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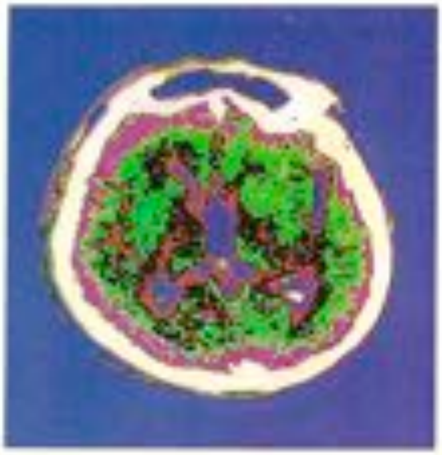
The newborn's brain: registering every flash of color, caress, scent, and other stimuli vital to the

MAKING OF A MIND

BY KATHLEEN McAULIFFE

"Give me a child for the first six years of life and he'll be a servant of God till his last breath."

—Jesuit maxim



A servant of God or an agent of the devil; a law-abiding citizen or a juvenile delinquent. What the Jesuits knew, scientists are now rapidly confirming—that the mind of the child, in the very first years, even months, of life, is the crucible in which many of his deepest values are formed. It is then that much of what he may become—his talents, his interests, his abilities—are developed and directed. The experiences of his infancy and childhood will profoundly shape everything from his visual acuity to his comprehension of language and social behavior.

What underlies the child's receptivity to new information? And why do adults seem to lose this capacity as they gain more knowledge of the world around them? Why is it that the more we know, the less we can know?

Like a Zen koan, this paradox has led scientists down many paths of discovery. Some researchers are studying developmental processes in infants and children; others search the convoluted passages of the cortex for clues to how memory records learning experiences. Still others are studying the degree to which learning is hard-wired—soldered along strict pathways in the brains of animals and humans.

Another phenomenon recently discovered: Long after patterns of personality have solidified, adults may tap fresh learning centers in the brain, new nerve connections that allow intellectual growth far after fourscore years.

Although much research remains to be done, two decades of investigation have yielded some dramatic—and in some instances unexpected—insights into the developing brain.

An infant's brain is not just a miniature replica of an adult's brain. Spanish neuroscientist José Delgado goes so far as to call the newborn "mindless." Although all the nerve cells a human may have are present at birth, the cerebral cortex, the gray matter that is the seat of higher intellect, barely functions. Surprisingly, the lower brain stem, the section that we have in common with reptiles and other primitive animals, dictates most of the newborn's actions.

This changes drastically in the days, weeks, and months after birth, when the cerebral cortex literally blossoms. During this burst of growth, individual brain cells send out shoots in all directions to produce a jungle of interconnecting nerve fibers. By the time a child is one year old, his brain is 50 percent of its adult weight; by the time he's six, it's 90 percent of its adult weight. And by puberty, when growth trails off, the brain will have quadrupled in size to the average adult weight of about three pounds.

How trillions of nerve cells manage to organize themselves into something as complex as the human brain remains a mystery. But this much is certain: As this integration and development proceeds, experiences can alter the brain's connections in a lasting, even irreversible way.

To demonstrate this, Colin Blakemore, professor of physiology at Oxford University, raised kittens in an environment that had no horizontal lines. Subsequently, they were able to "see" only vertical lines. Yet Blakemore had tested their vision just before the experiment began and found that the kittens had an equal number of cells that responded to each type of line.

Why had the cats become blind to horizontal lines? By the end of the experiment, Blakemore discovered that many more cells in the animals' brains responded to vertical lines than horizontal lines.

As the human brain develops, similar neurological processes probably occur. For example, during a test in which city-dwelling Eurocanadians were exposed to sets of all types of lines, they had the most difficulty seeing oblique lines. By comparison, the Cree Indians, from the east coast of James Bay, Quebec, perceived all orientations of lines equally well. The researchers Robert Annis and Barrie Frost, of Queens University, in Kingston, Ontario, attributed this difference in visual acuity to the subjects' environments. The Eurocanadians grow up in a world dominated by vertical and horizontal lines, whereas the Indians, who live in tepees in coniferous forests, are constantly exposed to surroundings with many different types of angles.

