Beverly is eight months into her first pregnancy, and she is very excited about becoming a mom. She has been avidly reading magazine articles about infant brain development—she wants to help her baby get off to the best start possible. From what Beverly has read, it seems that the baby’s brain gets “wired” during the first three years after birth. She wonders how this happens and what she can do to make sure her baby doesn’t miss important opportunities during the first years. One of her friends had a baby recently and frequently played classical music around her baby. Her friend says that Mozart’s music is supposed to help babies wire their brains for math and science. Can this be true? Can music and other sounds possibly have any effect on a child’s development? Also, Beverly has heard that other mothers enroll their infants in yoga classes in which they stretch and exercise their babies’ muscles. The sessions sound like a fun way to bond with infants. But will exercising the babies’ arms and legs and helping the babies bend their trunk muscles really help the babies to sit up, crawl, and walk? And what about some of the more basic questions, such as nutrition? Is breastfeeding better than using infant formulas? If Beverly chooses to breastfeed her baby, what are the recommendations about when she should wean her baby from the breast?

Like most new and prospective parents, Beverly is eager to support her baby’s development. What would you suggest? After studying this chapter, you should be able to give Beverly sound advice. Using at least a dozen research findings or concepts, you should be able to help Beverly sort out fact from the fiction and get her baby off to a great start.
Infancy is an exciting time that contains an impressive run of *firsts*: the first time parents see their baby; the first cuddles, first feeding, and first smiles; and, by the end of the first year, the first steps and the baby’s first spoken words. Infants begin life completely helpless and dependent on other people for care. By their second birthday, they are walking, running, climbing, and talking and have developed a sense of autonomy and independence from their parents and caregivers. Most babies end their toddler years with a solid foundation for moving into early childhood. Given the tremendous pace of change during the infant and toddler years, you can understand Beverly’s desire to get her baby off to the best start.

In Chapter 3, you learned several things parents can do to avoid teratogens, prevent birth defects, and have healthier pregnancies. In this chapter, we focus on physical development during the first 2 years after birth. We begin by looking at infants who are at risk because they were born too early or too small. We also look at infants who don’t survive their first year after birth. What lessons can be learned from these cases? Next we look at the typical patterns of physical growth and at nutrition during infancy and the toddler years. We also look at research on brain development. Neurons in the brain form complex networks of interconnections that allow the brain to process information and govern behavior. How important are the early years in the formation of the brain’s structure and neural connections? After discussing brain development, we will explore the sensory capabilities of infants—how well do babies see and hear after they are born, and how do these abilities develop in the early months? We end the chapter by turning to motor development, starting back in infancy with babies’ first reflexes. As children grow in size, they also learn to control their muscles, and we review some of the major motor development milestones that we see during these first years. Throughout the chapter, you can see how these developments in physical size, shape, and coordination lay the foundation for the other types of development we cover in the next chapters.

**Infants at Risk: Prematurity and Infant Mortality**

Take a look at the premature baby in Figure 4.1. Prematurity is one of the biggest threats faced by infants in our country. Only 11 percent of babies are born preterm, but these babies account for up to 67 percent of infant deaths in the United States (McCormick, 1985; Nathanielsz, 1992). Although the United States ranks first in the world in health technology, it ranks 17th among industrialized countries in the rate of low-birth-weight births, often associated with preterm birth (Children’s Defense Fund, 2001), and the rates of both preterm and low-birth-weight births are increasing. The incidence of preterm birth rose from 9.4 percent in 1981 to 11.6 percent in 2000. The rate of low-birth-weight births now stands at 7.6 percent, the highest level since 1973. The statistics for some groups within the U.S. population are even grimmer. For example, African American women have a low-birth-weight rate of 13 percent and a 17.3 percent prematurity rate; both of these percentages are nearly double those of whites (Matthews, Menacher, & MacDorman, 2002).
Clearly, there is reason for concern. But what do we know about the causes and effects of preterm birth and low birth weight? More important, what have we learned about how to prevent these serious problems?

