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[To come after editing]
Quiz

How Well Do You Know Your Child’s Brain?

1) Which action by a pregnant woman poses the greatest risk to her baby?
   (a) Drinking two beers one evening
   (b) Fleeing from a hurricane
   (c) Eating sushi for dinner
   (d) Flying in an airplane
   (e) Walking three miles

2) How do your child’s genes and his environment interact during development?
   (a) His genes influence his sensitivity to environmental features
   (b) His environment influences the expression of his genes
   (c) His genes influence how you care for him
   (d) All of the above
   (e) None of the above

3) What fraction of the calories eaten by a five-year-old go to power her brain?
   (a) One tenth
   (b) One quarter
   (c) One half
   (d) Two thirds
   (e) Nearly all
4) Which of the following is a good way to get your child to eat his spinach?
(a) Cover it in melted cheese
(b) Start the meal with a few bites of dessert
(c) Feed her with soy-based formula as an infant
(d) All of the above
(c) None of the above

5) Which of the following increases a baby’s IQ?
(a) Breastfeeding during infancy
(b) The mother eating fish during pregnancy
(c) Listening to Mozart
(d) All of the above
(e) None of the above

6) If you cover a doll, then remove the drape, what will a baby be most surprised to see?
(a) Two dolls
(b) A toy car
(c) An upside-down doll
(d) A stuffed octopus
(c) A cheeseburger

7) Which of the following activities is likely to improve a child’s school performance?
(a) Studying with a friend
(b) Listening to music while studying
(c) Taking breaks from studying to play video games
(d) All of the above
(e) None of the above

8) What kind of dream experience is not yet within the capacity of a three-year-old?
(a) Seeing a dog standing around
(b) Playing with toys
(c) Sleeping in the bathtub
(d) Watching tropical fish
(c) Looking at an empty room

9) What accelerates the ability to understand what other people are thinking?
(a) Learning a second language
(b) Having an older sibling
(c) Parents who talk about emotions
(d) All of the above
(e) None of the above

10) Which of these activities reduces a child’s risk of nearsightedness?
(a) Eating fish
(b) Playing outside
(c) Learning a musical instrument
(d) Getting enough sleep
(e) Resting her eyes

11) Which categories can an infant distinguish?
(a) Male faces from female faces
(b) Major chords from dissonant chords
(c) The mother’s language from a foreign language
(d) All of the above
(e) None of the above

12) Which of the following interventions has the largest effect?
(a) Ballet lessons improve gender identity
(b) Etiquette lessons improve empathy
(c) Moral lessons improve behavior
(d) Music lessons improve math ability
(e) Drama lessons improve social adjustment

13) What increases a child’s likelihood of becoming autistic?
(a) Being born prematurely
(b) Having an unresponsive mother
(c) Watching too much TV
(d) Receiving vaccinations
14) How does Ritalin improve focus in kids with attention-deficit/hyperactivity disorder?
(a) By altering the structure of brain circuits
(b) By sedating the child slightly
(c) By activating the same neurons as cocaine and amphetamine
(d) All of the above
(e) None of the above

15) Which of the following activities improves self-control?
(a) Pretending to be a fireman
(b) Being breastfed
(c) Watching baby videos
(d) Sleeping with parents
(e) Having cross-gender friendships

16) Brain imaging can do which of the following?
(a) Diagnose brain disorders
(b) Predict reading and math ability
(c) Determine when a criminal is lying
(d) All of the above
(e) None of the above
17) Which of these experiences is most associated with future reading difficulties?
(a) Being deprived of children’s books as a toddler
(b) Writing letters backward at the age of four
(c) Having difficulty identifying spoken sounds
(d) Speaking two languages
(e) Not hearing enough spoken language early in life

18) Which of the following is most likely to improve a shy child’s future life?
(a) Having parents who read science books
(b) Playing with toy trucks
(c) Growing up in China
(d) All of the above
(e) None of the above

19) Where did the disciplinary concept of “time out” originate?
(a) The rules of organized sports
(b) Frustrated parents
(c) Computer engineering
(d) Military slang
(e) Studies of learning in laboratory animals

20) How do children who learn a second language compare with monolingual children?
(a) Better at self-control
(b) Better at taking the perspective of other people
(c) Experience cognitive decline later in adulthood
(d) All of the above
(e) None of the above

Key: 1) b, 2) d, 3) c, 4) d, 5) b, 6) a, 7) c, 8) b, 9) d, 10) b, 11) d, 12) e, 13) a, 14) c, 15) a,
16) e, 17) a, 18) c, 19) e, 20) d
Introduction

The Brain That Builds Itself

Moms and dads ask a lot of questions. My son says video games make him smarter—is that possible? How essential is it to breastfeed the baby? Is it okay to eat fish during pregnancy? Are vaccines safe for kids? My preschooler is writing her Rs backward—is she dyslexic? And why can’t I drag my teenager out of bed?

Call us geeks, but when we hear such concerns, we think about neuroscience. All of these questions involve the brain and how it develops. Childhood is a period of dramatic brain growth and behavioral change—and parents have a front-row seat. If you find this process as fascinating as we do, or if you’re simply looking for some answers, this book is for you.

We cover the entire period from conception to college—because brain development goes on a lot longer than the first three years, where many other books stop. The growth and maturation of a child’s brain is an intricate process taking decades, in which the brain grows and adapts to the surrounding world. The job won’t be entirely finished until your child is in college. So whether your child is an infant, a toddler, or a teen, read on.

Between us, we have over forty years of experience as neuroscientists. Sandra started in the laboratory doing research on brain development and plasticity and went on to edit one of the leading journals in neuroscience. She has read thousands of papers, many of them reporting pioneering discoveries. Her critical eye comes from having a
view of the field that is both broad and deep. She knows when a result is sound and when it is fishy.

Sam is a professor and researcher at a great university. He has been publishing original research and teaching students for over twenty years. His own research concerns how the brain processes information and learns—and how this process can go wrong in early life.

Sam is also a dad. Before his daughter came along, he used to talk about what we called “cocktail party neuroscience.” Life has changed for him, so now it’s “preschool potluck neuroscience.” At these parties, parents and teachers ask lots of fun questions, but sometimes he’s noticed a touch of anxiety as well.

Your questions sent us to the library. Together we scoured the technical literature, studying many hundreds of papers in neuroscience, psychology, medicine, and epidemiology. We synthesized this vast literature into our best interpretation of what is known about children’s brains. This book is the result of all that research. In it, we explain the science, debunk myths, and include practical tips for you as parents.

Here’s our first instruction: **take a deep breath and relax.** Really. The things you’re worrying about are much smaller factors in your child’s well-being than you might imagine. Many modern parents believe that children’s personality and adult behavior are shaped mainly by parenting. This belief is not universal—and research paints a very different picture.

There is a simple way to summarize much of the research on the neuroscience of child development: they grow like dandelions. This term originates from Sweden, where the term *maskrosbarn* (“dandelion child”) is used to describe children who seem to
flourish regardless of their circumstances. Psychological studies suggest that such children are relatively common (at least when raised by “good enough” parents who do not abuse or neglect them). From an evolutionary perspective, this makes sense; children who can make do with whatever time and attention their parents can spare are more likely to survive and pass along their genes under tough conditions. For many brain functions, from temperament to language to intelligence, the vast majority of children are dandelions.

The developing brain has been shaped by thousands of generations of evolution to become the most sophisticated information-processing machine on earth. And, even more amazingly, it builds itself. For instance, you do not need to teach your children to notice—and eventually produce—human speech. Your son or daughter knows, very early on, that the noises you make have more meaning than other sounds. So even if you never give your children a speech lesson, they are highly unlikely to start imitating the air conditioner or the family cat. At least not convincingly.

Children are not passive recipients of parenting or schooling, but active participants in every aspect of their own development. From birth, their brains are prepared to seek out and make use of experiences that suit their individual needs and preferences. For this reason, brain development requires no special equipment or training, and most children find a way to grow in whatever conditions the world has to offer them.

If children are so adaptable and smart, why can’t they start using their brains for high-powered activities right away? In large part, it’s because the development process tunes each individual’s brain to the characteristics of a particular environment. This is one reason that people can live successfully all over the world. Genes provide the
blueprints for your child’s individuality, but the plans are certain to be modified during construction depending on local conditions—not only your actions as parents, but also your child’s culture, neighborhood, teachers, and peers. This matching process is automatic, with some support from you along the way. All this leads us to the major theme of this book: your child’s mind raises itself.

In a few circumstances, extra help is necessary. Things can go wrong if the genetic program has a flaw or if environmental conditions are very difficult, as happens in poverty or war. Modern life has also created some new challenges. Brain development can get into trouble when our modified environment fails to play nicely with our ancient genetic heritage. For these cases, we tell you how to give your child that extra boost.

We’ve organized the book around seven scientific principles that will help you understand how your child’s brain grows and changes along the path to adulthood.

**Part 1, Meet Your Child’s Brain** – This section is an introduction to your child’s brain and how it works. In particular, we talk about how innate predispositions for how to interact with the outside world initiate a two-way conversation between genes and environment that shapes neural development throughout childhood.

**Part 2, Growing Through a Stage** – The brain goes through periods when it builds upon earlier foundations and is exceptionally sensitive to certain types of information. This section describes the experiences that your child’s brain uses to shape the development of sleeping, eating habits, walking, and talking.
Part 3, Start Making Sense – Much of neural development relies on experiences that are easily available to almost any child. As parents, you get a free ride on this process: simply sit back and watch your child’s senses tune themselves to conditions in the local environment.

Part 4, The Serious Business of Play – One of the major ways that children adapt to their circumstances is through play. From preschool through adolescence, play is practice for adult life and helps to develop some of the brain’s most important functions. In this section, we explore what play does for the brain and explain what animal research can teach us about its importance.

Part 5, Your Child as an Individual – Distinctive features of the genetic program make your baby a unique person from the start. Here we explain how your child’s individual emotional and social characteristics grow and respond to the surrounding world.

Part 6, Your Child’s Brain at School – Most of the evolutionary history of our species happened before there were books, violins, and calculus—not to mention Facebook. We tell you how the flexibility of your child’s brain’s allows him or her to handle abstract concepts that our ancestors never imagined.

Part 7, Bumps on the Road – All environments present challenges to the developing brain. Most children can get what they need to grow, like dandelions, but a few are more
delicate flowers needing extra care or attention. We explore what you can do to help your child if anything goes wrong.

Feel free to dip in anywhere that interests you, though you might want to start by reading the first two chapters. Headings indicate the age range that is the focus of each chapter, so that you can easily find out whether we have something to say about your child’s brain, however old he or she is right now. Ready? Let’s get started.
PART ONE

MEET YOUR CHILD’S BRAIN

The Five Hidden Talents of Your Baby’s Brain

Epigenetics: Beyond Nature versus Nurture

In the Beginning: Prenatal Development

Baby, You Were Born to Learn
Chapter 1

The Five Hidden Talents of Your Baby’s Brain

Your baby is smarter than he or she lets on. For generations, the slow development of motor systems led psychologists to believe that babies had very simple mental lives. In a baby that has not worked out how to walk or talk, mental capacities cannot be measured by approaches used to test grown-ups. But in the last few decades, scientists have figured out better ways of getting information from infants. With these new tools, researchers have shown that babies’ minds are very complex right out of the box—as many parents have suspected all along.

All brains, young and old, have certain broad talents that help their owners to navigate life successfully. If you look closely, you can already see many of these talents in your infant. Although babies lack knowledge, they are born with certain tendencies that influence how they organize incoming information, and their responses to it. They are predisposed to seek out and make use of experiences that will help adapt their growing brains to their particular environment. Or, to put it more simply, your child’s brain naturally knows how to get what it needs from the world. For this reason, most brain development requires only a “good enough” environment (more on that later), which includes a reasonably competent (though not perfect) caretaker.

What do babies know and when do they know it? They can’t tell us in words, but researchers can still ask babies questions and get sophisticated answers about their cognitive abilities. A few simple, nonverbal ways of looking into the minds of infants and
even newborns have revolutionized developmental psychologists’ ability to tell what young babies think and feel.

Your infant isn’t good at controlling most of her body, but she can suck on a nipple immediately at birth. Not long after that, she can turn her head and eyes to look at an interesting object or event. These two abilities can be used to find out what catches her attention. For example, if your infant likes an event that happened while she was sucking and wants it to happen again, she will suck more vigorously. Your newborn will suck harder when she hears a recording of her mother speaking, but less so when she hears another woman. This is how we know that, from birth, infants recognize Mom’s voice.

Like adults, babies get bored. After your baby has looked at something for a while, he will turn away and look at something more interesting. Researchers can observe how long a baby looks at a particular scene. If the scene contains something surprising to the baby, he will look longer.

This response allows us to find out whether a baby can tell the difference between two things. For example, if you show your baby a series of pictures of cats, the appearance of a dog will attract a long look. This means that babies can distinguish cats from dogs—a feat that is extremely difficult to program into a computer.

Simple tools like these have allowed researchers to identify five brain talents that infants already have well before their first birthday.

The first talent is that babies can detect how common or rare particular events are. For example, a first step in learning a language is figuring out which syllables go together to form a word. Yet when speaking, people tend not to pause between words. One way to learn words is to determine which syllables are likely to occur together. For
example, when your baby hears the words “the baby” being spoken, how can she tell that it’s the English word “the” followed by “baby,” and not the made-up word “theba” and then “by”? One clue is that “baby” is a far more common pairing of sounds than “theba.”

A well-designed experiment showed that in general, babies really do think this way. Researchers generated four nonsense words, such as “bidaku,” each composed of three syllables. They then presented these nonsense words to eight-month-old babies in varying order, without pauses between the words. Once the babies were familiar with these new words, the researchers then presented either one of the nonsense words or a new one composed from the original syllables (like “kubida”). They let the babies control how long the words were played by looking in the direction of the speaker. The researchers found that babies listened significantly longer to the new words, even though the component syllables were the same. Since the babies had already heard all the syllables individually, the researchers concluded that they must have become familiar with the original groupings. This ability to detect the probability of events, shared by many animals, is a key component of learning. It provides the basis for answering important questions like, “Where am I most likely to find food right now?”

The second talent is that babies use coincidences to draw conclusions about cause and effect. After language develops, two-and-a-half-year-old children can make explicit causal statements like “He went to the refrigerator because he was hungry.” But well before this, babies appear to be able to detect such relationships.

In one experiment, a mobile was hung over the crib of three-month-old babies and attached to one leg by a ribbon. When a baby kicked, the mobile would move. The babies were fascinated by this new toy. They smiled more and looked at the mobile more than...
they did when a similar mobile was out of their control. After just a few minutes of training, they kicked more. Three days later, they still kicked when they saw the first mobile (but not the second), even when the ribbon was no longer tied to their legs. Since the kicking was a specific response to getting the mobile to move, these babies seem to be learning an elementary form of cause and effect. Using events that occur together to determine possible underlying causes is a key part of our ability to learn how the world works.

A third talent of your baby is distinguishing “objects” from “agents”—and treating them very differently. Infants—like all people—understand that objects are cohesive (all the parts of the object stick together), solid (something else can’t go through an object), and continuous (all the parts of an object are connected to other parts), and only move when something touches them. For many years, it was accepted that infants under eighteen months did not understand “object permanence,” the idea that objects continue to exist even when you can’t see them. This bit of popular wisdom, originally disseminated by the pioneering psychologist Jean Piaget, has recently been challenged by researchers who found the right ways to test infants.

Well before their first birthday, infants look longer if an object fails to be cohesive, solid, continuous, or permanent. In one experiment, five-month-old babies saw a car roll down a track whose middle section was hidden behind a screen. When an obstruction was then placed on the track behind the screen, five-month-old babies appeared to expect it to stop the car. We know this because, when researchers secretly removed the obstruction through a trapdoor, and the car continued to roll down the track successfully, the babies looked longer at the screen, suggesting that they were surprised
that the box was not solid. When evaluated in this way, babies as young as three-and-a-half months old show that they can think about objects that are out of view behind other objects.

Babies also recognize agents, beings that have intentions and goals and can move on their own. Hands, for instance, always belong to agents. If a hand is seen reaching for one of two objects and then the location of the objects is reversed, six-month-old babies look longer if the hand reaches for the same location (but a different object) on the second try. They seem to expect that a person reaching for an object wants that particular object. If instead a stick pokes the object, babies don’t act surprised when the stick fails to follow the object to a new location, because a stick is not expected to act like a conscious agent.

Like adults, babies are willing to attribute agency to things that are not really alive. When watching a film of a circle that seems to be chasing another circle, one-year-old babies look longer if the first circle moves away from the second circle than they do if the first circle moves straight toward its presumed target.

A fourth talent of babies is something we all do, both for better and worse. Our brains are naturally inclined to organize information into categories and people into groups. Three-month-old infants can do this too. When babies see a series of male faces, they spend less time looking at each new face, presumably because they’re bored with looking at men. When a female face then appears, they look longer. This is true even if the hair is not visible, so the babies seem to be using facial features, not hair styles, to distinguish men from women. These categories are relevant for babies’ everyday lives. Most babies prefer looking at female faces to looking at male faces—except when their
primary caretaker is male, in which case they are able to muster a slight preference for men.

Some broad categories like “animals” and “furniture” can be found very early in life; others are learned later. The boundaries of many categories, from phonemes to face perception, are shaped by experience to match your child’s local environment. But no one ever has to teach a baby that categorizing things is a good strategy; it’s built into their brains. This ability provides a primitive basis for adult categorization, which makes it possible to think sensibly about newly encountered objects and people. It is also the root of stereotyping and prejudice, as we will see in chapter 20.

The fifth talent is that our brains **select relevant information for attention while discarding most of what goes on around us**. As you may have noticed, babies are a lot less selective than adults about what captures their attention, but they still have distinct, automatic biases. From an early age, babies focus a lot on human voices, faces and moving things. Babies start showing this preference for faces at 30 minutes after birth, and human voices two days later. After three months of age, they notice objects that look distinctly different from surrounding objects, such as a red circle in a field of black circles.

Very early on, caregivers begin to influence the direction of a baby’s attention. Babies start to follow an adult’s gaze as early as four months of age. By twelve months they can point and direct their attention where someone else is pointing. At all ages, paying attention greatly increases the brain’s ability to learn about specific things. In computer models of brain function, innate biases in what information is given priority can provide a powerful mechanism for directing the learning of particular tasks. Babies’
innate interest in voices, for example, helps them to learn about language. All of these
talents help babies’ brains develop like dandelions, requiring only everyday types
stimulation that adults give normally—and instinctively.

In adults, these five talents are fundamental to the way our brains work. Indeed, in
most of us these talents are inclined to be hyperactive. When we find ourselves
considering our computers or our cars as if they had their own intentions and goals
(typically in opposition to whatever we’d like them to do), our tendency to perceive
agents is getting out of hand. When a baseball pitcher wins three games while wearing a
certain pair of socks, and then insists on wearing his lucky socks whenever he plays, he is
drawing conclusions about cause and effect from events that probably occurred together
by chance.

There’s a practical reason why most of our examples come from three-month-
olds: younger babies are harder to test. Based on the evidence we have, our own belief is
that these capacities are present from birth, at least in some primitive form. In the end,
though, we don’t think it matters very much whether babies are born with these abilities
or learn them soon after birth. By whatever route, all normal babies acquire these brain
talents very early in life. Either way, babies start relying on these tools from infancy, and
continue to use them all through their lives. On the other hand, these cognitive capacities
are just the beginning. All of them become significantly more elaborate as babies grow
and mature.

This emerging picture leaves little room for the outdated idea that babies are born
with the potential to develop in any direction: we all start with certain biases. The
cognitive talents that babies have in early life are essential for the development of their
brains. Computer scientists who model the brain confirm that these biases are necessary, though they may limit us in some ways. They have not been able to explain convincingly how an adult brain might develop from a learning machine that starts with no predispositions.

As a consequence of these core talents, children’s brains come ready to learn how to adapt themselves to the environment that they encounter during development. This ability allows them to grow almost anywhere. Our species has survived under a wide range of conditions through its history, and we have evolved to learn about the properties of the environment that were directly relevant to our survival. For this purpose, targeted learning mechanisms are often better than general mechanisms. These predispositions prepare the infant brain to learn many things—but not just anything.

BEGIN BOX

**Myth: If anything goes wrong, Mom is to blame**

Freud has a lot to answer for. His ideas were speculative and eventually discredited by further research, but they have left deep impressions on our culture. One of the most pervasive is the idea that a baby’s relationship with his or her mother serves as a model for all later relationships in life. This idea has led many people to conclude that a mother’s behavior has an incredibly strong influence on what kind of a person her child will later become. From this belief, we have
created a culture in which complete strangers feel a moral obligation to intervene
if they see a pregnant woman having a sip of wine or a mother yelling at her
young son. Psychiatrists have even blamed mothers for their children’s autism or
schizophrenia—both developmental disorders that are largely due to genetic
mutations.

It’s time to relax. Now that you know that children actively participate in their
own development, it should be clear that parents do not need to be perfect. We don’t
recommend yelling, but that’s mostly because it’s an ineffective way to modify your
child’s behavior (see chapter 29), not because your occasional bad mood is likely to do
serious, lasting damage to his psyche. Anyway, as you’ll see in chapter 17, parenting
style has much less influence on personality than most of us believe. We’d like to see
parents enjoying their kids more, rather than worrying over every aspect of their growth.
That approach would be just as effective in producing healthy adults—and much more
fun for everyone.

END BOX
Chapter 3

In the Beginning: Prenatal Development

When we watch a house being constructed, we’ve always found it surprising how quickly the framing is done. From the outside, the house looks almost complete very soon after it’s begun, but finishing the interior details and the wiring takes much longer. Building a brain is similar: getting the neurons into their correct positions is the (relatively) easy part, and it’s done before your baby is born. In contrast, wiring up all the connections is so complicated that the job won’t be entirely finished until your child is in college.

A baby’s brain is different from a house in one amazing way: from fertilized egg to newborn, its construction is largely automatic. The processes that form the brain are driven by a resilient genetic program, allowing babies to grow in almost any environment. Its main requirement is a healthy mother. As it says on the packaging of some of our favorite appliances, no assembly required.

This chapter will lay out some of the most valuable advice we have about prenatal development, including warnings about some of its hazards. But before we get into the details, we want to emphasize this point: most pregnancies turn out fine. Authors of many popular advice books (you know who you are) convey the message that women must avoid any risky behavior while pregnant, no matter how minor. While long lists of potential problems may frighten mothers-to-be and help to sell books, those lists can also lead to prenatal stress, which itself is bad for the baby’s development (see box, p. TK).

The effects of prenatal risks depend on their timing and seriousness. In most cases, when miscarriages or birth defects do occur, they are caused not by the pregnant
woman’s actions, but by genetic problems in the fetus. Throughout your life, it will be tempting to blame yourself for anything that happens to your baby or child, but keeping a clear perspective is essential. When one high-strung scientist friend of ours was pregnant, she had a beer once, to the consternation of her friends. Her rejoinder was that the reduction in her stress was far better for the baby than any possible injury from the alcohol. Today her son is thriving.

Many enlightened parents, like our friend, are so confident because they have a grasp of the process of brain development in babies. It is a technical subject—but bear with us: the basics are not as complicated as they might first sound.

Insert sub-heading: The basics of brain development

The construction of the brain begins early in pregnancy. During the first month, chemical signals cause a group of cells in the developing embryo to start becoming the nervous system. Beginning three weeks after conception, the neural plate, a cell layer running along the length of the embryo, brings its edges together to form the neural tube, which will later become the brain and spinal cord. The neural crest, a group of cells scattered above the neural tube, will become the peripheral nervous system, along with various non-neural tissues.

If the neural tube fails to close fully, miscarriage or birth defects can result. Folic acid deficiency in the mother increases the risk of neural tube defects, including spina bifida and anencephaly. For this reason, women who might become pregnant should take 400 micrograms of folic acid (a B-complex vitamin) every day. Another source is bread, which in the United States and many other countries is made from folic acid-
supplemented flour for this reason. If you are trying to have a baby, you should begin this supplement before conception, as many women do not find out they are pregnant until neural tube closure has ended.

The next stage of development is segmentation, which divides the neural tube into distinct regions by the sixth week of pregnancy. You can think of it as placing walls to define the rooms of a new house, except that segmentation is controlled not by physical barriers but by chemical cues. (In Frankenstein-like lab experiments, scientists have introduced errors in this process that produced an extra set of legs or wings.) The largest neural tube region, at the back end of the human embryo, will become the spinal cord. A smaller area at the head end is divided into three regions, which will eventually become different parts of the brain.

The hindmost of these three regions will become the brainstem, which controls mostly subconscious basic functions like reflexive movements of the head and eyes, breathing, heart rate, sleep, arousal and digestion. It also forms the cerebellum, which integrates sensory information to help guide movement (for instance, so that you know how forcefully you need to lift your foot when walking).

The middle region will become the brain’s midline structures, including the hypothalamus, amygdala, and hippocampus (see figure, page TK). The hypothalamus controls the more conscious basic processes, such as the regulation of sexual behavior, hunger, thirst, body temperature, and daily sleep/wake rhythms, and the release of stress and sex hormones. Emotions, especially fear, are the responsibility of the amygdala. The hippocampus puts facts and place information into long-term memory and is important for navigation.
The third region, at the front of the brain, will become the thalamus and cerebral cortex. Sensory information entering the body through the eyes, ears or skin travels to the thalamus, in the center of the brain, which filters the information and passes it along to the cortex. Scientists divide the cortex into four parts or “lobes.” The **occipital lobe** is responsible for visual perception. The **temporal lobe** is involved in hearing and contains the area that understands speech. It also interacts closely with the amygdala and hippocampus and is important for learning, memory, and emotional responses. The **parietal lobe** receives information from the skin senses, puts together information from all the senses, and directs your attention. The **frontal lobe** generates movement commands, contains the area that produces speech, and is responsible for selecting appropriate behavior depending on your goals and your environment.

Early in gestation, all these brain regions are tiny (and the embryo still has a tail, a vestige of our evolutionary heritage, which it will lose around week eight). As development continues, chemical markers divide the brain into progressively more regions, defining particular cortical areas, such as those for certain aspects of vision or language. Once all the brain areas are specified, they grow larger, maturing in sequence from the back of the brain to the front (see figure). This process continues through childhood and into adolescence (see chapter 9).

The main construction technique at this stage is the production of new cells—billions and billions of them. Cells of the neural tube and neural crest divide repeatedly to make additional progenitor cells. Later divisions produce cells that are committed to becoming neurons, which process information by communicating with each other, or glia (also known as glial cells), which provide essential support. The number of cell divisions
and what type of cells they produce are tightly regulated by a combination of chemical signals, which vary across brain regions, and interactions with pre-existing cells. The addition of new neurons is largely complete by about eighteen weeks after conception, though a very small number of neurons continue to be generated even into adulthood. In contrast, glia are generated throughout life.

Many cells must migrate within the brain to their final position, a process that may be guided mechanically by glial cells that extend long fibers across the brain or chemically by gradients of proteins. Cells derived from the neural crest migrate an especially long way, to form the nerves that carry signals from the limbs, the digestive system and elsewhere. (In the adult, there are as many neurons in the gut as there are in the spinal cord.) While they are migrating, these cells often continue to divide to make more cells.

During this period, cells are also beginning to differentiate, taking on particular jobs in the brain. Cells differentiate in a series of steps, as their jobs are slowly made more specific by increasingly restrictive chemical signals.

At a basic level, neurons have a lot in common (see figure). They receive chemical signals via neurotransmitters released from other neurons. Receptors on the dendrites of the recipient neuron translate the chemical signal into electrical signals that spread to the cell body. There the electrical signals are tallied up: have there been enough of them to merit sending a signal to other cells?

If so, this output signal, called an action potential or spike, is conveyed down the axon, a very long, thin fiber that reaches from the brain to the target, as far away as the toe in some cases. Each neuron has a single axon that often branches to reach multiple
targets. Neurotransmitters are contained in specialized areas at the ends of the axonal branches and released by the arrival of a spike. When a neurotransmitter binds to receptors on another neuron’s dendrites, that target neuron may be electrically excited or inhibited depending on the identity of the neurotransmitter. The point of connection between axon and dendrite is called a synapse. Final stages of differentiation often depend on neurons’ interactions at synapses.

Glia also come in different flavors. Some glia wrap themselves around axons like the insulating plastic sheath on electrical wire, acting as a layer called myelin to increase the speed of neural communication. Other glia line blood vessels to control which chemical signals are permitted to pass into and out of the brain. Still others form the brain’s defense system, engulfing and removing foreign matter and debris from dying cells. Glia too become differentiated by exposure to chemical signals, generally a bit later than the neurons in the same areas.

The first step in the wiring process occurs before birth, as these billions of neurons extend axons toward their targets. Fortunately, distances are much shorter in the fetus than they would be in an adult. It also helps that brain tissue is less crowded than it will eventually become, just as it’s easier to run electrical wires and plumbing in a house before the interior walls have been put up. Only the earliest-arriving axons must find their way by themselves, navigating via chemical signals or by finding particular guidepost cells.

Later axons extend along the pathways laid down by these early pioneer axons, just as you might guide a new wire through a bundle of previously installed wires, except that the new axon is actually being created as it progresses. A region at the tip of the
elongating axon called the “growth cone” samples the environment within the brain in different directions by extending and retracting small protrusions, making it look as though the growth cone is sniffing out the correct path. Depending on their identity, these chemicals may either attract or repel the growth cone. Some can even cause it to abruptly change its responsiveness to other molecular cues, a form of sophisticated navigational logic.

Once an axon has found its approximate destination in the brain, it must pinpoint its target cells from among millions of candidates. This process starts with molecular cues that tell the axon to slow down and start exploring an area whose boundaries may be marked with a repellent signal to prevent the axon from exiting. Some brain areas help the axon to navigate by providing a local map, in which the concentration of a chemical signal (or several) descends steadily across the area. Other areas use a large number of related proteins to mark local position so axons can find their way to the right neurons.

Once axons are close to their destination, they begin to make contacts with nearby cells, initiating the chemical conversation that leads to the formation of synapses. This process begins in the spinal cord five weeks after fertilization, and it is not complete until years after birth in some brain areas. Axons initially form a lot of extra synapses with targets that are only roughly appropriate. Only a fraction of these synapses survive in the long term. Synapses that are more successful at activating their target cells are more likely to be retained. This competition for synaptic survival provides a way of fine-tuning the brain’s function to match each child’s individual circumstances, whether that means adapting the responses of vision neurons to the distance between each child’s eyes or tuning the auditory cortex to respond most easily to the sounds of each child’s native
language. To a lesser extent, this process will continue throughout life, as a mechanism of learning and memory (see chapter 21).

The process of eliminating unnecessary components is a major theme of early development. The adult brain contains about 100 billion neurons and many more glia. However, the young brain produces even more cells than that and then reduces their number through planned cell death. In some brain regions, planned death kills as many as four out of every five cells born.

Why does the nervous system take such a wasteful approach? It seems to be a way of matching the size of the incoming population of axons to the number of neurons in the target region. Cell death occurs after the axons have reached their target and formed synapses. The target neurons produce a protein, necessary for cell survival, which is taken up at synapses and transported back along the axon to the cell body of the input neuron. Cells that have failed to form enough connections with the target do not get enough of the survival substance, so they die. This type of cell death is an active process, resulting from a biochemical death pathway within the cell. The best known survival protein (or neurotrophin) is nerve growth factor, which controls the survival of neurons involved in the sense of touch and the fight-or-flight reflex in the peripheral nervous system. Other factors also influence cell survival, including incoming synaptic activity and sex hormones, which control cell death in brain regions that differ between males and females.

Even after all the cellular elements of the brain are in place, much construction work remains to be done. Newborn neurons look very simple compared with mature neurons. Toward the end of gestation and especially in the first two years of life,
dendrites form additional branches, becoming more and more complex to accommodate the many new synapses that are added during this period. Synapse elimination begins in the first year of life and continues through early adolescence, forming one of the basic mechanisms by which experience helps to shape the brain (see chapter 5).

The final step in axon maturation is myelination, the formation of the glial insulation that allows spikes to move quickly down the axon. It’s as if the brain’s electrical system were installed with bare wires, and then the insulation got added afterward. This process begins just before birth in the brain (earlier in the spinal cord) and continues well into adult life (see chapter 9).

Insert sub-heading: Maximizing your baby’s growth

Considering the enormous amount of construction involved, it’s no surprise that the growing baby requires energy. Indeed, one of the biggest threats to a developing fetus is maternal malnutrition, whether caused by famine, poverty, or dieting. A particularly critical time is the second and third trimester, when brain size is increasing rapidly. Babies with a low weight at birth are at higher risk of many problems later in life, including deficits in cognitive development and intelligence. Another cause of low birth weight is cytomegalovirus infection, which affects roughly one pregnancy in a thousand and can cause mental retardation, deafness, and other problems.

During pregnancy, environmental toxins can be a threat if they are ingested. For instance, cocaine increases the risk of attention-deficit/hyperactivity disorder (ADHD). However, more severe effects on the brain result from two legal drugs, nicotine and alcohol. Low birth weight and a variety of brain development problems are linked to
smoking, the nicotine patch, and heavy drinking. So-called “crack babies,” whose plight got a lot of press in the 1980s, turned out to be damaged mainly by their mothers’ malnutrition and concurrent use of other drugs. In the *Mad Men* era, the sight of a pregnant woman with a drink in one hand and a cigarette in the other did not attract a second glance. Today, some U.S. states jail women for child abuse if they are caught taking cocaine while pregnant, but not for smoking or alcoholism. To put it mildly, this approach is not optimal for the baby’s health (see box, Practical tip: Less stress, fewer problems).

Another source of drug exposure during pregnancy is medical care. Pregnant mothers are advised to avoid a variety of over-the-counter drugs, especially during the third trimester. Yet drugs are often prescribed to treat medical problems, such as Depakote to treat seizure or bipolar disorder, or terbutaline to prevent preterm labor. These drugs can enter the placenta and therefore the baby’s developing brain, and increase the likelihood of neurodevelopmental problems, including autism. Physicians are often not aware that it is potentially risky to give drugs late in pregnancy, when the baby’s brain is growing rapidly.

The news is not all bad for drugs, though. One of our favorites, caffeine, is harmless in moderate doses (less than three cups of coffee a day), as are artificial sweeteners and monosodium glutamate (better known as MSG). Some doctors even approve of alcohol in small doses. So expectant mothers don’t need to give up all of their favorite habits. Indeed, a little less worry on this front might be a stress reducer.

An important threat to the baby occurs when the pregnancy cannot run its full course. A common cause of low birth weight is premature birth, which greatly increases
the risk of neurodevelopmental disorders. One Norwegian study found that babies born during gestational weeks twenty-eight to thirty have a four-fold higher incidence of mental retardation, a seven-fold higher incidence of autism spectrum disorder (see chapter 27), and a forty-six-fold higher rate of cerebral palsy than full-term babies. By the age of eighteen, one in twelve of these children was classified as disabled—five times the normal rate. Premature babies born later in gestation have lower rates of disability, but even at thirty-seven weeks, the risks remain elevated over babies born at full term (forty weeks).

One unintended consequence of recent changes in medical practice is an increase in the frequency of neurodevelopmental disorders. Preterm babies (less than thirty-seven weeks) now make up 12–13 percent of births in the U.S. This percentage rose steadily between 1981 and 2004, partly because their survival rates have grown as medical care has improved. Three-quarters of preterm births occur late in gestation, between thirty-four and thirty-seven weeks. Among babies born in this time range, 20 percent end up with clinically significant behavior problems, and the risk of ADHD is 80 percent higher than in full-term babies.

Therefore one of the best things you can do to protect your baby’s growing brain is to allow your pregnancy to run its full course whenever possible. Many premature births are unavoidable because of risks to maternal or fetal health, but some are not. Between 10 and 20 percent of U.S. deliveries are induced, and roughly half of these inductions are elective (not medically necessary). Reasons for elective induction include doctor or patient convenience, previous caesarean birth, and doctors’ concerns about legal liability, among others. A better practice is to follow the American College of
Obstetrics and Gynecology recommendation that elective induction should not be scheduled before week thirty-nine of pregnancy (this cutoff is set late because the exact stage of pregnancy is not always known with precision). To use a baking metaphor, that bun in the oven will turn out great—if you wait until it’s done.

BEGIN BOX

**Practical tip: Less stress, fewer problems**

Next time you’re stressing about your future child, ask yourself whether this stress is really necessary. In laboratory animals, maternal stress increases the risk of a variety of problems, including cleft palate, depression-like behavior, a touchy stress-response system in adulthood (see chapter 26), and attention deficits and distractibility (see chapter 28). Stress hormones released by the mother animal act on the fetus directly and also reduce the placenta’s ability to protect the fetus from these hormones in the future.

Because it would be highly unethical to stress pregnant women deliberately, most research in people has relied on looking for correlations, which is less reliable than experimental results (see box, Why epidemiology is difficult to interpret, in chapter 30). Some recent studies have examined children born after their mothers experienced natural disasters during pregnancy. This type of study comes as close as is ethically possible to randomly placing women into stressed and unstressed groups.
One group of researchers identified all tropical storms or hurricanes that hit Louisiana between 1980 and 1995 and then determined how many autistic children in the records of the state health system had been in the womb when their mother’s home was hit by one of these storms. The risk of autism was significantly higher for children whose mothers had been stressed during pregnancy.

By scientific standards, this is far from ironclad, but there are two reasons to believe it’s not mere chance. First, the incidence of autism was higher only for those children whose mothers were in the fifth, sixth or ninth month of pregnancy at the time of the hurricane, suggesting that there is a sensitive period for the effects of stress on development (see chapter 5). Secondly, children whose mothers were exposed to more severe storms had a higher risk of autism than children whose mothers were exposed to less severe storms. This research will need to be replicated before we can consider it definitive, but it does suggest that prenatal stress may increase the chances of autism (see chapter 27).

Similar studies have yielded comparable results. One found that children whose mothers experienced severe stress from a major ice storm while pregnant had lower IQ scores and language ability at age five. The risk of schizophrenia is higher in children whose mothers were in the first trimester of pregnancy when a close relative died or was diagnosed with a serious illness. Children whose mothers experienced an earthquake during pregnancy were more likely to be diagnosed with depression or to be born with a cleft palate. It’s not yet clear whether moderate stress, like dealing with an annoying boss, might cause similar problems, but as the research is ongoing, it’s best to keep it simple: it’s probably a good idea to avoid stress during pregnancy as much as you can.
Practical tip: Eating fish during pregnancy is good for your baby’s brain

Exposure to lead (usually from paint) or mercury in utero or in childhood can decrease intelligence. These heavy metals are harmful to brain development. For years, women were told to limit their consumption of fish because it might contain mercury. But fish is also a major source of omega-3 fatty acids, which are crucial for neural development. Indeed, their absence during brain formation can lead to mental retardation. Several long-term studies now show that children whose mothers eat fish during pregnancy have better-functioning brains than children whose mothers avoid fish—especially if the mother chooses fish species that are low in mercury.

One group of researchers evaluated the diet of 11,875 women living in Bristol, UK, during the third trimester of pregnancy and then tested the resulting children on a variety of cognitive measures. Mothers who avoided seafood were more likely to have children with fine motor deficits, and communication problems (as toddlers), poor social behavior (at age seven), and low verbal IQ (at age eight) than mothers who ate at least three six-ounce (170 g) servings per week. The more seafood a mother ate, the better her child’s brain functioned, which suggests that the effect was due to the fish itself and not
to related characteristics such as household wealth. No benefits were seen among mothers who ate fewer than two servings a week. Another study confirmed these findings and further showed that children of mothers who ate fish low in mercury during pregnancy had higher verbal intelligence than children whose mothers ate fish high in mercury, for the same fish consumption.

You may have heard that uncooked fish, especially wild Pacific salmon, can contain disease-causing parasites. Thorough freezing of the fish to kill the parasites, which is required of sushi consumed in the United States, minimizes this risk.

How do you know if your fish contains mercury? A good rule of thumb is the smaller the fish, the less mercury it is likely to contain. Top predators like swordfish or shark should be avoided because contaminants like mercury get concentrated as they go up the food chain. Your health department may have information on the risks associated with your local fish. The most important point, though, is that the benefit of getting enough omega-3 fatty acids seems to outweigh the risk of mercury contamination for fetal brain development.
No wonder babies sleep so much. They’ve got a lot of hard work ahead of them. Infants come equipped with a basic toolkit for learning, as we described in chapter 1. But that still leaves a lot of items on their to-do list. In the first year of life, babies must lay the foundations for all their adult abilities, from language to locomotion. Their brains are changing more quickly at this age than they ever will again. Many of those changes help babies to learn about the specific environment into which they have been born.

People can live in an astounding variety of places, from the frozen tundra to the sweltering desert, and in a vast array of social systems as well. Growing up in New York or Barcelona is a very different experience from growing up in a subsistence village in the Amazon, but babies come into both of those situations with nearly all the same genes.

Unlike many animals, people are not hard-wired to be a good fit to their environment at birth. Instead, babies arrive equipped with the skills required to adapt flexibly to a wide range of conditions, an ability that has allowed us to survive all over the world. The benefits of that approach are enormous, and so are the costs: children need a lot of care for a long time before they become independent. This high-risk, high-reward reproductive strategy affects the shape of most people’s lives for decades, first as children and then as parents.

Babies are driven to explore and test their ideas about the world—which is why they seem to be getting into things all the time—and they love making things happen. When a baby learns to push a bowl from her high chair to make a crashing mess, you can
see the glee as she triumphantly proceeds to do it again and again. Being effective in the world is enormously rewarding for children and adults alike. Infants, though, sometimes get confused about how they caused something to happen, so you can see them trying to coax an object into behaving by talking to it. This confusion between physical and psychological causality usually disappears by the first birthday.

Just as babies have been shaped by evolution to be super effective learners, adults have become equally effective teachers. It may look like a game of peek-a-boo, but there’s serious stuff going on here. Babies are extremely good at getting what they need from their adult caregivers—not only food and shelter, but also information and examples. As a mother coos to her baby that he’s such a good boy, he is learning about language, relationships, and much more.

Because of the brain talents we discussed in chapter 1, even newborns are not passive recipients of adult instruction. Instead babies actively seek out the information that is most useful to them at a particular stage of development, and their behavior reliably elicits the kind of help that they need from adults. For instance, people all over the world speak to babies in “motherese”—a high-pitched, sing-song, and slow version of regular language with elongated vowel sounds. Babies prefer to hear motherese and interact more intensely with people who speak this way, as most adults and older children do instinctively. It is probably not a coincidence that the properties of motherese, including clear pronunciation and pauses between words, are also very well suited for helping babies learn about language.

Of course these interactions with adults influence some aspects of how babies develop, such as determining which language the baby learns. All normal babies
eventually learn the things they need to know, but the rates and details of learning depend on the experience of growing up in a particular culture. For example, there are a lot of cross-cultural variations in timing and even occurrence of the stages of motor development that pediatricians use to determine whether your child is progressing normally (see box, Practical tip: Guided practice can accelerate motor development). In the U.S., learning to crawl is widely considered a prerequisite for learning to walk, but it is merely one of many ways to get around that infants may discover. Almost a third of babies in Jamaica do not crawl at all, and the rest begin to crawl at the same age as first walking, around ten months. Similarly, 17 percent of British infants never crawl, and a hundred years ago, 40 percent of U.S. infants did not learn to crawl, probably because babies in that era wore long gowns that made crawling difficult.

Experience with language influences the development of concepts. The Korean language includes a complex system of verb endings to carry information, whereas English relies heavily on nouns to convey meaning. Korean baby talk is full of verbs that contain implied prepositions (“moving into”) and often omits nouns entirely, while English baby talk contains a lot of nouns (“a doggy”). Perhaps because of this experience, American toddlers begin to categorize objects, for instance by sorting them into piles by type, at a younger age than Korean children. In contrast, Korean children learn to use a rake to retrieve a toy that’s out of reach earlier than they learn to categorize, suggesting that they find it easier to think about actions than about objects.

From birth, babies can imitate other people and seem to enjoy doing it, which not only is a powerful tool of social bonding, but also provides direct examples of behavior for babies to copy. Infants imitate the goals of actions, rather than their exact form, and
other people’s movements appear to be coded in their brains in terms of goals as well. For example, if a fourteen-month-old baby watches a person tap her head on a box, which then lights up, a week later he will tap his head on the box to make it light up. But if the demonstrator’s hands were wrapped up in a blanket when she used her head, then most babies will instead touch the machine with their hands, apparently assuming that the demonstrator used her head because her hands weren’t available.

During this period of intense learning, a huge number of connections between neurons are added to the baby’s brain. Just before and after birth, as many as 40,000 new synapses are added every second. A baby’s brain reaches 70 percent of adult size by the first birthday and 80 percent of adult size by the second birthday. This growth is pronounced in the cerebellum, a region that integrates sensory information to help guide movement, as babies are learning how to control their bodies. The cerebral cortex also has a lot of growing left to do at birth. It doubles in size over the first two years of life, with most of that growth happening before age one. Though a small part of the growth is due to birth of new neurons, most of it is caused by the formation of new connections. The elaboration of axons, dendrites, spines and synapses, all parts of a neuron that allow it to talk to other neurons, occurs rapidly throughout the first year. Myelination of axons is also intense during this time, as glial cells wrap themselves around axons to form an insulating layer that increases the speed and efficiency with which signals are carried from one neuron to another.