The sounds—as well as the sights—that an infant is exposed to can also influence his future abilities. The phonemes rah and lah, for instance, are absent from the Japanese language, and as might be expected, adults from that culture confuse English words containing *r* and *l*. (Hence the offering of steamed "lice" in sushi bars.) Tests reveal that Japanese adults are quite literally deaf to these sounds.

Infants, on the other hand, seem to readily distinguish between speech sounds. To test sensitivity to phonemes, researchers measure changes in the infants' heartbeats as different speech sounds are presented. If an infant grows familiar with one sound and then encounters a new sound, his heart rate increases. Although the evidence is still incomplete, tests of babies from linguistic backgrounds as varied as Guatemala's Spanish culture, Kenya's Kikuyu-speaking area, and the United States all point to the same conclusion: Infants can clearly perceive phonemes present in any language.

The discovery that babies can make linguistic distinctions that adults cannot caused researchers to wonder at what age we lose this natural facility for language. To find out, Janet Werker, of Dalhousie University, in Nova Scotia, and Richard Tees, of Canada's University of British Columbia, began examining the language capabilities of English-speaking adolescents. Werker and Tees tested the subjects to see whether they could discriminate between two phonemes peculiar to the Hindi language.

"We anticipated that linguistic sensitivity declines at puberty, as psychologists have commonly assumed," Werker explains.

The results were surprising. Young adolescents could not make the distinction, nor could eight-year-olds, four-year-olds, or two-year-olds. Finally, Werker and Tees decided to test infants. They discovered that the ability to perceive foreign phonemes declines sharply by one year of age. "All the six-month-olds from English-speaking backgrounds could distinguish between the Hindi phonemes," Werker says. "But by ten to twelve months of age, the babies were unable to make this distinction."

"It's probably fair to say that if you want bright kids, you should cuddle them a lot when they're babies because that increases the number of neural connections."

The cutoff point, according to Werker, falls between eight and twelve months of age. If not exposed to Hindi by then people require a lot of learning to catch up. Werker found that English-speaking adults studying Hindi for the first time needed up to five years of training to learn the same phoneme distinctions any six-month-old baby can make. With further testing, Werker succeeded in tracking down one of the learning impairments that thwarted her older subjects. Although there is an audible difference, the adult mind cannot retain it long enough to remember it. "The auditory capabilities are there," Werker says. "It's the language-processing capabilities that have changed."

Even a brief introduction to language during the sensitive period can permanently alter our perception of speech. Werker and Tees tested English-speaking adults who could not speak or understand a word of Hindi, although they had been exposed to the language for the first year or two of life. They found that these adults had a major advantage in learning Hindi, compared with English-speaking adults who lacked such early exposure.

Werker and Tees's studies show that there is an advantage in learning language within the first year of life. But when it comes to learning a second tongue another study has revealed some startling findings: Adults actually master a second language more easily than school age children do.

For four years Catherine Snow, of the Harvard Graduate School of Education, studied Americans who were learning Dutch for the first time while living in Holland. "When you control for such factors as access to native speakers and the daily exposure level to the language," Snow says, "adults acquire a large vocabulary and rules of grammar more quickly than children do. In my study, adults were found to be as good as children even in pronunciation, although many researchers contend that children have an advantage in speaking like natives."

Obviously not all learning stops when the sensitive period comes to a close. This observation has led some researchers to question the importance of early experiences. What would happen, for example, if a child did not hear a single word of any language until after one year of age? Would the propensity to speak be forfeited forever? Or could later exposure to language make up the deficit?

Because of the unethical nature of performing such an experiment on a child, we may never know the answer to that question. But some indications can be gleaned from animal studies of how early deprivation affects the development of social behavior.

