



# Your Child's Brain

*A baby's brain is a work in progress, trillions of neurons waiting to be wired into a mind. The experiences of childhood, pioneering research shows, help form the brain's circuits for music and math, language and emotion.*

BY SHARON BEGLEY

**Y**ou hold your newborn so his sky blue eyes are just inches from the brightly patterned wallpaper ZZZ:

a neuron from his retina makes an electrical connection with one in his brain's visual cortex. You gently touch his palm with a clothespin; he grasps it, drops it, and you return it to him with soft words and a smile. Crackle: neurons from his hand strengthen their connection to those in his sensory-motor cortex. He cries in the night; you feed him, holding his gaze because nature has seen to it that the distance from a parent's crooked elbow to his eyes exactly matches the distance at which a baby focuses. Zap: neurons in the brain's amygdala send pulses of electricity through the circuits that control emotion. You hold him on your lap and talk... and neurons from his ears start hard-wiring connections to the auditory cortex.

*And you thought you were just playing with your kid.*

When a baby comes into the world her brain is a jumble of neurons, all waiting to be woven into the intricate tapestry of the mind. Some of the neurons have already been hard-wired, by the genes in the fertilized egg, into circuits that command breathing or control heart-beat, regulate body temperature or produce reflexes. But trillions upon trillions more are like the Pentium chips in a computer before the factory preloads the software. They are pure and of almost infinite potential, unprogrammed circuits that might one day compose rap songs and do calculus, erupt in fury and melt in ecstasy. If the neurons are used, they become integrated into the circuitry of the brain by connecting to other neurons: if they are not used, they may die. It is the experiences of childhood, determining which neurons are used, that wire the circuits of the brain as surely as a programmer at a keyboard reconfigures the circuits in a computer. Which keys are typed, which experiences a child has determines whether the child grows up to be intelligent or dull, fearful or self-assured articulate or tongue-tied,

Early experiences are so powerful, says pediatric neurobiologist Harry Chugani of Wayne State University, that "they can completely change the way a person turns out.

By adulthood the brain is crisscrossed with more than 100 billion neurons, each reaching out to thousands of others so that, all told, the brain has more than 100 trillion connections. It is those connections - more than the number of galaxies in the known universe - that give the brain its unrivalled powers. The traditional view was that the wiring diagram is predetermined, like one for a new house, by the genes in the fertilized egg. Unfortunately, even though half the genes - 50,000 - are involved in the central nervous system in some way, there are not enough of them to specify the brain's incomparably complex wiring. That leaves another possibility: genes might determine only the brain's main circuits, with something else shaping the trillions of finer connections. That something else is the environment, the myriad messages that the brain receives from

the outside world. According to the emerging paradigm, "there are two broad stages of brain wiring." says developmental neurobiologist Carla Shatz of the University of California, Berkeley: an early period, when experience is not required, and a later one when it is.

Yet, once wired, there are limits to the brain's ability to create itself. Time limits. Called "critical periods." they are windows of opportunity that nature flings open, starting before birth, and then slams shut, one by one, with every additional candle on the child's birthday cake. In the experiments that gave birth to this paradigm in the 1970s, Torsten Wiesel and David Hubel found that sewing shut one eye of a newborn kitten rewired its brain: so few neurons connected from the shut eye to the visual cortex that the animal was blind even after its eye was reopened- Such rewiring did not occur in adult cats whose eyes were shut. Conclusion: there is a short, early period when circuits connect the retina to the visual cortex. When brain regions mature dictates how long they stay malleable. Sensory areas mature in early childhood; the emotional limbic system is wired by puberty; the frontal lobes - seat of understanding - develop at least through the age of 16.

The implications of this new understanding are at once promising and disturbing. They suggest that, with the right input at the right time, almost anything is possible. But they imply, too, that if you miss the window you're playing with a handicap. They offer an explanation of why the gains a toddler makes in Head Start are so often evanescent: this intensive instruction begins too late to fundamentally rewire the brain- And they make clear the mistake of postponing instruction in a second language (page 58). As Chugani asks, What idiot decreed that foreign-language instruction not begin until high school?"

