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How does a Baby's Brain Work?—Video from The National Geographic, January 2015

Baby Brains

The first year a baby's brain needs love to develop. What happens in the first year is profound.

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In the late 1980s, when the crack cocaine epidemic was ravaging America's cities, Hallam Hurt, a neonatologist in Philadelphia, worried about the damage being done to children born to addicted mothers. She and her colleagues, studying children from low-income families, compared four-year-olds who'd been exposed to the drug with those who hadn't. They couldn't find any significant differences. Instead, what they discovered was that in both groups the children's IQs were much lower than average.

"These little children were coming in cute as buttons, and yet their IQs were like 82 and 83," Hurt says. "Average IQ is 100. It was shocking."

The revelation prompted the researchers to turn their focus from what differentiated the two groups toward what they had in common: being raised in poverty. To understand the children's environment, the researchers visited their homes with a checklist. They asked if the parents had at least ten books at home for the children, a record player with songs for them, and toys to help them learn numbers. They noted whether the parents spoke to the children in an affectionate voice, spent time answering their questions, and hugged, kissed, and praised them.

The researchers found that children who received more attention and nurturing at home tended to have higher IQs. Children who were more cognitively stimulated performed better on language tasks, and those nurtured more warmly did better on memory tasks. Many years later, when the kids had entered their teens, the researchers took MRI images of their brains and then matched them up with the records of how warmly nurtured the children had been at both four and eight years old. They found a strong link between nurturing at age four and the size of the hippocampus—a part of the brain associated with memory—but found no correlation between nurturing at age eight and the hippocampus. The results demonstrated just how critically important an emotionally supportive environment is at a very young age. The Philadelphia study, published in 2010, was one of the first to demonstrate that childhood experience shapes the structure of the developing brain. Since then, other studies have shown a link between a baby's socioeconomic status and the growth of its brain. Despite coming prewired with mind-boggling capacities, the brain depends heavily on environmental input to wire itself further. Scientists are now discovering precisely how that development is molded by the interplay between nature and nurture.

Peering inside children's brains with new imaging tools, scientists are untangling the mystery of how a child goes from being barely able to see when just born to being able to talk, ride a tricycle, draw, and invent an imaginary friend by the age of five. The more scientists find out about how children acquire the capacity for language, numbers, and emotional understanding during this period, the more they realize that the baby brain is an incredible learning machine. Its future—to a great extent—is in our hands.

If the metamorphosis of a cluster of cells into a suckling baby is one of life's great miracles, so is the transformation of that wobbly infant into a walking, talking toddler capable of negotiating bedtime. While researching this story, I have watched that miracle unfold before my eyes as my daughter has gone from a fidgety bundle with only a piercing cry signaling hunger to a feisty three-year-old who insists on putting on her sunglasses before stepping out of the house. The blossoming of her mental and emotional abilities has been a string of marvels, deepening my amazement at how deftly a baby's brain comes to grasp the world.

The milestones she has passed would be recognizable to any parent. At two she knew enough to realize that she didn't have to hold my hand when walking on the sidewalk; she would reach for my hand only when we were about to cross the street. Around the same age, she also learned to block the drain in the bathtub with the ball of her foot—turning what was to be a quick shower into a playful bath. Before she turned three, she was holding lengthy conversations and coming up with rhymes: "If the candy tastes bad, Willy Wonka will be sad."

Despite millennia of child rearing, we have only a limited understanding of how babies take such gigantic strides in cognitive, linguistic, reasoning, and planning ability. The lightning pace of development in these early years coincides with the formation of a vast skein of neural the baby grows, receiving a flood of sensory input, neurons get wired to other neurons, resulting in some hundred trillion connections by age three.

Different stimuli and tasks, such as hearing a lullaby or reaching for a toy, help establish different neural networks. Circuits get strengthened through repeated activation. The sheath encasing nerve fibers—made of an insulating material called myelin—thickens along oft-used pathways, helping electrical impulses travel more quickly. Idle circuits die through the severing of connections, known as synaptic pruning. Between the ages of one and five, and then again in early adolescence, the brain goes through cycles of growth and streamlining, with experience playing a key role in engraving the circuits that will endure.

How nature and nurture combine to shape the brain is nowhere more evident than in the development of language ability. How much of that comes hardwired, and how do babies acquire the rest? To learn how researchers are answering that question, I visit Judit Gervain, a cognitive neuroscientist at Paris Descartes University who has spent the past decade probing the linguistic acumen of children, ranging in age from days to a few years. We meet on the steps of Robert-Debré Hospital in Paris, where Gervain is readying an experiment on newborns.