In *An Outline of Psychoanalysis*, Sigmund Freud refers to "the common assertion that the child is psychologically the father of the man and that the events of his first years are of paramount importance for his whole subsequent development." At the University of Wisconsin Primate Laboratory, the pioneering studies of Harry and Margaret Harlow put this belief to the test on our closest living relative—the rhesus monkey.

"Our experiments indicate that there is a critical period somewhere between the third and sixth month of life," write the Harlows, "during which social deprivation, particularly deprivation of the company of [the monkey's] peers, irreversibly blights the animal's capacity for social adjustment."

When later returned to a colony in which there was ample opportunity for interacting with other animals, the experimental monkeys remained withdrawn, self-punishing, and compulsive. Most significantly, they grew up to be inept both as sexual partners and parents. The females never became impregnated unless artificially inseminated. We don't know whether humans, like Harlow's monkeys, must establish close bonds by a certain age or be forever doomed to social failure. But an ongoing longitudinal study, the Minnesota Preschool Project, offers the encouraging finding that emotionally neglected four-year-olds can still be helped to lead normal, happy lives. To rehabilitate the children, the teachers in the project provide them with the kind of intimate attention that is lacking at home.

Perhaps one of the Harlows' observations sheds light on why the project was successful. During the critical period for social development, the Harlows found that even a little bit of attention goes a long way. During the first year of life, for example, only 20 minutes of playtime a day with other monkeys was apparently sufficient for the animals to grow into well-adjusted adults. L. Alan Sroufe, codirector of the Minnesota Project, tells the story of one four-year-old boy who was constantly defiant—the kind of child who would hit the other children with a toy fire truck. Instead of sending him to a corner, the teacher was instructed to remove him from the group and place him with another teacher. The message they hoped to impart: We are rejecting your behavior, but we're not rejecting you. Within a few months, the antisocial little boy learned to change his behavior.

If children aren't exposed to positive social situations until adolescence, however, the prognosis is poor. Like any complex behavior, human socialization requires an elaborate series of learning steps. So by adolescence, the teenager who missed out on many key social experiences as a child has a tremendous handicap to overcome.

Researchers are finding that each stage of life demands different kinds of competencies. This may be why sensitive learning periods exist. "When a baby is born it has to do two things at the same time," says biochemist Steven Rose, of England's Open University. "One is that it has to survive as a baby. The second is that it has to grow into that very different organism, which is a child and then finally an adult. And it is not simply the case that everything the baby does is a miniature version of what we see in the adult."

For example, the rooting reflex, which enables the baby to suckle, is not a preliminary form of chewing. There's a transitional period in which the child must begin eating solid foods. And then other sorts of skills become necessary—the child must learn to walk, talk, form friendships, and when adulthood is reached, find a sexual partner. "But the child does not have to know all that at the beginning," Rose says. "So sensitive periods are necessary because we have to know how to do certain things at certain times during development."

During the course of a sensory system's development, several sensitive periods occur. In the case of human vision, for example, depth perception usually emerges by two months of age and after that remains relatively stable. But it takes the first five years of life to acquire the adult level of visual acuity that allows us to see fine details. And during that prolonged period, we are vulnerable to many developmental problems that can cause this process to go awry. For example, a drooping lid or an eye covered by a cataract—virtually anything that obstructs vision in one of the child's eyes for as few as seven days—can lead to a permanent blurring of sight. This condition, known as amblyopia, is one of the most common ophthalmological disorders. Treatment works only if carried out within the sensitive period, before the final organization of certain cells in the visual cortex becomes fixed. After five years of age, no amount of visual stimulation is likely to reorganize the connections laid down when the young nervous system was developing.

Like molten plastic, the nervous system is, at its inception, highly pliable. But it quickly settles into a rigid cast—one that has been shaped by experience. Just what neurological events set the mold is not known. Some suggestive findings, however, come from the research of John Cronly-Dillon, a professor of ophthalmic optics at the University of Manchester Institute of Science and Technology, in England.