Neurobiologists are still at the dawn

of understanding exactly which kinds of experiences, or sensory input, wire the brain in which ways. They know a great deal about the circuit for vision. It has a neuron-growth spurt at the age of 2 to 4 months, which corresponds to when babies start to really notice the world, and peaks at 8 months, when each neuron is connected to an astonishing 15,000 other neurons.



### The Logical Brain

*SKILL:* Math and logic

*LEARNING WINDOW:* Birth to 4 years

*WHAT WE KNOW:* Circuits for math reside in the brain's cortex near those for music. Toddlers taught simple concepts, like one and many, do better in math. Music lessons may help develop spatial skills

*WHAT WE CAN Do ABOUT IT:* Play counting games with a toddler, Have him set the table to learn one-to-one relationships - one plate, one fork per peri-person. And, to hedge your bets, turn on a Mozart CD.

A baby whose eyes are clouded by cataracts from birth will, despite cataract-removal surgery at the age of 2, be forever blind. For other systems, researchers know what happens, but not - at the level of neurons and molecules how. They nevertheless remain confident that cognitive abilities work much like sensory ones, for the brain is parsimonious in how it conducts its affairs: a mechanism that works fine for wiring vision is not likely to be abandoned when it comes to circuits for music. "Connections are not forming willv-nillv." says Dale Purves of Duke University. "but are prompted by activity."

*LANGUAGE:* Before there are words, in the world of a newborn, there are sounds. In English they are phonemes such as sharp ba's and da's, drawn-out ee's and ll's and sibilant sss's. In Japanese they are different-barked hi's, merged rr/ll's. When a child hears a phoneme over and over neurons from his ear stimulate the formation of dedicated connections in his brain

auditory cortex. This "perceptual map." explains Patricia Kuhl of the University of Washington, reflects the apparent distance - and thus the similarity - between sounds. So in English-speakers, neurons in the auditory cortex that respond to "ra" lie far from those that respond to "la." But for Japanese, where the sounds are nearly identical, neurons that respond to "ra" are practically intertwined, like L.A. freeway spaghetti with those for "la." As a result, a Japanese speaker will have trouble distinguishing the two sounds.

Researchers find evidence of these tendencies across many languages. By 6 months of age. Kuhl reports, infants in English-speaking homes already have different auditory maps (as shown by electrical measurements that identify which neurons respond to different sounds) from those in Swedish-speaking homes. Children are functionally deaf to sounds absent from their native tongue. The map is completed by the first birthday, "By 12 months." says Kuhl, "infants have lost the ability to discriminate sounds that are not significant in their language, and their babbling has acquired the sound of their language."

Kuhl's findings help explain why learning a second language after, rather than with, the first is so difficult. "The perceptual map of the first language constrains the learning of a second." she says. In other words, the circuits are already wired for Spanish, and the remaining undedicated neurons have lost their ability to form basic new connections for, say, Greek. A child taught a second language after the age of 10 or so is unlikely ever to speak it like a native. Kuhl's work also suggests why related languages such as Spanish and French are easier to learn than unrelated ones: more of the existing circuits can do double duty. With this basic circuitry established a baby is primed to turn sounds into words. The more words a child hears

the faster she learns language, according to psychiatrist Janellen Huttenlocher of the University of Chicago. Infants whose mothers spoke to them a lot knew 131 more words at 20 months than did babies of more taciturn or less involved, mothers; at 24 months, the gap had widened to 295 words. (Presumably the findings would also apply to a father if he were the primary care giver.) It didn't matter which words the mother used - monosyllables seemed to work. The sound of words, it seems, builds up neural circuitry that can then absorb more words, much as creating a computer file allows the user to fill it with prose. "There is a huge vocabulary to be acquired," says Huttenlocher, "and it can only be acquired through repeated exposure to words,"

**Music:** Last October researchers at the University of Konstanz in Germany reported that exposure to music rewires neural circuits, In the brains of nine string players examined with magnetic resonance imaging, the amount of somatosensory cortex dedicated to the thumb and fifth finger of the left hand - the fingering digits - was significantly larger than in nonplayers. How long the players practiced each day did not affect the cortical map. But the age at which they been introduced to their muse did: the younger the child when she took up an instrument, the more cortex she devoted to playing it.

