this respect resemble more developmentally advanced human brains.

Some researchers speculate that greater energy efficiency in the brains of gifted individuals could arise from increased gray matter, which might provide more resources for data processing, lessening the strain on the brain. But others, such as economist Edward Miller, formerly of the University of New Orleans, have proposed that the efficiency boost could also result from thicker myelin, the substance that insulates nerves and ensures rapid conduction of nerve signals. No one knows if the brains of the quick-witted generally contain more myelin, although Einstein's might have. Scientists probing Einstein's brain in the 1980s discovered an unusual number of glia, the cells that make up myelin, relative to neurons in one area of his parietal cortex.

Hardworking Minds

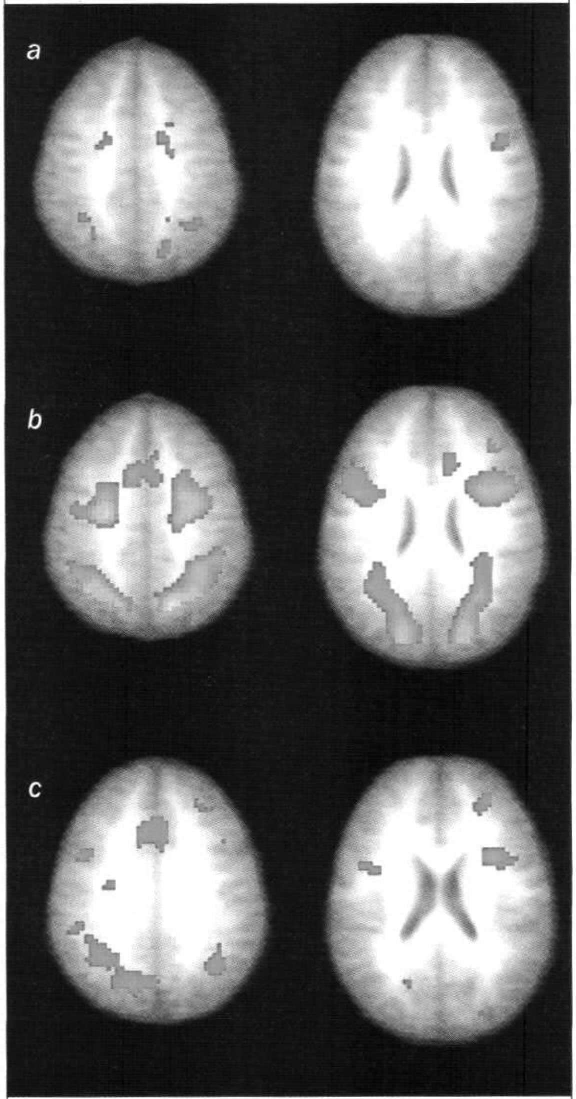
And yet gifted brains are not always in a state of relative calm. In some situations, they appear to be *more* energetic, not less, than those of people of more ordinary intellect. What is more, the energy-gobbling brain areas roughly correspond to those boasting more gray matter, suggesting that the gifted may simply be endowed with more brainpower in this intelligence network.

In a 2003 trial psychologist Jeremy Gray, then at Washington University in St. Louis, and his colleagues scanned the brains of 48 individuals

(The Authors)

Psychologists CHRISTIAN HOPPE and JELENA STOJANOVIC study the neuronal basis of intelligence at the University Clinic for Epileptology in Bonn, Germany.

Some experiments suggest a **bright brain** is a hardworking one, whereas others indicate it is one that can relax.



GIFTED BRAINS: Scientists found higher levels of brain activity in mathematically gifted boys (*b*) than in boys of normal intelligence (*a*) when they performed a mental rotation task. Some brain regions (*c*) were uniquely activated in the gifted boys.

using functional MRI, which detects neural activity by tracking the flow of oxygenated blood in brain tissue, while the subjects completed hard tasks that taxed working memory. The researchers saw higher levels of activity in prefrontal and parietal brain regions in the participants who had received high scores on an intelligence test, as compared with low scorers.

In a 2005 study a team led by neuroscientist Michael O'Boyle of Texas Tech University found a similar brain activity pattern in young male math geniuses. The researchers used fMRI to map the brains of mathematically gifted adolescents while they mentally rotated objects to try to match them to a target item. Compared with adolescent boys of average math ability, the brains of the mathematically talented boys were more metabolically active—and that activity was concentrated in the parietal lobes, the frontal cortex and the anterior cingulate [*see illustration at left*].