You might imagine that a baby’s experiences would determine where new synapses are formed, but that doesn’t seem to be what happens. Instead the brain produces a huge number of relatively nonselective connections between neurons in early
development, and then gradually removes the ones that aren’t used often enough (see chapter 5). If the brain were a rose bush, life experience would be the pruning system, not the fertilizer.

Motor development occurs in a sequence that is determined by brain maturation. Because the primary motor cortex contains a map of the body that develops in sequence, babies learn to control their head and face movements before they learn to reach, and only later do they learn to walk. By the third month of life, the infant’s brain has developed enough to produce significant advances in behavioral control. At this age, babies start to be able to inhibit reflexes and eye movements. Their motor abilities allow them to react to maintain equilibrium when their posture is disturbed. They also develop clearly goal-directed behaviors, including head–eye coordination and reaching for objects. This transition also reduces the amount of time that babies spend crying. Fortunately for the parents of fussy newborns, behavior in the first three months of life does not predict future temperament very well.

By four months of age, the eye movements of babies show that they can predict when an object will emerge from behind a screen, the earliest exercise of a skill that becomes increasingly important with age. Learning to anticipate future events, such as correcting your posture to offset a threat to balance before it occurs, is a key aspect of adult motor function. Predictive motor control is another function of the cerebellum, so its maturation is likely to be important for the development of this ability.

Even when they’re very young, babies know something about objects, but they still have much more to learn. The fact that space is three-dimensional seems to be apparent even to young babies. Newborns will duck away from objects that are heading
toward them, and as soon as they can control their arms, babies will try to reach in the
direction of objects that they desire.

The idea that objects have fixed properties, on the other hand, seems to dawn
slowly. In early life, motion seems to be a key to object perception. Adults use this cue
too—things that move together are seen to be parts of the same object—but babies take
the idea to the extreme. At five months, babies who are shown a stuffed animal going
behind a screen and a toy car emerging on the same trajectory do not appear surprised. At
that age they can certainly tell the difference between the two toys, but the object’s
motion appears to be more important to them. By the age of one, changes in most object
properties (such as shape or color) will elicit a reaction, suggesting that the brain’s
representation of occluded objects has become much richer.

A reaction known as “stranger anxiety” develops around the same age, seven to
ten months, probably as a result of the same advances in brain maturation. At this age,
babies become able to remember the immediate past and compare it to the present. This
new ability allows them to demand more continuity in their social interactions with
adults, leading them to become unsettled in the presence of strangers. It also allows
babies to experience more continuity in their interactions with objects, giving them the
tools they need to keep track of details about hidden objects.

Babies do all this work without needing any special classes or equipment. Any
baby with a normal brain and environment can develop the skills that are important
during this period of life. They are driven to practice these skills, and parents are well
suited to teach them, just by interacting with their children in everyday life. Most parents
of infants can simply do what comes naturally and enjoy watching and helping their babies make discoveries about the world.

BEGIN BOX

**Myth: Breast feeding increases intelligence**

Everyone seems sure that giving breast milk to babies will make them smarter. We thought so ourselves when we started writing this book, but our careful examination of the scientific literature shows that the evidence for this idea is questionable.

There’s no doubt that children who were fed exclusively on breast milk during infancy have higher intelligence on average than children who were not breast fed. The important question is why this correlation occurs. One possibility is that this difference has something to do with the characteristics of breast-feeding mothers.

Indeed, women who choose to breast feed their babies differ in many relevant ways from women who don’t breast feed. Compared to women who bottle feed their children, women who breast feed have higher IQs, are more educated, are less likely to be poor, and are less likely to smoke. An increase of about 15 points (one standard deviation) in the mother’s IQ more than doubles her likelihood of breast feeding her baby. Headlines reading “Smart mothers found to have smart babies” probably wouldn’t be so memorable.
Researchers have tried to deal with these confounding factors in a variety of ways. Using meta-analysis to combine multiple studies has produced inconsistent results: some papers report a small effect of breast feeding on IQ, and others find no effect. In general, though, studies with a large number of subjects have tended to find smaller effects. To a scientific reader, this is not encouraging news. Real effects (not due to chance) should be easier to see in large populations. One meta-analysis concluded that higher-quality studies were also less likely to find an effect of breast feeding on intelligence.

In one large study, the IQ differences associated with breast feeding were completely eliminated by taking the mothers’ characteristics into account. Among the 332 pairs of siblings in which one was breast fed and the other was bottle fed, there was no difference in IQ. Another study of 288 sibling pairs in which only one child was breast fed reported similar findings.

The ideal way to address these concerns would be to assign some infants to be breast fed and others to be bottle fed. One large study in Belarus came as close as ethically possible by randomly assigning some mothers to a support program that increased the duration of successful breast feeding. The authors reported that the support program substantially increased children’s IQs at age six. Unfortunately, their IQs were tested by pediatricians who had a stake in the program’s success and did not normally administer IQ tests. Indeed, when psychologists retested some of the children, their scores were significantly lower, causing considerable uncertainty about the size of the effects.

Overall, the weight of the evidence suggests that breast feeding has little or no influence on a baby’s later intelligence. Of course, we’re not arguing against breast
feeding, which has many other benefits, but mothers who are unable to breast feed should not worry that they are harming their baby’s intellectual development.

BEGIN BOX

Practical tip: Guided practice can accelerate motor development

Infants learn to hold their heads up, sit, and walk months earlier in cultures that provide a lot of tactile stimulation and help babies to practice motor skills. In African, Caribbean, and Indian cultures, mothers commonly massage and stretch infants after bathing them. These routines can include swinging infants around or even tossing them in the air. Babies carried in a sling improve their muscle strength and coordination as they adjust to the mother’s movements. Laboratory studies verify that such stimulation promotes motor development. Spinning an infant in an office chair twenty times over ten weeks (a safe and fun way to provide vestibular stimulation) or moving the legs to cause passive movement (twenty minutes daily for eight weeks) speeds the infant’s acquisition of motor skills.

To teach sitting, some African and Caribbean mothers hold young infants in the sitting position on their laps or prop them up with a cushion or other support. To promote walking, mothers hold infants in a standing position and bounce them up and down, which causes them to make stepping movements. Once babies are able to hold
themselves up, mothers encourage the babies to take steps while leaning against furniture or holding onto a railing, sometimes luring them with food. In such cultures, even young babies spend much of their time in sitting or standing positions. Western parents take such a deliberately planned approach only when teaching their toddlers how to climb stairs.

Trained infants develop motor skills more quickly than untrained infants, but only the skills that are specifically practiced. Laboratory studies verify that babies who practice crawling movements start to crawl earlier and babies who practice stepping start to walk earlier. In contrast, babies are slower to develop motor skills if their movements are restricted. Denver babies born in winter start to crawl the following summer three weeks younger than summer-born babies who learn to crawl in the winter, apparently because cold weather limits their opportunities to practice.

Do babies who learn to walk earlier end up with better motor skills than those who walk later? Probably not, if they spent the remainder of their childhoods in the same activities. In some cultures, adults routinely run long distances or carry huge weights, but those skills require many years of training, through childhood and beyond.
PART TWO

GROWING THROUGH A STAGE

Once in a Lifetime: Sensitive Periods

Talking Heads

Beautiful Dreamer

It’s a Girl! Gender Differences

Adolescence: It’s Not Just About Sex
Chapter 5

Once In a Lifetime: Sensitive Periods

Your child’s brain also is a bit like IKEA furniture: built through a series of steps that normally occur in order. Failure to complete certain steps on schedule—as we certainly have when assembling a table—can interfere with later steps in the process, usually delaying them but sometimes preventing them from happening at all.

In this chapter, we discuss a special type of development that is central to matching your child’s brain to the environment. “Sensitive periods” are times in development when experience has a particularly strong or long-lasting effect on the construction of brain circuitry. Receiving the correct sort of experience during a sensitive period is essential for the maturation of the particular behaviors that rely on that circuitry.

Not all aspects of early development are so demanding. Much of brain maturation occurs without special help. For example, neural circuits in the retina and spinal cord mature according to a set program that is not responsive to experience at all. Other regions—such as the hippocampus and the cerebral cortex (also called the neocortex)—are modifiable by experience not during a short period of time but instead throughout life. These two brain regions are always able to acquire new information, which helps us continue to adapt to our environment during adulthood.

Sensitive periods for particular functions are special because during these times, the quality of a child’s experience can have permanent effects. For example, the brain areas that are specialized for understanding language end up with different connections between neurons depending on whether your baby hears English or Mandarin during the
first few years of life (see chapter 6). The brain changes that occur in response to this experience make your child an expert at understanding and producing the sounds of his native language.

Later, you may still be able to learn a new language, but you have to work much harder. As an adult, your brain’s language areas are no longer under construction and their connections are more difficult to modify. Your sensitive period for language has passed.

Fortunately, as we have said before, experience isn’t something that happens passively, even to babies. Your child’s brain has definite preferences about what it should learn at various stages of development. The types of experience that can modify a developing neural circuit are determined by predispositions that are built into the brain as a result of our evolutionary history. In short, children actively seek out the experiences they need.

What do we mean by experience? Your child’s brain is potentially influenced by any event that can be detected by sensory receptors, transformed into electrical impulses, and transmitted to the brain. (As we will show you in chapters 10–12, all our knowledge of the world comes in the form of these electrical impulses.) Interactions with parents and other caregivers are only part of the rich tapestry of available stimuli. Physical changes in your infant’s brain also occur when she watches the mobile that hangs over her crib, when she sticks her toes in her mouth, and when sirens pass on the street outside. Later, her universe expands to include social interactions with other children, finding her way around the neighborhood, learning to play sports, going to school, and much more. All
these experiences leave their traces in her brain, some very long-lasting and others transient.

Because neural circuits mature at different times, there are a variety of sensitive periods in development, each corresponding to a particular brain function. Sensitive periods are most common in infants and toddlers because the brain is undergoing such dramatic growth at this stage, but they can occur at other times as well. Some sensitive periods occur before birth, such as the maturation of the sense of touch based on the baby’s experience within his mother’s womb. Many occur soon after birth, as when early interactions with caregivers shape the circuits of the brain that respond to stress (see chapter 26). Other sensitive periods, such as the one for the grammatical aspects of language learning, continue well into childhood. The last sensitive periods in development close when puberty arrives, though many of them end earlier. In most cases, sensitive periods seem to terminate when appropriate experience has caused the relevant brain circuit to mature.

As we described in chapter 3, pre-programmed chemical cues direct axons to their target regions and orchestrate the formation of a large number of synapses. Once those basic elements are in place, experience can influence the further development of the circuit by controlling the activity of those axons and synapses. Synapses that are more effective at activating their target neuron are more likely to be retained and strengthened, through biochemical plasticity pathways in the target cell, while those that are ineffective become weak or disappear. Synaptic activity can also trigger the growth or retraction of axonal or dendritic branches. Cells that fire together, wire together.
Once these plastic changes have occurred, the brain architecture often becomes more difficult to modify in the future, either because the extra axons and synapses are no longer available or because the biochemical pathways that modify synaptic strength change with age. In this way, the brain uses sensory experience to shape the connections within a neural circuit, pruning away the ones that are unnecessary while maintaining those that are strongest and most active to produce the perceptions and behaviors that are appropriate for that child’s individual environment.

Unnecessary synaptic connections are pruned throughout childhood. In the primary visual cortex, the brain’s total number of synapses increases rapidly from birth to its peak at eight months old, and then declines slowly to age five. The biggest reduction in synapse number in this region happens sometime between ages five and eleven. (We don’t know exactly when this change occurs because children ages six to ten have not been studied.) In the frontal cortex, synapse density remains high at least through age seven, falls somewhat by age twelve, and reaches adult levels in the middle teenage years (see chapter 9). Again it is not clear what happens between ages seven and twelve.

Synapse elimination has been studied in much more detail in other primates, and the results are roughly consistent with the sparse human data. In rhesus monkeys, an explosive increase in synapse density in the first few months after birth is followed by an initially gradual and later accelerating decline over the years of childhood. Adult levels of synapse density are reached after puberty. Although the increase is similar across animals, the decline occurs on somewhat different schedules in different individuals, supporting the idea that environmental events influence synapse elimination.
Energy use per gram tissue vs Age (in years)

Energy use increases sharply between 0 and 4 years, then peaks and declines until adulthood.

Adult level is indicated by the horizontal line.

Graph: Energy use per gram tissue vs Age (in years)
In all areas of the cortex studied in monkeys, synapse development follows a similar time course. It is not clear whether this principle of uniform synapse development also applies to children. Brain scans of developing gray matter, where all synapses are found, suggest that frontal regions reach their final volume somewhat later than visual cortex. However, because of the ages missing from the human synapse counts and variability between individuals, the evidence in support of this position is incomplete. In any event, brain energy measurements in children suggest that the differences in developmental timing among various cortical areas are relatively minor and that synapse elimination continues throughout childhood (see box, Your child’s brain consumes half of the body’s energy).

At the level of synaptic change, one of the best understood sensitive periods is the development of sound localization in barn owls. These birds hunt in the dark and must localize sounds accurately. They do this by comparing the difference in the time of sound arrival between the two ears, since a sound coming from the left side will reach the left ear before it reaches the right ear, and vice versa. The more difficult calculation of whether sounds come from above or below is determined from loudness differences created by the shape of the outer ear. An area in the owl’s midbrain receives information about discrepancies in timing and loudness and uses it to form a map of where sounds must be coming from. Because the incoming information depends on individual characteristics like head size and ear shape, it can’t be specified in advance, so this mapping is learned during development.

The owl’s brain learns this map by using visual experience to calibrate the auditory map. To study this process, researchers equip baby owls with prism glasses,
which make objects appear to be shifted to one side. At first the animals make a lot of mistakes as they try to move around with the glasses on, but gradually the brain adapts by changing its visual map to reflect the new reality. The auditory space map also shifts in response to prism glasses, even though the auditory information is unchanged.

The shift happens because the neurons that bring in timing and loudness information extend their axon branches to connect with new neurons in a different part of the map. The former connections remain in place, though their synapses are weakened, allowing the owls to return to the old mapping once the prism glasses are removed. This plasticity occurs in a sensitive period, until about seven months of age. In adults, whose sensitive period has ended, it is more difficult to rearrange connections because their axon arbors are limited to a smaller area of the midbrain and thus the wiring is not already in place to carry signals outside the range established in youth.

One of the basic principles of brain development is that the simplest building blocks are finished first. Later, more complex processes build upon earlier ones. For example, the areas of visual cortex that detect edges and shading must become functional before other visual areas can start to interpret these patterns as objects. For this reason, there is not a single sensitive period for vision, but a series of sensitive periods, each requiring experience for the maturation of a different region of the visual brain. If the experience required to complete an early developmental process is not available, the sensitive period is normally extended for a while, resulting in delayed maturation of that brain circuit and all the others that depend on it. Eventually, though, the window of opportunity closes, and any resulting damage may become permanent.
In some cases, higher-level brain areas can compensate for poor development at lower levels, so that adult behavior is relatively unaffected. For example, depth perception can be determined from a variety of visual cues, so people who lack binocular vision due to abnormal visual experience (see chapter 10) often can use other strategies to determine depth accurately.

As we have already said, learning language has a sensitive period. In extreme cases, children who grow up in a poor-quality language environment can fall progressively further behind as development continues. But in normal cases, babies are sponges for language. The dandelion qualities of language acquisition mean that you don’t need to train your baby to imitate your voice instead of the sounds of the family car because her brain areas for language are best activated by speech sounds and because language acquisition, like so many types of learning, is most effectively driven by social interactions. In the next chapter, we will consider language further as a well studied example of a sensitive period that depends on both brain predispositions and experience.

BEGIN BOX

Did you know? Your child’s brain consumes half of the body’s energy

As kids grow like weeds (and after all, dandelions are weeds), their brains are burning like torches. It’s expensive enough to support your mature brain, which uses 17 percent
of the body’s total energy though it accounts for only three percent of the body’s weight. But that’s nothing compared to the cost of building your child’s brain. The brain has nearly reached its full adult size at age seven, but it still contains connections that will be removed later as the child’s experiences help sculpt the mature brain. Synapses use most of the brain’s energy, so maintaining these extra connections is costly. From ages three to eight, children’s brain tissue uses twice as much energy as adult brain tissue. A five-year-old child weighing forty-four pounds (twenty kilograms) requires 860 calories per day, and fully half of that energy goes to the brain.

Researchers examine the brain’s energy use with an imaging technique called positron emission tomography (a PET scan) that detects radiolabeled glucose, a sugar that is the main fuel for neurons (see figure). In the first five weeks after birth, energy use is highest in somatosensory and motor cortex, thalamus, brainstem and cerebellum, the most mature parts of the brain at birth, which are responsible for basic functions like breathing, movement, and the sense of touch. At two or three months, energy use increases in the temporal, parietal, and occipital lobes of the cerebral cortex and the basal ganglia, which control vision, spatial reasoning, and movement, among other things. From six to twelve months, various parts of the frontal cortex increase their energy use, allowing babies to begin to regulate their own behavior for the first time. The amount of energy that the brain uses continues to increase until age four and then begins to decline around age nine, reaching adult values sequentially in various areas as they mature, until the pattern becomes fully adultlike around sixteen to eighteen years of age.
Did you know? The limits of brain plasticity

Optimistic popular writers have extolled the wonders of neural plasticity. The idea that experience can produce large changes in the brain is encouraging, as it supports the hope that people can learn and grow throughout life, overcoming obstacles along the way. Stories of untapped potential have a nearly unlimited appeal to the American character. But it's time to step back and take a careful look at the evidence.

As we discuss in the main text, even infants are not blank slates whose brains and behaviors are infinitely modifiable. Before sensory experience can act on a child’s brain, the neurons need to be able to talk with each other via synaptic connections. This initial wiring is put into place by developmental programs that specify particular patterns of connectivity, which are standard for all individuals. Unless there is a genetic error or a developmental accident, the ganglion cells of the eyes will send their axons to the visual areas of the thalamus, which will pass the information along to the primary visual cortex. Axons that carry signals from the touch-sensitive receptors in the fingertips will occupy more space in somatosensory cortex than axons carrying signals from the less sensitive elbow, and so on.

Under most circumstances, these connection patterns are adaptive, but in unusual cases, this may not be true. In people who cannot see, parts of the visual cortex can be
taken over by adjacent regions and used for other functions. Similar types of plasticity allow people to recover from impairments due to strokes by using another part of the brain to compensate for the damaged region, but if the damage is extensive, recovery is likely to be incomplete.

Plasticity outside a developmental sensitive period, if it is possible at all, usually requires more than simple exposure to stimuli. For instance, adults whose vision was impaired by amblyopia can improve their sight after extensive practice on a challenging task, a far cry from the effortless development of the same abilities in normal children. It is possible to change the floor plan of your house after it is complete, but it is much easier to change it during construction.

Retraining the brain in adulthood is possible in some cases, but it is slow and difficult—as it should be. Neural plasticity has costs as well as benefits. Perhaps most importantly, if routine experience could easily change your brain, then you would risk losing hard-won knowledge, abilities, and memories that you acquired earlier in life.

END BOX
Complex skills require deep foundations. Babies start to learn language a long time before they are able to speak, preferentially focusing their attention on speech from birth—or even earlier, as hearing becomes functional during the third trimester of pregnancy (see chapter 11). Because babies do not have the motor abilities to express all the knowledge that they have obtained, though, you may not realize how much language they understand at a given age.

Newborn babies already prefer their mother’s voice over other female voices, their native language over other languages, and speech over other sounds that have the same acoustic properties, including speech played backward. They can also detect a variety of vocal cues, including acoustic characteristics, stress patterns, and the rhythms of different languages. From early in life, your infant absorbs the huge amounts of information that will make him an expert in his native language, learning about its cadences, its sounds, the structures of its words, and the grammar of its sentences. Most adults instinctively help infants learn about speech by speaking to them in “motherese,” which is slower than normal language and contains exaggerated versions of consonant and vowel sounds.

Young infants can distinguish the sounds of all languages of the world, though adults often confuse the sounds of a foreign language. For example, the “r” and “l” of English sound the same to Japanese adults, but different to Japanese infants. As they acquire experience with speech, babies begin to specialize in the sounds of their own
language (or languages), which are called phonemes. By six months of age (for vowels) or ten months (for consonants), babies become better at identifying the phonemes of their native language and worse at identifying the phonemes of other languages. In other words, experience with language shapes the categories into which babies place sounds, determining which variations in acoustic characteristics are meaningful (reflecting different phonemes) and which should be ignored (reflecting different speakers, background noise, and so on).

Their neural activity reflects this phoneme learning. In older infants, the patterns of electrical signals in the brain (“event-related potentials” recorded from electrodes on the scalp) distinguish between a pair of sounds from the native language, while failing to distinguish two confusable foreign sounds. In younger infants, event-related potential patterns distinguish both foreign- and native-language sound pairs. This brain specialization is important for future language learning. Babies whose brains discriminate native sounds well (and foreign sounds poorly) at seven and a half months go on to learn language earlier than babies who show the less mature pattern of distinguishing all sounds equally well. The more discriminating babies learn words more quickly, produce more words and more complex sentences at twenty-four months, and produce longer phrases at thirty months than the less discriminating babies.

Social interaction is one cue that babies use to determine which sounds they should be learning. Nine-month-old infants who hear a tape recording or video of someone speaking a new language do not learn its sounds, but the same amount of speech from a live person is sufficient to allow the babies to discriminate phonemes in the new language. Indeed, certain measures of social interaction with a language teacher
(including a parent) predict how well individual infants will remember the sounds of the new language. In this respect, babies are like songbirds such as zebra finches, which as juveniles require social interaction with an adult tutor before learning their songs. The need for social interaction may be part of the reason that autistic children (see chapter 27), who do not interact well with other people (and do not prefer the sounds of motherese), have difficulty learning language.

The timing of speech production is determined by maturation of the brain regions that control movement. Forming understandable sounds requires considerable fine motor control and apparently a lot of practice. Babies first attempt to talk at around two months, when they begin babbling vowels, the least complicated speech sounds to produce. Some consonant sounds follow around five months, and the babbling becomes gradually more complex through the end of the first year, when it also starts to include language-specific phonemes—the sounds that make up words in the baby’s native language.

Word learning also starts long before babies can produce words of their own. Six-month-old infants know their own names and will look at a picture of their “Mommy” or “Daddy” when they hear the word. As we discussed in chapter 1, infants can listen to a string of nonsense syllables and determine which of them are most commonly heard together as “words.” They apply this talent to identifying words in normal speech, where words tend to run together without pauses. (To understand this phenomenon, think of the way a foreign language sounds—you can’t guess where one word ends and the next begins). Later, their brains learn about the regularities of sentence structure that constitute the rules of grammar in their native language. By nine months, familiar and unfamiliar words trigger noticeably different event-related potentials. By the first half of baby's
second year, these potentials are different for words whose meaning the child does or doesn’t understand. Babies’ brains also respond differently to made-up words depending on whether or not they obey the rules for which syllable should be stressed in the baby’s native language. Stress patterns appear to be another tool that babies use to determine which groups of sounds are words.

In the second year, as children learn more words and become able to say many of them, they become better at distinguishing similar words, like bear and pear. Babies at fourteen months will direct their gaze toward an object even when its name is mispronounced, suggesting that their brain does not yet represent the sounds in known words with complete accuracy. Similarly, at this age, brain activity does not distinguish between familiar words and similar-sounding nonsense words. This changes at around twenty months. The relationship between learning words and learning sounds seems to be bidirectional, so that learning sounds makes it easier to learn words, but learning more words also helps babies improve their ability to distinguish sounds.

Sentences add new layers of complexity to language learning. Again, children can comprehend sentences and grammatical connecting words before they’re able to use them in speech. To understand a sentence, your child must know not only the meanings of the individual words (called semantic information) but also how they relate to each other within the sentence (syntactic information). The brain handles these two types of information separately, semantics in a temporal cortex region called Wernicke’s area and syntax in a frontal cortex region called Broca’s area.

For almost everyone (excepting some left-handers), the left hemisphere is dominant for language production. Similar regions in the right hemisphere are
responsible for prosody, the tone and rhythm of speech that conveys much of its emotional content. (For example, prosody tells you when someone is being sarcastic or making a joke.) Laterality of language representations seems to be part of the basic pattern of brain connections laid down by genes before sensory experience becomes effective (see chapter 3) because it is apparent by two or three months of age and even occurs in deaf infants. If the dominant speech regions are damaged in childhood, though, especially before the age of five, the other side of the brain can take over their function, leaving language skills relatively normal. If the same damage occurs after puberty, it severely impairs communication abilities.

When we hear something that sounds “wrong,” event-potentials in our brains reveal whether we’re reacting to syntactic or semantic violations. “The boy walked down the flower” is an example of a semantic violation, while “The boy walk down the road” is syntactic. In small children, these mistake-detection responses develop slowly, starting as children transition from two-word phrases to their first full sentences, around thirty months of age. Brain responses gradually become faster and more precisely localized through childhood and into the early teens.

There seem to be at least two sensitive periods for language learning. We have already discussed the sensitive period for phonemes, in the first year or two of life, when babies’ brains become specialized for representing the sounds of their native language(s). There is also a sensitive period for learning about grammar. Children’s ability to acquire syntax rules declines gradually between age eight and puberty, while there is no relationship between age and language learning ability later in life (see box, Practical tip: Teach foreign languages in elementary school).
Occasionally adults manage to learn a second language to a high level of proficiency, but they use a slightly different area of the brain than the one that processes their native language. Most of us, though, no matter how hard we study in adulthood, will always have a foreign accent and make minor grammatical errors. In contrast, there does not appear to be a sensitive period for semantic learning, as new vocabulary words can be acquired equally well at any age. The event-related potential signal for semantic violations looks the same for both native and second languages, even in people who learned their second language late in life.

Children can learn more than one native language if they are exposed to both languages early enough, but their brains appear to represent the languages at least somewhat separately. Bilingual children reach language milestones at the same age and have the same risk of language impairment as monolingual children, though the details of their language development are somewhat different. Learning a second language also changes the brain. A region in the left inferior parietal cortex is larger in people who speak more than one language, and it is largest in those who learned the second language when they were young or speak it fluently.

It doesn’t matter if the same person speaks more than one language to a baby. Infants quickly learn to identify languages by their rhythms, their characteristic phonemes, and other cues. Bilingual children do sometimes mix languages in their speech, but they seem to do so for the same reasons and in the same situations as adult bilinguals, for instance substituting a word from one language when they don’t know the word for that concept in the other one. Though bilingual children have a smaller
vocabulary in a particular language than monolingual children of the same age, bilingual children know more words in total if you count both languages.

Children who hear more words while interacting with their parents in the first two years of life learn language faster than children who hear fewer words. These differences in home environments tend to fall along socioeconomic class lines. In one study, the poorest children heard 600 words an hour (many of them prohibitions like “Don’t touch that!”), working-class children heard 1,200 words, and children of professionals heard 2,100 words, with fewer prohibitions. These major differences in children’s language environment correlate with their later language development and IQ scores, though the finding that highly verbal parents raise highly verbal children may be partly due to genetic factors or the many other advantages of growing up in a professional household (see chapter 30).

Later research has shown that you can improve your children’s language skills by responding rapidly to their vocalizations, mimicking the turn-taking of conversation even before your baby is capable of forming words. Responding with a comment or a touch to your baby’s best attempts to communicate seems to encourage continued efforts to improve these skills. So talk to your baby every day, and put up a good show of understanding what she’s saying. It’s fun for both of you, and it will help her language skills to develop more quickly.

BEGIN BOX
Practical tip: Teach foreign languages in elementary school

From the perspective of neuroscience, it’s absurd to wait until high school to begin studying a foreign language. By puberty, the sensitive period for language acquisition has closed. Older students must work much harder than younger ones to learn a new language, and most of them will never master it completely. If you want your child to speak another language fluently, by far the best approach is to start early in life.

In one study, researchers tested the English grammar proficiency of Korean immigrants who had arrived in the U.S. at various ages and stayed at least three years. The test required participants to identify whether there were grammatical errors in sentences like “Tom is reading book in the bathtub” or “The man climbed the ladder up carefully.” The test was simple enough that native English speakers could ace it by the age of six, but the immigrants who began learning English after age seventeen missed many of these simple questions. Only people who came to the U.S. before age seven performed at the level of native speakers. Everyone in the group who arrived at eight to ten years of age did a bit worse, and those who arrived at eleven to fifteen were still less proficient.

Between ages eight and fifteen, researchers found a strong relationship between age of exposure and performance on the test. But, in adulthood, individual variability in performance was not connected to age. No matter whether they’d started learning English at 18 or 40, few adults learned perfectly.
The take-home message for parents and schools is clear: take advantage of young children’s superior language learning abilities by beginning instruction in elementary school. When it comes to language, there’s no substitute for an early start.
Chapter 7
Beautiful Dreamer

Sleep appears to be simple, but it is composed of many brain mechanisms working together—mostly seamlessly. In babies and young children, these brain functions mature at different times. The complex abilities involved in sleep become apparent in stages as your child grows. The intense need for sleep early in life may be related to its importance in facilitating learning.

The first function to appear, well before birth, is the internal “circadian” (Latin \textit{circa dies}, meaning approximately a day) rhythm. This clock can run for many days without external instruction, providing our brains and bodies with cues about our daily activities even if we can’t see the sun. The brain can generate an approximately twenty-four-hour rhythm without light, using a complex signaling clockwork made of genes and proteins. This clockwork’s output is used by other brain regions and organs to set their own daily rhythms, for hunger, bowel movements, body temperature, liver activity, and stress hormone secretion.

This daily rhythm of our brains and bodies is driven by the suprachiasmatic nucleus, a dab of tissue containing fewer than ten thousand neurons that sits over the optic chiasm, where the optic nerves meet and cross on their way toward the brain. The suprachiasmatic nucleus gets its signals from ganglion cells in the retina that are dedicated to transmitting information about light levels in the world. These ganglion cells, which make a pigment protein called melanopsin, convert light to impulses that
travel along the optic nerve to the suprachiasmatic nucleus. In this way, the brain knows when it is day and when it is night.

The fetus has a suprachiasmatic nucleus at eighteen weeks of gestation. Several weeks later, circadian cycles are found in the fetus's heartbeat and breathing. This rhythm is probably driven by day/night signals from the mother, such as rhythmic release of corticotropin releasing factor, cortisol, which helps you wake up, and the sleep-inducing signal melatonin.

Once your baby is born, that rhythm is suddenly lost. As any new parent can wearily tell you, newborns have highly irregular sleep patterns, though it is possible to drive the rhythm a bit through feeding times. For the first few weeks after birth, there is almost no day-to-day pattern. Their wake–sleep cycle lasts about ninety minutes on average, with no relationship to time of day.

Infants spend about two-thirds of their time sleeping, about half in rapid-eye-movement (REM) sleep. In adults, during REM sleep the muscles shut down, except for eyes and inner ear muscles. If they didn’t, we would act out our dreams. However, infants are hardly mobile and not in a position to act out much of anything. Moreover, it is unlikely that they are dreaming about movement or action, if indeed they dream at all (see box, What children dream about).

Whether dreaming or not, babies’ REM sleep may serve essential functions. As we saw in chapter 5, early development is a period of massive growth and pruning back of neuronal connections. In kittens, sleep enhances the remodeling of neocortical dendrites in response to visual deprivation. Conversely, sleep loss reduces the changeability of dendrite structure, a major component of neural plasticity. Research
suggests that this is true in both adults and children. Sleep, both REM and non-REM, may help to consolidate some kinds of learning, including the transfer of information from short-term to long-term memory (see chapter 21).

Over the next six months, as the baby encounters daily light and dark cycles for the first time, the circadian rhythm is gradually regained. The first sign of progress is a slight drop in core body temperature in the early morning every day. By three months, about two-thirds of children sleep at least five hours at night.

The conscious, awake state depends on columns of neurons deep in the brainstem called the reticular formation. The reticular formation is roused to activity when we are awake by mechanisms that are not fully understood, but involve neurotransmitters that are secreted in the brain's core, such as acetylcholine and norepinephrine.

REM sleep is controlled by brainstem neurons in the pons. These neurons send axons—and commands—both forward and downward. Descending connections prevent motor neurons from firing and therefore from causing muscle contraction, using several as-yet unidentified neurotransmitter pathways. The function of the forward-projecting connections is unknown, but they may drive plasticity—and perhaps dream activity.

During non-REM sleep, movement is still possible, but sensory input does not get through very well, especially during deep non-REM sleep.

As babies grow, sleep changes. The amount a baby sleeps declines gradually, reaching twelve hours per day by age two. At the same time, REM sleep diminishes dramatically, as do nighttime melatonin levels. By age three, children spend just one-fifth of sleep time in REM sleep, the same proportion as teens and adults. By age six, sleepers
alternate between non-REM and REM sleep over a ninety-minute period, the same
duration as the adult sleep cycle.

The development of sleep does not always go smoothly. While you sleep, many
events need to be suppressed to keep you safe. You don’t urinate. You don’t act out your
dreams by walking around or making noise, thereby attracting predators. In children,
these safety mechanisms are still under construction. Before the age of six, one child in
three experiences interruptions called parasomnias, which include a suite of problems
such as sleepwalking, bedwetting, and night terrors, . If these do occur, they begin
between three and six and are largely resolved by the onset of puberty. Parasomnias
usually happen during the first few hours of the night, during the deepest sleep just before
the evening’s first bout of REM sleep.

One parasomnia can particularly upsetting to a parent: night terrors, which occur
in one to six percent of children age three or older. In younger children, they can occur at
least once a week. Sleep terrors consist of waking, typically from deep non-REM sleep,
with expressions of fear, often including screaming. The child is inconsolable and takes
from five minutes to half an hour to settle down. In the morning, he does not remember
anything.

Night terrors are not simply nightmares. They occur at an age when children’s
dreams do not include fear, or for that matter any other emotion (see box, What children
dream about). Instead, the child is fearful, but cannot report any specific events. The
cause is likely to involve lack of regulation of brain structures that handle strong negative
emotions, such as the amygdala. The amygdala regulates the sympathetic nervous system
to mobilize the brain and body to fight or run away. In adults, this system can be
suppressed by other regions of the brain such as the hippocampus and neocortex. In children, such suppression may not be mature enough to be effective, especially during deep sleep.

Night terrors may be triggered by sudden waking. In one study, 84 preschoolers who sleepwalked or suffered night terrors were observed while they slept. More than half were found to have disordered breathing, such as obstructive sleep apnea. In this disorder, when respiratory centers in the brainstem receive a signal that breathing has stopped, the sufferer wakes up suddenly, gasping. In children, sleep apnea has several causes, including being overweight and enlarged tonsils. Remarkably, all the children with sleep apnea who underwent tonsillectomies in that study were cured of their night terrors.

In night terrors and sleepwalking, sleep mechanisms do not fully suppress behaviors that usually occur in waking life. In the other direction, sleep phenomena can also appear unbidden in the daytime. Examples include narcolepsy and cataplexy, in which an awake person suddenly falls asleep or loses conscious motor control. An upsetting example is sleep paralysis, in which a person wakes up but cannot move. In this case, touching the person usually ends the paralysis.

Another characteristic of children’s sleep is the need for naps, which is driven by a slow cycle that spans the entire day. In both adults and children, alertness and sleepiness are cyclical. Part of the cycle includes an afternoon lull, followed by a second wind. Until age five or six, the lull is low enough to require an afternoon nap. After that children are able to stay up all day, as adults can.

This is not to say that staying awake all day is the best strategy for grown-ups. Low afternoon alertness in adults may be a remnant of our need for an afternoon nap. In
one experiment, college students were required to focus on the center of a screen when the letter T or L flashed, followed after a brief pause by some diagonal bars shown elsewhere on the screen. Students tested early in the day identified both letter and the orientation of the bars even if they were flashed in quick succession. Later in the day, they needed them to be spaced at longer intervals. This slowing of perceptual capacities was prevented if the students were allowed to take a brief nap. Naps not only keep toddlers from getting cranky, but may also help our own mental performance.

So when you watch your baby or child sleeping, be aware that her brain is far from idle. Her brain is fulfilling a well-choreographed process that is coming along nicely without any special effort by her, or you. While sugarplums might not be dancing in her head, bigger things are changing—including events that may restore and rewire the developing brain.

BEGIN BOX

Practical tip: How to get your baby to sleep

The amount and type of sleep that a child needs is programmed over the course of normal development, without that much input from the environment. Triggering sleep is a somewhat different story, one that depends on learning mechanisms.
It is sometimes possible to induce drowsiness in babies. A small amount of alcohol added to mother’s milk (the equivalent of mom having a glass of wine) can slightly shorten the time until sleep begins, by about fifteen minutes. The total amount of sleep over the next three and half hours is reduced by an even greater amount, though, suggesting that this is a bad strategy. A better strategy is to watch for drowsiness and act quickly: put the baby down to sleep right away. Babies cycle in alertness, just as adults do, but more quickly.

For bedtime, small children learn quickly to associate particular cues with sleep. Like other associations, children can learn from a single example—or a single exception. Once formed, preferred bedtime habits are hard to break. For example, if children become used to having a parent present at the onset of sleep, that becomes a requirement. It’s better to leave the room so the child associates falling asleep with having the parent absent—which will turn out to be a boon later. In general, establishing a bedtime routine, including tooth brushing, stories, and winding down of attention paid to the child, provides a familiar landing procedure. Consistency is essential. For more information on this subject, an excellent resource is *Healthy Sleep Habits, Happy Child* by Marc Weissbluth.
Did you know? What children dream about

Most of us are familiar with the claim, popularized by Sigmund Freud and Carl Jung, that dreams symbolize hidden desires and fears. Perhaps in part because of this culturally driven expectation, we often assign meaning to our dreams after we wake up, making our reports unreliable.

Your child may also experience a version of this coaching if you ever ask what he dreamt about or wish him good dreams. It’s harmless, but it also means that you’re inadvertently encouraging storytelling that might not match what was actually dreamt. Unless adults practice recalling their dreams, most of a night's dreams are forgotten by morning. The same is likely to be true for children.

If you ask adults, they report having a dream 60–90 percent of the time after being woken up from REM sleep, and 25–50 percent of the time from non-REM sleep. They can also report what they were dreaming about. This approach can be taken with children too: wake them up and ask what they were dreaming about (or what was happening, if they are very young and do not know what a dream is). If you are unwilling to wake your sleeping child in the name of science, you don’t have to. Sleep researcher David Foulkes and his collaborators stayed up with children between the ages of three and twelve, either in a laboratory or at the children's homes. They woke the children in the night, and then asked what was happening just before they woke up.

At early ages, children's dreaming was simple and rare. Only 15 percent of three- and four-year-olds reported any dream events after being awoken from REM sleep, and there were no dreams at all during non-REM sleep. The dreams that preschoolers did
report were static and often involved animals: “a chicken eating corn” or “a dog standing.” The children themselves typically appeared as passive agents: “I was sleeping in a bathtub.” “I was thinking about eating.” At this age, dreams also lack social interactions or feeling. Preschoolers do not report fear in dreams, nor do they report aggression or misfortunes. This contrasts with their waking lives, in which they can describe people, animals, objects, and events around them.

At later ages, dreams take on more complex qualities. Around age six, dreams become more frequent and take on active qualities and continuity of events. By eight or nine, dreams are reported as frequently as they are in adults, have complex narratives, and feature the dreamer as an active participant. Dreams also start to include thoughts and feelings.

The static dreams of preschoolers occur when their visual–spatial skills are not fully developed. For instance, children who report more dreams are also better at recreating pictures of red and white patterns using blocks. At this age, children are also less able to imagine what an object looks like when viewed from a different angle. Such skills depend on the parietal lobe, which sits between neocortical regions that represent vision and space. The parietal lobe does not become fully myelinated until age seven, suggesting that at earlier ages, children may dream in static images because their brains are not fully competent to process movement.

What does this process tell us about child development? One potential answer is that dreams reveal the patterns of brain activity that are possible in the absence of external stimuli. In this respect, they may give us a window into the developing conscious minds of children.
Chapter 8

It’s a Girl! Gender Differences

Three-year-olds take gender roles as seriously as drag queens do. One of our colleagues, who was dedicated to freeing her kids from traditional gender expectations, bought a doll for her son and trucks for her daughter. She gave up her quest after she found the boy using the doll to pound in a nail and the girl pretending that the trucks were kissing each other.

Many puzzled parents have wondered where this highly stereotyped behavior comes from, especially in households where Mom wouldn’t be caught dead in a pink frilly dress and Dad would rather cook dinner than watch sports. All over the world, a phase of intense adherence to a sex role seems to be important for the development of a solid gender identity. This stubbornness reminds us of the stage of grammatical learning that happens around the same age, another area where kids apply newly learned rules more broadly than necessary (“That hurted my foots” instead of “That hurt my feet”).

In light of such striking behavioral differences, you’d probably imagine that the brains of little boys and girls are distinct in many important ways. Because of our society’s intense interest in sex differences, researchers have done many thousands of studies of this topic, and journalists have been eager to publicize them. This literature is vast and variable, so where possible we have relied on meta-analysis. This is a powerful statistical technique for combining the findings of multiple studies to increase our confidence in the conclusions. From careful review of such papers, a few important patterns emerge.
When evaluating reports of sex differences, it’s important to pay attention to the size of the effects. Most gender differences are too small to matter in any practical way, and a minority of differences are important when comparing groups. But only a few tell us anything significant about individuals. For instance, girls—on average—are more likely to hear a relatively quiet sound. But, it would be impossible to guess whether a particular child is male or female by knowing that child’s hearing ability, because all possible scores are found in both boys and girls. And what’s more, for nearly all sex differences, the differences among individual girls or among individual boys are much larger than the average differences between the sexes, with a few important exceptions.

What do we mean when we say that a gender difference is small or large? Let us be technical for a moment. Scientists often measure the size of a difference between two groups by calculating a statistic called “d-prime” (d') or effect size, defined as the difference between groups divided by the variability of one or both groups. If there is no difference, the d' is zero. The d' gets bigger as the size of the difference in average scores between the groups increases, relative to the range of scores within each group.

This idea is easier to explain in pictures than in words. The figure shows the differences between groups that correspond to typical d' values. The horizontal axis represents the possible scores, while the height of the curve represents the number of people in the population who get a particular score. From top to bottom, these differences would be considered small, medium, large and very large.

Let’s consider some specific examples. For gender differences in adult height in the U.S., the left curve in the bottom panel (d' =1.9) would represent women, and the right curve would represent men. The horizontal axis would show heights from short
(left) to tall (right), with the peak of the female curve at 5 feet 3.8 inches, the average height for women, and the peak of the male curve at 5 feet 9.4 inches, the average height for men. A man of average height is taller than 92 percent of women. In the research literature, a value of $d'$ that is at least 0.8 is considered large, so this would be a very large difference.

At the other extreme, let’s take as our example a small difference that we’ve already mentioned: hearing. Several authors have recently argued in favor of single-sex education based in part on the idea that girls have more sensitive hearing than boys and therefore respond best to teachers speaking quietly. For hearing sensitivity, the left curve in the top panel ($d' = 0.2$) would represent boys, and the right curve would represent girls. Because the difference between the two groups is small, as you can see, the two curves overlap substantially.

The individual differences in hearing within each sex are much larger than the differences between boys and girls. And, given that many boys have sharper hearing than many girls, it doesn’t make sense to argue for sex segregation on these grounds. If you think sensitive hearing affects the way people learn, you should separate them based on their hearing, not their gender—the two are not the same.

Only a few gender differences are big enough to predict individual behavior. The largest known behavioral difference at any age is toy preferences in three year olds. Parents who try to keep their sons from playing with toy guns soon discover that any stick—or, in a pinch, even a doll—can be converted to a weapon in a boy’s imagination. Given the choice between a boy-typical toy like a car and a girl-typical toy like a tea set, at age three children differ in their choice of boyish toys with a $d'$ of 1.9, a difference
corresponding to the bottom panel of the figure. This means that you can do quite well at
guessing the sex of a young child based on his or her choice of toys, as 97 percent of boys
are more likely to play with male-typical toys than an average girl. Because play helps
children learn and practice a variety of skills, sex differences in how children spend their
time can influence which abilities they carry through life (see box, Practical tip: Play
preferences can influence adult sex differences).

The emergence of toy preferences is an early stage in the development of gender
identity, defined as your child’s self-identification as male or female. Gender-influenced
toy preferences are seen across cultures, beginning around one year of age. Even babies
have some understanding of gender (see chapter 1), but only a few two-year-old children
can accurately state whether they are boys or girls or reliably distinguish men from
women in pictures. Most children—again across cultures—reach this milestone by two
and a half, and almost all children get there by age three. Children who have reached this
milestone are less likely to choose the “wrong” toy than children who have not.

