1 Revealing the Secrets of the Brain

Seeing stars, it dreams of eternity. Hearing birds, it makes music. Smelling flowers, it is enraptured. Touching tools, it transforms the earth. But deprived of these sensory experiences, the human brain withers and dies.

Scientists long have wondered how the brain can do all the things that make one person a poet, another a builder or musician, and still another a criminal or social dropout. Until recently, medical researchers never thought they could understand the brain's inner workings. They could see that a child who is loved and given stimulating experiences usually turns out to be a bright, affable person, while an abused child often becomes an abuser. But no one knew what happened inside the brain that made one person a success and another antisocial.

Researchers were resigned to measuring what went into the brain and studying what came out. The brain simply was considered the "black box." But now many secrets are being revealed.

Two of the most surprising and profound discoveries are that the brain uses the outside world to shape itself and that it goes through crucial periods in which brain cells must have certain kinds of stimulation to develop such powers as vision, language, smell, muscle control, and reasoning.

The new discoveries are overturning the old concept of a static brain, a self-contained unit that slowly begins the process of learning from a preset, unchangeable set of rules, like a tape recorder that stores whatever words it happens to hear.

Now, thanks to a recent revolution in molecular biology and new

imaging techniques, researchers believe that genes, the chemical blueprints of life, establish the framework of the brain, but then the environment takes over and provides the customized finishing touches. They work in tandem. The genes provide the building blocks, and the environment acts like an on-the-job foreman, providing instructions for final construction.

These discoveries are changing the way we think about thinking and are illuminating the biological causes of behavior.

"Within a broad range set by one's genes, there is now increasing understanding that the environment can affect where you are within that range," said Dr. Frederick Goodwin, former director of the National Institute of Mental Health. "You can't make a 70 IQ person into a 120 IQ person, but you can change their IQ measure in different ways, perhaps as much as 20 points up or down, based on their environment."

The discovery that the outside world is indeed the brain's real food is intriguing. The brain gobbles up its external environment in bits and chunks through its sensory system: vision, hearing, smell, touch, and taste. Then the digested world is reassembled in the form of trillions of connections between brain cells that are constantly growing or dying, or becoming stronger or weaker, depending on the richness of the banquet.

"Just as the digestive system can adapt to many types of diet, the brain adapts to many types of experiences," says Felton Earls, professor of human behavior and development at the Harvard School of Public Health and professor of child psychiatry at the Harvard Medical School.

How a newborn learns either English or Hindi or adjusts to being raised in Sweden or Ghana or to eating a diet of beef and potatoes or raw fish and seaweed are all due to the brain's great flexibility.

"All infants require milk before they can eat solids," Earls said. "Is there an equivalent state of affairs for the brain? The answer is clearly an affirmative one. It requires stimulation: touch, holding, sound, and vision."

Several recent animal experiments have demonstrated how brain cells can rearrange their 500 trillion or so connections in response to the stimuli they are being fed.

- Vision. Magrinka Sur of the Massachusetts Institute of Technology converted brain cells that interpret sounds into cells that can process visual images by reconnecting them to the stimuli coming in through the eyes. The experiment demonstrated the interchangeability of brain cells in early development.

- Touch. When monkeys were allowed to use only one finger to perform a task, neuroscientist Michael Merzenich of the University of California at San Francisco found that the brain cells that had been committed to the now-useless fingers switched their function to other parts of the hand. Amazingly, even mature brain cells can perform totally new tasks.

- Smell. Eager to learn from the moment of birth, an infant first bonds with its mother through its sense of smell. Michael Leon of the University of Southern California discovered that within seconds of the first time a newborn smells its mother's body, indelible networks rapidly form in its brain.

- Sound. Without proper stimulation, the connections that allow brain cells to process sound, and thus language, become scrambled. They don't form the neat columns of cells that are so characteristic of the brain's architecture. According to Martha Pierson of the Baylor College of Medicine in Houston, such scrambling may cause childhood seizures, epilepsy, and language disorders. Pierson's remarkable experiment showed how experience, or the lack of it, can physically change the brain and cause mental disorders.

"It's just phenomenal how much experience determines how our brains get put together," Pierson, a neurobiologist, said. "If you fail to learn the proper fundamentals at an early age, then you are in big trouble. You can't suddenly learn to learn when you haven't first laid down the basic brain wiring. . . . That's why early education is so important, why Head Start is so important," she said, referring to the federally funded program for preschoolers.

Essentially, a human comes equipped with a brain for all places

s to jets, and moon travel in a single lifetime.

But what the brain can do depends on whether or not it is used. It he ultimate use-it-or-lose-it machine, and it is eager to learn new lls. The ability to form abstract thoughts, for instance, is now seen a consequence of the brain's learning to read.

'A thousand years ago in medieval England most people did not nk abstractly," said Dr. Bruce Perry, a Baylor College of Medie neuropsychiatrist. "The majority of people viewed the world y concretely. When we look back now and think about how sustitious they were and all that kind of stuff, it's not that dissimifrom the way eight- or nine-year-old children today think about ngs and view the world.