Like other circuits formed early in life, the ones for music endure. Wayne State's Chugani played the guitar as a child, then gave it up. A few years ago he started taking piano lessons with his young daughter. She learned easily, but he couldn't get his fingers to follow his wishes. Yet when Chugani recently picked up a guitar, he found to his delight that "the songs are still there," much like the muscle memory for riding a bicycle.

**MATH AND LOGIC:** At UC Irvine, Cordon Shaw suspected that all higher-order thinking is characterized by similar patterns of neuron firing. "If you're working with little kids," says Shaw, "you're not going to teach them higher

mathematics or chess. But they are interested in and can process

## The Language Brain

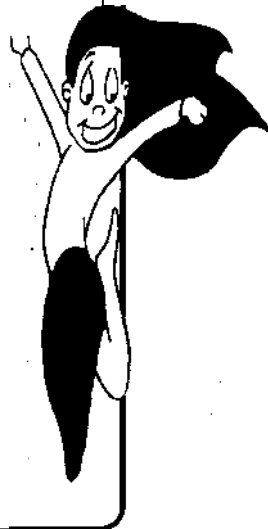
**SKILL:** Language

**LEARNING WINDOW:** Birth to 10 years

**WHAT WE KNOW:** *Circuits in the auditory cortex, representing the sounds that form words, are wired by the age of 1. The more words a child hears by 2, the larger her vocabulary will grow. Hearing problems can impair the ability to match sounds to letters.*

**WHAT WE CAN DO ABOUT IT:**

*Talk to your child a lot. If you want her to master a second language introduce it by the age of 10. Protect hearing by treating ear infections promptly.*



music." So Shaw and Frances Rauscher gave 19 preschoolers piano or singing lessons. After eight months, the researchers found, the children "dramatically improved in spatial reasoning," compared with children given no music lessons, as shown in their ability to work mazes, draw geometric figures and copy patterns of two-color blocks. The mechanism behind the "Mozart effect" remains murky, but Shaw suspects that when children exercise cortical neurons by listening to classical music, they are also strengthening circuits used for mathematics. Music, says the UC team, "excites the inherent brain patterns and enhances their use in complex reasoning tasks."

**EMOTIONS:** The trunk lines for the circuits controlling emotion are laid down before birth. Then parents take over. Perhaps the strongest influence is what psychiatrist Daniel Stem calls attainment - whether caregivers "play back a child's inner feelings." If a baby's squeal of delight at a puppy is met with a smile and hug, if her excitement at seeing a plane overhead is mirrored, circuits for these emotions are reinforced. Apparently, the brain uses the same pathways to generate an emotion as to respond to one. So if an emotion is reciprocated, the electrical and chemical signals that produced it are reinforced. But if emotions are

repeatedly met with indifference, or a clashing response - Baby is proud of building a skyscraper out of Mom's best pots, and Mom is terminally annoyed - those circuits become confused and fail to strengthen. The key here is "repeatedly": one dismissive harrumph will not scar a child for life. It's the pattern that counts, and it can be very powerful: in one of Stem's studies, a baby whose mother never matched her level of excitement became extremely passive, unable to feel excitement or joy.

Experience can also wire the brain's "calm down" circuit, as Daniel Goleman describes in his best-selling "Emotional Intelligence." One father gently soothes his crying infant, another drops him into his crib; one mother hugs the toddler who just skinned her knee, another screams "It's your own stupid fault!" The first responses are attuned to the child's distress; the others are wildly out of emotional sync. Between 10 and 18 months, a cluster of cells in the rational prefrontal cortex is busy hooking up to the emotion regions. The circuit seems to grow into a control switch, able to calm agitation by infusing reason into emotion. Perhaps parental soothing trains this circuit, strengthening the neural connections that form it, so that the child learns how to calm herself down. This all happens so early that the effects of nurture can be misperceived as innate nature.