A year later biologist Kun Ho Lee of Seoul National University in Korea similarly linked elevated activity in a frontoparietal neural network to superior intellect. Lee and his co-workers measured brain activity in 18 gifted adolescents and 18 less intelligent young people while they performed difficult reasoning tasks. These tasks, once again, excited activity in areas of the frontal and parietal lobes, including the anterior cingulate, and this neural commotion was significantly more intense in the gifted individuals' brains.

No one is sure why some experiments indicate that a bright brain is a hardworking one, whereas others suggest it is one that can afford to relax. Some, such as Haier—who has found higher brain metabolic rates in more astute individuals in some of his studies but not in others—speculate one reason could relate to the difficulty of the tasks. When a problem is very complex, even a gifted person's brain has to work to solve it. The brain's relatively high metabolic rate in this instance might reflect greater engagement with the task. If that task was out of reach for someone of average intellect, that person's brain might be relatively inactive because of an inability to tackle the problem. And yet a bright individual's brain might nonetheless solve a less difficult problem efficiently and with little effort as compared with someone who has a lower IQ.

Perfection from Practice

Whatever the neurological roots of genius, being brilliant only increases the probability of success; it does not ensure accomplishment in any endeavor. Even for academic achievement, IQ is not as important as self-discipline and a willingness to work hard.

University of Pennsylvania psychologists Angela Duckworth and Martin Seligman examined final grades of 164 eighth-grade students, along with their admission to (or rejection from) a prestigious high school. By such measures, the researchers determined that scholarly success was more than twice as dependent on assessments of self-discipline as on IQ. What is more, they reported in 2005, students with more self-disci-

Musical Minds

While some scientists probe the neural correlates of intellectual proficiency [*see main article*], others are investigating the biological underpinnings of musical talent. Like the quick-witted, highly trained musicians also seem to have distinctive brain anatomy and neural activity patterns as compared with those who lack a bent for music.

In 2002 neuroscientist Vanessa Sluming and her team at the University of Liverpool in England demonstrated by MRI a higher density of gray matter—that is, nerve cell bodies—in the brain's speech region, Broca's area, in orchestra musicians relative to a control group. In musicians, Broca's area is thought to mediate the visual skills and sequencing of fast motor actions required when sight-reading a piece. A year later psychiatrist Christian Gaser of the University of Jena in Germany and neurologist Gottfried Schlaug of Harvard Medical School also reported gray matter volume differences in motor, auditory and visuospatial brain regions in professional keyboard players as compared with amateur musicians and nonmusicians.

In 2007 Sluming and her colleagues reported functional peculiarities in musicians' brains. In particular, their findings suggest that the enlargement of Broca's area endows musicians with superior spatial skills. Not only were musicians especially good at a spatial task involving rotating objects in three-dimensional space, but performing these mental rotations also elicited a flurry of activity in Broca's area, as assessed by functional MRI, whereas no comparable activity occurred in the brains of nonmusicians.

While listening to music, the brains of musical prodigies may be unusually active in other regions, too. In 1998 neuroscientist Christo Pantev of the University of Münster in Germany and his colleagues reported that musicians exhibited approximately 25 percent more cortical activity when listening to piano tones than nonmusicians did, as measured by magnetoencephalography, which registers magnetic field potentials from the scalp. This extra neural commotion appears to occur only in response to music—which musicians may be analyzing in greater depth than the average person does—and not to spoken text, according to a 2001 study by psychologist Joydeep Bhattacharya, then at the Austrian Academy of Sciences in Vienna, and his colleagues.

PIANO PRODIGY: Pianist Lang Lang has performed in public since the age of five and won his first international prize at 11.

Many researchers believe that the bulk of these structural and functional brain differences result from lots of practice. After all, the most skilled musicians begin playing before the age of six, providing plenty of time for musical exercises to mold the developing brain.

—*C.H. and J.S.*

pline—a willingness to sacrifice short-term pleasure for long-term gain—were more likely than those lacking this skill to improve their grades during the school year. A high IQ, on the other hand, did not predict a climb in grades.

A 2007 study by Neubauer's team of 90 adult tournament chess players similarly shows that practice and experience are more important to expertise than general intelligence is, although the latter is related to chess-playing ability. Even Einstein's spectacular success as a mathematician and a physicist cannot be attributed to intellectual prowess alone. His education, dedication to the problem of relativity, willingness to take risks, and support from family and friends probably helped to push him ahead of any contemporaries with comparable cognitive gifts. M

WANG MUMU *Imaginechina/AP Photo*

(Further Reading)

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