"In the same way that we evolved a certain cognitive abstract caility as a function of our capacity to read, there is every reason to ieve that there are other untapped abstract capabilities of our brains t are not being developed by our traditional educational system."

In their quest to learn how the brain works, scientists have found t the three-pound, walnut-shaped mass of gray matter goes ough four major structural changes: in fetal development, after th, between four and twelve, and during the years thereafter.

Starting from a few cells at the tip of an embryo, brain cells mully at an astounding rate: About 200 billion are created in several nths. Their job is to get in touch with the body that is developing und them and they compete to succeed. Half of the brain cells die by the twentieth week of fetal life because they fail to connect to ne part of the awakening body.

This overproduction of brain cells is important: It is evolution's y of making sure there are enough cells to handle the develop-nt of new skills, just as brain cells did in past generations to deop upright walking and language.

During the winnowing-down phase, the brain is organized into re than forty different physical "maps," which broadly govern such ngs as vision, language, muscle movement, and hearing. How these ps are organized is influenced by electrochemical signals coming o the brain from all parts of the body, and by hormones. Sex hor-

or female brain and influence its skills, favoring such things as language in females and spatial abilities—mathematical concepts, for example—in males.

Alcohol and drug abuse can interfere with growing brain cells, jamming their genetic performance and increasing the risk of mental disorders. Alcohol-induced birth defects, for instance, are the leading known preventable cause of mental retardation in the United States, affecting 1 in every 800 to 1,500 newborns.

Long thought to be a clean slate to which information could be added at any time, the brain is now seen as a super-sponge that is most absorbent from birth to about the age of twelve. Thus, the brain can reorganize itself with particular ease early in life during crucial learning periods, when connections between brain cells are being made and broken down at an enormous rate. Information flows easily into the brain through "windows" that are open for only a short duration. These windows of development occur in phases from birth to age twelve when the brain is most actively learning from its environment. It is during this period, and especially the first three years, that the foundations for thinking, language, vision, attitudes, aptitudes, and other characteristics are laid down. Then the windows close, and much of the fundamental architecture of the brain is completed.

"A kind of irreversibility sets in," Harvard's Earls said. "There is this shaping process that goes on early, and then at the end of this process, be that age two, three, or four, you have essentially designed a brain that probably is not going to change very much more."

That's not to say that all is lost if this early learning period is not optimized. Using the tools left over from shaping brain cells and their connections, the brain gives its owner a big second chance which runs to about age twelve. Even after that the brain never stops learning. There is, however, a price to pay. Instead of being easy, learning becomes harder later on, as any adult who has tried to learn a foreign language knows. For a child, foreign languages are picked up easily.

The brain learns and remembers throughout life by employing the same processes it uses to shape itself in the first place: constantly

changing its network of trillions of connections between cells as a result of stimuli from its environment.

One of the most striking examples of this ability to change was shown recently by Bruce McEwen of Rockefeller University. During the four-day reproductive cycle of a female rat, he found, new connections are created and old ones are destroyed as hormones prepare their brains for pregnancy and later to care for their pups.

"People hear that and say, 'My God, that's amazing!' and these are neuroscientists," he said. "A lot of people are surprised at the rapidity with which connections can be made and broken down in the brain. It especially comes as a big surprise to people who take a more psychological view and separate the mind from the brain. They are part and parcel of the same thing. It doesn't degrade your ability to talk about higher cognitive function [when you] realize that there's a brain under there that's doing the work."

Surprisingly, almost anything can cause physical changes in the brain: Sounds, sights, smells, touch—like little carpenters—all can quickly change the architecture of the brain, and sometimes they can turn into vandals.

"The new thing is that the brain is very dynamic," said Dr. Robert Post, chief of the National Institute of Mental Health's biological psychiatry branch. "At any point in this process you have all these potentials for either good or bad stimulation to get in there and set the microstructure of the brain."

Post and his colleagues were startled to find that outside stimulation can permanently alter the function of brain cell genes. Stress and drugs like cocaine, for instance, can produce biochemical changes that directly affect the function of some key brain-cell genes, in effect laying down permanent, maladaptive behavior patterns.

Faced with the new evidence about how the brain develops and functions, many scientists are concluding that society is wasting a tremendous amount of the brain power of its young, and creating a lot of unnecessary problems—including crime, aggression, and depression—later on in their lives.

"We are underinvested in our children," said Frederick Goodwin. "We spend seven times more per capita on the elderly than we do on children. Now that we have better concepts of the plasticity of the brain, it is obvious we are wasting a tremendous resource."

Understanding the role of the environment in altering brain plasticity has opened the door to prevention. "The question now is if we can identify the kids who are the most vulnerable to being damaged by their environment and get the plasticity of the nervous system working for us to prevent such damage," Goodwin said.