Toy preferences almost certainly have an innate basis (though they are also
influenced by culture). One clue is that male monkeys prefer to play with trucks, while
female monkeys prefer dolls. Another clue is that boy-typical toy preferences are more
common in girls with a syndrome called congenital adrenal hyperplasia or CAH. Due to a
 genetic defect in adrenal hormone synthesis, CAH girls are exposed to an excess of
testosterone and other androgens, masculinizing their brains and to some extent their
bodies in utero. Because this hormonal malfunction can be treated starting at birth, CAH
girls offer an opportunity to look at the effects of prenatal exposure to male hormones on
later behavior.
As they get older, girls tend to become more flexible in their toy preferences. By age five, nearly half will pick a boy-typical toy when offered a choice. Boys, on the other hand, continue to refuse girl-typical toys, most likely because the social penalty for acting like a girl is very steep. Both peers and parents—especially fathers—actively discourage boys from playing with girl toys.

This discouragement may stem from concerns that boys who play with girl toys will turn out to be gay in adulthood. In fact, this is true more than half of the time. (Tomboy girls, on the other hand, rarely turn out to be lesbians.) Whether parents encourage or approve of their son’s habits, though, is irrelevant to their sexual orientation later in life. Playing with dolls doesn’t cause boys to become gay, but the father who tries to discourage this behavior might be opening a rift with his son. Psychiatric treatment aimed at encouraging boyish behavior has no effect on adult sexual orientation. The most likely explanation is that playing with girl toys and adult homosexuality both result from earlier influences on some boys’ brains, perhaps due to prenatal experiences or genetics. By the time you can observe the behavior, the outcome is out of your control, so you might as well get comfortable with it.

You’ve probably noticed two other sex differences in young children’s behavior. Boys are significantly more active and more physically aggressive than girls. These differences are medium sized, with a d' of 0.5, corresponding to the second panel of the figure on page TK. That means an average boy is more active and more physically aggressive than 69 percent of girls, which does not predict individual behavior very well, but does make groups of boys obviously different from groups of girls. These differences are also probably influenced by the action of hormones on the brain, not just by culture.
Juvenile male monkeys show more rough-and-tumble play than female monkeys, and this behavior can be modified by hormone treatment. Similarly, CAH girls are more aggressive and more active than other girls, again suggesting an early hormonal influence on this behavior.

Perhaps as a consequence of these behavioral differences, starting as early as two or three years of age, children prefer to play with other children of the same sex. These segregated play groups persist throughout elementary school. This pattern is seen across many societies and even in monkeys and apes, so it probably is not strongly influenced by culture. If there are only a few children available, boys and girls will play together, but when possible, they usually split the group by gender.

This behavior reinforces gender norms as children are learning about their gender identities. Social pressure from other children to conform to gender norms is particularly strong from age four to eight, perhaps because children’s early concepts of sex roles (and many other rules of society) tend to be written in black and white, with a more flexible understanding emerging later in development. We know a neuroscientist couple whose son was best friends with a girl throughout the preschool years. When he was six his male friends at summer camp let him know that playing with girls was unacceptable. Now their son will only see his female friend inside the house, with everyone involved sworn to secrecy so the other boys won’t find out. In single-sex groups, boys learn to hide their emotions (with the exception of anger) and to compete freely, while girls are encouraged to suppress aggressive and competitive impulses and to express fear.

Sex differences in behavior give girls a medium-sized advantage over boys in the classroom, where girls get better grades in high school and college. Girls’ brains mature a
month or two earlier than boys’ brains, and girls are moderately better at inhibitory control (d' of 0.4)—that is, sitting still and concentrating on their task—so the classroom culture is more friendly to girls. On average, girls are a bit more advanced in some areas of verbal development when starting school. Boys lag at fine motor coordination (d' of 0.6), giving them a moderate disadvantage in the ability to write letters, the largest sex difference in academic performance as school begins. These gaps persist through high school, with boys continuing to score lower on tests of both reading and writing.

But let’s put all these gender comparisons in perspective. All these differences have smaller effects than the difference between living in a middle-class neighborhood with good schools (judged by their average test scores) and living in a low-income neighborhood with poor schools. First graders from poor areas score lower than their middle-class counterparts (d' greater than 1.1) in both reading and mathematics performance, and those gaps too typically widen with age (see chapter 30).

Like other gender differences, gender-related differences in education may be modified by experience. Girls have recently caught up with boys in academic areas where they were lagging just a decade or two ago. In the U.S., there are no remaining gender differences in average performance on mathematical achievement tests through high school. In addition, women are now more likely than men to attend and complete college. In the U.S., there are 185 women for every 100 men with college degrees at age twenty-two. Because men take longer than women to graduate, this gap narrows considerably at later ages, but it does not close completely.

To help reduce this gap, we suggest that boys might benefit from extra training in language and study skills during the early school years. The most efficient way to
improve overall performance would be to provide such help evenhandedly to all children who need it, a group that would include more boys than girls.

Curiously, in the face of this female progress, the famous male advantage on the mathematics section of the SAT (originally Scholastic Aptitude Test, later renamed Scholastic Assessment Test I) has not narrowed at all \((d' = 0.4, \text{ thirty-five points as of 2009})\). Despite their SAT score deficit, however, women get better grades than men in college math classes. One study found that male freshmen get the same grades in college math classes as women whose math SAT scores are thirty-five points lower. Indeed, nearly all the standardized tests required for college admission underpredict the future grades of women. This poor prediction may be due to better study habits among women (giving them higher grades for the same aptitude), or it may be due to gender bias in the SAT (giving women lower scores for the same aptitude). Either way, the lower grades of college men relative to women can be attributed in part to the use of standardized tests for admission decisions.

Another well known group of sex differences fall in the realm of emotional behavior. These differences are not as large as most people believe. Effect sizes range from small to medium. These differences do not predict individual behavior very well, but some of them are noticeable at the group level. Girls are more likely than boys to express fear and to cry, but in both sexes the physiological responses to distress are similar. Many differences are so small that they are drowned out by individual variability within each sex. One example is the idea that boys make moral decisions based on justice \((d' = 0.19)\), while girls make moral decisions based on relationships \((d' = 0.28)\). Similarly, girls are only slightly better than boys at identifying emotions in other people’s faces \((d'\)
Boys are only slightly more likely than girls to take risks at all ages ($d' = 0.13$), with a larger effect between ages 10–13 and 18–21 ($d'$ around 0.25). The gender gap in risk taking seems to be closing over time, as it was smaller in later studies (1980s and 1990s) than in earlier studies (1960s and 1970s).

Kids return to mixed-sex socializing as teenagers. The hormones of puberty usher in a medium-sized sex difference ($d' = 0.53$): 70 percent of teenage boys masturbate more often than the average teenage girl, a pattern that continues into adulthood. The size of this difference has declined from a $d'$ of 0.96 over the past two decades, suggesting a strong cultural influence. Sex differences in self-esteem peak in adolescence as well, with teenage girls showing lower self-esteem than teenage boys ($d'$ of 0.33, another small difference).

One area where girls could clearly use extra support is body image. Especially as teenagers, girls experience much more dissatisfaction than boys with their bodies, which is a risk factor for eating disorders and depression. The size of this difference increased from a small $d'$ of 0.27 in the 1970s to a moderate $d'$ of 0.58 in the 1990s, perhaps because of the progressively thinner standards of female beauty across recent decades.

Even if you’re concerned about your daughter’s weight, criticizing her body is likely to be counterproductive. In one longitudinal study, teenage girls and boys who reported being teased about their weight by family members were much more likely than average to have developed an eating disorder or to have become overweight five years later. Similarly, in another longitudinal study, repeated dieting in fourteen-year-old girls (many of whom were not overweight) increased their risk of becoming overweight a year later by almost a factor of five.
One interesting thing about all of these sex differences is that the size of the difference does not predict how malleable it is. Though initial preferences can be modified by environmental influences, they often do launch boys and girls onto paths that can lead them to have different experiences for much of childhood. To sum it up, your child probably has some initial inclination toward fixing cars, taking care of babies, or whatever, but there are many opportunities to introduce him or her to new interests.

BEGIN BOX

**Practical tip: How can parents help children develop a broad range of abilities?**

The toys that children play with may affect their behavior and interests later in life. Although you can’t force boys to behave like girls or vice versa, by taking your children’s natural inclinations into account, you can help them to practice skills that they might not find on their own. You don’t know what the future holds, but we figure that you can’t go wrong by increasing the number of options available to them in adulthood.

One of the largest adult sex differences is that males are better at mentally rotating objects through space. (This ability affects the way we think about directions, as well as some practical skills like moving a couch through a doorway). This pattern emerges early in life and is then modified by later experience. Male infants at three to five months can recognize rotated objects, while female infants of the same age cannot do so. Otherwise
infants show no sex differences in their understanding of the behavior of objects (see chapter 1). In elementary school, the gap in mental rotation ability is small, but it continues to widen as children mature, reaching a d' of 0.66 to 0.94 (depending on how the test is scored) for adults, meaning that the average man performs better than 75 to 83 percent of women. This difference may be important because performance on mental rotation tests predicts performance on the math part of the SAT in both male and female high-school students and likely contributes to sex differences in map reading and navigation ability.

It makes sense that different styles of play might improve different skills. Exploring physical objects and their interactions is an important component of boys’ play. As they build towers of blocks and knock them down, wrestle, play catch, or ride bikes around the neighborhood, boys are learning about the rules of the physical world. As girls play with dolls and dollhouses, they are practicing nurturing and fine motor control skills. Girls also talk with each other during play more than boys do, which may help girls to become more fluent and have larger expressive vocabularies by the time they start school.

There are several reasons to believe that boy-style play develops spatial skills in all brains. Boys raised in deprived conditions don’t show an advantage over girls in their spatial abilities. In one study, boys from families with low socioeconomic status (SES; see chapter 30) scored lower on a mental rotation test than boys from medium- or high-SES families and performed no better than girls of any SES. The authors’ explanation was that boys from such families may not get the play experiences required to develop their object manipulation skills. Video games involving navigation or other spatial tasks
help boys and girls learn to visualize and rotate objects. Some studies find that these training effects are especially large in girls. Playing sports may also be helpful. College athletes of both sexes have an advantage over nonathletes in mental rotation tasks and other spatial skills, though this may be because people with good spatial abilities are more likely to play sports. Researchers have not yet demonstrated that these experiences lead to real-world improvements in spatial skills, but that will be the next step.

What can parents do to help all their children develop a broad range of abilities? Encouraging girls to play video games could improve their spatial reasoning (as well as their comfort with computers, a beneficial skill). We also suggest getting girls involved in sports (see chapter 15), preferably when they’re young, as self-consciousness may inhibit teenage girls from wanting to learn new physical skills. Language is strongly influenced by experience (see chapter 6), so parents can help boys to develop better language skills by talking and reading to their sons, starting in infancy. Boys may also benefit from extra help with phonological awareness in the preschool years, which parents can provide by discussing which letters make which sounds as they read. Similarly, you can take advantage of young boys’ attraction to the computer to encourage them to write stories onscreen or choose books about fighter pilots or dinosaurs to engage their interest in reading. You can find many other suggestions for helping girls and boys grow into well-rounded adults in neuroscientist Lise Eliot’s book *Pink Brain, Blue Brain.*
Chapter 9

Adolescence: It’s Not Just About Sex

You might dread your child’s adolescence, fearing a tumultuous period dominated by hormones and erratic behavior. But the truth is far more complex, and includes a raft of other changes, which are overwhelmingly for the good.

Although key steps in sexual maturation do occur during this time, a host of changes unrelated to sex also take place before and after puberty. More than anything else, the adolescent brain is highly dynamic. During adolescence, which spans ages twelve through twenty and sometimes beyond, children make major moves toward living on their own. They explore new interests, organize their own behavior, and pursue serious relationships outside the family. They revel in (or feel awkward about) their bodies’ new capabilities. Most people recall their teen years as a time of near limitless possibility, of idealism, and of innumerable options. Friends of ours often find their early teenage daughter up late studying Spanish verbs, working on an intricate and beautiful drawing, looking up song lyrics, doing a conditioning regimen for her circus aerials, or simply reading or thinking. Whew.

Adolescence is also a time of risk. Just as developmental events before and after birth can lead to disorders such as autism, other problems are likely to become apparent during adolescence. Depression, bipolar disorder, drug addiction, and schizophrenia become increasingly prevalent at this time. In addition, adolescents are prone to take risks because their sensation-seeking impulses become strong when self-control is not yet fully mature.
To superficial appearances, the brain appears to be nearly finished as children enter adolescence. By late childhood, the brain has reached 95 percent of its adult volume. Individual components are within 10 percent of adult size (some larger, others smaller). Behind this apparent maturity, though, some large changes are stirring.

The adolescent brain undergoes considerable reorganization as synapses are pruned away, continuing the process that began in childhood. The brain contains its maximum number of synapses (the connections between neurons) before puberty, in people as well as other primates (see chapter 5). By the age of eleven, the human visual cortex has reached adult synapse numbers and uses about one-fourth less energy than it did in early childhood. Even so, synapse elimination is far from complete. Indeed, the rhesus monkey brain is estimated to lose as many as 30,000 synapses per second during adolescence.

Before getting into what your adolescent child’s brain is up to, let’s get technical for a bit. To explain how and why your child’s behavior is changing, we need to give you some details at the level of cells and connections that will provide essential context.

As you might expect, the changes in synapse number are accompanied by visible changes in the gray matter of neocortex, where neurons, dendrites, and synapses are found. The general pattern is for gray matter to reach a peak thickness, and then decline by 5–10 percent. In this way, the brain’s circuits are shaped and refined before adulthood—while the brain’s owner is acquiring new abilities to contribute more actively to the process.

These maturational changes happen at different times in different parts of the brain. The first areas of neocortex to reach peak thickness are the most extremely frontal
and occipital (farthest back) regions. The areas in between are then filled in, starting from the back and moving forward. Temporal cortex reaches maximum thickness around age fourteen, followed by most of frontal cortex. Finally, the white matter, made of myelinated axons that carry long-distance information, bulks up, especially connections between frontal and temporal cortex.

One sign that adolescent brains are becoming more efficient is that activity is better coordinated between distant brain areas. This improvement is seen in signals varying together (coherency) and traveling over distances more quickly. White matter is only 85 percent of adult size and continues to grow even into the forties. As white matter grows, axonal fibers are likely to be widening, and fatter axons transmit signals at higher speeds. As white-matter axons mediate communication between distant brain regions, this change is likely to have strong functional implications—though at present we don’t know what they are.

The tempo of developmental change varies from child to child. In a study of children whose brains were imaged repeatedly as they passed through late childhood and adolescence, children of higher intelligence had gray matter thickness that rose to peak more steeply—and declined more quickly as well. This result suggests the possibility that a key to intelligence is not brain size, but capacity for change, though these differences are too variable for evaluating individuals. Indeed, rapid increases and decreases in gray matter thickness also appear in childhood-onset schizophrenia and ADHD, so these structural changes may reflect a variety of underlying processes in different children.

What do all these brain changes mean for your adolescent child’s thought—or lack thereof, as the case may be? One example is the relatively late maturation of frontal
cortex, which has received a lot of media attention recently. This area participates in executive function tasks such as self-control, planning, and resisting temptation. It becomes more active with age, an exception to the general trend of decreasing activity. In anterior and superior regions of frontal cortex, activity rises from ages twelve to thirty.

Adolescents seek novel experiences more often and weigh positive and negative outcomes differently from adults. Such judgments can be probed using the Iowa Gambling Task, a game in which people can pick cards from several decks to win play money. Unbeknownst to the player, some decks are stacked, leading to more losses overall, but large occasional gains. In a version of the game in which participants can play or pass, adolescents learn to prefer winning decks, but are less prone to avoid losing decks. Only in their late teens do players show full avoidance of bad outcomes. In this game, then, adolescents make decisions that recognize the possibility of a lucky win but give little weight to losing.

This laboratory finding is reminiscent of the real-life observation that teenagers tend to underestimate the consequences of their actions. This tendency, noted since ancient Roman times, is seen in areas as diverse as unprotected sex, experimenting with drugs, and impulsive speech. Even though adolescents are physically quite healthy, this risk-taking makes the mortality rate of this life phase high. Sam is fortunate to have survived his own youth, during which he habitually returned very late at night from social outings—the reward. Once he got into a bad car crash—a risk unforeseen by his adolescent brain.

These forms of impulsivity come at a time when white-matter connections between the orbitofrontal cortex and other emotion-processing parts of the brain are not
yet complete. The orbitofrontal cortex appears to orchestrate the connection between emotion and good judgment. In general, decisions are often informed by the brain’s evaluation of whether an outcome is desirable or undesirable. Such a decision carries some emotional weight—even when it’s as simple as picking an outfit to wear. People with damage to their orbitofrontal cortex are unable to sensibly manage their lives, making bad investments and unsuitable life choices. One patient (known by his initials EVR) had a benign tumor pushing on his orbitofrontal cortex. He lost his job and wife, married a prostitute, and divorced again in a matter of months. Removal of the tumor reduced these unadaptive behaviors.

Adolescent changes in mood, aggressiveness, and social behavior are driven by other aspects of brain development. These changes may be linked to increases in the size of the amygdala, a part of the forebrain that processes strong emotions, both positive and negative.

Even puberty itself is ultimately driven by the brain, because the hypothalamus, a grape-sized structure that sits under the brain just in front of the brainstem, secretes gonadotropin-releasing hormone as the first step in a chain reaction that ultimately leads to the release of estrogens and testosterone to drive sexual maturation. Together, these hormones powerfully reorganize the brain. Many of the brain changes we have described may be organized and shaped by hormone signaling.

Although sex and stress hormones rise during late childhood and adolescence, in most cases researchers have found little evidence for a direct effect of hormones on typical adolescent behavior. For instance, by itself the gonadal hormone testosterone is not very predictive of risk-taking. The combination of a poor parent–child relationship
with high testosterone has somewhat more predictive power. In adolescence, a good relationship forged in your child’s early years can pay off. This principle extends to siblings too: better relationships with brothers and sisters improve adjustment during adolescence.

A degree of impulsivity and aggression is probably unavoidable during this stage, but in some cultures, adolescent urges play a positive role. For example, among immigrants in big-city Chinatowns, aggression by male adolescents toward potentially violent intruders can protect the community from harm. Among the Mbuti, a hunter-gatherer group in the Congo, adolescents act on behalf of the group to punish deviations in adult behavior with mockery and even vandalism.

One hallmark of adolescent behavior in people and other mammals is an increase in what behavioral scientists call “approach,” the seeking of new social contacts and situations. Combined with other changes, this tendency can lead to the making of new friends—and also, sometimes, rebellion against older family members. Some conflict is typical, though extreme emotional turmoil in relationships with parents is experienced by only about one in ten adolescents. This happens in other species as well. For instance, adolescent rats sometimes attack their parents.

Another typically teenage behavior, the tendency to seek novelty, is likely to be driven by the brain’s reward systems. Dopamine is a neurotransmitter involved in initiating action and movement and in signaling rewarding events. In brain scanning data, orbitofrontal cortex and other regions that receive dopamine-secreting inputs are still maturing during the teen years. The serotonergic system—involved in sensation,
movement, and mood—is also changing in the adolescent years. Awkwardness and moodiness might be linked to this change.

Another change in the brains of adolescents is a proliferation of receptors for the signaling chemical oxytocin. Oxytocin mediates a wide variety of bonding behaviors. In people, oxytocin is secreted during feelings of romantic and maternal love. Indeed, these signals sometimes get crossed, so that a mother having a loving thought towards her partner might feel her milk drop. Romeo and Juliet were also probably feeling a newly strengthened oxytocin signal.

Adolescence is a time when the interplay between brain and environment takes on new complexity. Early adolescent brain changes increase a child’s appetite for stimulation and social contact, while self-regulatory systems continue to mature through late adolescence. In modern society, adolescence is viewed in terms of the delay between sexual maturation and true independence. Indeed, sexual, physical, and intellectual maturation are spread out over a decade or more, providing many opportunities for growth and change. What an adolescent does with this biologically defined period of transition depends on his or her culture—and the choices that come along the way. Around the world, how and when people enter society during this process varies, ranging from child workers to continuing students with children of their own. In all cases the brain has found ways to adapt to local circumstances—a testament to its flexibility.
Myth: Adolescents have a longer day–night cycle

The eight-year-old who got up early every morning has turned into a sluggish teenager. Although his body is in front of you, his brain is at least one time zone to the west. Everyone else is getting up, but he still wants to sleep—a kind of Adolescent Savings Time. What is going on?

Our brain’s circadian rhythm sets the times that we want to wake and sleep (see chapter 7). Individuals vary, so that “larks” have peaks and troughs earlier in the day than “night owls.” Adolescence is accompanied by a shift toward evening wakefulness—and not just in people. At puberty, a shift of one to four hours has also been seen in monkeys and a variety of rodents.

One popular view is that adolescents have a longer day–night cycle. This impression is false: if you take away normal light-dark signals or suddenly shift the signals, a teenager’s internal clock will react the same way as everyone else’s. But a real difference in in adolescent circadian rhythms is a decrease in melatonin levels. Melatonin helps trigger the onset of sleep. When puberty hits, nocturnal melatonin levels decline sharply, continuing a general decreasing trend that started back in infancy. So it’s possible that adolescents are simply experiencing smaller sleep signals than they did in previous years, leading to a delayed bedtime.

With puberty also come new social pressures. Even though they need only a little less sleep than children, adolescents are expected (or want) to adopt adult-like wake and sleep times. Their schools convene earlier in the morning. At the end of the day, there is homework, after-school activities, and spending time with friends. Intellectually and
socially, their world is exploding. Even after bedtime, communications such as text
messaging provide a continuing source of stimulation—and sleeplessness.

The net result is the need to catch up on lost sleep. In one study, researchers
surveyed sleep habits in Swiss, German, and Austrian girls for up to nine years after their
first menstrual period. The girls slept almost two hours longer per day on weekends than
on weekdays, compared to less than an hour of catch-up in younger children and adults.
Sleep debt has serious consequences, including reduced mental performance, depressed
mood, impaired health, and weight gain.

One name for this adolescent tendency, “social jetlag,” suggests that they might
be able to use some tricks of long-distance travelers. Here are a few:

1) Opening the blinds in the morning will activate the melanopsin pathway in your
retinas. At this time of the circadian clock, exposure to light creates a tendency to get up
a little earlier the next day.

2) Evening light leads to a later bedtime the next day. Combine that with a natural
tendency to stay up, and it’s a recipe for continued night-owl behavior. So even if sleep
isn’t coming easily, turn down the lights. And turn off that cell phone.

3) Exercise leads to secretion of melatonin by the pineal gland. An evening soccer game
or run might be just the thing to start a brain on the road to sleep.

END BOX
PART THREE

START MAKING SENSE

Learning to See

Connecting with Your Baby Through Hearing and Touch

Eat Dessert First: Food Preferences, Taste, and Smell
Chapter 10

Learning to See

As you haul your kids from music lessons to swim team practice, have you ever paused to give thanks that you don’t have to take them to vision class? Learning to see is a complicated process involving the coordinated development of dozens of brain areas. It does depend on experience: children’s eye problems can affect their ability to see. However, parents get almost a completely free ride.

This doesn’t mean your baby arrives ready to see. Far from it. An adult who could see as well as a newborn would be legally blind, with 20/600 vision. Babies’ visual acuity starts out forty times worse than adults’ and doesn’t become equal until four to six years of age.

Like other aspects of your child’s brain development, this maturation comes about as an interplay between genetic programs and experience. In this case the necessary experience is visual and is widely available to any baby who can see normally. Most baby books don’t talk much about this type of development (which scientists call “experience expectant”), perhaps because it doesn’t require or reward much effort from parents. But such robust (self-managing) processes are more the rule than the exception in early life. Experience-expectant development is one of the key reasons that most kids end up well adapted to their environment.

Though vision feels seamless, your brain actually constructs its image of the world from the neural activity in dozens of interconnected regions that specialize in particular aspects of seeing. These regions are organized into two main pathways. The
“where” pathway, which develops earlier, consists of the cortical areas that process motion and space. The “what” pathway is made up of areas that evaluate the properties of objects, including their shape, color, and patterning. Both pathways obtain information from a chain of connections that start at the retina, pass through the thalamus, and go to the primary and secondary visual areas of the cortex. From there, the two pathways diverge, involving different parts of the cortex, but with plenty of crosstalk between them.

All these cortical areas are immature at birth, making the vision of newborn babies quite poor. Babies don’t see what we see (see figure). Newborns mostly rely on subcortical pathways, from the retina to the superior colliculus region of the midbrain, which controls visual–motor reflexes and certain types of eye movements.

When the visual cortex starts to mature in the second month of life, it takes control from the subcortical pathways. This transition often does not go smoothly. At this age, many babies show “obligatory looking,” the inability to pull their gaze away from something that has caught their attention, sometimes for as long as half an hour. This difficulty is caused by the visual cortex inhibiting subcortical eye movement commands. Young babies track movement with jerky eye movements called saccades until two or three months of age, when cortical maturation allows them to smoothly follow a moving object with their eyes. In the first three months, babies also have difficulty focusing their eyes on far-away scenes, so they look at what is nearby (roughly seven to 30 inches away), which includes their own bodies and their parents’ faces.

The champion of the infant visual system is motion, which develops early and effectively. Babies can detect a flickering stimulus in a single location almost as well as
adults as early as four weeks of age, and the flicker frequencies that they can detect become adultlike by two months. To determine motion direction, it’s necessary to associate time-based changes coming from different locations in space, a capacity that appears around seven weeks. By twenty weeks, babies can discriminate different speeds of motion. Perception of large-scale motion patterns, like raindrops seen through the windshield of a moving car, improves rapidly between three and five months and then continues to develop slowly through middle childhood. This aspect of motion processing, the most vulnerable to disruption, is impaired in some developmental disorders, including dyslexia and autism.

The vision of infants is partly limited by the maturity of rods and cones, which translate light into neural signals in the retina. Cones, which provide sensitivity to color, mature rapidly. Though color vision is almost absent in newborns, four-month-old babies can see color as well as adults. Rods, which do not transmit color but detect photons in low light (which, incidentally, is why you can’t make out colors in the dark), mature by six months. Newborns can see better in their peripheral vision than in the center of their gaze, both because the cones in the peripheral retina are more mature and because cells in this part of the retina project more strongly to subcortical visual areas.

Visual acuity is easy to test because babies prefer to look at patterns. Researchers can tell whether babies can distinguish a pattern from solid gray just by whether they preferentially look at the patterned object. At three months of age, babies are still fifty times less sensitive to contrast than adults, meaning that infants find it very difficult to distinguish different shades of gray. These limitations explain why the most popular toys for young infants have bold black-and-white patterns.
For depth perception, both eyes need to work together. It’s very difficult to thread a needle, for instance, with one eye closed. The two eyes don’t see exactly the same part of the visual world, and the differences between them depend on head size, so the brain must use experience to figure out which signals come from which eye. This process depends on neural plasticity. Depth perception is almost nonexistent in newborns. The ability to use binocular cues develops abruptly, often in the fourth month of life.

From birth, babies are attracted to faces. It may be no coincidence that babies can focus best on objects about eight inches away, which is approximately the distance between the baby’s eyes and the parent’s face during feeding. Very young babies, though, are working from an approximate model of what a face looks like, as they will look at almost any round thing that has two “eyes” and a “mouth” in the right place. (This is not very surprising if you consider how poorly they see real faces.) By four or five months, their preferences are more realistic, and babies have begun to process faces differently from other objects. This change probably reflects maturation of the fusiform face area, a region in the temporal cortex specialized for face processing. This brain specialization enables ordinary adults to beat the world’s best computer programs in detecting subtle differences between faces. The fusiform face area appears to already be preferentially activated by faces in two-month-old infants.

Development of many visual functions requires experience during a sensitive period (see chapter 5). Early in cortical development, chemical cues direct axons from each visual area to innervate its appropriate target areas, where they form many more synapses than will be needed in the adult brain. Neural activity patterns then control axon retraction and synapse elimination, which fine-tune the connections so that the correct
neurons talk to each other. In primary visual cortex, for example, synapse number is greatest at eight months and then declines through middle childhood. Because different brain areas develop at different ages, the effects of visual deprivation vary with timing.

Children whose vision is impaired by cataracts provide information about the need for visual experience in human development. Babies who have cataracts from birth retain the poor acuity of newborns until their eye function is surgically restored, even as late as nine months of age. After that, with experience their acuity improves, but it does not catch up fully. Deprivation for the first three to eight months leads to acuity more than three times worse than normal at five years of age. Children who develop cataracts later on, starting between four months and ten years and lasting for two to three months on average, also end up with permanent deficits in acuity, but are not as impaired as babies whose cataracts were present from birth. Global motion perception is affected by cataracts only in the first three months of life.

Visual experience also influences the development of face-recognition expertise starting in infancy. Six-month-olds are as good at distinguishing individual monkeys as individual people, but by nine months, babies become better at distinguishing people and lose the ability to discriminate among monkey faces. Starting between six and nine months of age, babies also find it slightly easier to distinguish faces within their own racial group than within other racial groups, probably because most babies have more visual experience with their own racial group than with others. This process, which is reminiscent of phoneme learning (see chapter 6), probably involves the sculpting of synaptic connections by experience to tune perception to the characteristics of the local environment.
Because our abilities build on one another, sensory deprivation during a sensitive period early in life can initiate a cascade of problems later on. This also means that aspects of vision that develop later are more sensitive to disruption than those that develop earlier. For example, babies cannot distinguish fine stripes from solid gray until their second birthday. Even so, babies who have cataracts from birth to six months of age never develop this ability, apparently because of residual damage to their primary visual cortex.

These findings suggest that parents should be particularly careful to protect their children from sensory deprivation early in life. A variety of problems, including cataracts, amblyopia, or strabismus, can prevent babies and toddlers from getting the experience that they need to help the visual system develop correctly. Strabismus occurs when the two eyes do not point in the same direction, which interferes with the development of binocular vision. Amblyopia occurs when one eye sees substantially less well than the other eye, though both are apparently healthy. It can be caused by strabismus or by near- or farsightedness that occurs in only one eye. While strabismus or cataracts can be diagnosed by parents or doctors based on the child’s appearance, amblyopia can only be identified by trained professionals.

Routine well-baby exams should catch most problems of this sort, but if your child is diagnosed with a sensory deficit (or you suspect that one exists), getting it fixed as soon as possible will minimize the possibility of lasting damage to your child’s brain. Strabismus is usually corrected by surgery. Amblyopia can be treated by several methods. Corrective glasses should be the first step, as this approach solves the problem in a quarter to a third of children and improves the amblyopia in others. The next step is to put
a patch over the strong eye to force the weak eye to work harder. For all early visual
difficulties, the most important point is to act quickly, before serious damage occurs.

Fortunately, problems in visual development are the exception. It’s amazing when
you consider how complicated this process is, but in most cases, parents really can simply
sit back and watch their children’s new abilities grow.

BEGIN BOX

**Practical tip: Outdoor play is good for your vision**

The stereotype of the nerdy guy with glasses has some basis in fact. Myopia has the
curious quality of being both inherited (with a heritability of about 80 percent) and
strongly influenced by the environment. How this happens is a lesson on the complex
ways that genes and environment can interact.

Myopia (or nearsightedness) occurs when the lens of the eye focuses the visual
image in front of the retina, causing far-away objects to look blurry. The incidence of
myopia varies tremendously across populations, from 2–5 percent among Solomon
Islanders in the 1960s to 90–95 percent among modern Chinese students in Singapore.
The rate of myopia has increased considerably over the past few decades in many
countries. In Israel, 20.3 percent of young adults were myopic in 1990, increasing to 28.3
percent in 2002. Similarly, in the U.S., myopia rates went up from 25 percent in the early
1970s to 41.6 percent in the early 2000s. These changes have been happening so fast that the explanation couldn’t possibly be strictly genetic—some external factors must be involved.

As your child’s eyes grow, the distance between the pupil and the retina needs to be matched to the refractive power of the lens to keep the image on the retina in focus. Based on experiments with animals, we know that visual experience guides this process.

Children who spend more time outdoors are less likely to become myopic. One study compared six- and seven-year-old children of Chinese ethnicity living in Sydney, Australia, with those living in Singapore. The rate of myopia was more than eight times lower in Sydney (3.3%) than in Singapore (29.1%), despite similar rates of parental myopia (about 70% in at least one parent). Children in Sydney spent fourteen hours per week outside, on average, compared with three hours per week for children in Singapore.

It does not seem to matter exactly what the children do while they are outside. A U.S. study found that two hours per day of outdoor activity reduces the risk of myopia by about a factor of four compared with less than one hour per day. Playing indoor sports has no effect on visual development. Outdoor activity has a stronger protective effect for children with two myopic parents than for children with no myopic parents, suggesting that myopia-related genes may modify children’s sensitivity to environmental influences (see chapter 2).

Researchers are not sure why being outdoors protects children against developing myopia, but one possible explanation is that bright outdoor light is more effective than dim indoor light at driving the development of correct eye shape. Since our brains evolved under conditions in which every child spent many hours outside every day, it
makes sense that our eyes may develop in a way that takes advantage of that common experience. Our current lifestyles may well lead to other unexpected consequences of this sort, as our brains are forced to adapt to a world that’s very different from the one in which their genes originated (see box, Speculation: Modern life is changing our brains).

END BOX

BEGIN BOX

Speculation: Modern life is changing our brains

For millennia, children could reliably expect to have certain experiences. Infants would hear their parents and other adults talking. Babies would see objects, some of them colored, some of them moving. Children would play together in groups that were often mixed in age but segregated by gender. They would see their parents working and playing. Food would be obtained from nearby land. The sun would bring light when it rose and leave darkness behind when it set. Our brains evolved to make the most of these situations.

But times have changed. Since the invention of agriculture, and especially since industrialization, the environment has changed substantially and in many cases has come under our control, making some of these realities a lot less reliable. What happens when experiences necessary to our development are hard to find? Artificial light is much less
bright than sunlight, which seems to interfere with the normal matching of lens power to eye size by experience (see box, Practical tip: Outdoor play is good for your vision). Grocery stores are full of processed food, which lacks fiber, nutrients, and variety compared to our ancestral diet. Our brains have evolved to seek out sugar and fat because such foods were rare treats during our evolution, but now they are readily available. These dietary changes may contribute to the rise in obesity and some types of cancer.

These examples illustrate a fundamental conceptual problem with trying to separate the effects of genes from the effects of the environment: the two influences are inextricably linked together. Evolution has selected for genes that produced an adaptive outcome in our ancestral environment, but these genes may not interact as effectively with our current environment.

That doesn’t mean that there’s anything wrong with the modern world (we like our computers and antibiotics, thank you very much), nor that there’s anything wrong with our genes; it’s just that they don’t play nicely together in some cases. For instance, type II diabetes, which is linked to a variety of lifestyle risk factors, is also highly heritable. Based on what you’ve heard about nature and nurture, this may seem confusing, but as we suggested in chapter 2, it’s best to think of genes and environment as having a conversation about how growth should proceed. In this framework, particular genes and certain environmental conditions can easily interact to produce an unfavorable outcome that would not have resulted from variations in either the genes or the environmental conditions alone.

END BOX
Chapter 11

Connecting with Your Baby Through Hearing and Touch

We have big brains. This is one of the things that distinguishes humans from other primates, and it has many consequences, some of them unexpected. One is that, because women’s hips are only so big, our babies have to be born before their brains have grown to full size.

As a result, the brains of infants are very immature. Newborn infants can’t roll over by themselves, and they can barely see, as we learned in the previous chapter. Some parts of their brains are relatively well developed at birth, though, including those devoted to the senses of hearing and touch, which provide the best ways to connect with your new baby.

Your Baby’s Sense of Hearing

Hearing begins when the ear receives a sound, a set of pressure waves that move through the air the way a splash ripples across a pond surface. The time between arriving waves (frequency) determines pitch, and their height determines sound intensity. The outer ear transmits these waves to the cochlea, which contains sound-sensing “hair cells” arranged in rows along a long, coiled membrane (see figure). Sound pressure moves the fluid in the ear, which makes the membrane vibrate in different ways depending on the sound’s frequencies. This vibration moves a bundle of fine fibers that stick up from the top of the cell (hence the name hair cell), transforming the vibration into an electrical signal that can be understood by other neurons.
Hair cells at the base of the cochlear membrane sense the highest frequencies. As you move around the coil toward the other end, hair cells sense lower-frequency sounds. This organization forms a map of sound frequency, which is maintained in many of the brain areas that receive information that first passes through the cochlea. As in visual development, experience is important for fine-tuning connections in auditory brain regions, but the appropriate experience is easily available to any child who can hear.

A related group of organs in the inner ear, the semicircular canals (see figure), is responsible for sensing the body’s position via the vestibular system. These canals also contain hair cells arranged in a circle, where they are stimulated by calcium crystals—essentially little rocks that roll around inside the ear and settle on top of particular hair cells depending on which way is up. Imagine the beads inside a baby’s rattle: if you could feel the position of the beads, you’d be able to work out which way it was pointing. This is what the brain is doing with information from the semicircular canals.

The vestibular system matures early, in the second trimester. It is vulnerable to many of the same factors that can disrupt hearing, including prenatal infections—particularly cytomegalovirus, which accounts for 12 percent of congenital deafness—low birth weight, and bacterial meningitis in infancy. Disorders of the vestibular system can lead to developmental delay in motor function, as it is very difficult to learn to walk without reliable balance.

Babies can hear before they’re born, starting around the beginning of the third trimester. At this stage, they can hear only loud sounds at medium to low pitches—like a car horn or a truck rumble—which is convenient because those are the sounds that most easily reach the baby through the insulation of the mother’s belly. The mother’s voice
also reaches the baby’s ears strongly because it is carried within her body. With time, the auditory system gradually becomes sensitive to quieter noises and higher pitches, a process that continues after birth.

Auditory learning is already occurring during gestation. By the time they’re born, babies prefer their own mother’s voice to a stranger’s voice. Most newborns find the sounds that they’ve heard in utero to be soothing—anything from the theme song of Mom’s favorite soap opera to her heartbeat. They also prefer the sound of her language to a foreign language, probably because its cadence is more familiar to them.

At birth, babies are still less sensitive than adults to quiet or high-pitched sounds. A normal conversation sounds to a baby about as loud as a whisper sounds to you. By six months, frequency sensitivity is fully mature, allowing babies to hear high-pitched sounds. However, at this age loudness thresholds are only halfway to adult levels. Children’s ability to solve the “cocktail party problem” (discriminating a voice from background noise or from competing voices), which uses all of this information, continues to improve until age ten.

At all ages, children hear high frequencies better than most adults, whose hearing has been damaged by too many loud sounds (see box, Practical tip: Protect your child from noise, starting before birth). Some teenagers take advantage of this situation by using high-pitched “mosquito ringtones” to prevent teachers and parents from hearing the ringing of cell phones in situations when they’re forbidden. Adults have turned the tables by using loud high-pitched sounds to prevent young people from loitering outside businesses or in parks (though we do not support this approach because it may harm the hearing of infants and toddlers whose parents are unaware of the noise).
Meissner's corpuscle
Merkel's disk
Hair follicle receptor
Ruffini's ending
Free nerve endings
Pacinian corpuscle
Given the importance of hearing in a baby’s life, it is surprising that parents and doctors often fail to diagnose deafness in young children. Among babies who are not tested in the hospital at birth, the average age of diagnosis is fourteen months, by which time auditory and language development are already delayed. Babies should be screened for hearing loss (and treated if possible) before three months of age, especially if they don’t respond to sudden loud sounds or the voices of people who are out of their view.

Deafness resulting from damage to the cochlea can be treated with a cochlear implant, a device that transmits sound information directly to the auditory nerve. (If the deafness is due to damage in the brain rather than the ear, it usually cannot be corrected.) The signals sent by a cochlear implant are much less complex than the signals from a healthy cochlea, but the brain gradually learns to interpret the new signals correctly, especially if the implant is given in early childhood when the auditory system is best able to make adjustments. In general, cochlear implants can improve hearing at any age—but earlier is better.

**Your Baby’s Sense of Touch**

The development of the sense of touch also depends on experience—in this case, provided by adult caretakers. Luckily, most people love to snuggle babies, so a lack of stimulation in this area is rare. Touch is critical for parent–infant bonding, which has an important influence on the baby’s emotional and cognitive development. Early touch also influences adult stress responsiveness in many mammals, including people (see chapter 26).
The neural pathways that carry information from the skin develop early in gestation, before any other senses. Your baby’s skin contains many different receptor types—specialized nerve endings that sense touch, vibration, pressure, skin tension, pain, or temperature (see figure)—which are all in place by the end of the first trimester. Another set of receptors in muscles and joints provides information about body positioning and muscle tension. In all cases, touch is translated into the spikes we’ve been telling you about, and sent along axons into the spinal cord or brainstem.

The brain pathways that process touch information are not fully formed until the fifth month of pregnancy. The brain knows which kind of sensor is activated, and where it is on the body, because each sensor has a “private line” that uses spikes to carry only one kind of information to the brain. (There is a separate brain area for painful sensations.) At birth, babies can identify touch and temperature sensations: they turn away from a cold object touching their cheek and toward a warm object. Because the axons that carry touch information are not yet myelinated, babies are eight times slower than adults in sensing most types of touch. Children’s processing speed improves in the first year but does not reach adult levels until age six. The exception is pain, which is carried by unmyelinated axons even in adults and so is processed just as quickly by babies. yeeoww!

Some parts of your baby’s body are more sensitive than others. As in other sensory systems, the cortical areas that process touch are arranged in a map, with nearby parts of the body represented by nearby neurons. The proportions of these maps are based on the number of receptors in each part of the body, rather than its size, so that the part of the map that receives information from the face is larger than the area that receives
information from the entire chest and legs. Your face is much more sensitive. In adults, the highest density of touch receptors is found on the fingertips, with the face a close second.

This map develops sequentially, beginning at the head region, which is why newborn babies actively explore objects with their mouths but not with their hands. Think about the surprising number of familiar objects you’ve tasted in your life—doorknobs, grass blades, and so on. Evidently you’ve been tasting things for a long time.

The ability to discriminate objects with the hands develops slowly, and the face remains more sensitive than the hands even at age five. As the maps in somatosensory cortex mature, babies become able to localize touch more accurately and discriminate touches that are closer together on the skin. These maps are initially established by genetic mechanisms, but their maintenance depends on experience even in adulthood, as the cortical space devoted to an amputated limb is eventually taken over by inputs from adjacent areas of the body (the cause of phantom limb syndrome, in which amputees imagine they can feel sensations from a missing limb).

Babies who are not touched enough in early life become developmentally delayed, demonstrating one limit to the dandelion nature of brain growth. This problem happens most often in poorly organized institutional care, such as orphanages with inadequate staffing or intensive care units in which premature infants are isolated from human contact. Cuddling is more important than food to early bonding: in experiments, baby monkeys deprived of maternal contact spend most of their time with a soft surrogate made of terry cloth, ignoring a wire surrogate that provides milk except during brief visits to feed. In most homes, though, you’re more likely to have trouble getting family
members to stop playing with the baby at bedtime than you are to have a baby who’s not getting enough snuggling.

BEGIN BOX

**Practical tip: Protect your child from noise, starting before birth**

Another problem in our modern environment that evolution did not prepare us to handle is noise exposure, the most common cause of hearing impairment. Its victims are getting younger every year. One in eight U.S. children between the ages of six and nineteen now has some hearing loss, and it’s likely to worsen as they get older. Hearing loss is more common in boys than girls, probably because of differences in their activities. Noise can even induce hearing loss before birth, if the mother is exposed to chronic loud noise during the third trimester of pregnancy. In fact, babies’ hearing is most easily damaged by noise exposure in the last trimester and first six months of life. Premature babies are especially vulnerable to noise-induced hearing loss.

Loud noise destroys hair cells in the cochlea, starting with the most vulnerable cells, those that transduce high-frequency sounds. Doctors cannot reverse this damage, and hearing aids do not restore sound levels. The earliest symptom of hearing loss is usually difficulty understanding speech when there is background noise. By then, as many of half of the cochlear hair cells are already dead. Hearing loss is particularly
damaging in children because it can impair language learning and academic accomplishment.

Tinnitus, a constant ringing in the ears, is another potential consequence of noise exposure that can interfere with hearing. Noise is also a chronic stressor, which means tinnitus can interfere with child development in many ways (see chapters 26 and 30).

Hearing loss is caused by brief exposure to very loud noises, like firecrackers, or by chronic exposure to moderate noise levels, such as city traffic. (Living near a loud highway could damage your child’s hearing as much as setting off firecrackers in her bedroom.) The most common risk factors for kids are rock concerts and portable music players like the iPod. These devices are typically played at 75 to 105 decibels, which is equivalent to the range between a loud conversation and a Harley–Davidson. Temporary hearing loss or tinnitus after listening to music is a warning sign; repeated exposure to such noise levels will cause permanent hearing loss.

The volume makes a big difference. With standard iPod ear buds, you can safely listen at 80 percent of maximum volume for ninety minutes per day, or at 70 percent of maximum for four and a half hours per day, but at full volume only for five minutes per day. Your kids should be especially careful when listening to music in a noisy environment, such as on an airplane or in the subway, which generates a temptation to turn the music up too loud. You can protect your children by downloading software that limits the music player’s volume, or by investing in noise-cancelling headphones (if they don’t look too dorky for your child’s sense of style). Your kids may not appreciate it now, but at least they’ll be able to hear their own kids’ complaints someday.
Did you know? The neuroscience of snuggle

Different types of touch are transmitted to your child’s brain by “private lines” that carry those particular types of information exclusively. Your child’s brain (like your own) has a special pathway dedicated to the kind of touch that leads to emotional bonding. The skin contains more than a dozen anatomical types of receptors specialized for detecting particular sensations, such as temperature, pressure, and pain. One in particular is tuned to the pleasurable skin sensations that are produced by light stroking. The axons that carry information about these sensations to the brain are unmyelinated, meaning that their responses are slow. In human recordings, the electrical activity of these axons in response to gentle stroking is proportional to how pleasant the person reports the touch to be.