As you study this section, ask yourself these questions:

■ What are the differences among preterm birth, low birth weight, very low birth weight, and the designation “small for gestational age”?

■ What are the risk factors and possible effects associated with preterm and low-birth-weight babies?

■ What is the relationship between prematurity and infant mortality?

■ How can the rates of prematurity and infant mortality be reduced?

What Is Prematurity?

There is sometimes confusion about the meaning of the term premature. A full-term pregnancy is about 38 to 40 weeks long, and the average weight for full-term babies is 7 1/2 pounds. Birth within two weeks of the expected due date (2 weeks early or late) is considered full-term. A preterm birth is birth before 37 weeks’ gestation, or more than 3 weeks before the expected due date. A baby who is born weighing less than 5 1/2 pounds is considered to have a low birth weight. Newborns who weigh less than 3 1/2 pounds are classified as being at very low birth weight and are at even greater risk for serious problems. Infants who are small for gestational age (SGA) are those who are below the 10th percentile of birth weight for their gestational age (i.e., among the lightest 10 percent of babies born at a particular number of weeks since conception).

Why bother to distinguish among all these classifications? The reason is that their outcomes differ. In other words, different babies face different levels of immediate and long-term risk. Although preterm birth is certainly not good, many babies who are born preterm are at an appropriate level of development and weight, given their length of gestation. As long as birth weight is not too low and is appropriate for the gestational age—and provided that the infant receives appropriate treatment—many preterm babies go on to develop normally. Babies who are SGA, however, are particularly worrisome. Something has kept them from growing as well as they should have, given how long they were in the uterus. It is difficult to know what has gone wrong in these cases, but poor prenatal nutrition of the fetus is a likely factor. Perhaps the maternal diet was poor, there were problems with the placenta, or problems in the fetus prevented it from being able to utilize nutrients. As you read in Chapter 3, teratogens such as alcohol and cocaine also retard fetal growth, causing babies to be born small for their gestational age. SGA babies fare much worse than other preterm infants. They show greater rates of infection, brain damage, and death during their first year and are more likely to show long-term problems in academic achievement (Copper et al., 1993; Korkman, Liikanen, & Fellman, 1996).

In about half of the cases of preterm birth and low birth weight, the causes are not known. Research has identified numerous risk factors, however. Table 4.1 lists some of these along with the most common effects of prematurity.

If you look closely at the list in Table 4.1, one of the most striking things you will notice is that several of the risk factors are controllable. This is good news: It means that it might be possible to reduce the risk of serious birth complications to some extent. That might not be a simple task, however. For example, lack of prenatal care consistently correlates with preterm birth and low birth weight. The reason for this correlation could be that detection of early warning signs or high-risk behaviors cannot be addressed if the pregnant woman is not receiving regular prenatal monitoring. High-quality preventive
prenatal care is available, but many women who stand to benefit from this kind of care either do not have access to it or do not use it. To find out what it is like to have a baby who is very premature, read the Personal Perspective box entitled “Meet the Parents of a Very Premature Baby.”

Infant Mortality

The term **infant mortality** refers to deaths that occur before the age of 1 year. In spite of the medical community’s best efforts, many infants die each year. As you can see in Figure 4.2, the United States does not rank well when compared to other nations.

Think About Beverly . . .

Describe three or four things that Beverly could have done during her pregnancy to reduce her risk of having a premature baby.