Recent research shows that proper stimulation affects such brain functions as:

- Language. Children whose mothers talk to them frequently have better language skills than do the children of mothers who seldom talk to them. After about age twelve the ability to learn new languages declines rapidly.

- Vision. Lack of visual stimulation at birth will cause those brain cells designed to interpret vision to dry up or be diverted to other tasks, making perfectly healthy eyes permanently unable to see. This discovery has saved the sight of thousands of infants born with vision-blocking cataracts, which are now removed as quickly after birth as possible.

- Brain power. Mice and rats raised in enriched environments, with toys and playmates, have billions more connections between brain cells than similar mice raised alone in empty cages. Pioneering studies also show that the IQs of children born into poverty, or of those who were premature at birth, can be significantly raised by exposure to toys, words, proper parenting, and other stimuli.

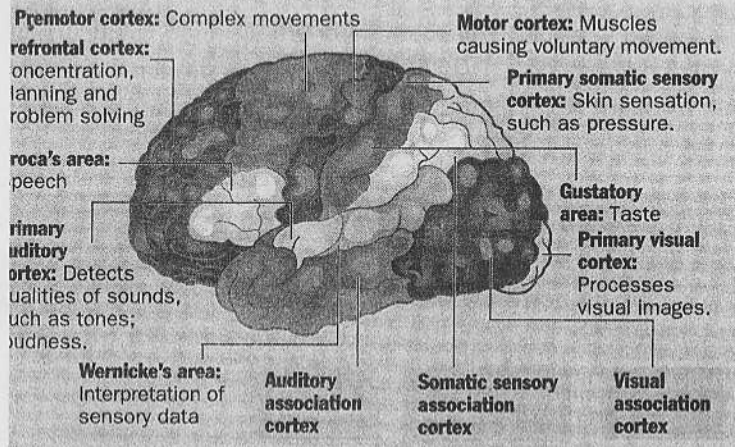
- Aggression. Early exposure to violence, stress, and other environmental pressures can cause the brain to run on a fast track, increasing the risk of impulsive actions and high blood pressure.

- Emotions. Animals exposed to unpredictable stresses while still in the womb develop anxious personalities. After birth, a little extra

THE BRAIN: HOW IT WORKS AND DEVELOPS

lew discoveries are changing old concepts of how the brain develops nd works. Two of the most surprising discoveries indicate that the brain ses the outside world to shape itself, and that it goes through critical eriods in which brain cells require specific types of stimulation to evelop such powers as vision, language, smell, muscle control, and easoning. A related discovery is that the brain has the ability to change apidly as it physically reshapes itself into a kind of biological map of the utside world. Researchers now believe that genes establish the amework of the brain, but the external environment provides the ustomized finishing touches.

lapping the cerebrum Areas and their known functions



HE GROWING BRAIN

lajor structural developments

Fetal development: Billions of brain cells are rmed in the first months of fetal life. Half of em die as hormones and other stimuli liminate and organize them to form the rain's basic scaffolding, e.g. male or female.

After birth: Trillions of brain cell connections re established and form the brain's physical maps" that govern such things as vision, nguage, and hearing.

Age 4 to 10: New learning reorganizes and einforces connections between brain cells. ew connections are formed as new things re learned.

After age 10: Still able to undergo physical hanges, the brain learns and remembers roughout life.

hicago Tribune/Steve Little, Terry Volpp

ASSOCIATION AREAS:

Areas that further interpret information received by primary areas.

Example: The primary auditory cortex detects simple sounds such as pitch and volume, while the auditory association cortex analyzes that information and enables recognition of whole sounds, such as spoken words.

Sources: *ABC's of the Human Body,* American Medical Association, *The Human Body.*

mothering has the opposite effect, instilling in them confidence and the urge to explore.

- Touch. Premature infants whose sensory systems are activated by being held and cuddled are more mentally alert and physically stronger than those who are routinely isolated in incubators.

- Education. The best time to learn foreign languages, math, music, and other subjects is between one and about twelve years of age, yet these years are usually put on pause, given over to youngsters to "enjoy their childhood."

"The aspects of brain development most closely tied to human behavior can be affected for better or worse by the care we give our children," said Yale University neurobiologist Martha Constantine-Paton. Such knowledge provides the moral and social imperative to prevent or cure brain damage caused by the lack of proper environmental stimulation during the brain's crucial periods of development in fetal life and childhood.

"Legislative and educational efforts aimed at nurturing the developing brain through these critical periods could be instituted in the immediate future if the collective public conscience realized that the actual structure of the brain can be adversely affected by neglect," she added.

What can parents do to ensure that the brains of their children develop properly?

"If you want to significantly influence a child's ability to think and to acquire knowledge, the early childhood years are very critical," said neurobiologist Peter Huttenlocher, whose studies helped open the door to understanding the brain's plasticity.

Rockefeller University's McEwen says: "The most important thing is to realize that the brain is growing and changing all the time. It feeds on stimulation and it is never too late to feed it."