Damage to these pathways as they run through the spinal cord impairs emotional responses to touch, without affecting the ability to identify an object by touch. In the brain, the “pleasantness pathway” brings touch information to a region of cortex called the anterior insula, rather than to the somatosensory cortex where most touch-responsive fibers send their signals. The anterior insula, which receives input from a vast variety of systems, seems to be involved in monitoring a range of internal states, from thirst to maternal love.
Chapter 12

Eat Dessert First: Food Preferences, Taste, and Smell

Unlike many American toddlers, Sam’s daughter loved sushi. From a young age it was impossible for her parents to eat their raw fish in peace, without tiny orange fish eggs flying everywhere. Though we can’t say for sure, we suspect that a trip she took before she was even born might be responsible for this odd turn of events.

Sam and his wife, a busy physician, traveled in the second trimester of her pregnancy. Sam’s wife adores sushi. As a physician, she knew that sushi is safe for babies in utero—and perhaps even beneficial for brain development (see chapter 3, Practical tip: Eating fish during pregnancy is good for your baby’s brain), so she ate a lot of it on that trip and afterward. When we started reading studies showing that children’s food preferences are influenced by what their mothers ate during pregnancy, we thought we might have found the connection.

Like vision and hearing, our basic ability to distinguish smells and tastes is built on sense organs and input pathways to the brain that develop largely on their own. Starting from our noses and tongues, the initial stages of input wiring connect with brain structures without much help. But much of the formation of preferences for smells and tastes depends on experience. This makes sense: we’re omnivores. People can eat such a wide range of foods that it would be difficult to program in innate food preferences that would apply to all possible environments. This may explain why food preferences are so idiosyncratic: for instance, many children in the U.S. like root beer, but in some parts of Europe, it is considered intolerable.
The learning process starts surprisingly early, well before birth. Newborns have smell and taste systems that are well developed—and already know a thing or two. They can express an immediate preference for the flavor of milk and their mother’s nipple, and they can even distinguish between the smell of their own mother and others. (Indeed, a mother can do the same, distinguishing a shirt worn by her baby from those of other newborns.)

In adults, smell and taste take a back seat to vision and hearing, which provide most of the information we use to navigate through the world. Infants, born with rather poor vision (see chapter 10), are more dependent on the chemical senses. They share this dependence with some of the oldest of animals. Over 800 million years ago, certain types of worm started to localize more refined chemical sensation in front—in other words, they developed noses. Even more primitive animals such as jellyfish are deaf, blind, and noseless, but can still detect the presence of noxious chemicals applied somewhere to surface of their bodies.

The flavor sense consists of multiple components in the mouth and nose. What hits the tongue is taste and includes the fundamental components of sweet, salty, sour, bitter, and umami (the taste of glutamate, found in tomatoes, many broths, and cooked meat or mushrooms). Combined with taste is the sense of smell, which comes in through the nose and is far more complex. Smell conveys most of the nuances we experience in food.

Smell signals are detected in the nose by the olfactory epithelium, a structure inside the nasal cavity (see figure). The olfactory epithelium contains a layer of sensory cells covered in a sticky layer of mucus that catches odors. Each sensory cell expresses
one type of odorant receptor. There are hundreds of distinct receptors, each with its own preference for a different set of odorant molecules. These sensory cells send their axons in a mad tangle, passing along the way through hundreds of perforations in a bone called the cribriform plate. The whole thing detangles to make a perfectly sorted landing pattern in the brain in the olfactory bulb, an oblong structure that lies underneath the frontal part of the brain. By the time the axons arrive, each part of the olfactory bulb receives a “private line” corresponding to one, and only one, type of odor receptor.

So when can babies start to smell things? The olfactory epithelium and bulbs are present by the eleventh week of gestation, toward the end of the first trimester. Then, sometime during the second half of the second trimester (weeks sixteen to twenty-four), the nostrils open up, allowing amniotic fluid to reach the olfactory epithelium. In premature infants, the earliest reported responses to smell occur at the end of this period, at six months into the pregnancy. This is possible not only because the nostrils are open, but because olfactory epithelia’s neurons have sent axons into the brain, to the olfactory bulb. In turn, neurons in the olfactory bulb send connections to other places in the brain, including the amygdala, which is involved in generating emotional responses, and the piriform cortex, which passes the information on to other brain regions (see figure).

To an infant, most smells are initially neutral. Some responses are innate: within twelve hours of birth, infants make faces when exposed to the scent of rotting eggs. Likewise, sugary water triggers an automatic smile: more, please. Generally, though, smells take time to become associated with positive or negative reactions, emotions, and memories. These associations to the world’s rich variety of food, drink, and smells are
acquired postnatally. This process is guided by the brain’s mechanisms for associating new smells with already-familiar signals and liked (or disliked) outcomes.

The developing brain’s first teachers for food preference are the tongue (taste) and gut (nutrient content). In the tongue, molecules that trigger one of the five basic taste sensations bind to receptor molecules in a taste bud, which then generates a chemical signal inside the neuron that bears the receptors. Each neuron, taste bud, and axon is a little communication line that is assigned the identity of “sweet,” “salty,” and so on by virtue of where it connects. These labeled lines convey basic information about chemicals found in foods.

Scientists used to think that sweetness taste buds were all found in one part of the tongue, but now we know that each type of taste bud is found all over the tongue, forming a patchwork in which every taste is found everywhere. Receptor cells form in the tongue very early, during week eight of gestation. By week thirteen, taste buds are present throughout the mouth and are connected to nerves that go to the brain. By the time the axons are functionally connected to brain structures, they are hooked up and interpreted correctly.

Taste signals are translated into electrical impulses that are conveyed along the neurons’ axons to the nucleus solitarius, a cluster of brainstem neurons (see figure). The nucleus solitarius is an important station not just for taste information, but also for other visceral signals, including the presence of fat in food. Other organs besides the gut also send signals: the cardiovascular system, liver, and lungs. The nucleus solitarius’s many jobs include generating the gag reflex, coughing, and responses relating to breathing, digestion, and the heart. A notable reflex in this general category is the gastrocolic
response, in which the eating of food, especially if is fatty, helps trigger defecation after about half an hour (in babies and grown-ups). This reflex is useful in making diaper-change time more predictable.

These labeled lines for taste and calorie content serve an important evolutionary purpose. Starting from early in life, everyone strongly prefers sweet tastes and calorie-rich foods. The benefit of a sweet tooth is obvious: sweet things are usually loaded with valuable calories. Glutamate, a component of protein, is similarly useful, as is salt. Bitter and sour tastes are rejected. In all cases, these experiences stimulate powerful teaching signals that tell the brain that something good or bad has happened. These teaching signals are conveyed through the nucleus solitarius onward to the thalamus, striatum, and neocortex.

DNA does not just encode receptors; it also carries instructions for what cells should make the receptor. One example that has been studied carefully is taste neurons that detect sweetness. These neurons all make the same sweet receptor molecule, a protein dedicated to the job of binding to sugar. Researchers have applied genetic engineering techniques to make mice that contain the DNA sequence for a receptor for morphine (which mice normally can’t taste) in the exact location where the sequence for the sweet receptor would normally be. Mice with this genetic alteration can’t taste sugar, but they can taste chemicals related to morphine—and consume them avidly, as if they were sweet. This is true even for low exposures of morphine-like drug that are far too low to be addictive. This result suggests that the surrounding DNA acts as a signpost that the receptor at that location should be hooked up to brain wiring that carries the message “it’s sweet, and I want more.”
In contrast to having just one sweet receptor, our genome has multiple receptors for other tastes—including dozens that are sensitive to bitter chemicals. Babies instinctively regard bitter flavors as unpleasant. Many toxic chemicals are bitter and are often found in plants. Bitterness is a natural signal to get us to spit these things out, but paradoxically, we can teach our brains to enjoy bitter flavors. This flexibility is useful, since it allows your child’s brain to adapt to a food that has nutritional value, but happens to contain one of the chemicals found in other bitter, less healthy substances that occur naturally. With practice, we can learn to like tonic water, coffee, and broccoli—and children should like broccoli (see box, Practical tip: How to get kids to eat (and like) their spinach). We train our brains to accept particular bitter flavors by using rewards (liked flavors, calorie content, social approval) and penalties (physical illness, social disapproval).

Learned preferences for food accumulate over the first few years of life. A liking for salt emerges by age two, and eventually for more complex flavors such as cherries. This process starts before birth. Indeed, preferences for the foods of one’s own culture may be transmitted through mother’s milk, and even in the womb.

The womb is not a flavor-free environment. Fetuses swallow cupfuls of amniotic fluid per day, and the stuff can reach their olfactory epithelia. At birth, newborns have a pronounced preference for the flavor of amniotic fluid over water. Amniotic fluid can also carry traces from the mother’s diet. After pregnant women drank about 10 ounces (30 centiliters) of carrot juice every other day for three weeks during the third trimester, their babies were less likely to make faces when given carrot-flavored cereal for the first time—and more likely to eat it.
Rabbit pups show an increased preference for juniper berry flavor after prior exposure to this taste in their mother’s milk or in the mother’s diet during gestation, or even if they are housed with juniper-scented fecal pellets. Pups seem to have multiple ways of learning about what might be okay to eat. It’s at least possible that some distinctive aspects of sushi flavors, such as fish and seaweed, could have reached Sam’s daughter before birth or in infancy.

Taste preferences can also arise indirectly. For instance, four-month-old infants are less likely to make faces when presented with salty water if their mothers experienced early-pregnancy nausea. We don’t know for certain why morning sickness would lead to a liking for salt. One possibility is that sick mothers become dehydrated or depleted of sodium, leading to the secretion of signaling molecules renin and angiotensin, which cause a desire for salt in adults.

Considerable information about flavors is also transferred through mother’s milk. One aspect of children’s experience is simple familiarity, leading to tolerance. If a lactating mother consumes garlic oil or carrot juice, babies are less likely to react, either positively or negatively, when the same stuff is added to a bottle.

Flavor preferences learned in infancy can last for years. A natural experiment has been done with baby formula, which comes in varieties based on milk, soy, and hydrolysate (for babies with allergies to milk and soy). Non-milk formulas are notably sour and bitter, and the hydrolysate formulas are particularly nasty. Try one sometime.

Children who were fed soy or hydrolysate formula before the age of one still chose to drink it at age four or five over milk-based formula (as opposed to milk-reared kids, who refused it and made yucky faces). Soy and hydrolysate-fed kids were
considerably more tolerant of sour or bitter flavors added to apple juice. They also were more positive about other bitter foods. When asked to rank their favorite vegetables, they were more likely to give broccoli a high rating.

Generally, just consuming a food multiple times is sufficient to reduce negative reactions. Infant taste is particularly malleable during the first few months. Babies fed a relatively bitter non-milk (such as soy-based) formula are more tolerant of broccoli as children.

As children become more verbal, they acquire additional ways of learning about flavors and smells. In both children and adults, perception and liking can be influenced by a word label. For example, adult subjects gave a more pleasant smell rating when they are given the label of “cheddar cheese” compared with “body odor” to accompany a test odor that combines elements of both. When the adults’ brains were scanned, activity was changed in rostral anterior cingulate cortex, the medial orbitofrontal cortex, and the amygdala. These regions receive information from both smell and taste pathways and appear to be places for making mental associations with flavors. As children grow, they learn to make associations between foods and complex contexts, including social value, as adults do. Pleasure can be a force for good in your child’s development, an idea that we explore in the next section.

BEGIN BOX

Practical tip: Getting your child to eat spinach, the nine-second rule
When Sam learned that one in five American toddlers don’t eat even one vegetable per
day, his immediate reaction was pride in his daughter. Thanks to her, somewhere out
there four toddlers are eating their vegetables. With some effort we could get Sam to
avoid misusing statistics in this way. But can we teach young children to like these bitter
foods?

Most parents use social approaches, which often work: involving the child in
preparing the food, or showing that parents or siblings like the stuff. Less appreciated are
techniques based on the direct experience of flavors.

Just consuming a food multiple times is sufficient to reduce negative reactions.
Infant taste is particularly plastic during the first few months. Babies fed a relatively
bitter non-milk (such as soy-based) formula are more tolerant of broccoli as children.
And when asked to rank their favorite vegetables, they are more likely to give broccoli a
high rating (see main text). Also, don’t forget to eat vegetables during pregnancy, as taste
preferences begin to develop in utero.

Combining a flavor with a well liked familiar flavor is another powerful way to
build a new preference. Researchers have found that the two tastes cannot be given more
than nine seconds apart in time. You can try this approach with your baby: simply mix
the two flavors together. For example, babies develop a preference for pure carrot juice
after having it mixed with milk. Sweeteners work too. A common way to introduce solid
food to babies is to puree it in a blender, an approach that lends itself very well to
mixing-and-matching of flavors. This pattern persists throughout life. College students
given broccoli with sugar later rate broccoli alone as being more pleasant than
cauliflower alone—and do the converse if they are given sweetened cauliflower. Coffee
drinkers often initially add sugar or milk but eventually take it black. Learning can even
be negative: pairing a flavor with bitter quinine, found in tonic water, can reduce liking.

One approach we don’t recommend is offering dessert as a reward for finishing
dinner. The urge to consume foods that contain calories is a powerful motivator, as
confirmed both by our everyday experience and by behavioral experiments. But when
kids eat dessert right after a meal, something odd happens: their preference for foods
eaten earlier decreases. Why?

Recall that our brains want us to like foods that are high in calories. And the gut
detects calorie content many minutes after we eat. So, because the calories from foods
eaten earlier are still being processed when dessert arrives, the earlier foods actually
encourage a preference for the taste of dessert rather than the reverse.

One solution to this problem would be to give dessert before the new flavor—
ideally within 9 seconds. There’s a converse problem if you give dessert too early: your
kid’s not likely to be hungry come spinach time. If you’re going to use this approach, we
recommend serving dessert more than thirty minutes after the meal—or offering a bite or
two right at the time of the meal!

END BOX
Practical tip: Worried about your child’s weight?

As a parent, it’s normal to be concerned about what your child eats, but anxiety about childhood obesity is usually neither necessary nor helpful for most children. Parents need to be careful that the solution they choose doesn’t end up causing more harm than the problem.

Because they’re growing, children need more calories than adults per pound of body weight. Young children also need to eat a lot more fat than adults do. The National Institutes of Health recommends that children under two should get 50 percent of their calories from fat, and children older than two should get 25–35 percent of calories from fat. Dietary fat is an essential contributor to early brain development. Food restriction is tricky in children: low-calorie diets may prevent them from growing properly, and low-fat diets are associated with inadequate intake of important nutrients. Complicating things further, it’s difficult to be certain how much a child should weigh at a given age because kids often put on some extra fat in preparation for a growth spurt.

Given these difficulties, how do you decide how much food your child should be eating? In most cases, if you provide a variety of healthy foods and opportunities for regular exercise, you can trust your child’s brain to manage food intake correctly. The brain’s weight-regulation system is extremely complicated, including more than twenty molecules that increase eating and a similar number that decrease eating, based on a variety of nutritional cues. The brain will do its best job of balancing food intake with energy use if children are simply allowed to eat when they are hungry and stop when they
are full. This approach also helps them learn to regulate their own eating as adults without binging or starving.

Growing up in a weight-obsessed culture is particularly difficult for girls. Healthy puberty requires the addition of body fat, in the form of breasts and hips, at just the age when girls are particularly sensitive to body image problems. Eating disorders affect more than one in a hundred young women between fifteen and twenty-four years of age. (There is roughly one man with an eating disorder for every eight women.) In one longitudinal study, teenage girls who reported dieting repeatedly or being teased about their weight by family members were much more likely than average to have developed an eating disorder or to have become overweight five years later, suggesting that strict parental efforts to control their daughters’ weight were typically ineffective—or even counterproductive. Girls who reported eating regular family meals in a pleasant atmosphere were less likely than average to develop an eating disorder or become overweight.
PART FOUR

THE SERIOUS BUSINESS OF PLAY

The Best Gift You Can Give: Self-control

Playing for Keeps

Moving the Body and Brain Along: Sports and Exercise

Electronic Entertainment and the Multitasking Myth
Chapter 13

The Best Gift You Can Give: Self-control

At the age of three or four, resisting temptation is always a visible struggle. Finding a good strategy is a key element to success—and the good news for parents is that strategies can be taught. Indeed, learning self-control strategies at an early age can pay off for years afterward.

Young children’s play contributes to the development of their most important basic brain function: the ability to control their own behavior in order to reach a goal. This capacity underlies success in many areas that parents care about, from socialization to schoolwork. The neural circuits that are responsible for it are some of the latest-developing parts of the brain, as any parent of a two-year-old can tell you. But even at this age, you can detect and encourage an early stage of their mental growth, the inhibition of behavioral impulses.

Preschool children’s ability to resist temptation is a much better predictor of eventual academic success than their IQ scores. The classic test for this ability is to put a marshmallow on the table and tell the child that she can have two marshmallows if she can wait a few minutes without eating the first one. Alternatively, she can ring a bell at any time to bring the researcher back into the room and get just one marshmallow. The average delay time is about six minutes for a four year old. A child who can hold out fifteen minutes at that age is doing exceptionally well and definitely deserves both marshmallows without further delay.
More than a decade later, those preschool delay times correlate strongly with adolescent SAT scores—predicting about a quarter of the variation among individuals in one study. Delay times in preschool also correlate with the ability to cope with stress and frustration in adolescence, as well as the ability to concentrate. Other tests of the ability to inhibit behavior for delayed gratification correlate with math and reading skills early in elementary school, which makes sense considering that learning academic subjects requires concentration and persistence.

As it improves with age, self-control continues to predict academic success. In a study of eighth graders, self-discipline at the beginning of the school year—measured in part by the students’ ability to carry a dollar for a week without spending it in order to earn another dollar—predicts grades, school attendance, and standardized achievement test scores at the end of the year. The students’ self-control ability accounted for twice as much of the variation among individuals on all these measures as their IQ scores.

The ability to regulate your own behavior is important not only for academic achievement but also for interpersonal success. Children who are skilled at behavioral self-control show less anger, fear, and discomfort and higher empathy than their peers of the same age. Other people rate these children as more socially competent and more popular, even years later, probably because they are good at regulating their own emotions and taking the emotions of others into account.

Some amount of brain maturation is a necessary first step in the development of self-control. Around ten months, in the earliest sign of this capacity, babies are able choose which aspects of the environment to select for attention (as opposed to paying involuntary attention to whatever suggests itself; see chapter 10). Once this occurs, they
can comfort or distract themselves and sometimes change their behavior instead of persisting on a course of action that’s not effective, as younger infants do. The more complex ability to deliberately inhibit behavior, control impulses, and plan actions, called “effortful control,” is first seen around twenty-seven to thirty months of age. It allows children to do things like remember to use their inside voice when they are excited or keep their hands out of the cookie jar. Toddlers develop the ability to inhibit behavior on command between their second and third birthdays. Effortful control then improves rapidly until the fourth birthday and more slowly through age seven. Resistance to distraction continues to get better throughout childhood, reaching adult values in the middle to late teens.

Two related skill sets depend on similar brain regions and thus tend to develop in parallel with effortful control. One is cognitive flexibility, the ability to find alternative ways to achieve a goal if the first attempt does not succeed, and to adjust behavior to fit the situation, like keeping your voice down in church. The other is working memory, the ability to remember task-relevant information for a short period of time, such as recalling which solutions to a puzzle you have already tried. Together, these three abilities are collectively called **executive function**.

As these abilities grow with age, children become progressively better at sequencing behavior appropriately, keeping track of multi-step tasks, and resisting or recovering from distractions. Executive function, which provides the core ingredients for self-control in adulthood, depends on the prefrontal cortex and the anterior cingulate cortex. The prefrontal cortex shapes behavior in pursuit of goals by activating or inhibiting other brain regions. The anterior cingulate is activated by tasks that require
cognitive control, particularly monitoring and detection of errors in performance and deciding among conflicting cues. Another part of the anterior cingulate is connected with the orbitofrontal cortex, hippocampus, and amygdala and is involved in regulating emotions.

One measure of a child’s growing executive function is the strength of his cognitive control. Cognitive control is typically measured by a so-called “conflict cue task,” in which children are asked to rapidly detect the appearance of a target. This task is easier (and so performance is faster) if the child knows in advance where the target will appear. In a simple version of the task, the target is preceded by one of two cues, a row of five arrows that all face toward the target’s future location (“congruent condition”), or another row with the center arrow facing the target location and the other four arrows facing the wrong way (“incongruent condition”). Response times are slower, for children and adults, when faced with incongruent conditions, because the brain must inhibit the automatic tendency to follow the majority of cues and instead concentrate on the center arrow alone. Performance on this test correlates with parents’ evaluations of their children’s self-control ability.

Stable individual differences in these measures become evident during early childhood. The ability to self-regulate is moderately heritable—some evidence suggests that this has to do with the genes that regulate the neurotransmitters dopamine and serotonin. But children’s experiences also have an important effect on their self-control in studies that take genetic influences into account.

Four-year-olds who do well on the marshmallow task typically distract themselves from thinking about the tempting object during the delay period. They cover...
their eyes, turn their backs on the marshmallow, or try to think about something else. One of the tricky aspects of self-control is that it has a certain circular quality: it takes discipline to learn discipline. Children who can focus on a task without giving in to distractions are also going to be better at improving this ability through practice. The key is for parents and teachers to provide scaffolding to support the learning process until the child’s self-control is strong enough to stand on its own (see chapter 29). This process is easier, especially in young children, if a child finds the task rewarding. So keep an eye out for age-appropriate, multi-step projects, like making art or building something, that your child enjoys.

Here’s some even better news. Improvement of self-control is not limited to a sensitive period (see chapter 5). We all know that even in adults, the ability to control your own behavior is limited. Even so, it can be increased by training. As psychologist Roy Baumeister puts it, willpower is like a muscle: the more you use it, the better it works. His studies show that self-control can be improved by practicing any sort of self-control, from dieting to money management to brushing your teeth with your left hand, on a regular basis. College students who did these exercises for several weeks reported improvements in their ability to complete a variety of tasks requiring self-control, from going to the gym regularly to managing money to doing housework.

This plasticity in adulthood strongly suggests that children should also be able to increase their self-control abilities through experience. In young children, warm supportive mothering is associated with improved self-control ability, even when the mother’s genetic contribution is factored out. During elementary school, computer-based
attention training can increase reasoning abilities, and children with the poorest attention before training show the most benefit.

Play with other children can also improve executive function. One promising preschool program uses structured play to improve self-control in children from disadvantaged backgrounds (see Practical tip: Imaginary friends, real skills). All these forms of training probably improve performance of the brain network involved in cognitive control.

You can help by encouraging your child to exercise as much self-control as possible in the context of routine tasks like taking a bath. A young child might be able to pick out toys to play with in the tub, while an older child could be responsible for taking a bath, brushing his teeth, and putting on his pajamas. If you stand over your child and manage every step of the process, you’re depriving him of the experience that will allow him to learn how to organize his own actions. On the other hand, if your child consistently fails to complete the task, then it may be too difficult for his developmental stage and need to be simplified. Success at completing challenging self-control tasks builds more success, but repeated failure may instead teach the child that there’s no point in trying.

Children who fail to develop an age-appropriate level of self-control can end up with troubles that multiply. In school, they are likely to get poor grades because they have difficulty concentrating and completing assignments. In addition, parents, teachers, and other students are likely to find them difficult to handle. Because punishment is more likely to induce resentment than to increase self-control (see chapter 29), its repetition can eventually establish the poorly self-regulated child as the “bad” or “rebellious”
member of the class or of the family. This image, in the eyes of teachers, parents, peers and the child, can outlast the original problem and contribute to a downward spiral into poor performance and delinquency.

Even young children can benefit from spending time directing their own activities, particularly if they are engaging in imaginative play, alone or with other children. Parents can help by encouraging children to pursue their own interests and enthusiasms. It probably doesn’t matter exactly what excites your children; as long as they are intensely engaged by an activity and stick with it, they will be improving their ability to self-regulate, and thus their prospects for the future. Play has many benefits for children, as we will explore in the next chapter.

BEGIN BOX

Practical tip: Imaginary friends, real skills

An average four-year-old child who is asked to stand still for as long as possible can manage it for slightly less than one minute. If he’s asked to pretend he is a guard outside a castle, though, he can hold his pose four times that long. The reason is simple: pretending is fun, which means it’s easy to get children to participate enthusiastically. Children can choose games that reflect their own interests, so they can supply their own motivation for achievement, which teaches self-control—an ability that is more useful in adulthood than modifying your behavior to please others. Most importantly, imaginative
play has rules that children take seriously. To play school, you have to act like a teacher or a student, and inhibit your impulses to act like a fighter pilot or a baby. Following these rules provides children with some of their earliest experiences with controlling their behavior to achieve a desired goal.

An innovative preschool program called Tools of the Mind has achieved remarkable success using the power of play to teach disadvantaged children how to control their impulses and organize their behavior in pursuit of goals. Children are asked to plan how they want to spend their play time (“I am going to take the baby to the doctor”) and then to stick to that plan. Teachers use physical reminders to help children regulate turn-taking, such as having one child hold a cardboard ear and another child a mouth to remind them who is supposed to be listening and who is supposed to be talking right now. The goal is to help children develop the ability to control their own behavior, rather than simply following rules to gain gold stars or avoid timeouts.

The program is only a few years old, but the early data are exciting. In one study, done in a low-income neighborhood, more than twice as many Tools of the Mind students could successfully perform a difficult attention-demanding task, in comparison to those who were in another preschool program. We look forward to future research aimed at finding out how long these self-control gains last, whether they improve later academic performance, and which of the techniques used in the program are most effective. In the meantime, we encourage parents to adopt some of these techniques to help their three- and four-year-olds learn to regulate their own behavior through imaginative play.
Practical tip: Learning two languages improves cognitive control

The process of learning two languages gives children cognitive advantages beyond the realm of speech. Learning multiple languages is challenging in part because the person must direct attention to one language while suppressing interference from the other. This interference causes bilingual people to be slower at retrieving words and have more “tip-of-the-tongue” experiences than monolingual people. There are a lot of benefits to meeting these challenges.

Bilingual children outperform monolingual children on a variety of tests of executive function. Before their first birthday, bilingual children learn abstract rules and reverse previously learned rules more easily than monolingual children. They are less likely to be fooled by conflicting cues, such as a color word like “red” written in green ink, a challenge that psychologists call the Stroop task. This pattern continues into adulthood and shows up in nonverbal tasks, so it does not depend on language skills directly. Extensive practice at selecting appropriate behavior in two different languages seems to strengthen bilingual children’s ability to show cognitive flexibility according to context—an aspect of self-control.
Bilingual children also outperform monolingual children on theory of mind tests, which measure the ability to understand what other people are thinking (see chapter 19). This advantage may develop because bilinguals get more practice at taking the perspective of other people, since they need to choose the appropriate language for the person they’re talking to.

Bilingual people may exert cognitive control not only better, but by using different brain areas. During a task that requires them to resolve differences between two conflicting sources of information, bilingual children’s brains show activation not only in dorsolateral prefrontal cortex, which everyone uses for conflict resolution, but also in Broca’s area, the speech region that processes grammatical rules.

Bilingualism may also protect the brain from cognitive decline in aging. People who have spoken two languages actively for their entire lives experience the onset of dementia four years later, on average, than their peers who spoke only one language.

That’s a lot of advantages—and we haven’t even mentioned the most important use of a second language, to communicate with people.
For Pigface, life at the zoo had recently improved. Previously prone to clawing and biting himself, he had been given sticks and other items, with which he developed various tricks. One was to push a basketball with his snout and sometimes snap at it. Hoops of hose were favorite objects, which he would nose and chew and sometimes swim through. On days when his tank was being cleaned, he would get in front of the stream of incoming water and remain there unmoving, just feeling the water run over his face. Once the refilling was done, he was off again. These activities make Pigface sound like an otter or a seal. Movies of him certainly look like such frolicking—except in very slow motion. The behaviors only look like mammalian play when played back at three times normal speed, because Pigface is a turtle.

Similarities run deep between how we and other animals play. When you watch your children play, you may think it’s cute—but they are also learning to match their capacities to future life needs. Object play such as pushing a truck or ball around resembles later activities such as wielding a hammer, hunting, or building machinery. Indeed, play can also take a distinctly animal-like quality. Babies and toddlers like to chew and pull things apart. Biting is a common nuisance in preschool centers—and it’s also practice for kinds of predation that our species once depended on for food.

Play is widespread among animals, beyond the familiar cases, mammals and birds, to vertebrates and even invertebrates. How can we be sure that an animal is playing? Researchers use three criteria. First, play resembles a serious behavior such as
hunting or escaping, but is done by a young animal or is exaggerated, awkward, or otherwise altered. Second, play has no immediate survival purpose. It appears to be done for its own sake and is voluntary or pleasurable. Third, play occurs when an animal is not under stress and does not have something more pressing to do.

These criteria for play are met by leaping needlefish, water-frolicking alligators, and lizards. In the National Zoo, monitor lizards play games of keep-away. The largest monitor species, the Komodo “dragon” lizard, plays tug-of-war with its keepers. It can pick a familiar keeper’s pockets of notebooks and other objects, then walk around carrying them in its mouth. A movie of a playing Komodo dragon looks quite a bit like play with a dog, only slowed down to about half speed. For example, it will play tug-of-war with a human over a plastic ring.

The behavior is not just displaced foraging or hunting. If the ring is coated in tasty linseed oil or animal blood, playfulness vanishes and is replaced by a pronounced possessiveness. YouTube videos of Komodo dragons swallowing whole pigs—or even other Komodo dragons—suggest that these food-oriented behaviors are not easily confused with play.

The fact that play is so widespread suggests that it arose long ago in the history of animals. It appears in many animals with far less social complexity than people. This universality suggests that even though play is literally fun and games, it must serve some vital function.

Play takes different forms in different animals. Its content provides some hint as to what it might be good for. Play researchers (there’s a fun-sounding job) recognize three major types of play. Most common is object play, like what Pigface does with
basketballs and hoops. Object play is typically found in species that hunt, scavenge, or eat widely. About as common is locomotor play, including such behaviors as leaping around for no apparent reason. Locomotor play is common among animals that move around a lot for a living, for instance if they swim, fly, live in trees—and notably, often must get away from predators. The third and most sophisticated form of play is social play. Social play can take many forms, including mock-fighting, chasing one another, and wrestling. Pretending is a major component of social play.

Social play is especially prominent in animals that show a lot of behavioral flexibility or plasticity. In mammals and birds, this boils down to a simple rule: if your species has a big brain for your body size, you probably engage in social play. Among these species, most of the variation in brain size occurs in the forebrain: different mammals or birds of a given body size will have about the same amount of brainstem, but very different amounts of neocortex (in mammals) or forebrain (in birds). Animals with more neocortex or forebrain typically live in larger groups and have more complex social relations. Ducks engage in “coordinated loafing,” in which they basically just hang around together. Great apes and their relatives form societies in which alliances are constantly shifting, and in which the young play recognizable games, such as chasing, wrestling, and tickling.

This phenomenon is not limited to vertebrates. Among invertebrates, perhaps the most complex brains are found in cephalopods, which include squid and octopus. Octopuses use their water jets to push floating objects like pill bottles back and forth in a tank or in a circular path. Despite this behavioral complexity, octopus brains are still small by vertebrate standards—half the diameter of a dime, smaller than those of even the
smallest mammals. Another invertebrate that appears to play is the honeybee, which has one of the largest and most complex nervous systems among invertebrates. As a counterexample, playlike behavior is not reported in houseflies.

Now, maybe play isn’t “for” anything. Perhaps play behavior is simply early maturation, precocious behavior that develops before it is absolutely required. Another possibility is that play is what our brains do when there are no more pressing matters—a screensaver for the mind, as it were.

But these ideas are contradicted by one key piece of evidence: play is fun. At first, this may seem like an odd argument. Aren’t fun activities the ones we engage in for their own sake? Superficially, yes, but dig a little deeper. The enjoyment of an activity is a survival trait. We are wired to like activities that are helpful for our survival. For example, we may think we seek sex because it’s fun, but in reality, sex is essential. Sex is fun because seeking it is adaptive. People who don’t like sex have a harder time finding mates and having kids. In general, enjoying an activity is a hard-wired response that causes our brain to seek out that activity. If these essential behaviors weren’t enjoyable, we might forget to do them, and then we wouldn’t make it through life very well. On these grounds, it seems that play must have an adaptive purpose, providing some survival advantage.

The brain generates chemical signals that encode a key component of fun: reward, the quality that makes us come back for more. Reward is conveyed within the brain by dopamine, a neurotransmitter that has many functions depending on where and when it is secreted. Dopamine is made by cells in the brain’s core, in the substantia nigra (see figure). In rats, dopamine and play are linked. Among chemicals that activate receptors
for various neurotransmitters, only a few increase play behavior, including drugs that activate dopamine receptors.

One way to find out what play is good for is to take it away from animals and see how they fare. The problem is that this experiment is nearly impossible to do. Animals (including children) are irrepressible: they play under the most adverse of conditions. The only way to get an animal to stop playing is to restrain its mobility. This severe restriction leads to decreases in physical activity and increases in stress, as measured by the amount of the stress hormone cortisol in saliva. Play, exercise, and stress are closely linked.

Though the deprivation experiment is hard to do, that very fact means that seeing an animal play already tells us something good about its state. In young squirrel monkeys, lower levels of cortisol are associated with high amounts of play, suggesting either that play reduces stress, or possibly that unstressed monkeys are more likely to play. In bear cubs during their first year of life, survival over the winter is highly correlated with the amount that cubs played during the preceding summer. This suggests that play might be an indicator of health or resistance to stress. No matter how you slice it, seeing your child play is a good sign.

Play activates other brain signaling systems as well, including the neurotransmitter norepinephrine. Its close relative epinephrine (also known as adrenalin) is released to the body as a fast component of stress-related signaling (see chapter 26). As the main activator of the sympathetic nervous system, epinephrine mobilizes our energies for “fight, flight, or fright,” as the medical-school mnemonic goes. Norepinephrine too is involved in rousing us to attention and action, but by acting as a neurotransmitter.
Norepinephrine also facilitates learning mechanisms at synapses. In some neurons, norepinephrine improves brain plasticity, so that change becomes possible when this chemical is present in elevated amounts. The same is true for dopamine, which accounts for how reward leads to long-term changes to make us want more—brains are rewired when reward occurs.

Though real-life stressors trigger the release of both epinephrine and cortisol, play does not increase cortisol. This hormone helps us in genuinely dangerous situations by shutting down functions that are dispensable for a little while, such as learning of experiences that are not immediately related to the stressful context. It is safe to say that if you find play to be a source of stress, you’re not doing it right. Even violent video games, which raise physiological arousal as measured by epinephrine-based response, do not increase cortisol. In some cases, cortisol levels actually decrease—people work off stress by shooting ‘em up. On the whole, play is associated with responses that facilitate learning.

The conditions of play—the generation of signals that enhance learning without an accompanying stress response—allow the brain to explore possibilities and learn from them. In other words, a major function of play may well be to provide practice for real life. As we’ve written before, the use of a skill or other mental capacity builds up that ability. Evidence from animals suggests that this is the case for play, which usually reflects an animal’s more serious needs. Kittens play at pouncing on things, a behavior that resembles the hunting they do later. Fawns don’t pounce much, but they do gambol around, a behavior that resembles escape.
So it’s possible that play is practice that prepares animals for the real activity later—when it matters. For example, in chapter 13 we described Tools Of The Mind, a preschool program that uses complex play to get children to make elaborate plans and exercise self-restraint—practice for the prefrontal cortex and self-control. Even before that the Kindergarten movement, which in the 19th-century popularized the concept of preschool education, was based on the idea that songs, games and other activities were a means for children to gain perceptual, cognitive, social, and emotional knowledge that would prepare them for entering the world.

In mammals, play is necessary for forming normal social connections. Rats and cats that are raised in social isolation become incompetent in dealing with others of their kind, typically reacting with aggression. In our species, dysfunction in adults is often presaged by abnormal play as children. A notable feature of psychopaths is that their childhoods were lacking in play. Serial killers are often reported to have abnormal play habits, keeping to themselves or engaging in notably cruel forms of play. Sometimes such problems are associated with early-life head injury. Such serious problems should not be confused with minor childhood cruelties like pulling wings off flies or throwing rocks at dogs. Needless to say, this sort of common play does not suggest that abnormal play does not mean that you are raising a serial killer.

Culture is also transmitted through play. Middle-class mothers in the U.S. encourage their infants to pay attention to objects from early in life and are likely to prompt them to play with toys such as blocks. In contrast, Japanese mothers encourage their babies to engage in social interactions while playing, for example by suggesting that they feed or bow to their dolls. Communities that emphasize the development of

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independence place more importance on object play, while interdependent communities encourage social play.

There are some downsides to it, too. For one thing, though play is defined as occurring in the absence of stressors or external threats, children aren’t always good at detecting threats, so play can be dangerous. People are not alone in having this problem. In a study of baby seal mortality, 22 of 26 deaths resulted from the pups playing outside the sight or sound of their parents. Play can distract people and other animals from recognizing danger.

But even here, play may be practice for real life. Risk-taking in children’s play may be an important developmental process. It tests boundaries and establishes what is safe and what is dangerous. In the U.S., playground equipment has been made very safe, leading to the unanticipated problem that children lack experience with such boundaries, which may lead to trouble later in life.

In addition to providing experience, play also helps children learn what they like and don't like. Nobel chemistry laureate Roger Tsien tells of reading about exotic chemical reactions before he was eight years old, then trying out the reactions for himself. He was able to get beautiful color changes to happen in his house or backyard. Because he didn’t have enough laboratory glassware, he had to make equipment from used milk jugs and empty Hawaiian Punch cans.

After he grew up, Roger won the Nobel Prize for developing colored dyes and proteins that become brighter or change hue when they encounter chemical signals in living cells, including neurons. (This can make certain biological processes, such as brain signaling, much easier to see and understand.) The invention of tools to visualize what is
happening in active biological systems, Roger’s great contribution to science, had its roots in that childhood interest in home chemistry experiments. Not all childhood experiments lead to such heights, of course, but no matter what your children’s eventual interests may be, discovering them may be one of the most important outcomes of play.

Think of it this way: play is the work of children. It is perhaps the most effective way for them to learn life skills and to find out what they like. For these reasons, it is important to prevent play from becoming a compulsory, dreary activity, as its enjoyable nature is part of what makes most children grow like dandelions. So, rather than trying to change your child’s personality through enforced activities (which is tough—see chapter 17), instead, let them play, and help them become who they’re going to be.

BEGIN BOX

Did you know? Play in adult life

In many people, play continues in adulthood and is a major contributor to problem solving. Physical scientists often report having built and taken apart machines when they were kids. Sam did this too, with activities such as building a sundial in elementary school.

Conversely, work in adult life is often most effective when it resembles play. Indeed, total immersion in an activity is often the mark that an activity is intensely enjoyable—the concept of flow, or what athletes call “being in the zone.” Flow occurs during active experiences that require concentration but are also highly practiced, where
the goals and boundaries are clear but leave room for creativity. It is most likely when your abilities are just sufficient to meet the challenge, in tasks that are neither easy nor impossible. This describes many adult hobbies, from skiing to music, as well as careers like surgery or computer programming. Such immersion can make solving a great challenge as easy as child's play. Encouraging your child to pursue tasks that produce flow is a great way to contribute to her lifelong happiness.
It’s obvious that your child is using her brain when she’s reading, but you may not realize that her brain is also getting a workout when she plays soccer. Sports and exercise in childhood are beneficial to motor control and cognitive ability—and perhaps most importantly they set up habits that can keep your child’s brain healthy into old age. For all these reasons, the recent trend to reduce or eliminate physical education in U.S. schools is likely to be bad news for children.

The control of movement and balance continues to improve throughout childhood. During this time, the brain gets better at coordinating its commands to various muscles and interpreting feedback from sensory systems. Skills like walking over rough ground may feel effortless to you, but your brain is working very hard to produce that impression. Controlling the body is genuinely difficult, and it requires practice. Computer experts have found it surprisingly difficult to make a robot that can play sports, or even walk steadily. The instructions are complicated.

Physical activity in children is correlated with a number of positive characteristics. Physical education programs that emphasize positive enjoyment over competition or criticism are most successful at producing all these benefits. Active children have higher self-esteem than inactive children. Feelings of stress, depression, and anxiety are less common in active than in inactive children. Some of these results may occur because depressed children are reluctant to exercise. But on the other hand, a few small intervention studies show that exercise modestly improves anxiety and
depression symptoms in children, as it clearly does in adults. Although parents sometimes worry that physical activity will take up time better devoted to academic effort, no study has shown a drop in academic performance as a consequence of increased activity.

Indeed, exercise is vital for cognitive ability. Across the lifespan, heart health is brain health. In childhood, aerobic fitness is correlated with math and reading achievement, while muscle strength and flexibility are not. In a meta-analysis, children (ages four to eighteen) who were more physically active tended to score higher on tests of IQ, perceptual skills, verbal ability, mathematical ability, and academic readiness, and the correlation is moderately strong (a d’ of 0.32—see the figure on p. TK). The relationship was strongest from ages four to seven and from eleven to thirteen. Fit children perform better on attention and conflict cue tasks (see chapter 13), both of which are associated with self-control ability. Fitness also improves performance on a “relational memory task,” remembering which pairs of pictures were shown together, which requires both the prefrontal cortex and the hippocampus.

Though the habit is best started young, the brain benefits of regular aerobic exercise are especially noticeable in old age. Problems with an aging circulatory system can reduce the blood supply that brings oxygen and glucose to your brain. Elderly people who have been athletic all their lives are better at planning and organizing their behavior and dealing with ambiguity or conflicting instructions than sedentary people of the same age. When inactive people get more exercise, even in their 70s, their brain function improves in just a few months. Exercise is also strongly associated with reduced risk of dementia, including Alzheimer’s disease, late in life.
Physical activity leads to growth and increased activity in the frontal and parietal cortex in adults. These brain areas are active during tests of reading comprehension and mathematical calculation, as well as during many tests of self-control. Fit adults, young or old, show reduced activity (suggesting increased efficiency) in the anterior cingulate cortex, which detecting errors and resolving conflict between alternatives.

Brain differences related to exercise are also seen in children. In physically fit nine- and ten-year-olds, the hippocampus and the dorsal striatum (a region important for response selection, cognitive flexibility, and the performance of learned behaviors) are larger than in sedentary children. The role of exercise in maturation of prefrontal cortex of children has not yet been examined, but the behavioral effects of exercise suggest that this brain region might be affected as well.

There are several possible ways that exercise might change the brain, and they are not mutually exclusive. In people and lab animals, exercise causes the release of “growth factors,” proteins that support the growth of dendrites and synapses and increase synaptic plasticity. Exercise also increases the survival of newly formed brain cells in the hippocampus of young adult and old lab animals—and even in rat pups whose mothers exercised during the pregnancy. Proteins that are released during exercise in juvenile and old lab animals stimulate blood vessel growth, helping nutrients from the circulation to reach the brain. Most of these effects have been studied in adult animals, but they probably also occur in children’s brains. The question of how exercise interacts with brain development remains to be studied.

To gain the benefits of exercise on the brain, children of all ages should have fun moving their bodies for at least an hour a day. Young children rarely need much
encouragement to run around, so most kids meet or exceed the activity requirement through elementary school. In addition to letting kids play tag and climb trees, which are unlikely to continue into adulthood, parents should take advantage of these active years to introduce their children to sports that can become lifelong hobbies and social activities, such as martial arts, dance, softball, or hiking. Parents can also help by limiting children’s exposure to sedentary activities like TV and computer time (see chapter 16) and by demonstrating to their children that exercise is a regular feature of adult life.

In our fat-obsessed culture, it is tempting to focus on weight control as a key benefit of exercise, but this approach is likely to be counterproductive (see box, Practical tip: Worried about your child’s weight?, in chapter 12). Thinking of exercise as a part of dieting defines it as an occasional activity, not something you do every day for fun—and makes it feel like a punishment for bad behavior, especially to young girls. No one looks forward to activities associated with shame and guilt, so using this type of motivation is likely to be actively harmful to your attempts to make exercise a regular and enjoyable part of your child’s life. Exercise is beneficial for everyone, fat or thin, whether or not it leads to weight loss.

There are also social reasons for children to master motor skills when they’re young. A swing and a miss, which is cute in a preschooler playing T-ball, may be mortifying to an adolescent boy in gym class. The embarrassment associated with attempts to catch up with the better-practiced skills of peers often leads to a lifelong distaste for athletics. In longitudinal studies, an inactive childhood is a strong predictor of an inactive adult life.
Parents’ efforts in laying this sort of groundwork during middle childhood are likely to pay off in adolescence and adulthood. Physical activity typically decreases in the early teen years, on average at age thirteen for girls and fifteen for boys, as organized activities and socializing squeeze out competitors like exercise and sleep (see chapter 9). For many kids, this stage of development marks the divide between an active childhood and a sedentary adulthood, with substantial consequences for adult health.