### Table 4.1 Risk Factors and Effects of Premature Births

<table>
<thead>
<tr>
<th>RISK FACTORS WITH PREMATURE BIRTH</th>
<th>EFFECTS OF PREMATURE BIRTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of prenatal care</td>
<td>Increased risk of infant mortality</td>
</tr>
<tr>
<td>Vaginal infection</td>
<td>Increased risk of difficulties in</td>
</tr>
<tr>
<td>Short interval between birth and subsequent pregnancy (less than 3 months)</td>
<td>• respiration (e.g., respiratory distress syndrome, apnea, anoxia)</td>
</tr>
<tr>
<td>Malnutrition</td>
<td>• circulation, leading to brain hemorrhage</td>
</tr>
<tr>
<td>Cigarette smoking</td>
<td>• feeding, due to poor sucking ability</td>
</tr>
<tr>
<td>Drug use (e.g., alcohol, cocaine)</td>
<td>• social interactions (difficult to rouse, difficult to calm, ambiguous interpersonal signals)</td>
</tr>
<tr>
<td>Maternal age (especially younger than age 15)</td>
<td>• regulating sleep, awake, alert cycles</td>
</tr>
<tr>
<td>Marital status (unmarried)</td>
<td>Increased longer-term risk of</td>
</tr>
<tr>
<td>Maternal illness affecting blood vessels (e.g., diabetes, high blood pressure)</td>
<td>• cerebral palsy</td>
</tr>
<tr>
<td>Membership in certain ethnic groups</td>
<td>• lowered academic achievement, lowered IQ</td>
</tr>
<tr>
<td>Genetic background and family history</td>
<td>• attentional problems</td>
</tr>
<tr>
<td>Personal history of spontaneous abortion or preterm labor</td>
<td>• poor language development</td>
</tr>
<tr>
<td>Multiple gestations (i.e., twins, triplets, etc.)</td>
<td>• motor and perceptual difficulties</td>
</tr>
<tr>
<td></td>
<td>• specific learning disabilities</td>
</tr>
</tbody>
</table>

infant mortality

Deaths that occur between birth and 1 year of age.

![Figure 4.2 • Infant Mortality](image) This graph shows infant mortality rates for selected nations. All data are for the year 2000 except the data for the United States, which are for 1999. (Organisation for Economic Cooperation and Development, 2002.)
Meet the Parents of a Very Premature Baby

Kim Powell and Larry Sikkink
Decorah, Iowa
Parents of Senia, born at 28 weeks’ gestation weighing 1 pound, 15 ounces

When did you learn that your baby would be premature? What were your first thoughts? Do you know what caused the prematurity?

Kim: I experienced a healthy pregnancy up to my sixth month. Then, at a prenatal exam, the doctor found I had high blood pressure as well as protein in my urine. The next day I was admitted to a hospital with a neonatal intensive care unit (NICU). At 28 weeks’ gestation, on the way to my first ultrasound, I began feeling light-headed and felt a sudden pain in my upper abdomen. I began throwing up and had a severe headache. The doctor said I had to have an emergency cesarean section if my baby and I were to live. I had HELLP syndrome (hemolysis, elevated liver enzymes, low blood platelets). There is no known cause or predictor for HELLP syndrome, and some mothers and babies die from the complications. I knew my baby would be born prematurely, but I was too sick to realize what that meant. Immediately after her birth, Senia was whisked away to the NICU, intubated, placed on a warming table, and connected to an IV feeding tube and breathing and heart monitors. My husband was still on the 90-minute drive from our home. Senia’s left lung collapsed after birth, requiring three days of lung massage therapy. At 2 weeks she was moved to an incubator, where she stayed for 4 weeks.

Larry: Senia had been delivered about 15 minutes before my arrival. The NICU team was attending to her, and I was told I would be allowed to see her in about 30 minutes. I was shocked. How could I be the father of a baby girl already? A NICU doctor assured me that given time, care, and love, our daughter’s chances for survival were very good.

Has your baby needed or used any special services? What is your baby like today?

Kim: At 4 pounds and 1 ounce, after seven weeks in the NICU, Senia came home on an apnea and bradycardia monitor. For 2½ months, Senia had episodes in which her breathing would stop and her heart rate would lower. She also had several bouts of pneumonia in her first year. It took 2 years for Senia to perform like others her age, but she is now all caught up. She is tall for her age and is at the fiftieth percentile in weight. Cognitively, she tests above age level. Senia started kindergarten at age 5 and loves writing, books, music, and dancing.

What advice do you have for other parents who may have a premature or low-birth-weight baby?

Kim: Educate yourself and read about other premature babies. Kim Wilson and I wrote Living Miracles: Stories of Hope from Parents of Premature Babies (Griffin Trade Paperbacks) so parents could share their situation. Above all else, though having a preemie is very stressful, parents should try to focus on the baby and enjoy every minute of watching the baby develop.