I follow her into a room down the hall from the maternity ward. The morning's first subject is wheeled in on a cart, swaddled in a pink polka-dot blanket, with dad in tow. A research assistant slips a skullcap studded with buttonlike sensors onto the infant's head. The plan is to image the baby's brain while playing a variety of audio sequences, like nu-ja-ga. But before any observations can begin, the baby emits a series of high-pitched cries, making it known he isn't going to submit. The assistant hurriedly removes the cap, and the dad cradles the baby.

After they leave, Gervain, who had just become a mother a few months earlier, tells me that such failures are not uncommon. Another newborn—also accompanied by dad—is wheeled in. Gervain's assistant follows the same protocol, and this time the observing goes off without a hitch. The baby sleeps through it.

Gervain and her colleagues have used a similar setup to test how good newborns are at discriminating between different sound patterns. Using near-infrared spectroscopy, the researchers imaged the brains of babies while they heard audio sequences. In some, the sounds were repeated in an ABB structure, such as mu-ba-ba; in others, an ABC structure, such as mu.ba-ge. The researchers found that brain regions responsible for speech and audio processing responded more strongly to the ABB sequences. In a later study they found that the newborn brain was also able to distinguish between audio sequences with an AAB pattern and those with an ABB pattern. Not only could babies discern repetition, they also were sensitive to where it occurred in the sequence.

Gervain is excited by these findings because the order of sounds is the bedrock upon which words and grammar are built. "Positional information is key to language," she says. "If something is at the beginning or at the end makes a big difference: 'John killed the bear' is very different from 'The bear killed John.'"

That the baby brain responds from day one to the sequence in which sounds are arranged suggests that the algorithms for language learning are part of the neural fabric infants are born with. "For a long time we had this linear view. First, babies are learning sounds, then they are grammatical rules from the beginning."

Researchers led by Angela Friederici, a neuropsychologist at the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, Germany, have found evidence of such comprehension in an experiment with four-month-old German babies exposed to an unfamiliar language.

The children first heard a series of Italian sentences representing two types of construction: "The brother can sing" and "The sister is singing." After three minutes they listened to another set of Italian sentences, some of which were grammatically incorrect, along the lines of, "The brother is sing" and "The sister can singing." During this phase the researchers measured the infants' brain activity using tiny electrodes placed on the scalp. In the first round of testing the babies showed a similar brain response to both correct and incorrect sentences. A few rounds of training later, the infants exhibited very different activation patterns when they heard erroneous constructions.

In just 15 minutes the babies appeared to have absorbed what was correct. "Somehow they must have learned it, despite not comprehending the meaning of the sentences," Friederici tells me. "At this point it's not syntax. It's phonologically encoded regularity."

Researchers have shown that children around two and a half years old are savvy enough to correct grammatical mistakes made by puppets. By the age of three most children seem to master a considerable number of grammatical rules. Their vocabulary burgeons. This flowering of language ability comes about as new connections are made among neurons, so that speech can be processed on multiple levels: sound, meaning, and syntax. Scientists have yet to unveil the precise map followed by the infant brain on the path to linguistic fluency. But what's clear, in the words of Friederici, is this: "The equipment alone is not enough. You also need input."

On my way to Leipzig to interview Friederici, my attention is drawn to a mother and her young son, engaging in conversation on a shuttle bus at the Munich airport. "What do you see in the distance?" the mother asks as the bus takes us from the terminal to the aircraft. "I see a lot of planes!" the kid exults, bouncing. Seated in a row ahead of me on the flight, the two keep up an unflaggingly spirited exchange. The woman stops to answer the boy's every question as she reads him one picture book after another, drawing on what seems like a limitless reservoir of enthusiasm. When we land, I learn that the mom, Merle Fairhurst, is a cognitive neuroscientist who studies child development and social cognition. It isn't surprising that she is determined to apply the emerging research on how stimulation can help the developing brain.

More than two decades ago Todd Risley and Betty Hart, both child psychologists then at the University of Kansas in Lawrence, recorded hundreds of hours of interactions between children and adults in 42 families from across the socioeconomic spectrum, following the kids from the age of nine months to three years.

Studying the transcripts of these recordings, Risley and Hart made a surprising discovery. Children in well-off families—where the parents were typically college-educated professionals— heard an average of 2,153 words an hour spoken to them, whereas children in families on welfare heard an average of 616 words. By the age of four this difference translated to a cumulative gap of some 30 million words. Parents in poorer homes tended to make shorter, more perfunctory comments, like "Stop that," and "Get down," whereas parents in wealthier homes had extended conversations with their kids about a variety of topics, encouraging them to use their memory and imagination. The kids in low socioeconomic families were being raised on a poor linguistic diet.