Through most of our evolutionary history, people were much more active than they are today. Our bodies and our brains are adapted to regular exercise, and they do not function well without it. There are exercises for every dandelion’s taste, from solitary distance running to competitive team sports to sociable yoga classes. Helping your children find a few that suit their personalities and talents will go a long way toward giving them a good start in life.

BEGIN BOX

**Practical tip: Protect your child from head injuries**

There’s one big exception to the rule that exercise is good for your brain—the risk of head injuries from contact sports. Consider the case of a 21-year-old college (and high school) football player named Owen Thomas. He is the youngest person known to have had chronic traumatic encephalitis, a neurodegenerative disease that was discovered at
autopsy after his suicide. He had never been diagnosed with a concussion and had no previous history of depression, but he was known as a hard hitter on the field.

Evidence is accumulating that repeated blows to the head increase the likelihood of developing neurological symptoms later in life, including dementia, movement disorders, and depression. As 1.6 to 3.8 million sports-related concussions occur each year in the U.S. alone, this is potentially a big problem. Girls are more likely to be diagnosed with concussions than boys in the same sports, although the difference may be simply that boys are less likely to report symptoms.

Chronic traumatic encephalopathy has a variety of symptoms, including depression, memory loss, and impulse control problems. Its symptoms are easily confused with those of depression, Alzheimer’s disease, Lou Gehrig’s disease, or Parkinson’s disease, so its prevalence remains uncertain. Individuals who carry the ApoE4 gene variant are at higher risk of Alzheimer’s disease, and this variant also seems to increase the risk of neurodegeneration associated with head injury.

Many popular childhood sports may be risky. Football, wrestling, rugby, hockey, karate, lacrosse, soccer, basketball, and skiing are all associated with repetitive head injury. It is not yet clear how the number, timing, and severity of head injuries relate to these long-term risks. Experiencing three concussions significantly increases risk in most studies, and some studies find increased risk after a single concussion (or undiagnosed head injuries, as in Thomas’s case).

Compared to adults, children take longer to recover from concussion. This may be because there is less space between the brain and the skull in childhood, making brain swelling after injury a more serious problem for children than adults. Children are also
especially susceptible to complications from reinjury during the recovery period. Over 90 percent of deaths due to sports-related head injury since 1945 in the U.S. have been athletes who had not yet finished high school.

Though longitudinal research is needed to sort out these questions, caution seems well justified already. Children whose family history puts them at risk of Alzheimer’s disease should be especially careful to avoid head injury. No child should return to play with any lingering symptoms of a concussion. (Not all concussions lead to loss of consciousness; confusion and memory loss after a head injury are also signs of concussion.) During recovery, children should rest their brains as well as their bodies, avoiding schoolwork and even reading. Finally, parents should seriously consider a non-impact sport for children who have suffered more than one head injury in their current sport. For more information, see http://www.cdc.gov/concussion.

END BOX
Chapter 16

Electronic Entertainment and the Multitasking Myth

We’re young enough to be distracted frequently by email or the Web when we’re trying to work, but we’re old enough that our brains didn’t develop under those conditions. In contrast, many of today’s children are growing up with continuous access to electronic media, from the TV in the bedroom to video games for the road. In the U.S., the average baby starts watching TV at five months of age, before he can sit up by himself. By seventh grade, 82 percent of children are online.

Your child’s brain is wired to seek out and pay attention to new information because our ancestors’ survival often depended on detecting changes in the environment—from the arrival of an antelope or a lion to the new expression on a mate’s face. But what happens to our brains when getting new information becomes too easy? Our society seems to be in the process of finding out, as the internet brings an avalanche of facts and ideas (along with daredevil stunts and keyboard-playing cats) into our lives.

Researchers do not yet know the full effects of exposing children to a constant stream of highly salient stimuli, as the new media environment is a recent occurrence. In theoretical terms, we have emphasized throughout this book that your child’s brain depends on commonly available sensory experiences to help determine which neural connections should be maintained or lost. If the character of these experiences changes dramatically, we would expect to see effects on brain development. The few experiments that have been done support this idea, though not with certainty.
Deciding which information should have your attention at a given moment is far from simple. Your brain needs to combine the ability to concentrate deeply on a particular problem with the ability to reorient itself quickly if important changes happen. To achieve this balance, top-down attention, the deliberate direction of your brain’s focus by the prefrontal cortex, must compete with bottom-up attention, the automatic capture of your brain’s focus by salient events, such as someone screaming—or the buzz of your cell phone reporting an incoming text message. You’ve probably experienced moments when one system dominated the other: either your concentration was so deep that you didn’t hear your baby cry, or you were getting interrupted so often that you couldn’t make any progress on your work assignment.

The bottom-up system is functional at birth, earlier than the top-down system, which can take control for brief periods by the end of the first year and continues to improve at least to age ten and perhaps into adolescence. This discrepancy in the maturity of the two systems is why younger children are easier to distract than older children. As we discussed in chapter 13, the ability to use executive function is a key ingredient of self-control and improves with practice. Other aspects of visual attention can also become more effective with practice.

A basic principle of neuroscience is that brains become better at doing whatever they do frequently. Video game players are an excellent illustration of this point, as they typically invest hundreds or thousands of hours into practicing games that require the rapid detection of targets and their discrimination from nontarget distractors. Daphne Bavelier and her colleagues have shown that this effort improves response speed (across
a variety of tasks) and visual attention abilities of players’ brains. Unfortunately, only shoot-'em-up rapid action games, of the type that parents hate, seem to have these effects.

The changes appear to be a direct effect of video game playing. Alternately, you might imagine that people with better visual attention would find video games more rewarding and so be more likely to play them, which would be an example of reverse causation. But researchers ruled out that interpretation because in some studies, college students who did not play regularly were randomly assigned to practice action video games (Grand Theft Auto, Call of Duty). The control group spent an equal amount of time practicing non-action video games (Tetris, The Sims). The training improved several aspects of visual attention, but only in the action video group. It also improved contrast sensitivity (the ability to see faint outlines, like cars in fog), an effect that lasts for years after training. Players react more quickly than nonplayers, with no difference in the number of errors they make in their reactions.

Similar randomized experiments cannot be done in children because it would be unethical to expose them to the violence in action games, which have been linked to increased aggression. We would guess, though, that if there is a difference between children and college students, it is likely to be that young brains are more plastic than adult brains. Researchers are looking for nonviolent games with similar beneficial effects, but they have not yet managed to find any.

Children who are already action video game players at home show most of the same advantages over nonplayers (or players of non-action games) that are found in college students. Across all ages from seven to twenty-two years, players are better able to orient their attention to a cued location, compared to nonplayers of the same age (in the
conflict cue task described in chapter 13). Distractor arrows (in the incongruent condition) slow the responses of players proportionately more than those of nonplayers, a fact which the authors of the study explain by saying that video game players pay attention to a broader field of view. Players are also better than nonplayers at detecting a target against a background of distractors, at rapidly processing a stream of visual inputs, and at tracking multiple targets simultaneously. Because video game players are mostly boys, these effects of practice may lead to gender differences in attentional processing, which have not existed in previous generations.

Another recent change in children’s sensory experiences is the rise of multitasking. In the U.S., children now fit 8.5 hours of media use into 6.5 hours per day, on average, by doing multiple things at once (text messaging while watching TV or listening to music while playing video games). Your child’s brain, like your own, cannot concentrate on more than one thing at a time, though almost all of us believe that we can multitask. A major source of interference between tasks seems to be the limited capacity of prefrontal cortex, a key aspect of the brain’s executive control system.

Many aspects of brain function, like walking or driving a familiar route, do not require direct conscious control. Planning your actions, though, does require attention, as you can recall the next time you get distracted and end up at a familiar destination when you meant to go somewhere else. People who claim to do multiple attention-demanding tasks at once are actually switching between the tasks repeatedly. Every transfer of attention from one task to another requires resources, as your brain must remember or reconstruct where you were on the abandoned task when you come back to it. For this reason, switching back and forth between tasks takes more time than completing the same
tasks one by one in sequence. These so-called “costs of switching” reduce performance on individual tasks. If both tasks are highly practiced, this switching cost can be reduced, or perhaps in rare cases eliminated. Under no circumstances, though, is it more efficient to do multiple attention-demanding tasks at once than to do them separately. In short, multitasking is a myth.

The cost of chronic multitasking may include diminished performance when single-tasking. One study found that college students who habitually do more than one thing at a time performed worse than habitual single-taskers at tests of distractibility and task-switching ability. Students who spend more hours using the internet also tend to spend more time using multiple types of media simultaneously. The performance of habitual multitaskers was more severely impaired by distractors, compared to students who were not in the habit of multitasking, though the two groups performed equally well when no distractors were present. In other tasks, habitual multitaskers also had more trouble ignoring irrelevant items in their memory and switching back and forth between two sets of rules. One thing we don’t know is whether naturally distractible people are more likely to multitask or whether multitasking actually increases distractibility. Either way, though, if your children spend a lot of time multitasking, it’s not likely to be good news for their academic achievement.

As we’ve discussed throughout this book, your children’s life experiences influence their brains in a variety of ways. Because the rise of electronic media is both so recent and so significant, scientists are working hard to determine its effects on child development. We do know that young children’s brains are strongly influenced by one-on-one interactions with caring adults, which cannot be replaced by anything that appears
on a video screen. Before age three, electronic entertainment has no benefit and clear costs (see box, Practical tip: Baby videos do more harm than good). For older preschoolers, educational TV can be beneficial. In school-age children, electronic media are a mixed blessing, improving some cognitive capacities, while perhaps impairing others.

Banning electronic media throughout childhood is probably unnecessary and certainly unrealistic. Even if you could enforce such a ban successfully, cutting your child off from his peers’ favored communication methods would place him at a severe social disadvantage, and lack of experience with computers might lead to professional difficulties later on.

Providing time for other activities by limiting screen time, though, is likely to be beneficial for development. There is no doubt that childhood experiences influence brain development, so it's worth making sure that the important ones are available to your child. Children need exercise (see chapter 15), they need face-to-face interaction (see chapter 20), and they need to spend time outdoors (see chapter 10). In that light, your Mom’s suggestion to “Go outside and play” still has a lot going for it. Even dandelions need to see the sun every so often.

BEGIN BOX

Speculation: Does internet use interfere with empathy?

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Who isn’t annoyed by the oblivious person in line who won’t get off his phone to talk to the cashier? Since 2000, there has been a sharp drop in empathy in the U.S., leading to experiences like the poor clerk’s. A meta-analysis found that today’s college students are 40 percent less likely than their counterparts two or three decades ago to agree with statements like “Before criticizing somebody, I try to imagine how I would feel if I were in their place.” In other surveys, many U.S. citizens report feeling that people have become less kind and considerate over the past decade.

This decline has only been identified recently, so its causes are not known for certain, but the rise of electronic media is a prime suspect. The most striking environmental change over this time period is that modern college students have grown up with electronic communications and video games as a constant presence in their lives. Texting has taken over from phone conversations—and many teens text even in situations where they could turn and speak to each other in person.

These changes could interfere with the development of empathy in a variety of ways. The culture of online interaction in communities like Facebook encourages people to ignore others who are perceived as overly demanding, which might reduce tolerance for people with problems in face-to-face interactions. Exposure to video game violence can desensitize children to the pain of others. Perhaps most importantly, children who learn about social interactions online are deprived of a variety of emotional cues like facial expressions that could help them to appreciate the feelings of other people. Without such real-world experience, empathy may not develop correctly—and that could be very costly for all of us.
Practical tip: Baby videos do more harm than good

Almost all children today start watching TV before they are two years old. This is not good news for their future. Marketers claim that baby videos like Baby Einstein and Brainy Baby can give your child’s brain a head start, but research shows that the opposite is true.

As we have discussed, sensory experience is important for brain development, particularly the growth and retraction of synaptic connections, which is vigorous during the first three years of life. We would expect that children’s brains should be affected by watching TV for as much as a third of their waking hours during this developmental window. The key question is how they are affected.

Babies’ brains are optimized to learn from social interaction. For example, babies learn little or nothing from exposure to a second language on video (see chapter 6). The electronic babysitter reduces the time that infants spend interacting with other people, which can impair many aspects of their development. Even if you watch TV with your baby in the room, without intending for her to watch it, its presence interferes with her play and reduces the amount of social interaction between you.
Infant TV watching is correlated with poor language development. U.S. babies of seven to sixteen months who spend more time in front of the screen know fewer words. Two or more hours of screen time before the first birthday is associated with a six-fold increase in the risk of language delay in Thai children. Even Sesame Street viewing by babies correlates with language delay, though this program has lasting beneficial effects on three to five year olds. Exposure to baby videos is also associated with reduced cognitive ability at age three.

The quick cuts and bright colors that are typical of baby videos may also interfere with the normal development of attention. Before ten months of age, your infant cannot direct his attention voluntarily (see chapter 13). Exposure to attention-grabbing stimuli like fast-paced entertainment programs may make the transition to voluntary attention more difficult. In a longitudinal study, children who watched violent shows before age three were more than twice as likely to have ADHD at ages five to eight. It is easy to imagine that parents of ADHD children might be tempted to use TV as a babysitter, creating a vicious cycle (see chapter 28).

No reliable research shows that TV watching has any benefit for babies. France recently banned programming directed at infants, but it is unlikely that the U.S. will follow suit. Instead, parents need to protect their babies by keeping them away from the TV until they are at least two years old.
PART FIVE

YOUR CHILD AS AN INDIVIDUAL

Nice to Meet You: Temperament

Emotions in the Driver’s Seat

Theory of Mind and Empathy

Playing Nicely with Others
As we wrote in the introduction, in many ways, children flourish to a similar extent regardless of circumstances, as long as conditions are "good enough." This is true of personality, where as for so many other brain functions, the vast majority of children are dandelions. Indeed, there are limits on how much parents can influence their children’s personalities. It may sometimes seem otherwise, but this is good news: you do not bear the sole responsibility for your children’s success and happiness in the world.

Many people start reading parenting advice books before their baby is born—not to learn how to change a diaper or breastfeed, but to find out how to make their baby intelligent or sociable. If it doesn’t seem a little odd to be trying to figure out how to build a good relationship with someone you haven’t met yet, perhaps that’s because your culture assumes that babies are blank slates. There’s a tendency among many parents to believe that life experiences will determine what kind of people their children will be. You can see this kind of reasoning across the political spectrum: from liberal parents who are horrified to find their son playing war with sticks after being forbidden to have toy guns to conservative parents who believe that therapy can turn their gay son into a straight man.

Although your child's personality is indeed shaped in part by environmental influences, it’s worth remembering that many of them don’t come from you. This may be easier to understand if you keep in mind that the nuclear family is a recent invention in the history of our species. During most of our evolution, children were raised by a
community and were often cared for by older children as well as adults. For many cultures, the situation is still the same today. Wherever you live, your child is likely to spend much of his time with others: in school, at play, and with friends, teachers, and other people. Taken together, these factors are usually sufficient to lead to a good outcome (though see chapter 30 for what happens when environmental conditions are not good enough).

First-time parents sometimes manage to hold onto the blank-slate illusion for a while, but anyone who’s had more than one child has clued in that this idea is wrong. Even at birth, babies differ from each other in important ways. Temperament is a psychological term for the individual differences in infants that form the basis for adult personality. Temperamental characteristics include activity level, attentional persistence, and how easily the child feels fear, anger, frustration, or happiness. Like most early differences between individuals, temperamental characteristics do not absolutely determine outcome, but they do influence the relative likelihood of various adult personality traits and the range of possibilities available to a particular child. Perhaps more importantly for parents, they also influence your child’s response to different parenting styles—and vulnerability to various developmental problems.

One of the best-studied aspects of temperament is whether babies react calmly or with distress to unexpected events. Nearly one in five infants are high-reactive babies, who kick and cry when exposed to something new or strange (but not especially scary), like a dangling mobile over the crib. As they grow into toddlers, such children tend to be what the scientific literature calls “behaviorally inhibited”—and what the rest of us would call shy or reserved. When high-reactive babies are followed into early adulthood, they
are likely to be introverted and are at higher risk than calm babies of growing up to be worry-prone adults, even if they don’t have a formally diagnosed anxiety disorder.

Various experiences can nudge a high-reactive child’s developmental path in a less-anxious direction. For example, infants who are unusually irritable at fifteen days of age are more likely than other babies to become insecurely attached to their mothers at one year (see chapter 20), but this outcome is much less likely if the mothers are trained to soothe restless babies effectively. In general, about half of all high-reactive babies raised in the U.S. become fearful children sometime before age seven. The good news is that only a third of these babies become anxious adults. The others tend to become detail-oriented, well prepared, and thus often successful people. Among other things, they make good scientists (Sandra was a high-reactive baby), though it’s rare for them to be the life of the party or to pursue careers as politicians or salespeople.

Among adults without anxiety problems, those who started life as high-reactive babies are more vigilant than people who were calm as infants. In one laboratory test, vigilant adults find it difficult to disengage their attention from threatening faces on a computer screen. Most people become tense when watching a blue screen that signals that they might be hit with an unpleasant air puff, but only adults who were high-reactive babies stay tense in the presence of the green screen that signifies safety. These laboratory reactions don’t matter much in everyday life, but there is a broader, important point: there are real biological differences underlying high-reactive temperament, and these differences persist into adulthood.

Among children or adults, personality doesn’t require that you must act a certain way all the time. Instead it sets thresholds that make you more or less likely than average
to produce certain types of behavior in a given context. For instance, most shy people
don’t feel inhibited in front of family members, and even an outgoing person might feel
shy while speaking to an audience of thousands. Still, personality has an important
influence on life outcomes. Indeed, personality traits are as effective as IQ (see chapter
22) or socioeconomic status (see chapter 30) at predicting the probabilities of various life
events, such as divorce or work success.

The most widely accepted model of adult personality contains five factors:
openness to experience, conscientiousness, extroversion, agreeableness, and neuroticism.
These factors vary among individuals across many cultures, from Malaysia to Estonia.
The stability of personality traits increases with age, being relatively stable after 30 years
of age, especially from 50 to 70. All five factors show strong heritability, meaning that
people who are more closely related are more likely to share personality traits. For this
reason, you are likely to have some personality characteristics in common with your
biological parents, even if you are adopted and have never met them.

On the other hand, even identical twins have noticeably different personalities, so
some life events must help to determine how personality matures. It has proven
surprisingly difficult for researchers to determine which aspects of experience influence
how temperament unfolds into adult personality. Behavioral genetics studies consistently
find that the environmental influences shared among children in the same family have
little or no effect on their adult personalities. Indeed, identical twins reared together are
no more similar in their personalities than those reared apart. As you may recall from
chapter 2, though, these studies sweep up gene–environment interactions into the
“genetic” category, which creates some misperceptions. This is important when it comes to personality, where gene-environment interactions have important effects.

Although parents don’t like to admit it, individual children within the same family are raised in different ways, often linked to their temperaments (see box, Your kids have different environments). In addition, the same environment may have different effects on children with different genes. As researchers have started to look for examples of how gene–environment interactions influence personality development, they have found a variety of effects. Temperamentally anxious children develop more empathy in response to gentle childrearing techniques than do bolder children (see box, Practical tip: Promoting the development of conscience, in chapter 20). Children with a specific receptor that makes them prone to hyperactivity and impulsivity (including ADHD; see chapter 28) are more sensitive to parenting style. Eventually, parents may be able to personalize their interaction styles to produce a desired outcome based on the characteristics of an individual child, but researchers have a lot of work to do before that dream becomes reality.

The development of antisocial behavior is one well-studied example of a feedback loop that starts with child temperament, which affects parental behavior, which then further modifies the child’s behavior. Children who are irritable or prone to aggression are challenging to raise, making them less dandelion-like than most children. Both biological and adoptive parents often respond to the child’s frustrating behavior with harsh restrictions and punishments. Parents who have their own problems with aggression are more likely to produce children of this type—and also more likely to discipline them harshly. In addition, parents who are frustrated for other reasons, such as a troubled
marriage or job insecurity, are more likely to respond harshly to their children. This rough treatment in turn increases the child’s aggressive behavior until eventually it may become uncontrollable. Interventions that reduce parental harshness also reduce the risk of future aggressive behavior in the child.

Environmental events that influence child development are not restricted to the family. All children have a life outside the house, and many of their interactions with the world leave permanent traces behind. They spend much of their time with teachers and friends, taking part in sports or other activities. Children learn a lot from their peers. For example, children of immigrants typically speak with the accent of their friends, not their parents, and they learn to speak the language of their peers fluently even if their parents don’t speak it at all. Children’s attitudes and behaviors typically change over time to become more similar to those of their peer group, and this influence can be positive. For example, a low-achieving child who falls in with a group of high-achieving friends is likely to improve his schoolwork. Of course, children choose their friends, rather than being randomly assigned to peer groups (as some scientists might prefer), so much of the similarity between children and their friends results from the selection of friends who are already similar in attitudes and interests. In longitudinal studies, though, children do become more similar to their friends than they were when the friendship started.

Culture strongly influences how temperament develops into adult personality—another example of how brain development matches children’s behavior to their environment. Behavioral inhibition is accepted and encouraged by Chinese mothers, who interpret it as reflecting self-restraint and maturity. In contrast, Canadian mothers endeavor to draw out children who show behavioral inhibition, which in that culture is
believed to reflect fearfulness and lack of social skills. Accordingly, high-reactive children in China are more likely than those raised in Western cultures to grow up to be reserved, a trait that leads to social success—in China. But parents are only part of a child’s environment. In general, the response of a parent to her child’s temperament is more influential if it’s consistent with the beliefs of the culture they live in.

Perhaps personality development is too complicated to study in people, since scientists can’t control (or measure—or perhaps even identify) all of the influences that might matter over our long childhood. Indeed, the clearest evidence that parenting influences personality comes from animal studies. Rat mothers who lick and groom their babies a lot produce offspring that are less timid and more prone to exploration. This is true even if the rat pups are born to low-grooming mothers, but raised by high-grooming mothers, in the equivalent of human adoption studies. Similar studies show that high-reactive monkeys are more vulnerable than low-reactive ones to variations in the quality of mothering, and as we noted above, some evidence suggests that the same is true of children. (For more details on this research, see chapter 26.)

Even if parents cannot entirely control how their children turn out, parenting is still important. First and most important, your relationship with your children is its own reward. How you get along, both as they’re growing up and after they’re adults, depends on how well you care for them. Second, your children’s behavior at home depends a lot on your household rules and how you enforce them (see chapter 29). This can have a strong effect on the happiness of their (and your) home life. Third, you can teach your children a wide variety of skills that are useful in adulthood, from cooking to financial literacy to car repair. You can also give them opportunities to discover their passions.
Fourth, you can help your child learn strategies to live comfortably and productively with his or her individual temperament, especially if it’s one that you both share.

Think of parenting not as growing the person you want, but as a process of helping your child discover how to make his or her unique abilities and preferences fit well with the rest of the world. As we all know, dandelions thrive nearly everywhere.

**Did you know? Why you’re turning into your mother**

On average, when it comes to personality, children turn out much like their biological parents. One reason is that your genes affect your life experiences. Babies’ temperaments influence how other people interact with them—a lot. People tend to talk about kids who grow up in the same family as if they share the same environment, but there are many important differences, including the ways that each child relates to parents, siblings, and eventually peers.

From the moment a baby is born, parents react to his or her individual characteristics. Parents would find it impossible (and senseless) to speak to a willful toddler in the same way that they do to an amiable one. Similarly, a child who is sociable will get more practice at speaking and listening than one who’s most interested in playing with his train set in another room. These are among the many reasons why it makes no sense to talk about heredity and environment as separable factors in development.

As children grow, their innate differences in temperament and the resulting individual differences in experience often reinforce each others’ effects. Older children
can control their environments to a greater extent than younger children, for example by choosing to take gymnastics lessons versus reading books in their free time. Perhaps for this reason, individual differences tend to become more pronounced later in life—and most obvious of all in adults. Genetically related people share more personality traits in common in adulthood than they do in childhood. People’s increasing ability to choose environments that are well matched to their individual tendencies could explain why.

END BOX

BEGIN BOX

Myth: Birth order influences personality

First-born children are self-reliant, traditional and successful, while last-born children are easygoing, creative and rebellious. Right? Actually, no. Despite the bottles of ink that have been spilled defending this idea, siblings show no consistent personality differences based on their place in the family. Thousands of psychology papers have been published on this topic—most of them flawed.

One of the biggest flaws is a demographic one. Both small and large families contain firstborn children, while children born third, fourth, fifth and so on are, by definition, only found in larger families. Many studies failed to control for differences in socioeconomic status between small families—generally well off and educated—and
large families, which are typically poorer and less educated. So first-born children, on average, have advantages over later-born children, simply because a larger proportion of the first-borns come from a small family. Many studies that claim to show greater success in first-born children than in later-born children suffer from this conceptual error.

A second problem arises when researchers ask parents to rate their children’s personalities. Generally, these ratings do not agree with ratings by outside observers. Birth-order effects on personality are perceptible when people are evaluated in the context of their families, but almost non-existent in the outside world. Part of the difficulty is that parents are necessarily comparing an older child with a younger child, and age is one of the strongest predictors of maturity for any personality type. Parent-rated studies are more likely than those that evaluate personality in other ways to find that first-born children are more mature than later-born ones. Another concern with this approach is that people act differently within the family than they do outside it, as is clear to any adult who goes home for the holidays and feels instantly reduced to the age of twelve.

One way to weigh all these studies is to do a "meta-analysis" (see also p. TK), a statistical approach in which multiple studies are combined to ask whether a result is likely to reflect a true effect. In a meta-analysis that only included studies with controls for family size or socioeconomic status, the remaining effects were small and inconsistent. More than half the studies found no effects of birth order on personality at all. And those that did show a pattern were more likely to be small studies, with few subjects, where chance plays a bigger role. This is the opposite of what we would expect for a real effect. By chance, small studies are more likely to be flukes, while large studies
have more statistical power and are thus more reliable. The largest study of this topic, with over 7000 subjects, found no differences in personality between first- and second-born children in families of two children. Sorry, first-born readers, but there is little credible evidence that birth order influences personality.
Chapter 18

Emotions in the Driver’s Seat

All of us have experienced emotions that seemed overwhelming and out of control. Imagine feeling that way all the time, and you have a picture of your young child's daily experience. One reason that life with young children is such a wild ride is that the parts of the nervous system that produce raw emotions mature earlier than the brain regions that interpret and manage them. It’s probably just as well that your children won’t remember that stage of their life. If only we could provide the same service to parents when it’s one of those days.

Emotions organize our minds. As basic survival signals, emotions are present from birth, though they become increasingly more complex as children grow up. At the most fundamental level, emotions (unlike moods) are reactions to the environment that help you to rapidly distinguish between rewarding and threatening aspects of the world. Emotions also compel you to pay attention to salient events, define what you value in life, prepare your body for action, and communicate your internal states to other people.

Certain emotions are universal, occurring in all cultures that have been studied. The facial expressions that signify these so-called basic emotions (fear, joy, disgust, surprise, sadness, and interest) are also built in to human biology, so that you could understand whether someone was glad to see you or angry, even if the two of you shared no history, language, or cultural heritage.

Newborn babies can smile, but they do not begin to smile in response to external events, such as faces, voices, or bouncing, until they are three to eight weeks old. By
about three months, they smile more at familiar faces, and show interest and surprise. By four months, babies are adept at laughing, and their appreciation for visual games, like peek-a-boo or seeing funny faces, continues to climb throughout the first year.

 Signs of negative emotion are also present early in life. The earliest to appear are startle, disgust, and distress, which (as with smiling) may not be related to external events in the first two or three months. Anger and sadness show up in facial expressions at three months, usually provoked by pain or frustration. All these emotional expressions help to evoke care from parents and other adults.

 You may remember the first time your baby smiled back at you. His ability to recognize emotions in other people’s faces develops almost as early as his ability to show facial expressions. By two or three months of age, the occipitotemporal cortical region, which is specialized for face processing, is already activated more by faces than by other objects, though its tuning at this stage is considerably broader than it will be in adulthood. At seven months, infants stare longer at a fearful face than they do at a happy or a neutral face, and their frontal cortex shows an electrical response associated with salient stimuli.

 An almond-shaped nucleus beneath the temporal lobe of the cortex, called the amygdala, sits at the center of the brain’s network for processing emotions (see figure). It receives input from a wide range of brain regions, including information from all your senses. The amygdala’s outputs also go to many brain areas, which constitute two major systems. One, acting via the hypothalamus and brainstem, activates the autonomic nervous system to produce changes in heart rate, blood pressure, and breathing that prepare the body for fight or flight (see chapter 26). The other, via various regions of the cortex, controls the cognitive aspects of emotion, including interpretation, regulation,
conscious perception, and emotional reactions to memory and imagination. These connections are reciprocal, with both systems influencing the amygdala in return.

Because these connections are so widespread, emotions influence almost every system in the brain. Emotional signals can improve visual perception, and their fingerprints are all over decision making. Even something as simple as choosing between a blue shirt and a green shirt is difficult for patients with damage to the emotional regions of cortex.

The amygdala prioritizes speed over accuracy, so it sends out a lot of false alarms. For instance, if you are walking in the woods and see a curved stick on the ground, you might jump back quickly, fearing a snake, before you have time to realize your error. Such a response is encouraged by a hardwired legacy from our evolutionary history. Often identified with fear, the amygdala actually has a broader mandate: it assigns value to stimuli, priming your brain to react appropriately based on your previous experience with that situation, person, or object. These values can be positive as well as negative, but they’re not very sophisticated. If your visual system isn’t sure whether that dark spot is a spider or a piece of dirt, the amygdala assumes it’s a spider until the cortex corrects that impression.

Even as infants, children show a wide range of individual variability in their tendency to express positive and negative emotions, which is a component of temperament (see chapter 17). Some of these differences result from genetics: identical twin infants are more similar than fraternal twins in sociability, inhibition, distress in response to pain, and shyness. The heritability of negative emotionality is particularly high, perhaps reflecting an unusually reactive amygdala. As a result, some children find it
more difficult to learn to control their emotions than others do and may need extra help from you in reaching this goal. As we suggested in the last chapter, the effects of your parenting may also be exaggerated in children like this (see chapter 17 and chapter 26).

As the cortex develops, around the middle of the second year of life, children begin to display the secondary emotions: pride, shame, guilt, jealousy, and embarrassment. These social emotions become more situation-specific as children come to appreciate the importance of their own behavior in causing particular outcomes. For example, at six, children feel guilty whenever something goes wrong, but by nine, they understand that guilt is only appropriate when their actions were responsible for what happened.

As we pointed out in chapter 10, the neocortex actively interprets external experiences, for instance turning raw sensory information into a coherent sense of vision. As emotion-related cortical areas mature, they also gain the ability to shape how emotions are experienced. The anterior cingulate, insular, and orbitofrontal regions of cortex combine numerous brain signals to construct the conscious experience of emotion. The orbitofrontal cortex computes the value of stimuli, in a more flexible and context-dependent way than the amygdala, while the anterior insula represents your internal state, receiving signals from a wide range of brain areas about everything from thirst to cigarette craving to love. The ventromedial subregion of orbitofrontal cortex and the anterior cingulate cortex control your visceral responses, linking situations to their outcomes by giving you “a bad feeling” about something, though you may not be consciously aware of the reason.
The conscious perception of an emotional state is influenced by memories, by inferences about causality, by ideas about how to respond to the situation, and by the social context. For this reason, in addition to lacking control over their emotions, young children probably do not experience emotional states as richly as adults do until the cortex matures.

When babies first start to direct their own attention, by eight to ten months of age, they start to use distraction to manage their emotions, for instance by turning to a new activity when a toy is taken away. Indeed, infants who can direct their attention to one particular thing for long durations express more positive emotions as babies and show better self-control later in life. As children’s brains develop more self-control in general, their ability to regulate their emotions grows as well, as the same brain circuits are involved in all forms of self-control (see chapter 13). Children’s brains apparently have to work harder than adults when trying to inhibit an ongoing behavior. Older children gradually learn to use other strategies, such as reinterpreting the meaning of an event to manage their emotional reactions (“That teacher doesn’t hate me; she’s just impatient because she was annoyed by Justin’s misbehavior.”). As they get better at managing their emotions, children also improve their ability to hide emotions, allowing them to smile at grandma for giving them a sweater—no matter what it looks like.

Until their own regulatory capacity is fully developed, your children rely on you to moderate their emotions, by soothing or distracting them, and to help them learn how it’s done. Parents who are more sensitive to their infant’s needs and respond quickly to emotional cues tend to raise children who are better at regulating their own emotions. Maternal warmth and the strength of the bond between mother and child (see chapter 20)
are also correlated with children’s self-control ability. In other words, a good relationship with Mom may be a long-term source of willpower. Finally, parents who explicitly coach their children on the experience of emotions, by labeling and validating feelings and suggesting constructive ways to deal with them, tend to have children who are better at regulating their emotions later in life. Since children with poor self-control ability are prone to aggression and are at risk of developing conduct disorders and ADHD (see chapter 28), helping them self-regulate can do them a great service.

The prefrontal cortex is very slow to mature, developing last in the back-to-front progression of the neocortex (see chapter 9), but its capacities are worth waiting for. During the first two years, its neurons increase their complexity and add many synapses. After that, this part of cortex enters the stage of experience-dependent synapse elimination (see chapter 5). Its connections do not become completely adultlike until late adolescence, and long-distance connections through white matter develop even more slowly. So your child’s ability to regulate his emotions and to recognize and respond appropriately to the emotions of others continues to improve throughout childhood. That promise should give parents something to look forward to on those days when life with a toddler is just plain exhausting.

BEGIN BOX

Myth: The right hemisphere is the emotional side of the brain
You’ve probably heard people talk about being “left brained” when they mean logical and “right brained” when they mean emotional. This hypothesis was formulated several decades ago, before the invention of functional brain imaging. It is true that the emotional content of speech (its tone or prosody) is processed by language areas on the right side of the brain, but in general emotions are equally effective in activating regions on both sides of the brain. And the two halves of the brain are so heavily interconnected that it makes no sense to claim that an entire half of the brain is somehow left out of the mix.

The basic principle is not that the left/right brain is emotional/rational, but that specific functions become localized. Evolution has selected for brains that use the least “wiring,” which is to say axons. This means that related functions often sit near one another in the brain. In many cases, different aspects of a function get collected in one particular brain area, which can be on the left or on the right. This pattern is especially noticeable in big-brained apes like us.

For emotions, there may be an interesting division of function between the right and left lateral prefrontal cortex. Many patients who have damage to this region on the left side of the brain become depressed, while patients whose damage is on the right side may become inappropriately cheerful or manic (though this finding is not completely consistent across studies.) These outcomes suggest that the left lateral prefrontal cortex may be specialized for positive emotions and the right for negative emotions. A related version of this idea holds that the left side carries signals for approach behavior, and the right side for avoidance behavior. The only practical difference between the two ideas is the characterization of anger, a negative emotion that makes you want to approach the person causing it (in order to punch his lights out).
Brain activity recorded via electrical signals from the scalp supports this hypothesis. The difference between hemispheres shows up very early in development. Some researchers have suggested that the balance between the right and left prefrontal cortex may be the source of temperamental differences in emotionality, determining whether a particular child has a stronger tendency to respond to the world by approaching or withdrawing.

**Did you know? Self-control is a key ingredient of empathy**

Babies often cry when they hear another baby crying, in the contagious form of empathy (see chapter 19). True empathy, the ability to appreciate other people’s feelings, develops between the ages of two and five. Children show great gains in self-control during that same period, and individual children who have better self-control also show more empathy and a more developed conscience. Similarly, children who are better at inhibiting an automatic behavioral response (for example, by saying “day” when shown a picture of the moon, instead of “night”) tend to have a more sophisticated theory of mind, the ability to imagine what other people are thinking and feeling, even when age, intelligence, and working memory are taken into account.
What’s the connection? To develop empathy, children need to have a certain ability to entertain alternatives and hypothetical possibilities, which is part of self-control. The prefrontal and anterior cingulate regions of cortex are involved in both self-control and empathy, so cortical development may limit children’s ability to understand other people’s feelings and their ability to control themselves. As part of the brain’s attention regulation system, the anterior cingulate is active when children concentrate on their own behavior or on other people’s feelings. Such concentration may be a necessary first step in the development of both these important functions. The prefrontal cortex is important for behavioral inhibition, and it is active during theory-of-mind tasks, which require people to concentrate on what someone else could know.
The first time your child tries to pull the wool over your eyes, take a minute to appreciate it. Even though we want children to tell the truth, gaining the ability to lie convincingly is a notable step in mental development. To even attempt it means the child thinks she can manipulate an adult’s knowledge. It also means that she knows that others have thoughts, some of which contradict reality. Understanding that others can have false beliefs is part of normal development—and appears to be unique to people.

People are intensely social animals. We form alliances, jockey for position, comfort one another, and play games. When we’re not doing that, we talk about each other, speculating on one another’s motives. All these activities require a capacity to think about other people’s state of mind.

This ability, called theory of mind, involves several components that appear in stages. As early as three months, infants divide the world into objects and agents (see chapter 1). Their ability to identify agents, which act with purpose and goals, provides a foundation for understanding other minds.

Theory of mind can be sorted into two categories, which rely on different but overlapping brain systems. Over the first two years of life, children develop the capacity to understand other people's emotions, perceptions, and goals, becoming able to grasp that people have beliefs and react to the false beliefs of others. In the second phase, also lasting about two years, children gradually develop a system for thinking explicitly—and
talking—about the beliefs of others. By around age four, children possess a full-blown theory of mind.

The understanding of feelings can occur at different levels. The brain has a system for rapid processing of emotional stimuli, which reacts in a contagious manner to the feelings of others. This process involves the sensory neocortex, the thalamus, and the amygdala. With enough time, such processing can also involve the neocortex, including temporal and frontal areas, in a cognitive form of empathy.

Contrary to the wisdom of some folk psychology, many animals have the contagious form of empathy. Rhesus monkeys will refrain from pulling a chain that delivers an electrical shock to another monkey, even if they know that pulling the chain will bring them a large food reward. Rats can help each other as well. When confronted with a squealing, wriggling rat suspended in a sling, another rat will press a lever repeatedly to bring the suspended rat to the floor, staying close to it the whole time. So as originally suggested by Darwin, empathy in its most basic form, the desire to assist members of one’s own species, is widespread among mammals.

Apes, which have a larger neocortex than rats or monkeys, are capable of more cognitive acts of empathy. For example, chimpanzees are seen to comfort sick and injured birds, gently straightening their wings to aid their attempts to fly. (Showing a lack of foresight, they sometimes then toss the birds from high places.) They are also reported to help unfamiliar people in distress.

As the neocortex develops over the first two years of life, children rapidly make the transition from rat/monkey-like empathy to ape-like empathy. As many parents know, the presence of one crying baby in a nursery often starts the others crying. As children
grow older, empathetic responses become more complex. Children imitate the distress behaviors of other children, as if trying them on to see how they feel. They soon shift away from feeling personal distress and start showing helping behaviors. In the second year of life, toddlers comfort younger siblings in distress by patting, hugging, or kissing them. Similarly, they may bring a security blanket to an adult in pain.

How does the baby's brain generate contagious empathy? Many scientists believe that recognizing emotions in others involves experiencing the emotion yourself. Indeed, scans of brain activity in adults show that the insula is activated when they experience feelings of disgust—and when they look at disgusted faces (see box, Mirror neurons and imitation). Similarly, the amygdala is activated when we look at frightened faces and also when we feel fear ourselves.

By internalizing the emotions of others, children develop a sense that others have desires. This appreciation is clearly visible at twelve months: if a baby sees someone look at an object with positive emotion, she expects him to reach for it—and looks for a longer time if he does not. (This measure of violated expectations, spontaneous looking when something unexpected happens, is one of the ways to measure infant abilities. For more on this, see chapter 1.) Between fourteen and eighteen months, babies acquire the capacity to understand that when a grown-up has indicated a preference for a food, the baby should give it to him—even if the baby doesn’t like that food himself. Children also begin to have some sense of what others feel about them, as shown in the development of self-conscious emotions such as embarrassment during the second year (see chapter 18).

In parallel with these social emotions, babies between the ages of thirteen and twenty-five months also begin to develop a framework for understanding when adults
have a belief that is not true. In one study, twenty-five month olds saw a bear puppet
stowing a toy inside one of two boxes for an observer to retrieve. Then, after hiding the
toy again, the bear switched the toys while the observer was looking the other way. When
she turned back, the children looked at the original box, as if expecting the observer to
look in the wrong location. In other tests, young children also look longer when agents
act as if they know something that they are not supposed to know, such as the location of
a tasty snack that has been covertly moved.

This level of sophistication is unique to people, but chimpanzees come close.
They understand the goals and intentions of others, for instance reaching for food that
another chimp cannot see instead of food that is visible to both. But researchers have not
yet found a way to get chimps to act on the wrong belief of another chimp or human.

Preschoolers have one more hurdle in their development of theory of mind: they
have to learn to verbalize their awareness of another person’s false belief. This ability
arises well after children begin to talk. In one classic test of theory of mind, a child is told
a story of two girls named Sally and Anne. Sally has a basket with a lid and Anne has a
box. While they are together, Sally puts a marble in her basket. Sally leaves, and while
she is away Anne moves the marble to the box. When Sally comes back, where will she
look for her marble? Most preschoolers will indicate Anne’s box, where the marble really
is. Only around the age of four will children start indicating the basket, where Sally is
likely to wrongly think her marble still is.

For many years, on the strength of evidence like this, it was believed that children
under four lacked the ability to attribute false beliefs to other people—and therefore
didn’t have a theory of mind. The prolonged-looking test allows researchers to see that
children can detect a false belief much earlier. In other words, the ability to think about others’ beliefs is implicit by age two, but only becomes explicit by age four or five.

If two year olds are able to react to adults acting upon knowledge they are not supposed to have, why can’t they explicitly represent this knowledge? Several possibilities come to mind. First, the children might have difficulty inhibiting an automatic response to the actual location of the item. The ability to consistently overcome automatic responses arises around the age of three or four (see chapter 13). Another possibility is that even though the knowledge is there, other brain systems for converting ideas to language need to be in place before a child can learn to talk about beliefs.

The ability to think about the thoughts and beliefs of others probably grows from earlier, more basic capacities. Activity measurements from the brains of adults provide an indication of where those earlier capacities might be localized. Parts of the neocortex near the posterior superior temporal sulcus are activated when people detect an agent, and the temporal poles of neocortex are active when social knowledge is generated. The inferior parietal lobule is activated by visual motion or the direction of another person’s gaze, which conveys information about that person’s intention.

A key component of theory of mind in the brain is the **medial prefrontal cortex**. This region is active when people are asked to distinguish someone’s mental representation from a real-world physical state. The medial prefrontal cortex is also activated during humor, embarrassment, and other moral emotions. This region develops relatively late, as does long-distance communication between frontal and temporal regions, perhaps accounting for why these capacities only come together starting around age four.

**Comment [SA28]:** This includes both ventromedial and dorsomedial PFC, so we don’t have a good illustration of it. Best to omit the figure reference, I think.
Around age two, children start to play simple pretend games. A year later, they show a more elaborate understanding, doing things like putting on a raincoat and boots in sunny weather, then pretending to splash in puddles. Developmental psychologist Alison Gopnik calls these “silly mental states”—a third state of mind, separate from knowledge of the world and absolute ignorance. Silliness is pretense chosen on purpose, just for fun. Children exercise this sense when they watch a puppet show and shout at the hero or heroine to watch out, or when their parents pretend not to know something. The ability to reach this state—and perhaps see it in playmates—may be a stepping-stone to a full-blown theory of mind.

Children at this age can remember what they were pretending before and have conversations with themselves in the present. Strangely, though, they cannot remember their previous mental states. For instance, if you give a hungry child his lunch, by the time he is done he is unable to recall that before eating, he was hungry. Likewise, if you play a game with a pencil box in which you surprise the child with crayons instead of pencils, once he has seen the crayons he cannot recall once thinking that there were pencils in the box. Adults also can have difficulty remembering their past mental states, such as whether they liked a rollercoaster while they were on it. Perhaps you know one or two people who are like this.

Thinking about one’s past or future self and thinking about other people are closely related. Both capacities involve self-projection—the ability to think about mental states that are not currently your own and to shift perspectives in general. These capacities require the most frontal parts of the brain, which are the latest to develop.
Frontal brain development has additional profound consequences. Children begin to see events from multiple points of view. Also, we learn to understand ourselves at least in part by observing others and their reactions to us. Finally, the ability to ascribe feelings and intentions to others is an essential component of mature religious beliefs, which depend on faith in unseen motives. Although fibbing is socially and often practically undesirable, it also represents the opening of new vistas for your child’s mind.