What can parents do to reduce their risk of having a premature baby? Which risk factors can they control in their lives?

industrialized countries with respect to infant mortality, even with our sophisticated medical technology. The African American infant mortality rate in 2002 was 13.8, almost twice the overall rate of 7.0 deaths per 1,000 live births. The rate for whites and Hispanics was about 5.7 deaths per 1,000 live births (National Center for Health Statistics, 2005). Infant mortality is related to poor or absent prenatal care, teenage pregnancy, poor nutrition, risky health behaviors during pregnancy, and higher rates of prematurity and low-birth-weight births. Experts agree that the steps that would reduce rates of prematurity and low birth weight would also reduce the rates of infant mortality.
Having a Healthy Baby

Although it is not possible to prevent all of the problems that newborns face, one thing is for certain: Access to and appropriate use of good-quality prenatal care results in healthier babies. In prenatal visits, practitioners can effectively identify and address many risk factors for problems during pregnancy. Again, these include poor nutrition; smoking, alcohol use, and drug use; exposure to environmental toxins; and maternal infections, illnesses, and pregnancy-related conditions that put the fetus at risk.

Another important component of prenatal care is education. Education can increase the mother’s knowledge of how the baby is developing, what she and her partner can do to improve their odds of having a healthy baby, and what options she has for labor and delivery. Participation in prepared childbirth classes and the supportive involvement of the woman’s partner and family can enhance this education. Further, making healthy lifestyle choices even before a woman becomes pregnant can often avert some birth complications. Although the medical community has made astonishing strides in the treatment of many problems suffered by newborns, it is far more effective and desirable to prevent such problems from happening in the first place.

We have some good news to report on this point: More women are now getting prenatal care. Overall, in 2003, 84 percent of pregnant women received prenatal care, and this was up from 76 percent in 1990. The percentage of Hispanic and African American women who received care increased from about 60 in 1990 to nearly 77 percent in 2003 (National Center for Health Statistics, 2005). Although there is a way to go before all women have early prenatal care, rates of care are clearly improving.

Think About Beverly…

How would Beverly benefit by receiving good prenatal care?
List several specific risks that might be avoided or reduced if she had good care.

Let’s Review…

1. Preterm births are defined as all births that occur before _____ weeks of gestation.
   a. 40
   b. 38
   c. 37
   d. 35
Growth of the Body and Brain

Whether they are full-term and healthy or premature and small, most babies grow very rapidly during the first year. In this section, we focus on physical growth. We look first at changes in height and weight, and then we discuss the importance of breastfeeding and other issues related to nutrition. We continue by exploring the intricate processes related to the growth of the brain and nervous system.

As you study this section, ask yourself these questions:

- What changes occur in height and weight during the infant and toddler years?
- Is bottlefeeding just as nutritious as breastfeeding? Why or why not?
- What are the main parts of the brain, and what are their basic functions?
- How does the brain shape the complex neural circuits that are necessary to process information and organize behavior?

Physical Growth

At birth, the average newborn weighs 7½ pounds, males weighing about half a pound more than females. Newborns lose a slight amount of weight in the first days after birth. During these early days, newborns spend almost all of their time sleeping; also, it takes time for newborns to adjust to the process of feeding. If they are breastfed, their mothers’ milk production is low the first few days. The main benefit of the initial breastfeedings is to pass antibodies from the mother’s milk to the baby. These antibodies will help the newborn fend off illnesses and infections. After the mother’s milk production increases and the newborn adjusts to life outside the womb, weight returns to birth levels—usually by about 2 weeks of age.

Figure 4.3 graphs weight and length gain across the first three years after birth. As you can see, babies double their birth weight by the time they are 5 months old. Changes in length are even more rapid. On average, newborns measure just under 20 inches at birth.
20 inches in length and add another 50 percent in their first year. By 2 years of age, children have already attained about half of their adult height.