Working with colleague Gary Perry, Cronly-Dillon studied growth activity in the visual cortex of rat pups reared under normal light conditions. To measure growth, researchers monitored the rate at which certain cells synthesized tubulin, a protein vital for forming and maintaining nerve connections. The researchers found that tubulin production in the visual cortex remained at a low level until day 13, which marks the onset of the sensitive period for visual learning. It coincides with the moment when the animal first opens its eyes. At that time, tubulin production soars, indicating a rise in growth activity.

Cronly-Dillon and Perry found that the rat's visual cortex continues to grow for the next week and then declines. By the end of the critical period, when the pup is roughly five weeks old, tubulin production drops to the level attained before the eyes open.

To Cronly-Dillon the surplus of tubulin at the beginning of the critical period and its subsequent cutback have profound implications. "It means that an uncommonly large number of nerve connections can exist at the peak of the critical period, but only a small fraction of them will be maintained at the end," he says. "So the question, of course, is which nerve connections will be kept?"

If Cronly-Dillon is correct, experience probably stabilizes those connections most often used during the sensitive period. "So by definition," he says, "what remains is most critical for survival."

Cronly-Dillon's work elaborates on a theory Spanish neurophysiologist Ramon Y Cajal advanced at the turn of the century. According to this view, which has been gaining broader acceptance in recent times, brain development resembles natural selection. Just as the forces of natural selection ensure the survival of the fittest, so do similar forces preserve the most useful brain circuits.

The beauty of this model is that it could explain why the brain is as exquisitely adapted to its immediate surroundings, just as the mouthparts of insects are so perfectly matched to the sexual organs of the flowers they pollinate. The textures, shapes, sounds, and odors we perceive best may have left their imprint years ago in the neural circuitry of the developing mind.

There is also a certain economic appeal to this outlook. Why, for example, should Japanese adults keep active a neural circuit that permits the distinction between *r* and *l* sounds when neither of these linguistic components is present in their native tongue?

Yet another economic advantage of the theory is that it would explain how nature can forge something as intricate as the brain out of a relatively limited amount of genetic material. "It looks as though what genetics does is sort of make a brain," Blakemore says. "We only have about one hundred thousand genes—and that's to make an entire body. Yet the brain alone has trillions of nerve cells, each one forming as many as ten thousand connections with its neighbors. So imagine the difficulty of trying to encode every step of the wiring process in our DNA."

This vast discrepancy between genes and connections, according to Blakemore, can be overcome by encoding in the DNA the specifications for a "rough brain." "Everything gets roughly laid down in place," Blakemore says. "But the wiring of the young nervous system is far too rich and diffuse. So the brain overconnects and then uses a selection process to fine-tune the system."

The brain of an eight-month-old human fetus is actually estimated to have two to three times more nerve cells than an adult brain does. Just before birth, there is a massive death of unnecessary brain cells, a process that continues through early childhood and then levels off. Presumably many nerve connections that fall into disuse vanish. But that is only part of the selection process—and possibly a small part at that.

According to Blakemore, many neural circuits remain in place but cease to function after a certain age. "I would venture a guess," he says, "that as many as ninety percent of the connections you see in the adult brain are nonfunctional. The time when circuits can be switched on or off probably varies for different parts of the cerebral cortex—depending on what functions they control—and would coincide with the sensitive period of learning. Once the on-off switch becomes frozen, the sensitive period is over."

This doesn't mean, however, that new circuits can't grow. There appears to be a fine-tuning of perception coinciding with these developmental events. And as the brain becomes a finer sieve, filtering out all but a limited amount of sensory input, its strategy for storing information appears to change.

"Studies indicate that as many as fifty percent of very young children recall things in

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pictures," says biochemist Rose. "And by the time we're about four or five, we tend to lose our eidetic [photographic] memory and develop sequential methods of recall."

To Rose, who is studying the neurological mechanisms that underlie learning, this shift in memory process may have an intriguing logic. "To be a highly adaptable organism like man, capable of living in a lot of different environments, one must start out with a brain that takes in everything," Rose explains. "And as you develop, you select what is important and what is not important to remember. If you went on remembering absolutely everything, it would be disastrous."