BEGIN BOX

**Did you know? Older siblings speed a child’s theory of mind development**

The ability to reason about the beliefs of others depends on brain maturation, but it is also influenced by experience. The more often a parent talks to a child about motivations and mental states, the sooner the child begins to demonstrate an explicit ability to speak in terms of the beliefs of others. An even stronger influence is growing up with older siblings. Having an older (but not younger) sibling speeds the onset of theory-of-mind capacity in three- to five-year-old children. The size of the difference is equivalent to four to six months of advance per older sibling, for up to three siblings. By age six, nearly all children have acquired the same level of understanding, but there may be lasting social advantages to developing this capability earlier (see chapter 20). So in the preschool years, living with older siblings can help a child’s mind mature faster.

END BOX
Did you know? Mirror neurons and imitation

Sam once stuck out his tongue, with the sides curled up, at his baby daughter, and she was able to mimic him perfectly on her first try. This was quite a surprise. Such a complex act of imitation meant that she was able to generate a strange new facial expression simply based on seeing the movement—a complex mapping of a visual stimulus to a coordinated set of corresponding tongue muscle movements. Of course, you might be less of a geek than Sam and just like the sight of your baby sticking her tongue out.

How can this imitation happen? Across many brain regions, direct experience activates some of the same neurons as vicarious experience. This may reflect a basic principle of how the brain learns through imitation, starting in infancy.

Giacomo Rizzolatti and his collaborators made a discovery while recording from neurons in the premotor cortex, a frontal brain region, which are active when a monkey makes a specific movement, such as grasping a piece of fruit to bring it to the mouth. They found that particular neurons, which they called mirror neurons, fired both when the animal performed such a movement and when the animal saw the same movement performed by someone else. Mirror neurons for specific actions are also found in the brains of people undergoing exploratory neurosurgery.
Emotion-related brain areas show similar properties. Both strong negative emotions and the sight of a face expressing the same emotion trigger activity in the insula, a cortical region that communicates with other emotion-processing regions such as the amygdala. The insula also receives information from premotor cortex, suggesting that mirror neurons could convey the emotional content of body language. Information goes in both directions between these brain regions, so they could even teach one another about emotions and their physical expressions. In normal ten-year-old children, brain regions that contain mirror neurons are more active in individuals with higher scores on a test of empathy, supporting this idea.

Mirror neurons are just one example of how single neurons can represent surprisingly abstract concepts. The inferior temporal cortex contains neurons that fire selectively in response to faces, body parts, other objects, the memory of recent objects, and even a person’s identity. Researchers have recorded a single human neuron that responds both to an image of actress Halle Berry and to the letters of her name. Recognizing a celebrity may not have the same social importance as learning empathy for other people, but the abilities of the neurons are just as amazing.
Chapter 20

Playing Nicely with Others

Those moments when you feel in sync with your baby, as you trade gestures, facial expressions, words, or just silly noises back and forth, are crucial for early brain development. To you, it’s a fun game of peek-a-boo. To your baby, it’s an education in self-control, as well as his first experience of relationships.

A sensitive adult can regulate the baby’s arousal level, which young infants can’t do for themselves, by responding to cues (such as turning toward the partner) that indicate when the baby wants more interaction, and to other cues that indicate the interaction has reached its best intensity (smiling) or that the baby is overstimulated (looking away). Even sensitive parents frequently misinterpret their baby’s cues, so that the baby gets a mixed experience of synchrony and missed connections. This seems to be optimal for development.

Babies reach out for this type of interaction thousands of times a day. Young babies become quite upset if their partner briefly stops responding by freezing in place. When this happens, the baby’s heart rate and stress hormone levels both increase. A lack of response is more upsetting to infants than physical separation from the mother or having her turn away to talk to someone else. Even after the partner starts responding again, babies are fussier and less responsive to interaction for a while. After six months, they slowly become better at coping with unreliable responses from their partners and more able to regulate their own arousal.
Problems affecting either parent or infant can interfere with the development of synchronous behavior. Depressed mothers respond more slowly to their babies, are less sensitive to their cues, and show less affection than nondepressed mothers. Their babies are less responsive to faces and voices and show less distress when their partner stops responding to them than the babies of nondepressed mothers. Premature babies’ brains are not mature enough to support normal synchronous interactions, so they are more irritable, signal less clearly, and have more trouble tolerating mismatched interactions. These deficits are likely to be important because better synchrony in infancy predicts more secure attachment at one year of age, better self-control at two through six, and more empathy at thirteen.

Infants do not attach to their parents until about six months of age. This may seem curious, since parents begin to form attachments much earlier, within a few weeks after birth. But it makes sense from an evolutionary perspective: babies are safer if they are around a protective adult. Young babies pretty much stay where you put them, so at first it’s more important for the parent to attach. Attachment on the part of the baby serves a protective function only after they can move on their own. Before this age, it appears that the frontal cortex is not yet mature enough to allow the baby to form attachments.

Most babies form attachments to more than one person, though the strongest attachment is usually to the mother. Synchronous interactions contribute to the development of attachment, which is just what it sounds like: a strong and persistent desire to be close to a familiar caregiver, especially when the child is stressed or upset. All babies with normal brains and consistent caregivers form attachments, but the quality of that attachment varies quite a bit. Babies who are securely attached (over half of the
population) use their mother as a base for exploration, periodically keeping in touch with her as they play, are mildly distressed when she leaves, and are comforted when she returns. Babies with the insecure–ambivalent pattern (under a quarter of the population) stay close to their mother when she is present, are extremely distressed when she leaves, and are alternately clingy and angry when she returns. Babies with the insecure–avoidant pattern (about a fifth of the population) show little apparent distress when the mother leaves and refuse to engage with her when she returns. A rare fourth category, disorganized attachment, is characterized by inconsistent behavior and occurs mainly in babies who have been abused or neglected. Babies may show different attachment styles with different caregivers, but by age five children typically use a single dominant style, which is moderately stable for the rest of their childhood.

By nine months, as babies develop the ability to direct their attention, they become better at initiating synchronous interactions, and they start to experience stranger anxiety, becoming uncomfortable around unfamiliar people. Babies also begin to draw their partner’s attention to objects in several ways: by smiling at the object and then smiling at the person, or by pointing at the object, or by looking alternately at the object and the person. This behavior is more common among infants who respond, when their mother stops interacting, by smiling and making other attempts to engage her socially. Initiating joint attention to an object is one of the earliest indications of social skills, and babies who do a lot of it at nine or ten months are more likely to be rated as socially competent at thirty months.

The outcome of these early social interactions cannot be pinned on either inborn tendencies or parenting style alone. Because social interactions are reciprocal, your baby
influences your behavior as much as you influence hers, making it difficult for researchers to sort out the causes of particular interaction patterns. Babies who respond positively to care are likely to receive more attention than babies who are less happy or are difficult to comfort, probably because their parents find taking care of happy babies more rewarding. For this reason, many parent–infant interactions are self-reinforcing, either positively or negatively. For instance, infants who cry more at six months end up with mothers who respond less at twelve months, but mothers who respond more to their infants at six months end up with infants who cry less at twelve months.

We know that synchronous interactions are important to attachment formation because interventions to improve maternal sensitivity increase the probability of secure attachment. Several other factors also contribute importantly to attachment formation, including physical contact, socioeconomic status (see chapter 30), and temperament. Babies are more likely to form secure attachments if poor mothers use a harness to strap the baby to their bodies than if they use a car seat to hold the infant.

Notably, for most children, going to daycare does not interfere with secure attachment. A longitudinal study in Sweden found only positive effects of daycare, though a similar U.S. study found that children with insensitive mothers were more likely to form insecure attachments if they also went to daycare before one year of age.

Several long-term studies have found that secure attachment in early childhood predicts social competence and better social outcomes in later childhood, particularly in children with a shy or inhibited temperament. For example, attachment security predicts self-control much more strongly in children with the short allele of the 5-HTT serotonin receptor (see chapter 26) than in children with the long allele. The effects of attachment
security on later life are small to moderate, so other factors contribute importantly to socialization as well.

Social competence is built on a foundation of basic skills, including self-control (see chapter 13), emotional maturity (see chapter 18), and theory of mind (see chapter 19). All four abilities develop along a similar time course and tend to track together within individuals as well, though with some variability. The similarities probably occur because these abilities are limited by maturation of some of the same brain regions, particularly the anterior cingulate and prefrontal cortex, the latest-developing part of the brain. Social cognition also involves many other regions of cortex, including the posterior superior temporal sulcus, the temporo-parietal junction, and the anterior insula, as well as the amygdala.

As children grow older, they socialize outside the family more and more. At all ages, children are most likely to choose friends whose characteristics are similar to their own. The earliest peer relationships in toddlers are one-on-one interactions characterized by turn-taking and mutual imitation, an early form of cooperation, and by frequent conflict, usually over toys. Group interactions are not well developed at this age. Older preschoolers increasingly participate in imaginative play and games with rules, both of which require the prefrontal cortex. Helping and sharing become more common during the preschool years, and aggression declines after age three. At this age, conflicts are more likely to involve ideas and opinions than struggles over things, and language become progressively more important to social relationships. Social competence is already associated with social success at this age, probably through a feedback loop in
which better socialized children make more friends, which allows them to improve their social skills still more.

Successful socialization involves both formation of individual friendships and acceptance into peer groups. Friendships are the major source of affection, while group interactions are the main source of power and status. These two forms of socialization are both associated with good psychological health across cultures, though different societies may emphasize one aspect more than the other.

Once children enter school, their peer interactions become more frequent and less closely supervised by adults. In this age range, verbal aggression (threats, gossip, and insults) largely replaces physical aggression, and positive interactions also increase. Hostility begins to be expressed as persistent dislike of a particular person, rather than being restricted to a situation. The frequency of rough-and-tumble play peaks during the early school years. Competitive interactions via formal or informal games become more common. Children’s concepts of friendship become more sophisticated, moving from shared activities in preschool to shared values, self-disclosure, and loyalty by early adolescence. Social interaction between boys and girls drops off sharply around age seven (see chapter 8) and resumes again in early adolescence. Almost all children of this age are members of a group of three to nine children who rarely play with anyone outside the group.

As children near adolescence, their group memberships usually become more fluid, as they interact with a larger number of other people in a variety of contexts. At this age, attempting to figure out what other people think and feel requires more prefrontal cortex activity than the same task in adulthood, as these parts of the brain continue to
develop until the late teens (see chapter 9). Romantic relationships start to appear by age twelve, and their duration and frequency increase through the teen years. The quality of earlier friendships, particularly those involving negative interactions, moderately predicts the quality of later romantic relationships.

Both the major components of social competence—sociability and behavioral appropriateness—are strongly influenced by the culture in which your child is raised. Within a given culture, certain children are more inclined to shyness than others, probably due to genetic biases, but identical twins raised in different cultures behave differently. Societies that encourage social interaction (such as the U.S. and Italy) produce children who tend to be less shy or inhibited than children whose societies value modesty and cautiousness (such as rural China and India). These differences can already be observed in toddlers. In the former countries, shyness (especially in boys) is met with disapproval or punishment from parents and rejection from peers, while in the latter countries parents and peers react to shyness with acceptance and approval. These differences mean that extroversion gives people an advantage in some societies but not in others. For example, in the U.S., shyness predicts lower educational and professional achievement, but in Sweden shyness has no such effect.

The value placed on behavioral appropriateness also varies across cultures. In traditional, agrarian societies made up of extended families, group harmony is considered very important, and children are mainly cooperative and compliant. Mothers in these cultures spend a lot of time in physical contact with their young children, expecting and receiving a high level of obedience. Older children, beginning as early as age five, are
assigned household tasks, and their responsibilities increase substantially as they get older, to as much as six to seven hours per day at age ten to twelve.

In urban and industrial societies, individual accomplishment and competition are more highly valued, and children are more likely to be defiant or aggressive. In general, displays of anger toward other people are more common in societies where parents respond to them by trying to coax the child into feeling better and less common where parents express disapproval of such behavior. Children also respond to their peers’ attitudes about aggression, which may increase children’s status in individualistic cultures but decrease it in group cultures.

Of course, not all peer relationships are positive. About a third of school-age children report having a relationship characterized by mutual dislike, which can have significant developmental effects. Children with such negative relationships are more likely to have problems, ranging from depression and withdrawal to aggression. They are also less likely to do well in school and more likely to experience a variety of difficulties with their peers, including being bullied, being unpopular, and having trouble forming friendships. Girls and boys are equally likely to have negative relationships, and these relationships are equally likely to be between children of the same sex or different sexes.

Social withdrawal in childhood may also lead to trouble. On average, behaviorally inhibited children show higher than normal activity in the right frontal cortex, the area associated with emotions that lead to withdrawal (see box, Myth: The right hemisphere is the emotional side of the brain, in chapter 18). Children who are reluctant to interact with other children miss opportunities to practice their social skills, so the condition is often self-perpetuating. In the U.S., for example, social withdrawal at age seven predicts
depression, loneliness, and negative self-image at fourteen. Shyness is equally prevalent in boys and girls, but the costs are higher for shy boys, who experience more stress and more peer rejection than shy girls, presumably because of different cultural expectations for male and female behavior. About a quarter of socially withdrawn children are targeted for bullying. (For comparison, about half of overly aggressive children are targeted.)

What can you do to help an inhibited child to avoid these problems? As we said earlier, warm and sensitive parenting with lots of physical contact promotes secure attachment, which predicts improved social competence for inhibited children. It’s not helpful to micromanage your child’s behavior; that can interfere with the development of social skills. But gentle encouragement to join groups of other children can be useful. Children who rarely express negative emotions like sadness and anxiety to their peers tend to be better accepted and less likely to be bullied, so improving emotional regulation might be one useful avenue to explore. Poor emotional regulation predicts poor social adjustment across the lifespan. Participation in organized sports or other extracurricular activities may be helpful, as talents valued by other children also promote peer acceptance. Early intervention is preferable because it is easier for children to catch up when their social skills haven’t yet gotten too far behind those of other children of the same age.

In all cases, building a connection with your children while respecting their individual temperaments provides a solid foundation for socialization and many other forms of learning. As with most aspects of child development, some factors that contribute to your child’s socialization are beyond your control, but there are ways that
you can help. Anyway, building a warm relationship with your child should be a worthwhile goal in itself.

BEGIN BOX

**Did you know? Stereotyping and group socialization**

The way that the brain produces a sense of group membership has a dark side. Social groups are defined not only by their members but also by the people who are outside the group. Especially in situations where groups are competitive, your brain easily attributes negative characteristics to the opposing group, the way that Duke basketball fans have a tendency to denigrate the University of North Carolina. This hostility isn’t restricted to the players, but is often worse among the fans, and may generalize to denunciation of the entire university, not just the basketball program.

As we discussed in chapter 1, your child’s brain is naturally inclined to put things and people into categories. Young children tend to use the most visible characteristic to sort out categories. For this reason, young children are sensitive to superficial group differences like race, whether or not they are explicitly pointed out. This sensitivity starts to emerge during the preschool years, when children begin to socialize in groups. A difference as meaningless as giving children shirts of different colors can create a feeling of membership that causes them to like children within their own group better than
children of the other group. Unless parents actively teach children not to attribute characteristics to people by race, they are likely to socialize preferentially with others of their own race. This pattern persists throughout the school years even among children who go to mixed-race schools and daycare facilities.

Practical tip: Promoting the development of conscience

The first stirrings of moral behavior in children come from the brain's emotional system, which remains an important contributor to our moral sense in adulthood. Some precursors of the moral sense are probably built into the brain—even young babies like agents who help others better than those who hinder (see chapter 1)—but parenting has clear effects on its development.

The earliest precursor of conscience is your child’s desire to please you, which tends to be stable across situations, whether you’re teaching her to count or asking her not to write on the walls. Before age two, children begin to show individual differences in their likelihood of feeling guilty when they’ve done something wrong, which is linked to their ability to follow rules when no one is watching. Receptiveness to parental guidance
predicts individual differences in conscience at later ages, including older children’s ability to reason about moral situations.

You might think that children would be more likely to obey strict parents, but this approach is actually more likely to produce a rebel. Parents who repeatedly assert their power interfere with the development of guilt and later conscience, producing children who blame external factors for their faults. The parents who receive the most obedience are the warm ones, whose children comply willingly with their parents’ wishes from a desire to make them happy. Mutually positive parent–child interactions are a strong predictor of later moral behavior, particularly in securely attached children.

Your child’s characteristics also influence the development of conscience. Children with strong self-control show more mature moral abilities than impulsive children of the same age. Children who are temperamentally fearful are prone to guilt, which leads to more compliant behavior, so for them warm and sensitive parenting is the most effective path to conscience, as the development of excessive guilt can lead to later anxiety disorders. For children who are less fearful, attachment security, which leads to an interest in pleasing the parent, is the best predictor of later conscience.

END BOX
PART SIX

YOUR CHILD’S BRAIN AT SCHOOL

Starting to Write the Life Story

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Chapter 21

Starting to Write the Life Story

Considering that young brains are so good at learning, it’s odd that children can’t remember what happens to them in the first few years of life. That memorable episode involving chocolate pudding, your fancy clothes, and your two-year-old? He won't remember it when he's ten. What's going on here?

The brain has many different types of learning, only one of which is dedicated to facts and events that we can consciously recall. Early experience makes a strong impression on brain function in many ways, as we discussed in chapters 1, 3, 4, and 5. In contrast, the type of memory used to remember events develops comparatively late, so the life story is not reliably recorded until age three or four.

All kinds of learning are driven by cellular mechanisms that alter neurons and the synapses that connect them. Children and adults undergo similar cellular changes during everyday experience, but they function somewhat differently in children. The properties of these learning mechanisms may explain why we never forget how to ride a bike and why taking breaks from study can aid learning.

Different forms of memory call upon different brain regions. In adults, the principal distinction in memory type is the difference between declarative and nondeclarative memory. Declarative memory is the recall of a fact or an episode from the past. Formation of declarative memories requires the hippocampus, a horn-shaped structure found on both sides of the brain (see figure, Chapter 14, page TK) that is also necessary for spatial navigation. Another key region for declarative memory is the
neocortex, especially its medial temporal regions. Declarative memory continues to improve throughout childhood.

It is possible to see glimmerings of hippocampus-dependent memory before age two. For example, your preschooler might be able to describe an episode that happened to her before she could speak. Even so, memory is difficult to probe in the very young because children cannot declare much until they have a good command of language. For this reason, compared with nonverbal measures, verbal measures of memory underestimate memory competence in children up to age six.

A better way to examine memory during this period is to observe spontaneous actions (see chapter 1) or to give children a task that does not require speaking. For example, in the laboratory, eighteen to twenty-four month olds can learn to navigate with the help of distinctively shaped objects as landmarks to remind them where to go. In real life, your child may complain if you take an unusual route to school or day care. These behaviors are evidence of memory for the locations in question.

The other major category of memory is nondeclarative, encompassing a wide range of nonverbal memories: learned associations, skills, and habits. One type of nondeclarative memory that is readily studied in infants is the formation of associations, for example, anticipating that Mom is about to leave the house when she puts on her coat. Associative learning is present from a very early age, though infants also forget associations relatively quickly (see box, Babies forget faster than older children). Associative learning can involve the amygdala for emotional responses or the cerebellum for other forms of sensory learning.
Another type of nondeclarative memory is *procedural learning*, the acquisition of habits and skills, such as learning to tie your shoes. Shortly after the first birthday, children can perform procedures in a sequence, such as making a rattle by putting a ball inside a container, putting the lid on, and shaking it. This procedural learning requires the striatum, a structure in the basal ganglia that is necessary for movement and initiating actions. Procedural skills are learned more robustly than declarative memories requiring the hippocampus. This is why you never forget how to ride a bike.

To learn the new, an infant must get used to the old. As described in chapter 1, infants are good at detecting new information in their environments. A necessary part of this capacity is the ability to identify objects as familiar. Infants less than one year old will look with interest at a new object revealed when a cloth is pulled away. With successive repetitions, they slowly lose interest and eventually stop orienting altogether, a process called *habituation*. After a waiting period of minutes, the baby recovers from habituation and looks with renewed interest. Some of this memory is longer lasting: if you start over again, it doesn’t take as long for the infant to habituate as it did the first time. Eventually the infant ignores the object entirely.

Habituation does not initially require long-term changes in the brain. It is present in nearly all animals, including sea slugs, fruit flies, and even some single-celled organisms. Habituation depends on short-term changes, such as the accumulation or depletion of intracellular chemical signals, which then inhibit neurons from firing or prevent synaptic terminals from releasing neurotransmitter.

Similar chemical signals are also triggered by novel experience. These signals can cause long-term changes in the structure and composition of neurons and synapses—the
nuts and bolts of learning. Most of these changes are unlikely to include the generation of new neurons. Nearly all neurons that the brain will ever contain are already present soon after birth (see chapter 3). After that, new neurons are produced only in the olfactory bulb, part of the hippocampus, and at a trickle in the neocortex. Also, because neurons have formed most of their axons and dendrites within the first few years of life, the possible locations where a neuron can form new synapses are also somewhat constrained.

Given these commitments, a major site for learning to occur is within existing neurons and at the synapses between them. Existing synapses can grow stronger or weaker, as neurotransmitter receptors are added or removed, or as the neurotransmitter chemical becomes more or less likely to be released at the connection when the presynaptic neuron fires. In response to external events or internal processes, information in the brain flows along paths of neurons that fire with characteristic patterns and sequences.

The process by which individual synapses become stronger is called long-term potentiation. It requires particular patterns of neuronal firing as well as signals such as dopamine, acetylcholine, and other long-distance neurotransmitters. When these conditions are met, a group of neurons firing together in sequence can trigger biochemical processes that strengthen the connections between all the neurons. Just as we described in chapter 4, cells that fire together, wire together.

Just as important in learning is the weakening of synapses. Synapse strength is reduced in a process called long-term depression when two connected neurons fire independently of one another, which can happen when the postsynaptic neuron is being driven by other neurons. Or, in a slogan often used to teach neuroscience students, “Out
of sync, lose your link.” In addition, as we saw in chapters 3 and 9, childhood is a period of ongoing synapse elimination, in which many synapses disappear entirely as a part of normal development—the refinement of your child's brain circuits. Synapse elimination is driven not only by activity but also by the availability of trophic factors, proteins that are necessary for the growth and maintenance of dendrites and axons.

The formation and breakage of synapses is another major site of information storage. In most of the brain, neurons form synapses with only a small fraction of their neighbors, so the growth and elimination of connections can establish entirely new pathways for information. This process is happening on a very large scale during childhood, when synapses are produced in large numbers, and then eliminated according to experience (see chapter TK for more). In addition, neurons can change how they respond to synaptic input, for instance by changing their electrical and chemical response properties. All of these processes require new proteins and cellular structures to be made and broken down.

You may know that Paris is the capital of France, but you are far less likely to recall where you were when you learned this fact—unless you learned it recently. In contrast, your child might be able to recall where he heard it. The conversion of short-term to long-term memory seems to involve physical transfer from one brain region to another. Initial storage of a fact requires the hippocampus and other brain structures nearby, in medial temporal parts of the neocortex. The hippocampus sends connections to the neocortex, and with time, factual information is reprocessed to join our storehouse of general knowledge. The relatively late development of synaptic connections in the
hippocampus may be the reason that children have poor declarative memory in their early years.

Synapses are modified not only when we encounter new information, but also later, as memories are reprocessed. Perhaps surprisingly, memories appear to be rewritten frequently. Unlike a computer’s memory, a biological memory is reinforced by recall. It is as if the ink on a printed page got darker when the page was read. This process is known as reconsolidation, in which a stable (consolidated) memory is re-strengthened. Changes can even happen offline when we are not actively thinking about the information, as memories are also strengthened during sleep (see chapter 7).

These changes in synapses and neurons participate not only in the learning of facts in school, but in all changes in the developing the brain. As it matures, your child’s brain undergoes transitions that go well beyond what we think of as learning. Socialization, the development of motor skills, and long-term changes in behavior and attention all rely on the fact that the brain is plastic, as inborn developmental programs and experience work together to shape your child’s brain.

BEGIN BOX

Practical tip: The best study habits for your child’s brain
Decades of research have identified study techniques that can vastly improve learning—but most teachers don’t practice them, and few parents know about them. Fortunately, these techniques aren’t complicated, and your child can use them at home.

Students often wait until the last minute, then make up for lost time in a marathon study session. This strategy flies in the face of one of the most reliable results in research on learning: the power of spaced study. The brain retains many kinds of information longer if there is time to process the learned information between training sessions. Two study sessions with time between them can result in twice as much learning as a single study session of the same total length. Spaced training works with students of all ages and ability levels, across a variety of topics and teaching procedures. In general, the longer the gap between study sessions (up to a year in some cases), the longer people will remember the material.

One possible reason why this approach works is that breaks allow time for newly acquired information to be consolidated (see main text). Memories are not written just once, but reinforced either during recall or even offline, for instance during sleep. Both declarative and procedural memory appear to be consolidated during sleep, so it’s important to make sure your child gets enough of it.

Because memories are reconsolidated when they are recalled, tests actually improve learning (and slow down subsequent forgetting) by compelling the student to actively recall the course material. Passive reading is much less effective for learning. Multiple-choice tests do not improve learning, while short-answer questions do. You can take advantage of this fact by quizzing your child at home during study time to improve her performance at school and by teaching your child to test herself as a study strategy.
A third way to improve your child’s learning is to mix it up. Children who see ten similar examples in a row learn considerably less than children who see ten different examples. This strategy works across domains, affecting the way we learn sports, art history, math, or any other subject. Varying the timing and location of study sessions also improves recall, probably because learning is contextual, so learning in multiple contexts gives your child’s brain a deeper connection to the material.

At first, your child may find these approaches discouraging because they often result in more errors during studying—but they will produce better test performance with no more effort than traditional study techniques. And good results will change their tune quickly.

**Did you know? Babies forget faster than older children**

For a long time, “infantile amnesia”—the near-absence of memories from before one’s third birthday—was interpreted to mean that infants only have a primitive capacity to form memories. But young children can recall things that happened earlier, suggesting that information is stored but gets lost on the way to adult life. One possibility is that the
brain is incapable of transferring memories into long-term storage in the neocortex. Recent evidence suggests that an alternative cause is instability of the initial memory.

As we described in chapter 1, infants can learn to form associations, as evidenced by their ability to learn to kick when their foot is attached by a ribbon to a mobile. When they get older, they outgrow this game, so that researchers have to come up with something more complex, such as pressing a lever to cause a miniature train to go around a track.

However, associative learning does not last long in infancy. At two months of age, babies remember for only a day. By three months, the duration increases to a week. After that remembering grows steadily, until at eighteen months, children can remember simple associations for three months. With time, babies also develop another form of memory, the ability to remember complex actions that they’ve observed and imitate them later. Six month olds can reproduce a facial or body movement after a day. At eighteen months, they can make a more complex movement, like dressing a teddy bear, after a delay of four weeks.

Infant remembrance can be boosted with timely reminders. A six-month-old baby’s performance on the miniature train task lasts only two weeks after a single day of training, but a single additional session with the train doubles the retention time. Four reminders spread over six months lead babies to remember the task for a full year. Reminders are effective even if the initial association appears to be forgotten. As memories fade, reminders that are similar but a little bit off can distort the original memory, as also happens in adulthood. These findings raise the interesting possibility that
appropriate reminders of an event that happened in early infancy could enable recollection of the event much later—perhaps even as an adult.
Chapter 22
Learning to Solve Problems

If your child believes that intelligence is a fixed characteristic, that belief will make her act less smart. Children who think a test measures their innate competence do not try as hard or perform as well as those who think that effort is the major determinant of success or failure. Because children who believe intelligence can’t be improved tend to see failure as a sign of low ability, they are likely to give up in shame when faced with a challenging task. In contrast, children who believe that hard work can improve their cognitive abilities often welcome difficult tasks and bounce back from failure, feeling that they have learned from the experience. For this reason, emphasizing the importance of intelligence to children may paradoxically reduce their chances of success.

Accordingly, interventions to change students’ views of intelligence can improve academic performance. In one longitudinal study, math test scores were static over two years in students who entered seventh grade believing that intelligence is fixed, while scores improved over time in their peers who believed that intelligence is influenced by experience.

The researchers then went to a different school and offered seventh graders an eight-week class (half an hour per week) on brain function and study skills. One group’s lessons included the idea that intelligence can be modified through practice, which leads to the formation of new connections in the brain. The other group got a lesson on memory. Later, the first group scored significantly higher on math tests than the second group, though the two groups had performed similarly before starting the class.
Parents can encourage their children to handle failure constructively by praising them for what they do rather than for what they are. Though telling a child that he is smart or artistic or athletic may seem like a good way to make him feel good about himself (see box, Myth: Praise builds self-esteem, which protects against many problems, in chapter 29), it also teaches him to view those characteristics as fixed traits. On the other hand, praising your child for effort or improvement, or for choosing a particular way to respond to a problem, communicates that his behavior and choices are what matter to you. Since he can control his behavior but not his traits, that message is more empowering. (It’s also great to communicate that you’re on his team no matter what, but there are better ways to do that, such as saying “I love you.”)

The question of how much circumstances can modify people’s intelligence remains controversial even among academics. This argument is ongoing partly because the development of intelligence has political implications for disadvantaged groups and partly because the issue is genuinely complicated. You may find the next section easier to follow if you first go back and read the box in chapter 10 (Practical tip: Outdoor play may reduce the risk of nearsightedness) to remind yourself of how a trait can be highly heritable and strongly affected by the environment at the same time.

**Learning Intelligence**

Let’s start by defining what we mean by intelligence. Individual people’s performance on any cognitive test is moderately predictive of their performance on any other cognitive test. These broad correlations between different cognitive skills reflect the existence of a general reasoning ability, often called g, which is measured (though not
perfectly) by IQ tests. Intelligence can be subdivided into knowledge (crystallized intelligence) and reasoning skills (fluid intelligence). Throughout this chapter, when we say “intelligence,” we refer to fluid intelligence. Intelligence measurements change over time during early childhood, but by adulthood, IQ is more stable than any other behavioral measure.

Higher-intelligence brains process information more efficiently, reacting more quickly to stimuli and requiring less activity to solve problems than less intelligent brains. Intelligence is closely related to working memory, the ability to hold information in your mind temporarily while you’re doing something with it. Working memory can be as simple as remembering how much salt a recipe requires while you reach into the cupboard, or it can be as complicated as keeping track of the steps in a multi-stage process while you’re also evaluating whether it’s working correctly. People with high intelligence are resistant to distraction: they are less likely to lose their place when they return to a task after temporarily turning their attention to something else.

During development, fluid reasoning ability first emerges at age two or three. It grows quickly until middle childhood and then more slowly until it reaches a plateau in mid-adolescence. After that, it declines very slowly through adult life, and then more quickly in old age. (In contrast, crystallized intelligence continues to increase through adulthood and remains stable in old age, except in cases of dementia.)

Intelligence predicts later academic and professional achievement, social mobility, and even physical health. Still, parents (and teachers, and everyone else) should keep in mind that intelligence accounts for a bit less than half of the variation among individuals on most cognitive tests. The remainder of the test variance is attributable to
mood, motivation, specific cognitive strengths and weaknesses, and experience with the particular test and with testing in general. Self-control too is important for later achievement; as we noted in chapter 13, the marshmallow test at age four predicts later SAT scores twice as well as IQ. Finally, life success depends not only on ability, but also on opportunity and effort.

Twin and adoption studies demonstrate conclusively that genes strongly influence individual differences in intelligence. Among middle-class populations, the heritability of intelligence increases substantially with age, from 30 percent in early childhood to 70–80 percent in late adolescence and adulthood. This change occurs partly because as children grow older, they become more able to choose environments that suit their personal characteristics. In particular, intelligent children tend to place themselves in intellectually stimulating circumstances if they can, which improves their cognitive development. This gene–environment interaction increases the apparent strength of genetic influences (see chapter 2).

It is important to note that this interplay of genes with environment is far weaker under conditions of deprivation (see chapter 30). If the environment is sufficiently impoverished, there is little or no correlation between genetic inheritance and intelligence. This probably happens because such environments offer children few opportunities to develop their genetic potential.

There are many uncertainties involved in measuring (or perhaps defining) intelligence early in life, before it has fully developed. One of the best early predictors of IQ is habituation in infancy, that is, how quickly a baby becomes bored with a new stimulus and looks away. This measure is not very reliable, as it predicts only 17 percent
of the variability in later intelligence and often produces different results when researchers retest the same child over time. Cognitive testing in babies and young children can distinguish mental retardation from normal intelligence, but cannot distinguish moderate differences in normal intelligence. The results of IQ tests get progressively more stable through childhood, becoming fairly reliable around age seven or eight and adultlike by age twelve. Young children’s brains are not finished enough to allow parents or teachers to determine who will turn out to be merely bright and who will be truly gifted.

Curiously, although researchers have identified about 300 genes associated with mental retardation, not a single specific gene has been definitively linked to normal variations in intelligence. One reason, of course, is that intelligence is influenced by many genes—which makes isolating them that much harder. For comparison, forty genes are known so far that contribute to height, but they explain a total of only 5 percent of variation among individuals; more than likely, many more height genes remain to be identified. The genetics of intelligence seems likely to be even more complicated.

Brain structure itself is heritable and is correlated with intelligence. This correlation becomes stronger with age, and both measures are influenced by similar genes. Overall brain size moderately predicts intelligence—though there are exceptions, most notably that men have larger brains than women but equal intelligence—as do the volumes (or cortical thickness) of various brain regions. In a longitudinal study of children, the pattern of developmental changes in cortical thickness predicted intelligence more strongly than did the adult configuration at age twenty (see chapter 9). Dendritic branching in neurons has also been correlated with intelligence in a few studies.
As you might imagine, intelligence is not located in a single brain region. Reasoning requires the transfer of information between brain regions, and so brain connectivity is important. Among the major bottlenecks are certain long-distance connections within the brain; intelligence is correlated with making these connections easily and effectively. One study found that links from a region of prefrontal cortex to the anterior cingulate and parietal cortex were stronger in more intelligent children and adolescents.

In adulthood, a network of frontal and parietal cortex regions seems to be most important for intelligence. In patients with brain damage, lesions in the left frontal and parietal cortex impair working memory, a key component of intelligence that allows you to remember things like where you are in a multi-step task. Damage to the left inferior frontal cortex impairs verbal comprehension, and right parietal damage impairs perceptual organization. An area called the rostrolateral prefrontal cortex seems to be activated specifically during tasks that require participants to integrate multiple mental representations, as you do when plotting your next move in a game of chess.

A handful of imaging studies suggest that children may use their brains differently from adults during abstract reasoning. Compared to adults, children ages six to thirteen recruit the rostrolateral prefrontal cortex for easier tasks. Children use this brain area to answer single-relationship questions like “What is the best match to a fish? (a) field, (b) water, (c) tree, (d) oatmeal,” while adults activate it only for two-relationship questions, such as verbal analogies (leaf is to tree as petal is to what?).

The role of the environment in the development of intelligence is also substantial, but it has proven more difficult to define. Heritability estimates are somewhat misleading
in this regard because their calculation assumes that the effects of genes and environment are independent of each other. As we discussed in chapter 2, that assumption is rarely reliable, and it seems unlikely to be correct in this case. In U.S. children living in poverty, for instance, the heritability of intelligence is close to zero. This statistic suggests that environmental disadvantages limit the development of intelligence in poor children, leaving their full genetic potential unrealized. Similarly, a meta-analysis shows that adopted children have higher IQs, on average, than their siblings who remained in the birth family, presumably because adoptive families with higher socioeconomic status provide an environment better suited to cognitive development (see chapter 30). These findings and others suggest that improving the environment may increase the apparent contribution of genetics to individual differences. Poverty probably does not provide the only environmental influence, though. James Flynn—a moral philosopher who turned to social science and statistical analysis to explore his ideas—first noted that average IQ scores were rising by three points per decade in many countries, and even faster in some countries like the Netherlands and Israel. For instance, in verbal and performance IQ, an average Dutch eighteen-year-old in 1982 scored twenty points higher than the average person of the same age in his parents’ generation in 1952. The same improvement was seen when these eighteen-year-olds were compared with their own fathers.

It might be tempting to say that this younger generation had evolved to be more intelligent than their parents, but evolution takes much longer than a few decades. These IQ increases over a single generation (known as the Flynn effect) must instead reflect some environmental change. Flynn points out that modern times have increasingly rewarded complex and abstract reasoning, and that this has been happening for over a
century. This change may be responsible for increasing IQ over time, both directly (by increasing your child’s reasoning ability) and indirectly (by increasing the reasoning ability of others in your child’s social group and thus making the social environment more complex). The change appears to be restricted to fluid intelligence, since capacities requiring less of it, such as vocabulary or arithmetic, have not shown comparable increases.

So, if changes to the world can make your kids more intelligent, shouldn’t we be able to control that as parents? Well, yes and no. Some experimental interventions can increase intelligence—in children and even in adults. But there’s a catch: the successful approaches all require a lot of hard work in exchange for a small increase in reasoning ability. There are good reasons for your child to devote months to learning to play a musical instrument, but a gain of three IQ points isn’t the first among them (see box, Practical tip: The benefits of music and drama lessons, in chapter 23). Similarly, in adults, extensive practice on a difficult working memory task leads to a four-point IQ gain. Researchers do not yet know whether such gains last after you stop training or whether they translate to improved professional or academic performance, or any other such desirable outcome. These studies are promising, but they are not yet ready for widespread application.

You have probably seen a variety of advertisements for products that claim to increase your child’s brainpower, but we are skeptical of their value. The marketing departments have gotten far out ahead of the data in claiming gains in brain function from programs that have not been tested adequately—or in most cases, at all. Some of these programs are actively detrimental to children’s development (see box, Practical tip: Baby
videos do more harm than good, in chapter 16). Even those that do no damage directly are displacing other activities that may benefit children more, such as free play (see box, Practical tip: Imaginary friends, real benefits, in chapter 13) or time spent outdoors.

In all, we suspect that unless your children enjoy such activities for other reasons, their time may be best spent discovering the pursuits that motivate them to achieve excellence for their own satisfaction. Childhood offers the chance to develop a variety of abilities that are important to a well balanced life. Once your child has found an activity that matches his interests and abilities, you may find that effort and opportunity take care of themselves.

BEGIN BOX

**Practical tip: Social rejection reduces IQ dramatically**

Because intelligence is so closely connected to working memory, a lot of events that distract you can make you temporarily less smart. In particular, unpleasant or awkward interactions with other people can greatly influence performance on tests of cognitive function.

In one study, college students in a randomly selected group were told that a personality test showed they were likely to end life alone, while a second group was given bad news of a different kind: they were told that the test showed they were likely to have many accidents later in life. The first group performed much worse on an IQ test or the analytical section of the Graduate Record Exam (GRE) immediately after the
prediction. They also had more trouble recalling information for a difficult reading comprehension task. The effects were large, corresponding to a 25 percent drop in IQ.

Social rejection did not affect performance on less-demanding tasks. The two groups showed no difference in their ability to memorize nonsense syllables or their ability to answer easy reading comprehension questions. Based on these results, the researchers suggested that the prediction of future social rejection impaired the ability to reason intelligently because it depleted participants’ capacity for self-control (see chapter 13), a finding that was later confirmed.

Parents concerned about academic achievement might do well to focus on building their children’s self-control ability and social skills (chapter 20). There is good evidence that these capabilities can be modified by experience, and they contribute not only to a happy and successful life but also to intellectual achievement.
You may have noticed that your child's attention span increases dramatically when he is focused on music. Whether it's singing a favorite tune or banging away on an instrument, there's something about music that can keep him focused for as long as half an hour, an eternity for a small child (and perhaps those listening to him).

Building on children’s natural affinity for music, parents often try to deepen this relationship through lessons. The goals are not just aesthetic, but practical: in coaxing their children to become more involved with music, parents often hope to improve their children’s minds. For this reason, when Sam was a child, his parents attempted to introduce him to the accordion, which thankfully did not stick, then to the violin, and finally to the piano, which did. Products like Brainy Baby purport to improve infants’ minds simply by exposing them to music at an early age.

Do these interventions does any real good? Based on research, the answer is mixed. Listening to music does not make children any smarter, but it does improve their moods, which leads to some secondary benefits. In contrast, there is some evidence for direct cognitive benefits from learning to play an instrument. In both cases, though, the research literature has to be taken with a rather large grain of salt (see box, Practical tip: The benefits of music and drama lessons).

The brain processes music starting early in life, but its capacities continue to develop through age nine. As we discussed in chapter 3, the brain develops from back to front, with brainstem maturing first, followed by midbrain structures, and finally the
neocortex. This general sequence is reflected in the order of development of a child’s capacities for recognizing music.

Music perception emerges not long after birth and becomes apparent during the first year of life. From the start, infants prefer higher-pitched singing to lower-pitched singing, as well as song that is specifically directed toward them or sung in a loving tone. By seven months of age, babies can perceive complex sounds such as a piano note, which combines multiple frequencies.

Infants even have innate ideas about what notes go together. One example is consonance, which occurs when one note occurs at a frequency that is at a simple multiple of another (e.g. frequency ratios of two to one, a perfect octave; or three to two, a major fifth). You'll find consonance in most songs, including simple children's songs like Twinkle, Twinkle Little Star. Dissonance occurs when you bang your fist on a piano, as well as in certain types of jazz and experimental music. Infants look longer towards the source of a note when it is followed by a consonant note than when it is followed by a dissonant note such as an augmented fourth (F-sharp compared with C, a ratio of 45 to 32)—blech! This preference is apparent as young as two months of age. Indeed, dissonance is such a turnoff that when it occurs at the beginning of the experiment, infants check out permanently and stop looking at the speakers.

Beyond consonance, infants are open to different tonal structures. Eight month olds are equally good at distinguishing changes in Western scales or Indonesian scales, which are quite different once one gets past basic octave-level consonance. This ability arises around the same time that infants develop the ability to distinguish vowels and consonants of their own language from other languages (chapter 6). Western adults and
older children, however, are much better with Western scales. Musical capacities are
another example of how the brain’s abilities and preferences are tuned to match the local
environment during development.

Babies absorb major features of music, like language, well before they can
produce it. One example is rhythm and meter. In Kindermusik, a method of early
childhood education in music and movement, infants are exposed to rhythm by activities
such as being bounced on the knee in time to a simple, repetitive beat. After two minutes
of bouncing to every other beat, the baby is more interested in new rhythms of that type,
as opposed to rhythms that emphasize every third beat in a waltzlike fashion. The same
effect happens in reverse if babies are bounced in a waltz rhythm.

In the preschool years, additional capacities develop. By age four, children show a
good ability to detect different intensity (i.e. loudness), followed by frequencies (i.e.
pitch), and finally tone duration. Intensity and frequency are processed in the earlier-
maturing lower auditory system, while duration requires later-maturing structures such as
the neocortex. This developmental process depends on experience. In deaf children who
receive cochlear implants, the process is delayed by the period of deprivation. The need
for learning may explain why young children have difficulty staying in tune or on
rhythm.

Around the same time, children develop an advanced aspect of music processing:
key and harmony. As early as three, children know whether notes are in key, can pick out
dissonant notes in a familiar song such as “Twinkle, Twinkle, Little Star,” and even
adjust their pitch to match another singer. At this age, children also can detect harmony
between notes played together, an ability that emerges clearly by age six. Key and
harmony preference are both refined by music training. Progress in these areas adds up to
general musical aptitude, which by age nine reaches a degree of maturity that remains the
same throughout life. By then, parents and teachers can get a sense of what kind of
musician a child could become. If by that age she’s got a tin ear...perhaps it’s time to
reconsider those flute lessons.

As you might expect, many brain structures that reflect musical aptitude have an
auditory function. The auditory cortex, which is found in the temporal lobe, below the
temporal–parietal sulcus, is a major site of music processing. The primary auditory cortex
is largely found in structures called Heschl’s gyrus and the planum temporale, whose size
stabilizes around age seven. The hemispheres seem to be specialized, with a note’s
fundamental frequency processed in the left hemisphere and its spectral pitch (the actual
frequencies contained in the note) in the right hemisphere.

In adults, the size of these structures is strongly related to musical ability—the
largest known structural variation connected with ability. Trained musicians, whether
professional or amateur, have over twice as much gray matter in anteromedial Heschl’s
gyrus compared with nonmusicians. This difference is larger than any other known
structural variation that is connected with ability. The additional gray matter is active,
too: when a tone is played to musicians, they produce characteristic brain signals, found
between fifteen and fifty milliseconds after the tone, that are considerably larger than in
nonmusicians. At fifty milliseconds, the signal is five times as large in musicians.

These distinctive characteristics suggest that it might be possible to predict
musical aptitude based on brain anatomy. To an extent, this is true: the gray matter
volume of anteromedial Heschl’s gyrus is related to musical aptitude with a correlation
coefficient (called $r$) of about 0.7. What this means is that under most circumstances if an adult has an above-average amount of gray matter, odds are about three to one that he or she is above average in musical aptitude.

Can practice alter the size of this brain structure? Does experience influence the size of this brain structure related to musical aptitude, can you change it with practice? Possibly, yes. A clue that such a change is possible can be found in the white matter, which contains long-distance connections between distant brain regions. The long-distance connections through the white matter are organized differently in professional musicians than in nonmusicians. If musical training starts earlier in childhood or involves more cumulative hours of practice, these differences are larger. So extended childhood practice seems to result in measurable changes along with the hard-won skills, though it remains possible that children who started with a larger Heschl’s gyrus were more likely to stick with music lessons.