Feeding and Nutrition

Nearly all health officials agree that human breast milk provides the best form of nutrition for most infants. Considering the scientific evidence, the American Academy of Pediatrics (2005) noted that human milk is better than any other form of infant formula or supplement for the general growth, health, and development of infants. Breast milk provides all of the nutrients, calories, protein, and fat that young infants need, in a balance that is easy for new babies to digest.

During the first few days of breastfeeding, the mother’s milk contains a high concentration of colostrum, a thick, yellowish substance that contains important antibodies.

Newborn babies average about 20 inches in length and weigh an average of 7½ pounds. Children reach half of their adult height by the time they are 2 years old.
antibodies that are passed to the newborn baby. These antibodies offer infants protection against a variety of infections, viruses, and illnesses. After about three days, mothers produce a higher volume of milk, and the milk becomes thinner and lighter in color. Although the milk is now not as concentrated with colostrum, important antibodies continue to be passed from the mother to the baby for the duration of breastfeeding.

Babies who are breastfed are at lower risk for a variety of infant diseases and illnesses, including diarrhea, respiratory infections, ear infections, diabetes, lymphoma, and sudden infant death syndrome (American Academy of Pediatrics, 2005). There are also important health benefits for the mother, which may include faster recovery of the uterus, less blood loss after delivery, earlier return to prepregnancy weight, reduced risks of ovarian and breast cancers, and a delay in the next ovulation (which can help to increase the spacing to the next pregnancy). The academy noted that by improving the health of both infants and mothers, breastfeeding can reduce health care costs and the number of days parents miss from work to care for themselves or sick infants.

The academy also concluded that

- breastfeeding should begin as soon as possible after birth, preferably within the first hour;
- during the first six months after birth, breast milk is usually all that is needed to provide nutrition for optimal growth and development for the infant (water, juice, and other supplements are not necessary these first six months for most infants who are breastfed);
- from 6 to 12 months of age, iron-rich solid foods should be introduced gradually;
- breastfeeding should continue at least until the infant is 12 months of age and as long thereafter as the infant and mother desire.

Infants weaned before 12 months of age should receive iron-enriched infant formula (not cow’s milk). Breastfeeding might not be convenient when mothers are working or are away from their babies for long periods during the day. In many of these situations, mothers can still pump their breast milk and store it so it can be given to infants by bottle.

How many babies are breastfed? Results from a recent U.S. survey are presented in Figure 4.4. As you can see, fewer than half are being breastfed at 3 months, and well less than one quarter at 12 months. Younger mothers and mothers who are African American are less likely to breastfeed their babies. Although this is not shown in the figure, the survey also found that mothers are more likely to breastfeed when they are married, have more education, or have higher family incomes. They are also more likely to breastfeed when their choice is supported by their husbands or partners. In one recent study, mothers’ choices to breastfeed were related more strongly to what their partners thought they should do than to the mothers’ own attitudes or intentions about breastfeeding (Rempel & Rempel, 2004). Although the choice is ultimately the mothers’, it is clear that partners play an important role in supporting women’s choices to breastfeed or bottle-feed.

Worldwide, there is a push to increase the rates of breastfeeding, especially in poor countries, where many infants are malnourished. In the poorer areas of central Africa, for example, only about 5 percent of infants under 4 months of age are exclusively breastfed, while in the more affluent countries of Egypt and Saudi Arabia, the rate is just over 60 percent (World Health Organization, 2003). A challenge in poorer countries is to provide proper nutrition to women who are pregnant and nursing so that they can produce sufficient breast milk. When babies are bottle-fed, a challenge is to
educate mothers to mix formulas properly so that they use clean water and do not try to stretch their supply by watering down the infant formula. Watered-down formulas do not provide infants the calories, nutrients, and other nutritional elements they need for healthy growth.