Stress and constant threats also rewire emotion circuits. These circuits are centered on the amygdala, a little almond-shaped structure deep in the brain whose job is to scan incoming sights and sounds for emotional content. According to a wiring diagram worked out by Joseph LeDoux of New York University impulses from eye and ear reach the amygdala before they get to the rational, thoughtful neocortex. If a sight, sound or experience has proved painful before - Dad's drunken arrival home was followed by a beating - then

the amygdala floods the circuits with neurochemicals before the higher brain knows what's happening. The more often this pathway is used, the easier it is to trigger the mere memory of Dad may induce fear. Since the circuits can stay excited for days, the brain remains on high alert. In this state, says neuroscientist Bruce Perry of Baylor College of Medicine, more circuits attend to nonverbal cues - facial expressions, angry noises - that warn of impending danger. As a result, the cortex falls behind in development and has trouble assimilating complex information such as language.

**MOVEMENT:** Fetal movements begin at 7 weeks and peak between the 15th and 17th weeks. That is when regions of the brain controlling movement start to wire up. The critical period lasts a while: it takes up to two years for cells in the cerebellum, which controls posture and movement, to form functional circuits, "A lot of organization takes place using information gleaned from when the child moves about in the world," says William Greenough of the University of Illinois. "If you restrict activity you inhibit the formation of synaptic connections in the cerebellum." The child's initially spastic movements send a signal to the brain's motor cortex; the more the arm, for instance, moves, the stronger the circuit, and the better the brain will become at moving the arm intentionally and fluidly. The window lasts only a few years: a child immobilized in a body cast until the age of 4 will learn to walk eventually, but never smoothly.

There are many more circuits to discover, and many more environmental influences to pin down. Still, neurolabs are filled with an unmistakable air of optimism these days. It stems from a growing understanding of how, at the level of nerve cells and molecules, the brain's circuits form. In the beginning, the brain-to-be consists of only a few advance scouts breaking trail: within a week of conception they march out of the embryo's "neural tube," a cylinder of cells extending from head to tail. Multiplying as they go

(the brain adds an astonishing 250,000 neurons per minute during gestation), the neurons clump into the brain stem which commands heartbeat and breathing, build the little cerebellum at the back the head which controls posture and movement, and form the grooved and rumped cortex wherein thought and perception originate. The neural cells are so small, and the distance so great, that a neuron striking out for what will be the prefrontal cortex migrates a distance equivalent to a human's walking from New York to California, says developmental neurobiologist Mary Beth Hattn of Rockefeller University.

Only when they reach their destinations do these cells become true neurons. They grow a fiber called an axon that carries electrical signals. The axon might reach only to a neuron next door, or it might wend its way clear across to the other side of the brain. It is the axonal connections that form the brain's circuits. Genes determine the main highways along which axons travel to make their connection. But to reach particular target cells, axons follow chemical cues strewn along their path. Some of these chemicals attract: this way to the motor cortex! Some repel: no, that way to the olfactory cortex. By the fifth month of gestation most axons have reached their general destination. But, like the prettiest girl in the bar, target cells attract way more suitors - axons - than they can accommodate.

How does the wiring get sorted out? The baby neurons fire electrical pulses once a minute, in a fit of what Berkeley's Shatz calls auto-dialing, cells fire together, the target cells "ring" together. The target cells then release a flood of chemicals, called trophic factors, that strengthen the incipient connections. Active neurons respond better to trophic factors than inactive ones. Barbara Barres of Stanford University reported in October. So neurons that are quiet when others throb lose their grip on the target cell. "Cells that fire together wire together." says Shatz,

The same basic process continues after birth. Now, it is not an auto-dialer that sends signals, but stimuli from the senses. In experiments with rats, Illinois's Greenough found that animals raised with playmates and toys and other stimuli grow 25 percent more synapses than rats deprived of such stimuli.

Rats are not children, but all evidence suggests that the same rules of brain development hold.

## The Musical Brain

**SKILL:** Music

**LEARNING WINDOW:** 3 to 10 years

**WHAT WE KNOW:** *String players, have a larger area of their sensory cortex dedicated to the fingering digits on their left hand. Few concert-level performers begin playing later than the age of 10. It is much harder to learn an instrument as an adult.*

**WHAT WE CAN DO ABOUT IT:**

*Sing songs with children. Play structured melodic music. If a child shows any musical aptitude or interest, get an instrument into her hand early.*