More convincing evidence comes from a prospective study that followed two groups of children for fifteen months in which one group took weekly keyboard lessons, while the other group participated in a school music class involving singing while playing rhythm instruments. There were no differences in brain structure at the beginning of the study, when the children were six on average, but by the end, the keyboard group had larger volumes in the frontal gyrus and corpus callosum. There was also some increase in the size of Heschl’s gyrus, but it did not reach statistical significance. Longer follow-up may show a practice-based increase in this region as well.
The processing of melodies involves additional brain regions, including the temporal and frontal areas of neocortex. These regions are critical for tonal working memory, for instance holding a melody in one’s head.

Playing music calls into action yet more brain regions, as the musician must generate precisely timed sequences of motor activity. In brain scanning experiments, activity during sequence learning and production encompasses motor-related regions of the neocortex as well as the basal ganglia and the cerebellum of musicians. These brain structures are necessary for the initiation and guidance of movement.

The same brain regions, as well as parietal parts of neocortex, are activated when people listen to musical sequences. The cerebellum is active in both musicians and music listeners, which likely means it plays a role in both producing precise timing and processing purely auditory information. Even more brain regions are activated when people hear complex sequences and combinations of notes.

Such widespread recruitment of brain areas is not surprising if we think of the complexity of recalling a musical sequence. Try to remember the following numerical sequence: 1, 1, 3, 5, 8, 6, 6, 4, 5, 6, 5. Doable, certainly, but you’d have to rehearse it in your head many times to get it. But what if those numbers were translated into music notes, like this?

- INSERT FIGURE, 23 _ On Top Of Spaghetti.jpg -

Even a nonmusician can memorize this melody. Add rhythm and harmony, as you probably did without trying if you know the song, and the piece becomes even more
On top of spaghetti, all covered in cheese
complex. A powerful property of music is its capacity to call into action mechanisms for recalling and producing sequences with a rich structure. In this regard, students of music achieve levels of memorization, recall, and technique that are unattainable without music’s capacity to guide and organize brain activity. Music provides scaffolding for mental feats that are otherwise hard to attain.

BEGIN BOX

**Myth: The Mozart effect**

The belief that passive experience leads to brain improvements is widespread. One of the most persistent brain myths is that playing classical music to babies increases their intelligence. There’s no scientific evidence for this idea, but sellers of classical music for children encourage the belief every chance they get.

This myth began with a 1993 report in the scientific journal *Nature* that listening to a Mozart sonata immediately beforehand improved the performance of college students on a complex spatial reasoning task. The researchers summarized the effect as equivalent to an eight- to nine-point gain on the Stanford–Binet IQ scale. Journalists were not especially interested in this finding when it was first published.

The turning point in this idea’s popularity was the publication of *The Mozart Effect* by Don Campbell, an influential bestseller. A low point of the craze was reached when Georgia governor Zell Miller played Beethoven’s “Ode to Joy” to the legislature and successfully persuaded them to spend $105,000 to send classical music CDs to all
parents of newborns in the state. Almost two decades later, the idea that classical music makes babies smarter has been repeated countless times in newspapers, magazines, and books. It is familiar to people in dozens of countries. In the retelling, stories about the Mozart effect have progressively replaced college students with children or babies. Some journalists assume that the work on college students applies to babies, but others are simply unaware of the original research.

Since 1993, scientists have attempted to repeat the original experiment on college students, with mixed success. The closest that anyone has come to testing the idea on babies is that preschoolers do somewhat better on cognitive tests after hearing age-appropriate children’s songs. Even then, like the college students listening to Mozart, the effect is short-lived, not long-lasting, and probably attributable to improvements in their mood.

Practical tip: The benefits of music and drama lessons

Playing classical music for your kids isn’t likely to help their brain development. But what about having them play music for you?
Music lessons make children better—at music-related capacities. These improvements can begin as early as age three and continue as children advance musically. A more common question, though, is whether music training makes a child smarter. Psychology journals are filled with studies showing that music lessons predict visual, motor, attention, and mathematical skill. There is a problem, though: nearly all of these studies are correlative. Perhaps the musically experienced people who took these surveys were smarter to begin with. Statistically, they often come from advantaged families, as parents who fund music lessons tend to be well educated and financially secure.

Psychologist E. Glenn Schellenberg sought to eliminate this variable. He placed advertisements, recruiting families with six year olds for free art lessons. They were then split into four groups: standard keyboard lessons, age-appropriate vocal music lessons, drama lessons, or placement on a waiting list for one year (after which they received the promised lessons). The drama and lessons-deferred kids provided two control groups against which the other two groups could be compared. Music lessons were given at Toronto’s prestigious Royal Conservatory of Music.

The children were given IQ tests before lessons began and then tested again after thirty-six weeks. On average, the children receiving music lessons scored not quite three IQ points higher than the two control groups, which were similar to one another. The differences were spread over categories that included resistance to distractibility, processing speed, verbal comprehension, and mathematical computation. The effect size was modest, 0.3 (see figure in chapter 8): the average child receiving music lessons scored better on the IQ test than 62 percent of the control children.
Drama classes showed an unexpected, larger benefit: better social adaptation. Children who took drama lessons, which were given by teachers at the conservatory, showed marked improvement on a rating scale for adaptability and other social skills. The effect size was 0.57, so that the average child receiving drama lessons scored higher than 72 percent of children in the non-drama groups. Perhaps deliberate practice at inhabiting the character of another person served to improve the performance of brain areas involved in daily social interactions.

In general, practicing any activity is likely to have the strongest effect on the brain capacities that the activity directly requires. Although learning to play music has some benefits that span a variety of cognitive abilities, perhaps related to training of the brain’s attentional networks, it may be more sensible to think about the intrinsic benefits of playing music for its own sake.

Consider other rewards such as whether your child likes playing the instrument or will enjoy music more in adulthood. This benefit of musical training goes beyond the utilitarian. Musical training gives your child access to music at a deeper level and can contribute to a lifelong love of music.
As Barbie famously said, “Math class is tough!”—and not just for girls, but for everyone. Your child’s brain is optimized to provide rapid solutions to everyday problems. That means it is better suited to calculating whether it would be a good idea to punch the guy who just insulted him than to solving an algebraic equation. This social calculation does involve some numerical ability, as it’s important to determine whether he has more friends available than you do. Young babies and many other animals share a brain system that supports this sort of rough number sense. Under the right conditions, it can combine with our species’ ability to create and manipulate symbols to produce formal mathematics, found in some societies but not others. Indeed, math, a seemingly inhospitable place for dandelions to grow, is surprisingly fertile ground.

In the last few decades, our appreciation for babies’ ability to form number-related concepts has expanded tremendously. Infants express surprise by looking longer (see chapter 1) if one object goes behind a screen and two come out. If an infant sees a Mickey Mouse doll go behind a screen and then the screen lifts to show a truck, she doesn’t care. If she sees a Mickey emerge along with a second Mickey, now that’s a surprise, as evidenced by her long gaze. This ability to notice an extra object—the twoness of the Mickeys—is a necessary component of numerical concepts.

This ability goes beyond small numbers. When a six-month-old infant sees a series of pictures, each containing a number of objects—dots, faces, anything—he will notice if the number either doubles or decreases by half. This general sense of
“numerosity” gets better with age, too. While infants can recognize a 1:2 ratio (for instance comparing 4 and 8 objects, or comparing 6 and 12) without counting, adults can recognize a 7:8 ratio.

Numerosity detection, the ability to distinguish between groups of different sizes, is one ability that all humans have. Subitization is another universal capacity, and refers to the ability to immediately distinguish small numbers without counting, and comes from the Latin word for “sudden,” *subitus*. Both abilities are apparent in other animals—and they involve some of the same brain mechanisms as in people.

Subitization and numerosity are apparent in a wide variety of animals, including mice, dogs, and even pigeons. These abilities provide an obvious survival advantage: they allow us to estimate the quantity of something, from food sources to possible enemies. For instance, members of a pride of lions react differently to roaring sounds depending on how many lions they hear—and on how many members are in their own group. If they are outnumbered, they call to the rest of the pride for backup. Similarly, chimpanzees avoid conflict with other groups when they are outnumbered.

One reason that it took so long to understand young children’s number sense is that early researchers (such as Piaget) asked the wrong questions. If asked “which row has more objects?” children of three or four will point to a smaller number of clay pellets if that row is spaced out to look longer. Change the pellets to chocolate candies that they can have right away, though, and children do much better. In retrospect, it appears that this research tested for two things: a sense of number and the ability to express it in a clear way. Your three year old knows, but evidently she isn’t saying. Aside from her
mouth being too full of chocolate to talk, her awareness isn’t accessible to an interviewer’s questions.

Oddly, two-year-olds do fine with either pellets or candies. This result seems to imply that at that age, children have a clear sense of numerosity, but then they lose the abstract sense of it for about a year. What could be happening here? One possibility is that at three or four, children’s brains are in the midst of hooking up their intuitive understanding of quantity with an explicit, later-developing sense of abstract numbers. By five it’s all sorted out, at which point she simply counts the pellets—and perhaps wishes for candies instead.

Grabbing candy bits may seem somewhat primal, as indeed it is. Evidence suggests that chimpanzees can also combine quantities in a mental operation that resembles addition. If a chimpanzee is shown two trays in succession, each with a different number of chocolate bits, he can determine whether the combination of the two trays contains more or less than a third tray. The rudiments of arithmetic are therefore evolutionarily older than our species, and are basically one facet of your toddler’s inner ape.

These senses of number involve similar brain regions in people and chimpanzees. Numerical information seems to be represented in the prefrontal and posterior parietal lobes. One key location is the intraparietal sulcus, a buried groove in the brain where specific semantic number content is represented. When this brain region is damaged, people can give approximate but not exact answers—at about the level of a chimpanzee.

This retained ability for general numerosity has led scientists to suggest that our brains represent numbers in a way that relates to their relative magnitude, as a mental
number line. One piece of supporting evidence for this idea is that when we are asked to judge which of two numbers is larger, it takes longer to answer when the two numbers are close (8 versus 7) than when they are far (8 versus 2), as if the closer numbers are actually closer in mental space. Judging between closer numbers produces more activity in the intraparietal junction. You could imagine numbers being stored in some computerlike, digital fashion, where small differences are just as easy to detect as large differences, but instead, brains seem to use a more ordered representation, akin to marks on a ruler.

This sense of approximate number is represented in parts of the intraparietal sulcus (see Fig. TK [if we have a general picture of all the lobes of the brain]), a deep groove on the lateral surface of the parietal lobe on both the left and right side of the brain. In monkeys, there are neurons that fire when the animal encounters a particular number of objects—or an approximately similar quantity. In general, these brain regions are part of the same major pathway in the brain for identifying where things are, including how many things are there and where they are going.

The “where” capacity of parietal cortex (see chapter 10) seems to encompass a variety of functions. Posterior parietal cortex becomes active, in both monkeys and people, in conjunction with eye movements. The same regions become active when people do mental addition and subtraction problems, even though the eyes are not moving. Nearby parts of the brain with many shared connections to this region are intimately involved in visual functions, such as the abrupt eye movements called saccades, attention, and detecting which way a visual pattern is moving. Thus the way we look at space might be closely tied up with our mental number line. The pattern of
activity in posterior parietal cortex can even be used to predict with middling accuracy whether a person is adding or subtracting.

This seemingly odd overlap in the brain of eye movement commands and basic arithmetic suggests that some aspects of our brain’s ability to process abstraction are built upon our capacities for dealing with the physical world. Many cognitive abilities other than arithmetic seem to be “embodied” in a similar manner. In this way we are able to think abstractly with brains that evolved for more concrete actions such looking at prey or finding a path through a forest.

Converting these approximation abilities into the precise representations of formal mathematics requires symbolic representation. This capacity comes with language, which is an elaborate means of representing information efficiently. Parrots, dolphins, macaque monkeys, and chimpanzees can use symbols to represent numbers. For example, two macaques named Abel and Baker were able to pick the larger of two digits to get a larger number of candies. For the most part, animals cannot combine the symbols to add or subtract. One exception is a chimpanzee named Sheba: who after several years could perform some simple addition.

Even though people have the mental capacity for arithmetic and mathematics, we don’t always use it. Researchers Stanislas Dehaene and Pierre Pica investigated the Mundurukú, an Amazonian group that lacks arithmetic and has very few words for numbers. What words they do have are at first precise (pug ma = one, xep xep = two), but become increasingly approximate (ebapug = between three and five, ebadipdip = between three and seven). Mundurukú do approximate addition of large groups of objects very well, performing as accurately as Western, numerate adults. But exact calculation of
small numbers is beyond them: for instance, if six beans are placed in a jar and four are drawn out, when asked how many are left, they say zero or one more often than they say two.

Formal arithmetic ability is predicted by a child’s earlier capacity for approximate number. This suggests that individual children differ in their general ability to handle quantity even before they begin to count. Can this capacity be trained? One could imagine that children could be taught to do approximate number problems to improve their later acquisition of arithmetic skills. Although this idea has not been tested, it presents an intriguing possibility.

From the basic senses of number—subitization, numerosity, and symbolic representation—a host of more complex concepts can be constructed, such as negative, fractional, and real numbers. In addition, it becomes possible to imagine the universe of mathematics: multiplication, trigonometry, functions, calculus, and more.

The study of how the brain produces abstract mathematics has barely begun, but researchers have taken a few first steps. At higher levels of math, additional concepts come into play—and many brain regions. For example, algebra requires kids to combine their numerical abilities with symbolic, more abstract manipulation. Beginning students can come at algebra by different routes. For instance, it is often easier to solve a word problem than to solve an equation. These different approaches emphasize different brain regions.

To monitor what brain regions are activated by different approaches to solving a problem, researchers have taken functional magnetic resonance imaging (fMRI) scans of people doing story problems (If Cathy makes $10 an hour and gets $12 in tips at the end
of an four-hour shift, how much money has she earned in total?) and similar equation problems (if \(10H + 12 = E\) and \(H = 4\), what is \(E\)?). The scans showed that solving story problems preferentially activates left prefrontal cortex, an area associated with working memory and quantitative processing. Equation problems activate regions associated with the mental number line, such as parts of parietal cortex and the precuneus, as well as parts of the basal ganglia that are essential in nonalgebraic life for action and movement.

This difference suggests that beginners at algebra may may want to try several different approaches to the same problem. For harder problems, in addition to the cortical areas we have mentioned, many more regions in the left hemisphere are activated. Higher math such as trigonometry or calculus has not been investigated thoroughly, but it is believed that these capacities also build upon brain systems for symbolic and spatial manipulation.

At some level, this supports Euclid’s aphorism about geometry that “there is no royal road to learning.” Mathematics is an incredibly complex system, one of humanity’s great achievements, and it’s remarkable to think that brain systems for telling stories and moving the eyes have been harnessed to generate, understand, and use it. It’s a feat of matching the brain to an environment that our ancestors never imagined.

BEGIN BOX

**Practical tip: How stereotypes influence test performance**
People’s performance changes a lot if they’re reminded of a stereotype just before an exam—even by checking a box for male or female. Any relevant negative stereotype, such as those related to gender, race, age, and socioeconomic status, can impair performance, especially when people believe that the test is designed to reveal differences between groups. Stereotypes can be activated even if test takers are not aware of the reminder, for instance when African-American faces are briefly flashed on a computer screen. Even more curiously, these effects can occur in people who are not members of the stereotyped group: young people walk more slowly after hearing stereotypes about the elderly. This appears to happen because thinking about the stereotype takes up working memory resources that would otherwise be used for the test.

A little effort can minimize this problem. Obviously, teachers shouldn’t expect certain students to perform more poorly than others. Standardized tests should collect demographic information at the end of the answer sheet, not at the beginning. The effect also works in reverse: exposure to material that contradicts the stereotype improves performance, as in girls who hear a lecture on famous female mathematicians before a math test.

Most people belong to more than one group, so perhaps the most practical approach is to bring a more positive stereotype to the task. For example, a mental rotation task shows consistent sex differences, with men performing faster and more accurately than women. When college students were reminded of their gender before this test, women got only 64 percent as many correct answers as men. In contrast, when they were reminded that they were students at a private college, the women got 86 percent as many
correct answers as men. The men did better when reminded of their gender, while the women did better when reminded that they were elite students. Thus the gap between men’s and women’s scores was only a third as large when women were reminded of a positive stereotype that fit them as opposed to a negative stereotype. The remaining difference is likely to be a real sex difference: a single shot of testosterone temporarily improves women’s performance on this test.

Stereotyping is a strong brain tendency, and it is unlikely to disappear anytime soon (see box, Stereotyping and group socialization, in chapter 20). Instead, we recommend taking advantage of these sorts of brain shortcuts by reminding your children of a stereotype that will improve their performance.
The Many Roads to Reading

The human brain took its present form before the first word was ever written. In the 5000 years since the alphabet was created, our brains haven’t changed that much. So reading (like advanced math) must use circuitry that originally evolved to fulfill other functions. Brain-scanning studies have started to reveal how the systems for reading mature. In children who learn alphabet-based languages such as English, patterns of brain activation change in a sequence that reflects certain stages of development. These steps follow a different trajectory in dyslexic children—but also in children learning to read Chinese. Evidently the road to literacy takes multiple paths, some of which may be smoother for one child than for another. The right choice of a language may improve the odds of a dandelion outcome.

At its core, reading consists of learning the relationship between words and marks on paper. In Western languages, the marks are letters; in Chinese, characters. Most children start learning to read and write around age five or six. Over years of practice, this process becomes automatic and effortless.

When adults read, their brains show activity in many regions, including the frontal lobe, the cerebellum, and the area where the temporal lobe of the neocortex meets the parietal and occipital lobes. One especially important region is a part of the fusiform gyrus within the left inferior temporal cortex. This region appears to have a special importance in the recognition of written language (which is why it’s sometimes called the “visual word form area.”) This region is active when a person is shown either words (cat)
or objects that look like words but are not (jat). This discrimination is not simply a matter of recognizing whether the pattern is pronounceable. Chinese characters are composed of stroke patterns with no intrinsic pronunciation—you can’t “sound out” the pronunciation of a Chinese word; you just have to know it. And yet nonsense characters that resemble real words also activate the visual word form area in Chinese readers.

Word-form recognition is learned through experience. This capacity seems to be an example of a more general ability of the inferior temporal cortex to visually recognize objects (see chapter 10). Some neurons fire when a monkey or person sees specific objects, such as a flower, a hand, or faces of monkeys and people. The latter neurons, found in the right inferior temporal cortex, are quite specific, responding only to faces and not to individual features, rearranged images of faces, or even upside-down faces. Recognition is more likely if an object is familiar or important to the viewer. For example, part of the region that is specialized for face recognition also responds to specific car models—in the brain of a car expert.

Most naturally occurring objects look the same when viewed from the left or the right. Perhaps for this reason, mirror-image confusion is common in animals and people. Your child's brain (and yours) is optimized to provide rapid solutions to everyday visual problems—but for most of evolution, those problems have not included reading. There may not be much everyday advantage to distinguishing left- from right-side views of objects. Therefore the right inferior temporal cortex may not be wired to detect asymmetry. This characteristic suggests why it might be useful for the inferior temporal cortex on this side of the brain to drop out of the reading circuit.
Attempts by your child’s inferior temporal cortex to horn in on reading can pose a problem, because words and letters are loaded with asymmetry. In reading, the ability to distinguish mirror images is often important, for instance in distinguishing $b$ from $d$ or $AM$ from $MA$. As a result, the brain must suppress any tendency to perceive left and right views as being the same, which may explain why many brains don’t take naturally to reading. Mirror image confusion might interfere with recognition of letters and words—thus leading to reading failure.

Because natural objects such as faces look the same from either side, the more efficient recognition strategy is often to treat left and right views as being the same. Overcoming the natural tendency to treat mirror images as equivalent is a major milestone for beginning readers. In kindergarteners, the ability to make left–right distinctions is correlated with readiness to read, and children at this age routinely reverse letters. The relationship between left–right detection capacity and early reading disappears by first grade, suggesting that most children clear this hurdle by the age of six. From then on, readers rely more and more on regions in the left frontal and temporal lobes. Conversely, dyslexics frequently have left–right confusion, as well as difficulty distinguishing mirror images from one another. Perhaps for this reason, dyslexic children often retain a capacity for mirror writing, which most children lose.

Even though monkeys can’t read, they share with your child a natural affinity for visual symmetry. Studies in monkeys suggest that suppressing that affinity is likely to come with decoupling of the right inferior temporal cortex. Like most animals, monkeys have trouble telling apart left–right asymmetric stimuli. After damage to their inferior temporal cortex, they do not get worse at this task—and sometimes they get better. It
seems as if part of the work in this task is overcoming the natural tendencies of inferior temporal cortex for shape recognition.

It appears that the right inferior temporal cortex may be the culprit in early reading difficulties. One group of researchers showed words to English language readers aged six and older. In beginning readers, both left and right inferior temporal cortex are active during reading. This slowly fades until by age sixteen, inferior temporal cortex activation has shifted largely to the left side. At ages in between, six to ten year olds showed a wide variety of activation on the right side. Right-side activation and reading test scores were negatively correlated. That is, kids with less right inferior temporal activation were better readers.

Another likely step in learning to read successfully is the ability to recognize sounds, a capacity known as phonological awareness. Phonological naming predicts reading proficiency, and deficits in this capacity may be a central cause of dyslexia. One brain region activated in early readers, the left-posterior superior temporal sulcus, is more active in children with a better ability to recognize and classify spoken sounds. More broadly, in both early and mature readers, activity is seen in areas in temporal and parietal cortex. These brain regions are well positioned to receive both auditory and visual information, and so might be important for integrating these modalities with one another for word recognition.

The involvement of brain regions that process sound makes sense in the case of alphabetical languages such as English, which require sounds to be linked with letters. However, not all languages work this way. One example that has attracted recent interest from language researchers and neuroscientists is Chinese.
A Chinese child beginning to read faces a formidable task. The written language is composed of thousands of different complex characters. Each character represents part or all of a word and is a dense squarish assemblage of one or more components called radicals. About 620 radicals must be learned, each containing one to several dozen strokes. Finally, the visual appearance of a character usually does not reveal how it is pronounced.

How does a child navigate such a thicket? The time-honored approach has been to learn by writing. A major component of Chinese language instruction is the writing of characters, stroke by stroke. This is very unlike reading lessons in alphabetic languages, which begin by learning individual letters and the sounds they represent. Correspondingly, there are differences among children who speak different languages in the neural pathways during beginning reading.

Functional brain imaging shows that unlike English-learning children, Chinese children show only small increases in activity in parietal cortex when reading. Instead, widespread activation occurs in a region centered around left middle frontal cortex. The activated areas overlap strongly with dorsal and lateral prefrontal cortex, which are used in working memory. Readers also show activity in premotor cortex, which is likely to be activated during the execution of fine movements—such as those that would occur when writing out a Chinese character.

These findings suggest that the active recall and rehearsal of writing characters may be central to learning to read Chinese. Thus the gap between verbal language and reading can be bridged not only phonologically, but also with the help of neural circuits for movement.
Phonological and movement mechanisms are at least partly independent of one another are separate, or at least partly so. Phonological awareness is a weaker predictor of reading success in Chinese than in English. Also, the prevalence of dyslexia in China appears to be lower than in Western countries—perhaps as low as 2 percent, compared to 5 to 15 percent of English-speaking children. On the other hand, reading difficulties are more common when children are taught Chinese using an alphabetical scheme for writing called pinyin.

As with math, the best strategy for learning to read may differ from person to person. There are dyslexic children in China and Japan (where the written language is similar to Chinese) who reportedly learned to read English at average levels or higher by taking a phonics-based approach—but not by using a word-copying approach. For a few Chinese children, the motor-based route may be difficult. For English-language dyslexics, the phonological route may be difficult.

This brings us to another useful conclusion: if you have a dyslexic child trying to learn English, he may profit from systematic, repeated copying of entire words by hand—as if they were single symbols. Copying could activate motor circuitry to assist the mapping of language to the visual appearance of words. This differs significantly from the usual, phonics-based approach for early reading. (It also differs from whole-language reading instruction, a rival school of reading that focuses on subject matter and context.) The seemingly laborious, frontal cortex-based approach taken by Chinese children suggests the possibility of a third route for overcoming reading difficulties—study by detailed writing.
No matter how children learn to read, the general pattern is that starting from a very focused group of brain regions, children eventually come to use a much broader network. The ability of the brain to organize such distant areas in the service of a cultural innovation, such as reading, is a testament to the flexibility of our brains when faced with a new opportunity.

BEGIN BOX

Did you know? The causes of dyslexia

Dyslexia is defined as “persistent difficulty in reading when other intellectual functions and educational opportunities are sufficient.” Its frequency suggests that it is not a disorder, but simply one extreme of a range of normal variation. Indeed, in preliterate times dyslexic tendencies might not ever be noticed.

Like other neurodevelopmental disorders, dyslexia arises through genetically determined mechanisms. If one identical twin is dyslexic, the other twin has a nearly 70 percent chance of having the disorder too. The probability is also high for nonidentical twins and siblings of dyslexics, 40 percent, suggesting that dyslexia in a child is triggered by one or a few variant genes.

In most cases, the genes whose variants make us susceptible to dyslexia are those that affect either the migration of neurons to their final destinations or the growth of axons. One such gene is ROBO1, which is involved in determining whether axons will
cross the left–right midline. Researchers should eventually be able to understand how these genes cause dyslexia-inducing variations in neuronal circuits, either within a part of the brain or in connections among brain regions.

Dyslexic children often have difficulty with phonological perception tasks, such as identifying spoken syllables or the order in which they occur. This disability might create difficulties in making rapid, automatic associations between sounds and letters, a necessary component of smooth, automatic reading. The task is difficult in English, which is filled with irregularities. Indeed, the incidence of dyslexia is lower in languages such as Italian or German, where pronunciation rules for letters are consistent.

For some capacities, mirror confusion may be an asset. The right half of the neocortex is generally involved in perceptual judgments. This raises the question of whether strong perceptual abilities in right inferior temporal cortex might be bad for reading—but good for other capacities. Dyslexia is frequently reported among artists. One survey at Göteborg University in Sweden revealed a remarkably high fraction of dyslexics among art students compared to students in other majors. Whether or not these students’ exceptional capacities caused their dyslexia, they have identified an elite pursuit that does not require written language.
Practical tip: Reading at home

Many videos claim to teach early reading to infants. The creators of such products state that literacy skills are best taught from birth to about age four. Yet during this time, children lack the capacity to distinguish b from d, much less read whole words. No studies show that babies are doing anything more than forming associations when they watch these videos. To paraphrase one product: no, your baby can’t read.

The timetable of perceptual development does raise another question: what is the benefit of children’s books? Despite the recommendations of pediatricians, lecturing, whether verbal or literary, is a remarkably ineffective method of behavior change (see chapter 29). Children’s books are more likely to provide new ideas for misbehavior than lessons for how to behave or think.

On the other hand, one story does expose a child to hundreds of words of spoken language. The daily number of words spoken to a child in the first three years of life is strongly correlated with cognitive achievement. Although it is unclear whether such a correlation is predictive, or simply a marker of high socioeconomic status (see chapter 6), books still convey a simple message that reading is fun. They also provide an excellent focus for parent–child bonding, which has many benefits.
PART SEVEN

BUMPS IN THE ROAD

Hang in There, Baby: Stress and Resilience

Mind-Blindness: Autism

Old Genes Meet the Modern World: ADHD

Catch Your Child Being Good: Behavior Modification

A Tough Road to Travel: Growing Up in Poverty
Chapter 26
Hang in There, Baby: Stress and Resilience

Compared with adults, children start with a double disadvantage in dealing with stress: they have limited power to change their environments, and they aren’t as good at managing their emotions. Every child has to find ways to deal with stress, though. It’s an inevitable part of growing up, whether the problem is as ordinary as a fight with a friend or as serious as the death of a parent.

For adults, coping involves some combination of changing your circumstances and changing your attitude. Resilient adults are optimists. Rather than passively denying and avoiding stressful situations, they use active coping strategies such as solving the problem, reinterpreting the situation in a more positive light, seeking social support, and finding meaning in hardship. Adult resilience is influenced by early experience. In general, children seem to develop their coping skills most effectively if they are exposed to a moderate amount of stress, high enough that they notice it, but low enough that they can handle it—a level that is different for every individual and changes with age.

Animals learn to cope with stress by starting small. Young monkeys who are separated from their mothers for one hour a week grow up to manage stress more effectively than monkeys who were never separated from their mothers. In adulthood, these mildly stressed monkeys show lower anxiety and lower baseline stress hormone levels and perform better on a test of prefrontal cortex function. Rat pups that are separated from their mothers for fifteen minutes a day also become more resilient as adults. In contrast, pups that are separated for three hours a day grow into adults who are
more vulnerable to stress, show more anxiety, are slower to learn, and drink more alcohol (when it is offered to them) than unseparated animals. Controllable stressors—the ones you can manage or reduce through your own actions—are more likely to lead to resilience than uncontrollable ones. Rats that learn to escape from a mild electric shock to the tail are less likely to develop learned helplessness (which psychologists consider to be an indicator of depression) when confronted with an unpredictable and uncontrollable shock later on.

Infants must rely on their parents and other caregivers to act as a surrogate coping system, as babies can signal their own needs but not meet them. Preschoolers tend to cope in a limited number of ways, by seeking help from caregivers, confronting the problem, withdrawing, or distracting themselves with another activity. Around age three, they start to try negotiating for what they want. Older children rely most heavily on the strategies of support seeking, problem solving, escape and distraction. Cognitive strategies for distraction (such as thinking about something pleasant) and better problem-solving ability emerge in late childhood and increase to age twenty-two. Rumination and anxiety also increase during this period, though, as thinking about problems doesn’t necessarily contribute to solving them.

As children get older, they learn to choose different strategies to cope with different situations, and they begin to show more personal tendencies and preferences. Some of these individual differences can be traced to their temperaments. For example, children with high negative reactivity (quick to experience anxiety or anger; see chapter 17 and box, Practical tip: Dandelion and orchid children) are particularly vulnerable to
stress, in part because they are slow to develop self-control. Parents who are overly protective of high-reactive children may interfere with their development of coping skills.

Our biological response to stress is most effective in dealing with immediate threats to our physical well-being. When a stressful event occurs, two systems become activated. First, the sympathetic nervous system releases epinephrine and the neurotransmitter norepinephrine in less than a second, preparing your body to run or fight by directing energy to muscles, increasing the heart’s blood-pumping ability, and shutting down non-essential systems. This reaction is better suited to dealing with a mugger or a bar fight than with the more common stressors of a grumpy boss or a troubled marriage.

The second, hypothalamic–pituitary–adrenocortical (HPA) system (see figure) works on a time scale of minutes. The hypothalamus sends corticotropin-releasing hormone (CRH) into the pituitary, which releases β-endorphin (a natural painkiller) and corticotropin into the blood. Corticotropin then signals the adrenal cortex to release glucocorticoid hormones (mainly cortisol in people) into the blood. In the short term, that’s a good thing, leading to changes in gene expression within the brain that help repair damage caused by the initial stress response, such as replenishing energy stores. Cortisol also increases arousal and vigilance, while inhibiting other processes, including growth, repair, reproduction, digestion, and immune responses, all of which might divert energy from the solution of the immediate problem.

An effective stress response starts quickly and ends quickly. Binding of glucocorticoids to receptors in the hippocampus activates a negative feedback loop that shuts down CRH release and thus halts glucocorticoid production. This is important because if glucocorticoid levels stay high for a long time, you can end up with a number
of ailments, including high blood pressure, damaged immune system function, osteoporosis, insulin resistance, or heart disease. Chronically elevated cortisol can also lead to brain problems: it may inhibit the birth of new neurons, disrupt neural plasticity, kill neurons in the hippocampus, or cause structural changes in the amygdala. Over time, the hippocampal damage not only impairs learning but also reduces the brain’s ability to terminate the stress response, initiating a cycle of problems that lead to more hippocampal damage.

These two systems interact extensively with each other. Neurons that produce CRH and influence stress responses are also found in the amygdala, the prefrontal, insular, and cingulate cortex, and other brain regions. The amygdala neurons, for example, project to the locus coeruleus, which regulates the activity of the sympathetic nervous system. In turn, neurons in the locus coeruleus can increase production of CRH in the hypothalamus.

As parents help their young children to cope with stress, the quality of their support regulates the children’s HPA responses. Physiological stress responsiveness declines over the first year of life in normally developing children. They still cry to get help from their parents, but this type of crying is not accompanied by an HPA response. Toddlers and older children in secure attachment relationships show less elevation of cortisol in response to stress than children with insecure attachment relationships, those who do not see their parents as a reliable source of comfort (see chapter 20).

The strongest stress responses are found in children with disorganized attachment relationships, in which the parent often makes the child afraid, either through aggression toward the child or by being extremely anxious. Such children also have the highest risk
of behavioral or emotional difficulties. In all cases, as children become adolescents, they transition to adult patterns of stress responsiveness, becoming more vulnerable to stressful events. This may be related to the increased risk of psychopathology during those years (see chapter 9).

The stressors that you can expect to encounter in life depend on the characteristics of your particular environment. In many mammalian species, babies’ brains prepare themselves for the type of world they’ll find when they grow up by tuning their stress-response systems based on their experiences during early life. This process is one of the best-understood examples of so-called “epigenetic modification,” in which the environment permanently influences the way our genes are expressed, and ultimately, our long-term behavior (see TK).

Stress profoundly affects the developing brain. In chapter 2, we wrote about the effects of prenatal stress, as studied in the pregnant Louisiana women who escaped from hurricane strike zones, as well as pregnant women who experienced other forms of severe stress such as the death of a close relative. Babies born to these stressed mothers had a substantially increased risk of problems, including autism, schizophrenia, decreased IQ, and depression.

Broadly speaking, the effects of early life stress seem to be similar in people, rodents, and monkeys. Babies whose mothers were stressed or depressed during pregnancy show increased responsiveness (HPA activity) to stress later in life. Adults who were abused as children also respond to stress with stronger HPA and sympathetic nervous system activity than those who weren’t. Probably as a consequence, previously abused adults have smaller hippocampal volumes and an increased risk of diabetes,
cardiovascular disease, depression and anxiety, schizophrenia, and drug abuse as adults. Other brain structures are likely to be affected as well, though this is less well studied.

How does early experience tunes the stress response? The relationships of rats and their pups can shed some light on the subject. In rat pups, maternal licking and grooming reduce physiological stress responses. Mother rats vary naturally in how much time they spend licking and grooming their pups during the first week of life, and there is evidence that rats are able to develop normally either way. But mothers who groom a lot raise pups that are less fearful as adults and whose HPA stress responses are smaller and don’t last as long, compared to animals raised by low-grooming mothers. Experiments where rat pups in one group were “adopted” by mothers from the other group confirm that this effect is due to environment, rather than genetics.

It’s tempting to think of high-grooming mothers as the “good” mothers, but that would be a misconception. Instead, both types of mothers are matching their pups’ adult behavior to local conditions, one of the key aims of neural development. Remember: not all stress responses are bad. Pups born into difficult circumstances may survive better if they are vigilant and their HPA system is reactive. If mothers who were high-grooming with their first litter of pups are stressed during their second pregnancy, they become low-grooming mothers for those pups and also for their third litter, meaning their future offspring will have more reactive HPA systems.

Other indicators of a tough environment during gestation, such as protein deprivation or exposure to bacterial infection, also increase adult HPA responsiveness in rats. Not only that, pups who receive low levels of licking and grooming reach sexual maturity earlier and are more likely to become pregnant after a single mating session than
pups raised by high-grooming mothers. In a tough environment (see chapter 30), these benefits for survival and early reproduction may constitute a worthwhile trade-off for a higher risk of chronic diseases late in life.

Canadian researcher Michael Meaney and colleagues have traced the molecular and neural consequences of early licking and grooming in the rat. These maternal behaviors trigger the release of the neurotransmitter serotonin in the pup’s hippocampus, where it initiates a series of intracellular signals that reduce the epigenetic silencing of glucocorticoid receptor genes by methylation (see chapter 2). Because methylation is a lasting modification to DNA, pups that receive a lot of grooming grow up to have high levels of glucocorticoid receptors in the hippocampus, and thus can terminate stress responses effectively throughout life. They also grow up to be mothers who lick and groom their own pups a lot, thereby passing the epigenetic modification to the next generation. In rats reared by low-grooming mothers, treatment with a drug that removes methyl groups from DNA can reverse the heightened HPA stress responsiveness.

The HPA stress response in monkeys is also tuned by early experience. To mature normally, young rhesus monkeys (like children) need to form an attachment to at least one reliable adult, usually the mother. Monkeys who are raised in a peer group instead of by mothers (a situation that, in humans, would constitute criminal child neglect) show a variety of unusual behaviors. As young animals, they explore little and play less. As adults, they are fearful and aggressive in response to threats and have a strong HPA response to separation from their peer group.

This phenomenon is especially severe in monkeys that carry a particular variant of the serotonin transporter gene, which is also reported to increase vulnerability in people.
The serotonin transporter removes serotonin from the synapse after its release by neurons, terminating the neurotransmitter’s activity. Among primates, only people and rhesus monkeys show variation in this gene. Monkeys carrying the short allele show higher HPA reactivity than animals with two copies of the long allele, but only when raised in a peer group. When raised by mothers, both types of monkeys have similar adult outcomes. Researchers conclude that variation in this gene produces behavioral flexibility, which in turn allows rhesus monkeys—and people—to thrive in many different environments.

So what determines stress responses in people? Recall from chapter 2 that specific combinations of genetic and environmental factors lead to certain outcomes when neither factor alone has an effect. These interactions are challenging to tease out because so many combinations are possible.

One major contributor to our understanding has been a longitudinal study that followed over 1000 children born between April 1972 and March 1973 in Dunedin, New Zealand, from age three into adulthood. In this study, Avshalom Caspi, Terrie Moffitt, and their colleagues identified several psychiatric examples of gene–environment interactions, in which an experience increases the risk of a certain outcome only in people who carry a particular gene variant.

The best-known finding of the Dunedin longitudinal study is that the risk of depression following childhood maltreatment or stressful life events is higher in people with the short allele of the serotonin transporter gene (and higher still in people with two copies of the short allele). People with two copies of the long allele are most resilient, with a low risk of depression regardless of their childhood experience. In contrast, people
with two copies of the short allele have a risk of depression that increases in proportion to the childhood abuse they’ve suffered. Severe maltreatment doubles the risk of depression in this group.

The Dunedin study uncovered two other dangerous gene–environment combinations. Childhood maltreatment is more likely to lead to antisocial behavior in people with a genetic variant that leads to low monoamine oxidase A activity. This enzyme degrades serotonin, dopamine, and norepinephrine, all neurotransmitters involved in stress responding and mood regulation.

Also, heavy marijuana use during adolescence increases the risk of schizophrenia in people with the valine variant of the catechol-O-methyltransferase gene. Catechol-O-methyltransferase is involved in dopamine metabolism, and the valine variant is the most active. People who start using marijuana as adults do not have an increased risk of schizophrenia, regardless of genotype.

In general, gene–environment interactions are complex and thus difficult to demonstrate, so all these findings remain somewhat controversial (see notes). The interaction between the 5-HTT gene and early life stressors is the strongest result. It has been replicated in sixteen studies, though some others drew different conclusions. The marijuana–schizophrenia link is the weakest, resting on a single study so far.

The study of resilience in the face of adversity has contributed a great deal to our understanding of how experience affects child development. It’s become increasingly clear that some environmental influences are individually variable, having different effects on different children. We know that life events can lead to different outcomes depending on which genes a child carries. There are likely to be even more complicated
interactions that researchers cannot identify with current techniques, such as those involving multiple environmental conditions and multiple genes. Scientists may never unravel all these influences, but we can now say for certain that neither genetic inheritance nor environmental conditions alone are destiny for any child.

BEGIN BOX

**Practical tip: Dandelion and orchid children**

If certain genes make children more vulnerable to damage under stressful conditions, why do they persist in the population? Some researchers think it’s because children who are more sensitive to the environment may fare better in stable, supportive conditions—though conversely, difficult environments are harder on them. Some psychologists have suggested that we might replace the label “difficult children” with “orchid children”: they’re sensitive, but if raised well, the results can be great.

As we have already mentioned, most children are dandelions—they flourish in any reasonable circumstances. In contrast, orchid children with difficult temperaments (quick to anger or fear) benefit measurably from supportive parenting. The combination of difficult temperament and harsh or unreliable parenting is a strong predictor of delinquency and psychiatric problems in many studies.

Under good rearing conditions, the outcomes for these children may be better than for dandelion children in many ways. For example, in one prospective study of high-
stress families, high-reactive children were sick much more often than low-reactive children in the same families. In low-stress conditions, the advantage was reversed: high-reactive children were sick less often than low-reactive children. In short, outcomes for orchids were more variable, for good and for bad.

Similar results were found in an experimental study with rhesus monkeys. Highly reactive infants raised by especially nurturing mothers showed the most resilience in response to stress, and ended up high in the colony’s dominance hierarchy. High-reactive infants raised by average mothers had the worst outcomes. For infants born to average mothers, in contrast, being raised by nurturing or average mothers had little effect on adult behavior.

The orchid idea is consistent with several other findings. For example, inborn difficulties with reading could be associated with greater artistic capacity (chapter 25), and an interest in science might be associated with autism susceptibility genes (chapter 27). Parents can take heart from the idea that the special care that’s necessary in handling their difficult children may lead to good outcomes later on.

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Most babies are interested in socializing from birth, but for children with autism, the social aspects of brain function are severely impaired. As we described in the first part of this book, the first steps in development are programmed by genetic mechanisms, and go awry only in cases of severe environmental flaws such as high doses of toxins. Sometimes, though, flaws in the genetic program can have a profound effect.

Development is a complex business, depending on thousands of genes. Any given gene comes in different versions called alleles, which are part of normal genetic variation. When by chance children inherit an unlucky combination of alleles from one or both parents, neurodevelopmental problems such as autism can result.

At autism’s core is a distinctive and profound disorder. One way to describe the problem is a deficit in theory of mind, the ability to imagine what other people know and what they are thinking or feeling (see chapter 19). Autistic people have difficulty recognizing when others are lying, being sarcastic, mocking them, or taking advantage of them. They have particular trouble in reading facial expressions, especially of emotion. At the same time, some functions appear to be within normal limits, such as basic sensation and the ability to make plans and act upon them. In analogy to traits such as colorblindness, autistic children seem to have "mindblindness."

True autism is relatively rare, affecting one or two children per 1000 born in the U.S., and is diagnosed based on three major problems: impaired social interactions, defective or absent communication, and repetitive or restricted behavior. Many children
with autism have other types of disrupted brain function such as mental retardation or epilepsy. Related to autism are less severe disorders, such as Asperger’s syndrome, in which language and cognitive ability are largely intact. Collectively, these so-called “autism spectrum disorders” affect about one in 150 children, 75–80 percent of whom are boys. Siblings of these children are also at risk: they are almost ten times more likely to have an autism spectrum disorder than the general population (though the risk is still only one in 20).

The recorded rate of autism spectrum disorders has increased dramatically in the last few decades. Much of this increase is due to changes in diagnosis. Autism was not recognized as a formal diagnostic category of the American Psychiatric Association until 1980, and a 1994 revision of the criteria made a larger fraction of children eligible for the diagnosis. More children are being screened, as pediatricians now routinely administer questionnaires to identify autism. In addition, therapies have become available to reduce the severity of autistic symptoms, which increases the motivation to identify children with autism: doctors are more likely to make a diagnosis when they know they can offer a treatment program. Researchers calculate that these factors can account for most -- or perhaps all -- of the apparent rise in the rate of autism. Other possible contributors are increases in early induction of labor and decreases in infant mortality, both of which can lead to genuine increases in the number of children with neurodevelopmental problems (see chapter 3). The overall result is a boom in reported cases—and in public awareness.

Signs of the social and communication deficits in autism can be seen as early as one year of age. At this age, infants with autism are less likely than non-autistic mentally retarded infants to respond to their own names, to look at people, or to use gestures to
communicate. There are striking deficits in joint attention to objects that people are holding, an early precursor to social behavior (see chapter 20), along with an inability to enjoy tickling or to understand simple games such as peek-a-boo. These differences are relatively subtle, though, and few babies are diagnosed this young unless they have an autistic older sibling. Autistic infants do form attachments to their parents, though these feelings may be expressed in unusual behaviors, and respond differently to strangers than to familiar people. In the second year of life, many autistic babies begin to have obvious developmental problems, such as language delay or repetitive behaviors.

In the U.S., autism is usually diagnosed in a visit to the pediatrician, typically at twenty-four months. The Autism Diagnostic Observation Schedule survey can be given as early as twelve months, but there is some risk of making a premature interpretation. Some children simply take a little longer to develop but end up fine. By the third birthday, diagnosis is reliable.