Although breast milk is the healthy choice for most infants, there are a few situations in which mothers are advised to use infant formulas instead of breastfeeding. Some infectious diseases can be spread through breast milk. Mothers with HIV, for example, should not breastfeed their babies. Mothers with conditions such as tuberculosis, hepatitis B, and chickenpox should consult their doctors before breastfeeding. Mothers who are receiving medications for high blood pressure, cancer, anxiety, depression, and even migraine headaches should also consult their physicians because harmful products from some of these medications can be passed to the infant through

Breastfeeding rates are low in many of the poorer nations of the world. When mothers use infant formulas, a challenge is to find sanitary water to mix with the formula. Mothers sometimes dilute the formula to try to stretch their supply, but this deprives infants of the calories, nutrients, and other nutritional elements they need.
breast milk. In other cases, infants who inherit certain metabolic disorders (e.g., phenylketonuria or galactosemia) might require special formulas designed to help them avoid problems with their disorders. Finally, in Chapter 3, we mentioned that polychlorinated biphenyls (PCBs) are toxic industrial chemicals that can leach into groundwater and enter the food chain. These chemicals are absorbed by fish and eventually consumed by some pregnant and nursing mothers. The chemicals then pass to infants through breast milk. Exposure to PCBs has been linked to a variety of neurological and cognitive impairments in infants. This is just one of many reasons why a clean and healthy environment is important.

Except for conditions such as those that we just described, infants should receive only breast milk for the first four to six months. After that, baby cereals, mild-flavored vegetables, and fruits are good choices for first solid foods that can be added to the diet. Avoid foods that are high in sugar, fat, or salt. Also foods should be soft or diced small enough to avoid choking. Toward the end of the first year, infants enjoy finger foods such as cheese, plain crackers, cooked vegetables, and sliced fruits. By 2 years of age, most toddlers are having meals at the table, eating most of the same foods as the rest of the family. Although the toddlers might still be breastfeeding, breast milk is no longer their main source of calories and nutrition.

Structure of the Brain and Nervous System

The brain and nervous system are the structures that give rise to all of our thoughts, emotions, and behaviors. The most complicated organ in the body, the brain is one of the first structures to form when tissue differentiation begins in the embryo, and at birth, the brain and head are already more than half their adult sizes. In Figure 4.5, you can see that the head represents one fourth of the newborn’s total length but only one eighth of the adult’s height. The cephalocaudal (head-to-tail) pattern is evident here. At birth, the brain and head region are much further along in growth and development than the trunk and legs are.

The study of how the brain grows and forms the intricate web of connections necessary to code our thoughts, memories, and motor actions is one of the most fascinating areas of science today. How does the brain grow and form internal connections? If the proper experiences are not available for infants, will their brains develop normally? In this section, we outline the major structures in the brain and describe how the brain forms in early development.

The major structures in the human brain are shown in Figure 4.6. The brain and the spinal cord together form the central nervous system. The spinal cord is the body’s “information superhighway”—it allows vast amounts of information to be exchanged between the body and the brain. At the top of the spinal cord, the brain stem controls automatic functions (such as breathing and heart rate) and regulates the general level of alertness throughout the higher levels of the brain. The cerebellum, on the back of the brain, controls posture, body orientation, and complex muscle movements. The cerebral cortex is the “gray matter” that forms the top portion of the brain; it is divided into four major lobes (frontal, temporal, parietal,
The many convolutions (folds) in the cortex allow a greater amount of surface area to fit within the confines of the skull. The cortex is actually a thin layer of material, less than one eighth of an inch thick, so it is important that its surface area be maximized.

Many areas within the cortex have specialized functions. The motor area, in the middle of the cortex, controls voluntary muscle movements from raising the eyebrows to wiggling the toes. Just behind the motor area is the somatosensory area, which registers sensory input from all areas of the body. Wernicke’s area processes speech input, and Broca’s area organizes articulation for speech output. The visual area in the back of the brain receives messages from the eyes for visual processing. The large frontal lobe is involved in organizing, planning, and other executive functions that are important in higher-level thinking, problem solving, and creativity. Although researchers continue to discover specialized functions of various parts of the brain, it is also clear that most of our thoughts, perceptions, emotions, and memories are governed by complex communications occurring throughout the brain.