The Russian neurologist A. R. Luria had a patient cursed with such a memory—the man could describe rooms he'd been in years before, pieces of conversations he'd overheard. His memory became such an impediment that he could not hold even a clerk's job; while listening to instructions, so many associations for each word would arise that he couldn't focus on what was being said. The only position he could manage was as a memory man in a theatrical company.

"The crucial thing then," Rose says, "is that you must learn what to forget."

Some components of the brain, however, must retain their plasticity into adulthood—otherwise, no further learning would be possible, says neuroscientist Bill Greenough, of the University of Illinois, at Urbana-Champaign. While the adult brain cannot generate new brain cells, Greenough has uncovered evidence that it does continue to generate new nerve connections. But as the brain ages, the rate at which it produces these connections slows.

If the young brain can be likened to a sapling sprouting shoots in all directions, then the adult brain is more akin to a tree, whose growth is confined primarily to budding regions. "In the mature brain," Greenough says, "neural connections appear to pop up systematically, precisely where they're needed."

Early experience, then, provides the foundation on which all subsequent knowledge and skills build. "That's why it's extraordinarily difficult to change certain aspects of personality as an adult," says neuroscientist Jonathan Winson, of Rockefeller University. "Psychiatrists have an expression: 'Insight is wonderful, but the psyche fights back.' Unfortunately, one of the drawbacks of critical-period learning is that a lot of misconceptions and unreasonable fears can become frozen in our minds during this very vulnerable period in our development."

Greenough acknowledges that the system isn't perfect; nevertheless, it works to our advantage because you can't build on a wobbly nervous system. "You've got to know who your mother is, and you've got to have perceptual skills," he explains. "These and other types of learning have to jell quickly, or all further development would halt."

Can these insights into the developing brain help educators to devise new strategies for teaching?

"We're a very long way from being able to apply the work of neurobiologists to what chalk-faced teachers are trying to do," says Open University's Rose.

But he can see the rough outline of a new relationship between neurobiology and education, which excites him. "We can now say with considerable certainty that there are important advantages to growing up in an enriched environment," he says. "That does not mean that you should be teaching three-year-olds Einstein's theory of relativity on the grounds that you will be turning them into geniuses later on. But it's probably fair to say that if you want bright kids, you should cuddle them a lot as babies because that increases the number of neural connections produced in the brain." (For another perspective on early learning, see Mind, by Dr. Benjamin Spock, on page 28.)

Although early learning tends to overshadow the importance of later experience, mental development never ceases. Recent studies indicate that our intellectual abilities continue to expand well into our eighties, provided the brain has not been injured or diseased. Most crucial for maintaining mental vigor, according to Greenough, is staying active and taking on new challenges. In his rat studies, he found that lack of stimulation—much more than age—was the factor that limited the formation of new neural connections in the adult brain.

As long as we don't isolate ourselves as we grow older, one very important type of mental faculty may even improve. Called crystallized intelligence, this ability allows us to draw on the store of accumulated knowledge to provide alternate solutions to complicated problems. Analyzing complex political or military strategies, for example, would exploit crystallized intelligence.

There is a danger in believing that because the brain's anatomical boundaries are roughly established early in life, all mental capabilities are restricted, too. "Intelligence is not something static that can be pinned down with an I.Q. test like butterflies on a sheet of cardboard," says Rose. "It is a constant interplay between internal processes and external forces."

To be sure, many types of learning do favor youth. As violinist Isaac Stern says, "If you haven't begun playing violin by age eight, you'll never be great." But in the opinion of Cronly-Dillon, the best time for learning other types of skills may be much later in life. Although he will not elaborate on this until further studies are done, he believes we may even have sensitive periods with very late onsets. "There's a real need," Cronly-Dillon says, "to define all the different types of sensitive periods so that education can take advantage of biological optimums."

It is said that the ability to learn in later life depends on the retention of childlike innocence. "This old saw," insists Cronly-Dillon, "could have a neurological basis."

"Bad day at the lab, dear?"