The amount of talking parents did with their children made a big difference, the researchers found. The kids who were spoken to more got higher scores on IQ tests at age three. They also performed better in school at ages nine and ten.

Exposing children to more words would seem simple enough. But language delivered by television, audio book, Internet, or smartphone—no matter how educational—doesn't appear to do the job. That's what researchers led by Patricia Kuhl, a neuroscientist at the University of Washington in Seattle, learned from a study of nine-month-old children.

Kuhl and her colleagues were exploring a key puzzle of language acquisition: how babies home in on the phonetic sounds of their native language by the age of one. In the first few months of their lives, babies show a knack for discriminating between sounds in any language, native or foreign. Between six and 12 months of age, however, they start losing the ability to make such distinctions in a foreign language, while getting better at discriminating between native language sounds. Japanese children, for example, are no longer able to distinguish between "l" and "r" sounds.

In their study the researchers exposed nine-month-olds from English-speaking families to Mandarin. Some of the children interacted with native Chinese-speaking tutors, who played with them and read to them. "The babies were entranced by these tutors," Kuhl says. "In the waiting room they would watch the door for their tutors to come in." Another group of children saw and heard the same Mandarin-speaking tutors through a video presentation. And a third group heard only the audio track. After all the children had been through 12 sessions, they were tested on their ability to discriminate between similar phonetic sounds in Mandarin.

The researchers expected the children who'd watched the videos to show the same kind of learning as the kids tutored face-to-face. Instead they found a huge difference. The children exposed to the language through human interactions were able to discriminate between similar Mandarin sounds as well as native listeners. But the other infants—regardless of whether they had watched the video or listened to the audio—showed no learning whatsoever.

After gaining power in Romania in the mid-1960s, the communist leader Nicolae Ceausescu implemented drastic measures to transform the country from an agricultural society into an industrial one. To increase the population, the regime limited contraception and abortion, and imposed a tax on couples older than 25 who were childless. Thousands of families moved from villages to cities to take jobs at government factories. These policies led many parents to abandon their newborn children, who were then placed in a state-run institution called a leagan—the Romanian word for "cradle."

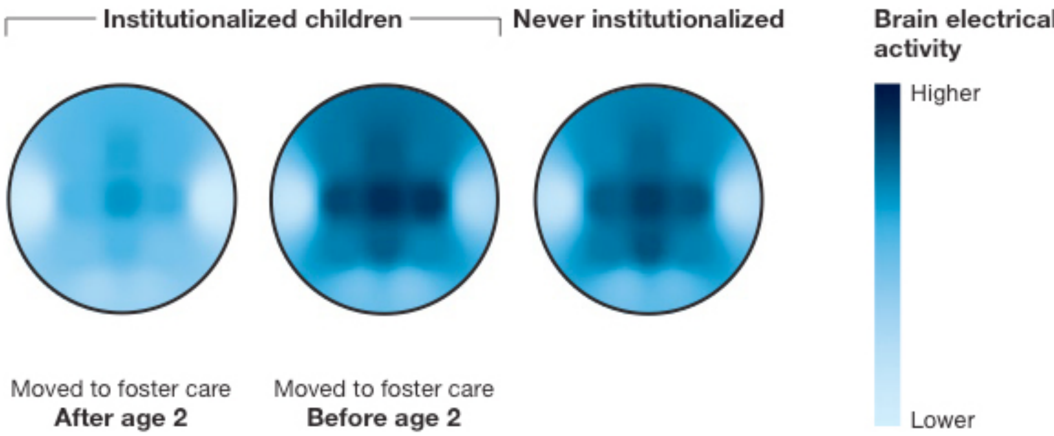
It was only after Ceausescu was deposed in 1989 that the outside world saw the horrific conditions in which these children were living. As babies, they were left in cribs for hours. Typically their only human contact was when a caregiver—

each responsible for 15 to 20 children—came to feed or bathe them. As toddlers, they hardly received any attention. The system of institutionalized care was slow to change, and in 2001, U.S. researchers began a study of 136 children from six institutions to investigate the impact of neglect on their development. The researchers—led by Charles Zeanah, a child psychiatrist at Tulane University; Nathan Fox, a developmental psychologist and neuroscientist at the University of Maryland; and Charles Nelson, a neuroscientist at Harvard—were struck by the children's aberrant behaviors. Many of the kids, less than two years old when the study began, showed no attachment to their caregivers. When upset, they wouldn't go to the caregivers. "Instead, they showed these almost feral behaviors that we had never seen before—aimlessly wandering around, hitting their heads against the floor, twirling and freezing in one place," Fox says.