At the microscopic level, communication throughout the nervous system is controlled by specialized cells called neurons. The process involves neural impulses (electrical impulses) that travel through the neurons and neurotransmitters (chemical messengers) that transmit the impulses from one neuron to another. Neurons have three main parts, as shown in Figure 4.7. Dendrites are branchlike structures that receive input from other neurons. The cell body contains the nucleus and governs the function of the neuron. The axon, a relatively long fiber, carries electrical impulses that send messages to other cells. Mature axons are covered by a myelin sheath, a fatty substance that insulates the axon and speeds the axon’s transmission of electrical impulses.

**Figure 4.6 • The Major Structures in the Brain and Spinal Cord.**
(Adapted from R. Fabes & C. L. Martin, 2003.)

This image from a scanning electron micrograph shows the web of connections that forms among neurons in the human brain. You can see the cell bodies (yellow) and the complex web of axons and dendrites that send messages throughout the web.
activity. The end of the axon branches out to form terminal buttons. Synapses are the open spaces between terminal buttons of one neuron and dendrites of the next neuron. When the electrical impulse reaches the end of the axon, it causes the release of chemical neurotransmitters from the terminal buttons. The neurotransmitters flow across the synapse to the dendrites, where they can stimulate or inhibit the response of the neighboring cells. This process of electrochemical stimulation allows neurons to communicate throughout the nervous system.

Forming the Brain and Nervous System

Now that you’re familiar with the major parts of the nervous system, let’s step back into prenatal development and take a look at how the brain forms and develops. At about 4 weeks after conception, the human embryo folds over to form a neural tube. The neural tube will later develop into the central nervous system (the brain and spinal cord). By 7 weeks after conception, neurons have begun to form at the neural tube. By 10 weeks, some of the neurons begin migrating to the top of the tube, where they form the first layer of the cerebral cortex. The cortex will eventually have six layers of neurons. The innermost layers form first. As more neurons grow, they migrate past the first layers to create the outer layers. New neurons form at an enormous pace. By 20 weeks of gestation, the cerebral cortex has approximately 80 billion neurons, and this is the approximate number that infants are born with (Kolb, 1999). To get to such a huge number, the brain needs to gain an

Figure 4.7 • Parts of a Neuron

Each neuron in the brain and nervous system contains a cell body, dendrites, and an axon. Dendrites receive input from neighboring cells. Messages move down the length of the axon to the terminal buttons, and across the synapses to neighboring cells. (Adapted from Fabes & Martin, 2003.)
average of over half a million neurons per minute after neurons begin to form in week 7!

The focus of brain development now shifts from the creation of new neurons to the growth of connections among the neurons. By 20 weeks, axons and dendrites have begun growing (Huttenlocher, 1999). By 23 weeks, the first synapses have formed. The formation of new synapses is called synaptogenesis. Dendrites and axons grow longer and branch out to form an enormously large number of synapses with neighboring neurons. Thousands of synapses can form rather randomly as the axons of one neuron come into proximity with dendrites from another (Huttenlocher, 1999). Although the first synapses begin to form by the 23rd week of pregnancy, the process of synaptogenesis doesn’t accelerate until late in pregnancy, and most synapses form after birth. By 31 weeks into pregnancy (only 7 to 9 weeks before a full-term birth), the cerebral cortex has grown enough that it begins to fold inside the skull, forming the convolutions that characterize this part of the brain. At birth, the newborn’s brain has the same outward appearance as an adult’s brain, although inside, much growth has yet to occur.

Myelination is the growth of the myelin sheath around the axon. The myelin sheath insulates the axon, which more than triples the speed of transmission of the synaptogenesis
One form of neuron maturation in which dendrites and axons branch out to form an enormously large number of connections with neighboring neurons.

myelination
A form of neuron maturation in which the fatty insulation (myelin sheath) grows around the axons.

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**a social policy perspective**

**Can Mozart Stimulate Neural Connections in Infants?**

In his 1999 budget, then Georgia Governor Zell Miller proposed that the state spend $105,000 to send a CD or cassette of classical music home with every baby born in the state. Miller commented that “[n]o one questions that listening to music at a very young age affects the spatial, temporal reasoning that underlies math and engineering and even chess” and that “[h]aving that infant listen to soothing music helps those trillions of brain connections to develop” (Sack, 1998).