It has been a challenge to researchers to understand how this strange combination of symptoms can arise. Brain abnormalities are typically observed after death, decades after the initial recognition of autism. It is unclear whether the abnormalities are present in early childhood, or whether they arise after years of the disorder’s progress. In scans of the brains of living autistic people, a common feature is a malformed or small amygdala, an almond-shaped structure at the heart of the brain (see figure, page TK). Not surprisingly, the amygdala is necessary for the generation of emotional reactions (see chapter 18) and is activated when people are asked to evaluate emotion in other people’s facial expressions, something autistic children have difficulty doing.
Even more frequently, the structures most consistently affected in autistic brains are the **cerebellum** and other regions that are connected to it. At both the level of brain scans and numbers of neurons, cerebellum-related problems are seen in three-fourths of autistic brains. This widespread finding provides a potentially powerful clue to what makes autistic brains different - but is also a current puzzle to researchers. Traditionally, the cerebellum has been thought to be principally involved in processing sensory information to guide physical action, functions that are disrupted when the cerebellum is damaged in adults. Autistic children are sometimes clumsy, but not in a debilitating way - and they usually have their senses. So what's going on?

One possibility is that the cerebellum is essential for translating sensory events, such as the sight of a mother's smiling face, into a message with social import. Recall that we wrote that your child's brain goes through phases of experience-expectant development (chapter 3), in which the brain is ready to wire itself up normally, as long as it receives normal input. Such an arrangement is known to occur in the case of sensory experience. The brains of autistic children may have trouble translating everyday social experiences into a meaningful signal - thereby depriving themselves of a necessary experience early in life. If an abnormal cerebellum is involved in this derailed developmental process, it might do so through its connections to other brain regions, which include the cingulate cortex, which is involved in face processing, and the prefrontal cortex, which is involved in complex planning and executive function. These brain regions are also suspected to have altered function in autistic persons.

One piece of evidence that autistic toddlers experience social sensory experiences in a different way comes from watching their reactions. They show difficulties with
detecting natural biological motion such as walking, as well as with interpreting common social cues. When adults speak, typical toddlers look at the eyes, but autistic toddlers tend to look directly at the mouth, where the sound is coming from. In one study, toddlers saw a movie of lights attached to various points on a model’s head and body while he played a make-believe game with a teddy bear. Autistic toddlers spent equal amounts of time looking at the video played forward and the same video played upside-down and backward. Typical and non-autistic disabled children focused mostly on the right-side-up movie.

Perceptual difficulties persist throughout development and into adulthood. Autistic people often show an inappropriate degree of sensitivity to routine sounds and even the sensation of their own clothing. Temple Grandin writes of her own experience as an autistic person: “… loud noises were also a problem, often feeling like a dentist’s drill hitting a nerve. They actually caused pain. I was scared to death of balloons popping….Minor noises that most people can tune out drove me to distraction….My roommate’s hairdryer sounded like a jet plane taking off….” L.H. Willey, who has Asperger’s syndrome, writes: “I found it impossible to even to touch some objects. I hated stiff things, satiny things….Goose bumps and chills and a general sense of unease would follow.”

Abnormalities in the cerebellum may cause deficits in perception. The cerebellum is important for distinguishing between touch from oneself and the touch of others. A prominent example is the phenomenon of tickling: you cannot tickle yourself because your brain generates larger signals when the sensation comes from another person. One place where activity is increased during touch from others is the cerebellum.
In identical twins, if one twin is autistic then the probability that the other is autistic is between 60 and 90 percent. Non-identical twins, who share only half their genetic material with one another, have a much lower rate of diagnostic concordance. These facts suggest that autism’s roots are genetic, and that they involve multiple genes. Researchers have been able to find warning signs as early as four months of age, indicating that developmental consequences of a genetic inheritance can appear very early in life.

In the last few years, genes that are associated with a higher likelihood of autism have begun to be found. Some of these genes are involved in cerebellar development. Others encode proteins that are found at synapses, suggesting that they may affect the development or some other function of synaptic connections. Although it is not clear exactly how these genes increase the risk of autism, they point toward the idea that if neurodevelopmental processes encounters multiple difficulties, a sufficiently large perturbation will cause the brain to veer away from a typical path and toward autism spectrum disorder.

One question is why the genetic factors that underlie autism would persist in the population. After all, aren’t these the kinds of defects that disappear through evolution? This is generally the case, but an important exception occurs when combinations of genes cause a problem but confer some benefit individually. A well-known example is the gene for the oxygen transport protein hemoglobin. When a child inherits one copy that is altered in a particular way, he has increased resistance to malaria. When both copies are altered, sickle-cell anemia results.
Similarly, individual autism risk genes may have other functional effects. For example, autistic people tend to be very good with details, perhaps because of a lack of higher control from the frontal cortex. A small number of people in the population with an exceptional ability to focus on tasks could be a good thing for those persons - and for society. In the words of Temple Grandin, “What would happen if the autism gene was eliminated from the gene pool? You would have a bunch of people standing around chatting and socializing and not getting anything done.”

One consequence of carrying autism susceptibility genes is an enhanced interest in technical fields. Sam recently surveyed an entire entering freshman class at Princeton University. He found that among students expressing an interest in a technical field (science, engineering, or mathematics), one in twenty-five reported having a sibling with autism spectrum disorder. This rate was over three times as high as that found for aspiring humanities and social science majors, one in eighty-two. Similarly, physics and math majors at the University of Cambridge report autism spectrum relatives far more commonly than English and French majors. These findings suggest the possibility that autism susceptibility genes might lead to a predisposition to look for systematic explanations for natural phenomena (or conversely, a predisposition not to think in terms of social explanations).

Autism does not occur together in every pair of identical twins, suggesting that environmental causes may also contribute to the disorder. These environmental effects probably act during early infancy or even before birth. One example is the drug Depacote, which is given for epilepsy and psychiatric illness, and can increase the rate of autism when mothers take it during the second trimester of pregnancy. Another example
is prenatal stress in the fifth, sixth, or ninth month of gestation, which is associated with a higher rate of autism (see box, Practical tip: Prenatal stress increases the risk of developmental problems, in chapter 3).

Despite reports to the contrary, it is a myth that autism can be triggered by vaccination. In the 1990s, specific blame was leveled at a particular vaccine, MMR, which is typically given at the age of twelve months. The original report was widely covered in the popular press, but has now been retracted, an event that received far less press attention. In several communities where the MMR vaccine has been withheld, the rate of autism has stayed the same, and in some cases the rate has increased. Since the developmental steps leading to autism are already well under way before the age of one, the main effect of withholding vaccination is to increase the risk of disease to your child and to his friends.

Even though the genetic causes of autism are starting to be understood, effective treatment is far off. Currently, autism has no silver bullet. One treatment that yields some positive outcomes is behavioral therapy. Unfortunately, this can be a hard road (see box, Practical tip: Behavioral therapy is helpful if started early).

Some of parents’ motivation to determine the causes of autism and seek treatment for their children may come from a feeling of guilt, even though they are not at fault in any way. Although these efforts are essential in driving forward research into causes and treatments, parents should be careful about embracing unproven and pricey new treatments, many of which have no benefit. Examples include chelation and nutritional therapy, facilitated communication, and hyperbaric oxygen treatment—the list goes on. These treatments are unlikely to be any better for a child than doing nothing, and in some
cases they carry a significant risk of harm (see box, Practical tip: How to evaluate nonstandard treatments, in chapter 28).

For autistic children, the strongest contribution that parents can make is to recognize the potential for problems early in life—and to act early, by the age of two if possible. In most cases, babies simply mature on their own timetables, but for this disorder, intervention can make a critical difference. Although the challenges posed by autism spectrum disorder are considerable, the possible benefits seen in their nonautistic relatives suggest that like other developmental processes, some of the genes that make a child autistic may help others to thrive and contribute to society.

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Practical tip: Behavioral therapy is helpful if started early

In the 1970s and 1980s, Ivor Lovaas and his collaborators at the University of California Los Angeles developed a therapy for autistic children consisting of intensive one-on-one instruction, supervised training play sessions with typical (unimpaired) children, inclusion in regular classroom activities, and parent training for further at-home therapy. This intensive approach improves function in autistic children.

Behavioral therapy can begin as early as age two or three, when autism is usually diagnosed. The UCLA model starts by getting children to respond to unambiguous instruction, starting with simple tasks. Correct responses are initially rewarded by foods
and desirable sensory and perceptual objects. Later the children feel rewarded by praise, tickling, hugs, and kisses. Once they can answer questions, take turns, and engage in basic play, they are paired with typical children who give feedback during supervised play. Eventually the autistic child is introduced to classroom situations and group play.

Compared with other therapies or regular special education, children receiving behavioral therapy are more socially engaged and have better language, with improvements in IQ averaging twenty points. After behavioral therapy concludes, about half of children are eventually able to enter regular education.

Behavioral therapy is expensive and arduous. The cost is approximately U.S. $50,000 per year. Even this large cost may be cheaper than caring for an autistic person over his or her lifetime. Therapy requires at least thirty hours per week of direct attention by clinic staff or by parents working under staff supervision. Focus is required: in moderately impaired autistic children aged four to seven, combining behavioral therapy with other approaches has been reported to be far less effective, perhaps because efforts to give the effective therapy are diluted.

Given the developmental history of autism, it would seem logical to start therapy as early as possible. One research team has described Catherine, the one-year-old sister of an autistic child. Catherine obsessively closed open doors, had little language, and spent much of her time balancing long objects such as rulers vertically on her hand. Catherine underwent intensive treatment for three years, after which she entered regular kindergarten and tested above average in cognitive and language skills. At the end, Catherine blended in with typical children.
Although this anecdotal case cannot prove whether Catherine would have otherwise become autistic, her successful outcome does suggest the potential benefit of identifying children at risk for autism before the age of two. Catherine’s case may also demonstrate that a sufficiently mild dose of autism susceptibility genes may carry “orchid” advantages (see box, Practical tip: Dandelion and orchid children, in chapter 26) under suitable conditions, as evidenced by her eventual above-average performance.

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Speculation: Are feral children autistic?

Mythology and modern history contain many reports of feral children. Typically these children are reported to lack the power of speech, usually grunting or howling instead. They reject clothing, reminiscent of perceptual difficulties in autistic persons, and are unable to socialize normally with others. Could it be that these children are not feral but instead autistic?

Such children are often said to be raised by animals, most often wolves but sometimes dogs, apes, bears, and even the occasional gazelle. Developmentally disabled children are mostly male, and reminiscent of this, “wolf-reared children” are nearly always boys, whatever the country of the tale’s origin. Romulus and Remus were said to
be suckled by a she-wolf. Other such children in ancient Greek and Roman lore are usually male, though some cases are highly fanciful, such as a god being nursed by bees. A more modern example is Victor the Wolf Boy of Aveyron, who appeared to be about 11 years old when he was found naked and wandering in the French countryside in 1800.

Of course these children are never found in the actual custody of animals—their improbable rearing is reflected in their behavior. In the few cases where children can speak, they often describe running away from home and joining a group of animals. It seems more plausible that an abandoned, high-functioning autistic child could manage the same act of survival long enough to be found.
Chapter 28
Old Genes Meet the Modern World: ADHD

When Charlie Gross was a boy in the 1950s, he was deemed hyperactive. Although he was bright, his teachers bored him, so he was considered to be a troublesome child. He found other challenges, becoming an Eagle Scout and winning the Westinghouse Science Talent Search as a high school student. Years later, as a leading brain researcher, he was the first to discover single neurons in primate brains that respond to complex features, such as faces (see chapter 25).

If he had been born fifty years later, there is little doubt that he would have been offered treatment for ADHD. This disorder is estimated to occur in 5 percent of children worldwide. A looser definition gives an estimate as high as 17 percent, and in some school systems, up to 20 percent of boys receive drug treatment for ADHD. Is a phenomenon that is so widespread—yet so variable in estimated occurrence and treatment—a clearly defined medical disorder?

One reason for skepticism is that definitions of ADHD have changed several times since 1980 and are not always applied consistently. According to the American Psychiatric Association’s Diagnostic and Statistical Manual of Mental Disorders (DSM-IV), evaluators ask whether a child “is often easily distracted by external stimuli,” “often talks excessively,” or “often blurts out answers before questions have been completed.” Most children (including Sam in his earlier years) meet at least some of these criteria. Indeed, your child may have some of these characteristics, many of which are common in all children.
The strongest evidence that ADHD is a real disorder comes from genetics. The susceptibility to ADHD is inherited. In genetic linkage studies, ADHD has a heritability of 70–80 percent, on par with autism and greater than schizophrenia. There are dozens of identified ADHD susceptibility genes, many of which are involved in development and are also associated with autism and schizophrenia. Indeed, ADHD brains show changes in the growth trajectories of gray and white matter compared with normal development (see chapter 9).

At the same time, ADHD is also a product of social and cultural pressures. Your child's brain was originally optimized by natural selection to help him handle everyday problems, which did not include sitting in a classroom, much less resisting the attraction of a television or text message. The mismatch between evolution and civilization has not always been addressed by treatment. Long ago, children who made trouble often dropped out of school and sometimes society—think of Huckleberry Finn. Some of them ended up working on farms or drifting into crime. In most developed countries, we no longer let such children go down their own paths. Stimulant drugs and other therapies provide a means to treat such children—perhaps as well as other children who do not belong in this category.

Attention-deficit hyperactivity disorder is misnamed: children with this condition have the capacity to pay attention, but they lack the ability to control where it goes. Many such children have problems with executive function, a suite of capacities that includes planning ahead, inhibiting undesirable responses, and holding information in working memory. One consequence is that ADHD children are bad at estimating time intervals of up to a minute, missing wildly. A second area of deficit is an inability to forgo a small
immediate reward in order to get a larger one that comes later. For this reason, future rewards are counted hardly at all when such children make decisions about what to do.

Teachers and parents may be motivated to look for ADHD by the availability of drug treatments for improving children’s ability to focus. Most prominent among these is methylphenidate. This drug was first synthesized in 1944 by chemist Leandro Panizzon. His wife Rita, who had low blood pressure, used the drug to pep herself up before tennis games. In a romantic gesture, Leandro named the drug Ritaline after her—today, Ritalin. In addition to its alerting qualities, Ritalin also helps mental focus and began to be used for ADHD in the 1960s.

Ritalin’s major biological action is to prevent the neurotransmitter dopamine from being taken back up into neurons after it is released by electrical activity. Neurons in the ventral tegmental area and the substantia nigra release dopamine for a wide variety of functions: to regulate movement, to signal a rewarding event, and to control attention (see chapter 14). Dopamine uptake blockade is also the mechanism by which cocaine and amphetamine act. When cocaine, amphetamine, or Ritalin is present, dopamine hangs around longer in brain tissue and reaches higher concentrations—thus providing a stronger signal and better control over attention.

Only a few genes related to dopamine signaling have been linked to ADHD, and these genes have been shown only to have a small influence on whether children develop problems. So despite the effectiveness of Ritalin, ADHD is not necessarily caused by a dysfunction of dopamine signaling. A more plausible explanation is that developmental steps impair the brain's ability to direct attention, with dopamine signaling as one
mechanism that feeds into the circuitry. Differences in this circuitry have been probed by measuring both activity and size of key brain structures.

Distinctive patterns of brain activity are seen in ADHD children. Electroencephalographic (EEG) recording can record electrical signals at the scalp that reflects the activation of neurons near the recording electrode, in approximate synchrony. At this broad level, brain activity oscillates at a variety of characteristic frequencies, with different frequencies becoming more prominent depending on the task at hand. For instance, the theta rhythm, which rises and falls between four and seven times per second, is active in idling brains—a signal that indicates that a person is spacing out. Higher frequencies include the alpha (eight to twelve times per second) and beta (twelve to thirty times per second) rhythms, which become more prominent in a variety of states including relaxation, inhibition of action, and alert concentration. All of these can be measured using EEG.

In children and adults with ADHD, alpha and beta rhythm are smaller in strength relative to theta rhythm than in typical children. The disparity between these rhythms occurs in ADHD children resting with their eyes open or closed, as well as when they engage in other activities such as a drawing task or solve a problem. It appears that the brain rhythms associated with idling are stronger relative to those associated with other mental states in ADHD children.

Based on these differences, it may be possible to improve function in ADHD kids’ brains without resorting to drugs. Researchers have devised exercises in which EEG signals are presented to the child as a form of “neurofeedback.” In a typical regimen, the child participates in a video-game-like exercise in which rewards are given for a desirable
change, for instance a decrease in the theta rhythm or an increase in the beta-to-theta ratio. A meta-analysis of fifteen studies indicates that neurofeedback training reduces impulsivity and inattention considerably, with an effect size larger than seen for behavior modification alone—and comparable to the improvements seen using Ritalin.

As might be expected from the EEG findings, differences are also seen in functional brain imaging studies. In this case, though, the differences are found when groups of ADHD children are averaged. Imaging methods are also far more expensive than EEG. Although some advertisements claim otherwise (see box, Myth: Brain imaging can diagnose developmental disorders), functional imaging is not reliable enough to be useful as a clinical or diagnostic tool.

The brains of ADHD children have some subtle distinguishing features. In ADHD children between the ages of six and nineteen, brains are 3 percent smaller on average than those of typically developing children. This difference is not uniformly distributed over all parts of the brain. The largest reductions are seen in white matter, which is made entirely of axons. White matter is reduced by 5 to 9 percent, suggesting that long-distance axons in ADHD children are narrower (and therefore slower) or reduced in number. There is also a slight thinning of the gray matter of prefrontal and temporal cortex as well as the vermis, or central part, of the cerebellum.

One consistent finding in brain scans has been a reduction in the size of the caudate nuclei. These nuclei (left and right) form one component of the dorsal striatum of the basal ganglia, which communicate with many parts of the neocortex. The basal ganglia are involved in directing attention, for instance in switching from one subject to another. One facet of switching is updating the importance of a particular stimulus or
event. In addition, the basal ganglia inhibit actions that would interfere with a desired movement. Deficits in this ability could account for the difficulty that people with ADHD have in refraining from making an automatic response - for instance, looking in the direction of a distracting sound.

The caudate receives a powerful projection from the ventral tegmental area and the substantia nigra. This finding suggests that Ritalin may work by increasing the strength of dopamine signals coming into the caudate. Think of attention-switching mechanisms as an unresponsive light switch, and Ritalin as a means for pushing the switch a little harder.

Although ADHD is sometimes useful for identifying children who might need additional help, it is a temporary designation. The signs of ADHD can change over time—mostly for the better. For example, though small children are generally not big on attention, in only the most extreme cases would it make sense to say that they have ADHD. By age eighteen, ADHD symptoms have subsided in about 60 percent of boys with the diagnosis earlier in life.

Most adults who once had childhood ADHD do not experience emotional or behavioral problems. In the long term, Ritalin does not improve academic outcomes—nor does it increase the risk for substance abuse, as you might fear for an amphetamine-like drug. ADHD kids are at higher risk for criminality and substance abuse, but the largest known predictor of this outcome is whether antisocial tendencies and conduct problems arise during adolescence.

All in all, the boundary between ADHD and normal function is a blurry one that is determined by both biology and cultural expectations. To some extent, differences
between ADHD and typical brains simply reflect a delay in development. In both groups of children, neocortical gray matter reaches a peak at or before the onset of puberty, but the peak occurs about three years later in ADHD children. Furthermore, the difference in caudate essentially disappears by mid-adolescence.

These lags suggest that ADHD is at its core a matter of slightly slower brain maturation and that brains catch up by adulthood. In this respect, ADHD appears to be just part of the natural range in attentiveness that results from generation-to-generation shuffling of the gene pool. Evolutionarily speaking, most of this range has generated functional people for most of the history of our species. Stimulants such as Ritalin should probably be used sparingly. For this reason the right prescription for many kids may be, to paraphrase the old physician’s advice: wait two years and call us in the morning.

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**Practical tip: How to spot untrustworthy treatments**

When evaluating possible treatments for any problem, parents should ask this key question: Is the argument for this treatment based on peer-reviewed literature or on inspirational stories? If it’s based on stories alone, there is no reliable evidence for whether the treatment works. Other warning signs for quackery are the claim of a cure for a disorder whose causes are not understood, a single treatment that is claimed to be
effective for multiple different disorders, and a failure to measure improvement objectively.

A few rules of thumb can help you identify which treatments are likely to be legitimate. Treatments that work for most people should be backed up by key phrases such as “peer-reviewed study,” “controlled study,” or “control group.” When enough studies are done, meta-analyses can combine them into an even stronger form of evidence. If these elements are missing, all that is left are anecdotes—which do not guarantee that your child will obtain any benefit. Particularly if a website is dominated by individual testimonials or the authority of one person, watch out!

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**Myth: Brain imaging can diagnose developmental disorders**

We live in an age of celebrity spokespersons. For example, model and comic actress Jenny McCarthy is an advocate for a popular—but thoroughly disproven—connection between vaccines and autism. How should parents react to this onslaught of advice?

There is a long list of products sold using marketing claims that are poorly supported by science. These include brain scanning to diagnose and treat ADHD, balancing exercises for dyslexia, chelation therapy for autism, and nutritional

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supplements to aid brain function. Unfortunately, it's often difficult to distinguish between scientists with no financial interests and companies trying to manipulate their data to sell products.

Often a speculative treatment is based on some loosely related piece of evidence. For example, in many disorders such as autism, abnormalities are seen in the cerebellum, a structure that is traditionally associated with movement. Organizations such as the Dore Programme assert that movement exercises can alleviate all sorts of problems, including dyslexia, autism, and learning difficulties, but there is no credible peer-reviewed evidence for these sweeping claims. Indeed, it is a danger sign when one treatment is presented as a cure for many problems.

Another popular chain of clinics is operated by Daniel Amen, a cheerful celebrity doctor and bestselling author. At his Amen Clinics, expensive SPECT brain imaging scans are claimed to identify patterns of activity to design custom treatment for ADHD, anxiety, obesity, and the prevention of Alzheimer’s disease—and even marital problems. These claims have no scientific validity. The only documentation of these methods is Amen's books, which are filled with vignettes in which the treatments are consistent with what most psychiatrists would do on hearing the patient's symptoms, without any brain imaging at all.

Scientists have offered to test the Amen Clinic’s diagnostic tools under controlled conditions in which the evaluator makes a diagnosis without knowing the patient’s problem in advance. Amen has declined this opportunity. Although neuroimaging may someday be useful in diagnosing brain ailments, no one yet has the ability to do it.
When it comes to getting your kids to pick up their toys, we have good news and bad news. The good news is that children’s behavior is strongly influenced by the positive or negative consequences that immediately follow from certain actions. If you can set appropriate expectations for behavior and get the consequences right (more on that later), then your children will follow your household rules—most of the time, anyway.

The bad news...well, it’s the same news. If whining or throwing tantrums gets your kids something they want, then that’s what they’ll do. You may not think of nagging as a way of rewarding your child for misbehaving, but even yelling can actually encourage the behavior you’re trying to stop, especially if that’s the best way for your child to get your attention. Completely ignoring the problem behavior is usually the most effective way to get it to stop—if you can stick with it long enough.

Many parents put extra pressure on themselves and their kids by believing that learning to obey family rules shapes children’s eventual adult character. This belief may sound normal and reasonable, but in fact, it’s rarely true. No matter how you handle toilet training, your child is probably not going to be wetting the bed at twenty-five. As we discussed in chapter 17, parents do not sculpt children’s personalities nearly as much as our culture leads us to believe. Understanding that your child’s future is not at stake in routine parent–child conflicts, no matter how they turn out, should allow you to relax a bit.
The main effect of parents’ rules and their consequences is to determine how your children behave while they’re living with your family—and when they return home for holiday dinners as adults. Researchers find surprisingly little similarity between an adult’s personality as evaluated by his friends or colleagues and his personality as evaluated by parents and siblings (see box, Myth: Birth order influences personality, in chapter 17).

If you’re not building your child’s character, why bother to enforce rules? There are several good reasons. Learning to abide by sensible restrictions does help children to develop self-control ability (see chapter 13). On the flip side, growing up in a chaotic household full of conflict is a common source of stress that can interfere with the development of resilience (see chapter 26). The most important reason, though, is simply that it’s very difficult to build a good relationship with your children if you’re trapped in a constant struggle over their behavior. Effective discipline allows everyone to put their energy into more important aspects of family life.

The foundation of a smoothly functioning household is warm parent–child relationships (see box, Practical tip: Promoting the development of conscience, in chapter 20). Enjoying fun times together with your child is good for its own sake, of course, but it also helps to keep everyone on the same side, wanting what’s best for each other. The easiest children to discipline are the ones who want to please their parents. Research shows that spouses who have fewer than five positive interactions for every negative interaction are at high risk of divorce. Despite the occasional temptation, parents and children cannot divorce one another, but a similar rule probably applies to distinguishing happy families from unhappy families. If you spend much of your time with your child
nagging and correcting, it’s worth giving some thought to how you can both get more enjoyment out of the relationship. That should improve both the quality of your home life and your child’s behavior.

Broadly speaking, when parents talk about discipline, they want children either to do something or to stop doing something. One of the most effective methods of reducing the frequency of an unwanted behavior goes by the scary-sounding technical name of extinction, which is nothing more than ignoring the behavior. Your child whines; you act as if you didn’t hear her say anything. Once you start that approach, though, you’ve got to hang tough until the child stops whining of her own accord. The very last thing you want to teach your child is that you’ll give in after many hours of persistent whining—which is what a lot of kids end up learning, once their parents’ resistance is worn down.

For that reason, it’s easier to stop bad behavior before it’s become entrenched. You should be very skeptical of the phrase “just this once” when it pops into your head in moments of parenting stress. Frankly, whatever you’re thinking of doing, you’re unlikely to do it only once. So unless you’re prepared to spend hundreds of hours in the car with your baby, don’t use a car ride to put her to sleep. Along the same lines, putting your toddler to sleep by crawling into bed with him is setting yourself up for a lot of nights of teddy bear duty.

The practice of giving your child a timeout derives from studies of extinction in lab animals, where it is called “time out from reinforcement.” As the name suggests, its purpose is to prevent children from getting any form of attention for bad behavior. Even negative attention is still attention. Like rewards, the timeout should immediately follow the behavior, or it will not be effective. Lecturing or touching your child during a timeout
defeats its purpose and will probably act as an attentional reward. Brief timeouts of a minute or two are sufficient to change behavior. If at the end, you briefly praise your child for cooperating with a timeout, he will be more likely to do so again the next time. If your child refuses to take a timeout when asked, try reinforced practice when you are both calm (see box, Practical tip: Getting to good).

In brain terms, extinction is not a form of forgetting, but an additional form of learning. Laboratory studies show that extinction does not directly modify the synapses involved in the original behavior, but instead strengthens the frontal cortex’s ability to suppress the existing activity of those synapses. As a result, the undesired behavior may suddenly pop up again at moments when frontal cortex function is weak—such as when your child is tired or has spent a long time focusing on something, like homework or chores. This outcome is expected and does not mean that the approach has failed, but it might mean that the kid needs a rest. As long as you don’t reward the problem behavior, it will go away again on its own.

Focusing your discipline on preventing negative behavior is ultimately a losing battle. To make changes stick, you also need to promote positive behavior, which is often simply the opposite of the behavior you want to remove. If, for instance, your child is whining too much, it’s not enough simply to ignore the whining; you have to also encourage positive behavior: when your child asks nicely, once, for what he wants, reward him. Yay! If your child does that, even one time, jump on the opportunity to reward the behavior with praise—and if possible, by granting the request. Teaching your child a positive replacement behavior reduces the odds that the extinguished negative behavior will come back.
Consistent, small rewards for small achievements work much better than large rewards for big goals, especially for younger children. After all, you wouldn’t expect your child to learn to read if you paid him no attention until he’d finished his first book. Why set such a high expectation for behavioral self-control? Food and toys are often the first rewards that come to mind, but they are not the most effective. Your approval, expressed enthusiastically and accompanied by a pat on the shoulder or a high-five, should produce more behavior change than a cookie. Children also enjoy earning more control over their lives: the right to decide what’s for dinner, stay up ten minutes later, or pick the destination for a family outing. These all make good rewards for positive behavior.

Explaining exactly what you’d like your child to do is the first step in behavior change—not the last, as many lecture-happy parents seem to believe. In the beginning, you should do whatever it takes to help your child succeed at earning the reward for good behavior, offering a reminder or two (but no more), standing in the room until the job is done, or even stepping in to help (without taking over the whole job). Such interventions provide scaffolding to support the behavior until it can stand on its own, but they should be temporary. If this week’s behavior is better than last week’s behavior, then your efforts are working and you just need to stick with the program.

Parental inconsistency is a common cause of failure or slow progress. So is attempting to change too many behaviors at once. The best way forward is a slow, systematic approach to working on one behavior at a time, while rewarding that behavior every time your child produces it. You won’t make your best decisions in the heat of the
moment, so it’s better to make a plan when you’re calm, rather than trying to bribe your child on the fly with one-off promises and threats, which are notably ineffective.

You’d be superhuman if you were able to stay calm through everything your kids can throw at you. The occasional bout of yelling isn’t going to do them any lasting damage. If reacting in the moment becomes your habit, though, you may be shortchanging your children and yourself. The next time you feel your temper getting the better of you, try giving yourself a brief timeout.

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Practical tip: Getting to good

It’s more effective to reward your child for being good than to punish him for being bad. But how can you reward him if he won’t do what you want him to do? There are two options, and you can use both of them together.

The first option is to reward him for being a little bit good. Say that you want him to pick up all his toys before dinnertime, but you can’t reward him for that because he never does it. Instead of turning the interaction negative by nagging or giving up on the whole idea because it’s too much hassle, set the bar lower at first. The first day, if he picks up a single toy, praise him immediately and enthusiastically, telling him exactly what part of his behavior made you so happy. For young kids, there is no way to go too far with this strategy. You should sound as pleased as you would if he’d just bought you a
new car. Over the next week or two, gradually set the bar higher, waiting until he’s done a bit more before telling him how well he’s doing, until he’s picking up all the toys by himself. Don’t forget to continue to appreciate the good behavior after it’s established.

The second option is to reward him for good behavior in a practice run. This approach is especially helpful for situations that are difficult because either you or your child is too emotional for calm interaction. For example, if your morning routine is too stressful to allow time for behavior training, pick a moment when both of you are in a good mood and suggest that you play a game. If she successfully pretends to get her clothes on and come downstairs for breakfast, then you’ll give her a small treat. A few trial runs should pave the way for offering a similar reward for the real thing. For more details on using this approach correctly, see The Kazdin Method for Parenting the Defiant Child. In spite of the title, this book provides lots of helpful information for all parents on how to handle ordinary disciplinary challenges.

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Myth: Praise builds self-esteem

In the 1970s and 1980s, low self-esteem was held responsible for almost everything that could go wrong in a person’s life, from fear of intimacy to child molestation to violence.
As a result, government programs and private foundations worked hard to make children feel good about themselves. The idea was that because people with high self-esteem are happier, healthier, and more successful, encouraging the development of self-esteem would improve society.

Unfortunately, the research behind this belief suffered from many flaws. The most obvious was the problem of reverse causation: success makes people feel good about themselves, so of course successful people are confident. Another problem is that people with high self-esteem say a lot of positive things about themselves (that’s pretty much the definition of high self-esteem), but many of those assertions are objectively incorrect. For example, people with high self-esteem rate their own intelligence as high but do not score better than average on IQ tests. In the end, interventions to improve self-esteem failed to improve academic achievement, job performance, or other objective measures of success.

The self-esteem movement had strong effects on parenting practice in the U.S. and elsewhere—but not necessarily good ones. Children do not benefit from routine empty praise, like the cries of “Good job!” that ring out over modern playgrounds. Indeed, when an adult praises them for small accomplishments, children over the age of six perceive it as a slight: they see the praise as reflecting the adult’s low expectations. Comparing your child to other children—even favorably—is also counterproductive.

Praise is most effective when it is specific and refers to something that your child can control, such as his own actions. “You’re so smart!” doesn’t give your child any hint of what to do next time and may actually reduce perseverance (see chapter 22), while “Wow, you really worked hard on that math homework!” carries a clear message about the desired behavior. Parents who communicate high but achievable expectations, along
with detailed guidance about how to get there, give their kids the tools to achieve real success in the world—which turns out to be the best route to true self-esteem.
A Tough Road to Travel: Growing Up in Poverty

Growing up under conditions of deprivation can damage children’s brains. This is an exception to the general principle we have expressed throughout this book that most children are resilient, and that variations in normal (“good enough”) parenting do not appear to have a strong influence on how they turn out as adults. This chapter is about the other side of the coin: what happens to children whose developing brains match themselves to an environment that does not encourage them to express their full potential. After all, even dandelions can’t grow in the desert.

Where your children grow up is one of the most critical factors in their development. When you move into a new house or apartment—or another country—you’re determining not only your children’s schools, but also their neighborhood and the characteristics of the group from whom your children will select their friends. Children learn a lot from other kids and from the culture by which they are surrounded (see chapters 17 and 20). It’s hard to raise children to reject the attitudes and assumptions of their peers, as parents have discovered everywhere from religious communities to inner-city neighborhoods. This is one of the many reasons that children start life at a disadvantage when they grow up in places with high unemployment, unsafe streets, and poor education.

Poverty itself isn’t exactly the problem, unless children are actually starving, which is rare in developed countries. The risks instead come from conditions that are made more likely by poverty, in particular growing up in a chronic state of fear and/or
stress. Poverty is stressful due to a combination of economic insecurity (inadequate living conditions, frequent moves), disorganized households and harsh parenting (common side effects of parental stress or addiction), and social subordination (being treated as inferior because of social class and/or race). Heightened fear and anxiety can result from living in a high-crime neighborhood, food insecurity, and parental mistreatment (again more common when parents are stressed).

Inadequate parenting can and does occur in any segment of society, of course. Indeed, the middle class, which is the country’s biggest economic group, contains the largest number of chronically stressed or threatened children, as well as the largest number of children with behavioral problems. In addition, some especially resilient people who grow up in very difficult conditions become highly successful and happy adults. Even so, poor children grow up in environments that statistically increase their risk of a variety of disorders. Indeed, some of these “problems,” such as chronic anxiety or early reproduction, may actually constitute adaptive responses to insecure living conditions (see chapter 26).

Socially and economically disadvantaged people are much more likely than middle-class people to suffer from medical, emotional, cognitive, and behavioral problems. Socioeconomic status (SES) is an umbrella term for the resources that people have available to them relative to others in their society. At minimum, it includes income, occupation (with associated prestige), and education, each of which can be broken down into more detailed measures. Across a variety of countries with different social systems, lower SES predicts substantially increased risk of a broad range of medical problems, including heart disease, respiratory disease, diabetes, and psychiatric conditions. As
family SES decreases, children have increased risk of low birth weight, premature birth, infant mortality, injury, asthma, and various chronic conditions, including behavioral disorders. Community SES also influences child outcomes in studies that control for family SES.

Health and SES are related in linear fashion across the full range of SES—the relationship is not merely a consequence of very poor health at the bottom of the scale. Overall, the lower people’s SES, the earlier they are likely to die, with a difference of decades in some countries between the highest- and lowest-SES groups. The gradient is steepest at the bottom, though, with the biggest step between poor and working-class groups. These differences are large. In the U.S., adults with the lowest SES are about five times more likely to report having “poor” or “fair” health than the highest-SES adults.

SES is closely connected with health even in countries with equal access to health care and for diseases that medical care cannot prevent, such as juvenile diabetes and rheumatoid arthritis. So it is not primarily due to differences in medical care—though such differences can make the problem worse. Only part of this discrepancy (about one third in one study of British government workers) can be explained by lifestyle differences, such as high rates of smoking and drinking, poor diet, and infrequent exercise among low-SES groups. Lung cancer is still more prevalent in low-SES than high-SES groups even when comparing people who smoke the same number of cigarettes, so there must be some problem beyond lifestyle choices.

The relationship between SES and health may be attributable to the effects of stress, which can damage the brain and the rest of the body (see chapter 26). In many species, life at the bottom of the dominance hierarchy involves chronic stress and a
poorly functioning biological stress response system. You could imagine that animals with poor stress responses are just more likely to become subordinate, but researchers have found that social subordination occurs first and causes poor stress responsiveness, and not the other way around.

It can be most stressful to be a high-ranking animal in some species or under special circumstances, for instance when dominance can be maintained only by fighting a lot. But in people, it’s usually the low-ranking members of society who experience the most stress. Social status is so important to people that reducing the power or status of middle-SES adults in an experimental situation decreases their ability to concentrate, ignore distractors, and inhibit inappropriate behavior. We speculate that chronically low social status may have a similar effect on low-SES children. In one study, by age ten, children in Montreal already showed a sharp relationship between SES and cortisol, with blood levels twice as high in the lowest-SES children as in the highest-SES children.

How we interpret the circumstances of our lives also has a strong effect on our stress responses (see chapter 26). Low-SES people not only experience more chronic stresses and negative life events, but they also experience ambiguous events as being more stressful, compared to higher-SES people. When people are asked to give their own position in society on a drawing of a ten-rung ladder, their ranking is a stronger predictor of health than their actual SES. People who are satisfied with their standard of living and feel financially secure are healthier, regardless of their actual income, occupation and education, than people who are unsatisfied and anxious about the future. Along the same lines, countries, states, or cities with greater income inequality have steeper gradients of SES versus health. This may be because income inequality interferes with the feeling of
community, which provides many types of social support to counteract stress. Increased crime also correlates with income inequality—again, better than with absolute poverty. So the existence of strong inequality in society may be a major driver of stress.

Which part of children's brains are damaged by deprivation? We know from animal studies that chronic stress can cause structural changes in the hippocampus and amygdala (see chapter 26). In people, subjective SES and other sources of chronic stress are linked to reduced hippocampal volume. Long-term memory, which depends on hippocampal function, is impaired in low-SES populations. In experimental animals, chronic stress can cause neurons to die, prevent new neurons from being born or surviving, and cause dendrites to become less complex (a change that is reversible) in the hippocampus. Scores on a variety of language tests also vary strongly with SES, perhaps due to the less complex language environment provided by low-SES parents (see chapter 6).

In people, the perception of low SES is associated with stronger activity in the amygdala in response to threats. It’s understandable: if you believe that you are low on the totem pole, it’s natural to feel vulnerable, and therefore respond strongly to danger. Indeed such increased vigilance may reflect a sensible reaction to real dangers in the environment. The amygdala is important for rapid processing of events that induce fear and other emotions (chapter 18), and it is extensively interconnected with the stress response system. Salivary cortisol evoked by uncontrollable social stressors correlates with reduced activation of the hippocampus and amygdala in functional imaging studies.

Across the lifespan from infants to adults, low SES predicts decreased executive function, perhaps because the environment offers fewer opportunities to strengthen these
abilities through practice. The medial prefrontal cortex (including the anterior cingulate and orbitofrontal regions) is an important inhibitor of the stress system. In experimental animals and people, it can be affected by chronic stress. The prefrontal cortex is involved in working memory and planning and organizing behavior (aspects of executive function), and it is also necessary for learned suppression of fearful reactions to situations that are no longer dangerous. People who perceive themselves as having low SES have reduced volume in one part of the anterior cingulate cortex. One promising intervention for low-income preschool children, Tools of the Mind, focuses on promoting behaviors that depend on the prefrontal cortex (see box, Practical tip: Imaginative play can improve self-control, in chapter 13).

The causes and possible solutions to the SES–health gradient are hotly debated, within the scientific community as well as in society. The key problem for research is that people aren’t randomly assigned to be poor, so we can’t draw conclusions about causality by comparing the characteristics of low-SES and high-SES people (see box, Why epidemiology is hard to interpret).

Do people develop problems because they’re disadvantaged? Or do they become (or remain) disadvantaged due to poor health or other problems? There is evidence in favor of both positions. The health of adopted children is best predicted by their adopted parents’ income, not their biological parents’ income, suggesting that family income can influence health independently of genetics. On the other hand, the adult income and (particularly) education of adopted children does depend partly on their biological parents’ characteristics.
It’s important to remember that these two classes of explanations aren’t mutually exclusive. Indeed, the most likely relationship between poverty and achievement is a vicious cycle, in which starting life with few resources leads children to develop a variety of problems, which then make their life situation worse, reducing their resources (and their children’s resources) still further.

Some of the relationship between SES and cognitive achievement may be attributable to exposure to environmental hazards, more common in poor neighborhoods, that can cause substantial, lasting impairment in brain function. Children exposed to lead before or during elementary school age have lower IQs and impulse control, as well as higher aggression and delinquency, compared with children of the same SES. All these problems persist through adulthood. Mercury exposure also reduces IQ, along with attention, memory, and language development.

Children who live in noisy environments, such as near airports or highways, are delayed in learning to read compared with other children of the same SES. Chronic noise exposure also causes deficits in attention and long-term memory, perhaps because it is known to increase stress hormone levels. Crowded or chaotic environments (at home or at school) impair cognitive development and academic performance and increase psychological distress in both parents and children, again independent of SES. These environmental conditions are all common in the lives of low-SES children and often occur together.

Growing up in a low-SES family predicts poor health even for children whose SES improves in adulthood. For example, in a group of nuns who had been living together since early adulthood, disease risk and longevity still varied depending on their
education (whether or not they had gone to college). For more than 50 years, the nuns had
shared the same meals, the same housing conditions, and a very similar lifestyle, but the
traces of their early experiences were still substantial, with educated sisters living an
average of 3.28 years longer than less educated sisters. In general, people whose SES
improves later in life gain less advantage from the change than people whose SES
improves in childhood.

Children whose families move out of poverty improve in some areas but not
others. One study followed 1420 poor children in North Carolina from 1993 (at ages nine
to thirteen) through 2000. American Indian families were more than twice as likely as
non-Indian families to be below the poverty line when the study began. In 1996, a casino
opened and began to distribute some of its profits to every person on the reservation.
Children whose families moved above the poverty line showed a 40% decrease in
antisocial behaviors during the study, while children whose families remained poor
showed no change in antisocial behaviors. In contrast, moving out of poverty had no
effect on symptoms of depression and anxiety, though children who had never been poor
had fewer symptoms than always-poor or ex-poor children.

If indeed poverty leads to a vicious cycle like the one we’ve described, then it
should be easiest to break that cycle in young children, before they fall too far behind
their peers. Intensive preschool enrichment programs can have positive effects that last
into adulthood, substantially increasing the odds of a poor child graduating from high
school, finishing college, getting a skilled job, and owning a home. These programs can
also reduce the likelihood that a child will need special education or repeat a year of
school.
Mostly these effects do not depend on increasing children’s IQs. Instead the positive outcomes seem to stem from improvements in social competence, including perseverance and motivation (see chapter 13) and emotional well-being. The programs that produce these results tend to be extensive, long-lasting interventions, which require a considerable commitment from both families and funding agencies. These programs are often still cost-effective for society in the long run, if they reduce the likelihood that children will need special education or repeat a year of school or that they will receive welfare payments as adults.

Intervention is difficult for exactly the same reason that it is important: because it requires interrupting the developing brain’s strong tendency to match itself to the local environment. As we’ve discussed throughout this book, evolution has made that matching process resilient and hard to disrupt. If a child’s environment is toxic, though, it can do more harm than good. Fortunately, the reward for intervening is also large—turning that child into an adult who can function successfully in a safe and productive world, like the one we all want for our children.

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Did you know? Why epidemiology is difficult to interpret

The tools of epidemiology, appropriately, are best suited to the study of epidemics, which are caused by a single factor (a germ). The same tools are increasingly used to study
conditions like heart disease, which have far more complex causes. Epidemiological studies of this kind are far more difficult to interpret and should be approached with a skeptical eye.

In a typical epidemiology study, scientists collect data on a large group of people for years and then attempt to correlate risk factors, such as excessive drinking, with health outcomes, such as deaths due to injury. Studies of this sort have serious limitations, which are rarely taken into account in your local newspaper or when health agencies make lifestyle recommendations based on their findings.

It is almost impossible to draw reliable conclusions about cause and effect from correlation data. One pitfall is reverse correlation. For instance, obesity is correlated with poverty. Does poverty lead to poor diet and lack of exercise, which then cause obesity, as is commonly assumed? Or might obesity cause poverty due to wage discrimination against fat people? Another pitfall is that an additional (unstudied) factor might cause both parts of the correlation. Harsh parenting is correlated with later antisocial behavior. Does that mean harsh parenting causes antisocial behavior? Or could it be that some parents pass along a genetic tendency to antisocial behavior to their children, who then are likely to misbehave, evoking harsh parenting, even from adoptive parents? We did not invent these two examples. In both cases, there is good evidence for the second interpretation, at least as a partial explanation of the observed correlations.

Making interpretation even more difficult, risk factors tend to travel in packs. Postmenopausal women taking hormone replacement therapy have fewer heart attacks, but they are also less likely to die from homicide or accidents—effects that are unlikely to be caused by hormones. The explanation is that women who take hormone

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replacement therapy typically have a variety of healthy characteristics: compared to other women, they pay more attention to their health, exercise more, and are richer, more educated, and thinner. On the other side of the fence, as discussed in the main text, poor people tend to be less educated, get poor medical care, be exposed to more toxins, and to have higher rates of smoking and obesity. When the risk factors are correlated with each other, it becomes very difficult to sort out causes from accidental “bystander qualities,” even if the correlations are strong.

Epidemiology can be very useful. The link between cigarette smoking and lung cancer was established through this technique because the correlation is large (heavy smokers have 20 or 30 times more risk than nonsmokers) and the rate of lung cancer in nonsmokers is low. Many side effects of approved drugs have also been identified by epidemiology. But most lifestyle effects are small to moderate, and most of the common diseases in developed countries are influenced by multiple factors. Under those conditions, epidemiology can only generate hypotheses that must be tested by other means. Such studies should be interpreted with care and caution.