When the researchers conducted an EEG test of the children's brains, they found that these signals were weaker than the signals recorded from similarly aged children in the general population. "It was as if a dimmer switch had been used to turn their brain activity down," Fox says. He and his colleagues then placed half of the kids with foster families that they picked with the help of social workers. The remaining kids stayed at the institutions. The foster families received a monthly stipend, books, toys, diapers and other supplies, as well as periodic visits by the social workers. Fox and his colleagues followed the children over the next several years and saw dramatic differences emerge between the groups. At age eight the children placed with foster families at age two or earlier showed EEG brain patterns that were indistinguishable from those of typical eight-year-olds. The kids who had remained at the institutions continued to have weaker EEGs. Although all the children in the study had smaller brain volumes than similarly aged kids in the general population, the ones who received foster care had more white matter—axons connecting neurons—than the institutionalized kids. "It suggests that there were more neuronal connections made in the children who experienced the intervention," Fox explains.

The most striking difference between the two sets of children—evident by the age of four—was in their social abilities. "We find that many of the children who were put into our intervention, particularly the children who were taken out of institutions early, could now relate to their caregiver in the way that a typical child would," Fox says. "There's enough plasticity in the brain early in life that allows children to overcome negative experiences." And that, Fox says, is the best news: Some of the debilitating effects of early deprivation can be addressed with appropriate nurturing, as long as it is provided within a critical period of development.

A parental training program led by neuroscientist Helen Neville at the University of Oregon in Eugene aims to do just that. The researchers sign up participants from among families enrolled in Head Start, a U.S. government program that gives a leg up to preschoolers from low-income families. Parents or care providers come in for a class every week over a twomonth period. In the first few classes they get tips on lowering the stress involved in the day-today care of children. As any parent can testify, these stresses can at times be overwhelming to even the most Zen-like among us, and they can feel even more burdensome to parents dealing with financial worries. “You find yourself on edge because you don’t have certain things,” says Patricia Kycek, a Eugene mom who’s taken the classes.



CRITICAL YEARS

The amount of brain activity in the earliest years affects how much there is later in life. These EEG scans of eight-year-olds show that institutionalized children who were not moved to a nurturing foster care environment before they were two years old have less activity than those who were.

Parents learn to emphasize positive reinforcement, expressing praise for specific accomplishments. “We encourage them to shift the focus from scolding your child every time they are doing something wrong to noticing every time they are doing something right,” explains Sarah Burlingame, a former parent instructor. In later weeks parents learn how to stimulate the child. In one activity that they are encouraged to try at home, the parent asks the child to pick out various objects—a spoon, a bottle, a pen—and guess which will float and which will sink. Then the child gets to test each prediction in a bucket of water or in the bathtub.

The children receive training in attention and self-control in a 40-minute session every week. They work on focusing on a task in the midst of distractions—for instance, coloring inside the lines of figures while other kids bounce balloons all around. Instructors also teach them to better identify their emotions through a game called Emotional Bingo, in which children match states like “happy” and “sad” with facial expressions. In some later classes the kids learn to practice calming techniques, like taking a deep breath when they are upset. At the end of the eight weeks the researchers evaluate the kids on language, nonverbal IQ, and attention. Through a questionnaire given to the parents, they also assess how the kids are doing behaviorally. In a paper published in July 2013, Neville and her colleagues reported that kids in

Head Start who received the intervention showed significantly higher increases on these measures than those who did not. Parents reported experiencing much lower stress in managing their children. “When you change parenting and stress level goes down, that leads to increased emotional regulation and better cognition for the kids,” Neville says.

Tana Argo, a young mother of four, decided to go through the program to make sure she wouldn’t subject her children to the kind of neglect that she had suffered as a child. “I grew up with a lot of stress and drama,” she says. “I told myself, I’m going to remember this with my kids. This won’t happen to my kids.”

What she learned—she says—has altered the family’s dynamic, creating more time for play and learning. When I visit her at home one afternoon, she describes how happy she felt a few days earlier when she saw her four-year-old daughter—the youngest—plop down on the carpet to thumb through a children’s encyclopedia. As I’m leaving, I notice the encyclopedia resting on top of a stack of books, most of them for children. In the best of circumstances, that stack would perhaps serve as a wall against the generational dominoes of poverty and neglect, helping Argo’s kids build a future that she never had a shot at.