Does research evidence support Miller’s claims? Frances Rauscher and her colleagues published a series of intriguing studies suggesting that extensive music training significantly enhanced the spatial-temporal skills of preschool children. These researchers also found that listening to a Mozart sonata improved college students’ spatial-reasoning IQ scores by eight to nine points (Rauscher, Shaw, & Ky, 1993, 1995; Rauscher et al., 1997). The spatial-reasoning scores involved were on tests of reasoning about proportions, ratios, and other concepts in mathematics. Improvements in these skills after exposure to classical music has been labeled the “Mozart effect.” Reports about the Mozart effect and about how early experience wires the developing brain led the proactive governor of Georgia to propose jump-starting infants’ brain development with classical music.

But will it work? For the college students, the benefit of listening to classical music was temporary, lasting only 10 to 15 minutes (Rauscher et al., 1997), and several other researchers have been unable to replicate the Mozart effect (e.g., Nantais & Schellenberg, 1999; Steele, Bass, & Crook, 1999). Still, the excitement over the initial findings prompted the Florida legislature to pass a law requiring that toddlers in state-run schools hear classical music every day (Goode, 1999).

On the basis of information in this chapter, how would you suggest that state and local governments, other agencies, schools, and parents enhance brain development in infants and toddlers? What information would you use to support new social policies in this area?
impulse and communication with other neurons (Bornstein & Arterberry, 1999). Although most axons are myelinated by birth, some areas of the brain are not completely myelinated for several years. For example, the motor and sensory areas in the cortex are still forming myelin until about 4 months after birth. It is not until after the motor areas are myelinated (after 4 months) that babies accomplish coordinated motor actions such as sitting, reaching, and standing. The frontal lobe is probably one of the last areas in the brain to be completely myelinated; some areas in the frontal lobe are still forming myelin all the way into our early 20s (National Research Council and Institute of Medicine, 2000).

Here is an interesting fact: Human beings lose half of their neurons before they are even born! Before birth, neurons proliferate at a tremendous rate and migrate to their final destinations, where they form the structures in the brain and the rest of the nervous system. But during migration and during periods of heavy synaptogenesis, about half of our neurons die. Researchers refer to this process as programmed cell death (Kandel, Schwartz, & Jessell, 2000). Neural activity determines which neurons will survive. The brain diverts its energy supplies toward the neurons that are more useful and active; the neurons that are less important or not very active begin to lose energy and die. Genetics provides an overabundance of neurons, and the brain manages to chisel away the excess until the final form is achieved.

Some years ago, a Georgia governor pushed for legislation aimed at enriching the environments of all newborn babies. To see how far his policy went, take a look at the Social Policy Perspective box entitled “Can Mozart Stimulate Neural Connections in Infants?”

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**Let’s Review…**

1. Children reach about half of their adult height by the time they are:
   - a. 1 year old.
   - b. 2 years old.
   - c. 5 years old.
   - d. 8 years old.

2. In the United States, how many mothers follow the recommendation of the American Academy of Pediatrics and breastfeed their babies until the babies are at least 12 months of age?
   - a. fewer than one quarter
   - b. about half
   - c. a little more than half
   - d. about two thirds

3. According to health experts, when should parents first introduce juices, soft foods, or other supplements to their breastfed babies?
   - a. after the first month
   - b. after 3 months
   - c. after 6 months
   - d. after 12 months

4. The first synapses form in the brain at around:
   - a. 10 weeks of gestation
   - b. 15 weeks of gestation
   - c. 23 weeks of gestation
   - d. 30 weeks of gestation

5. True or False: Compared to other babies, those who are breastfed are more likely to have a variety of infant diseases and illnesses.

6. True or False: Programmed cell death is nature’s way of improving the efficiency of the brain as it develops.

**Answers:** 2, 3, 4, 5, 6, 1
Sensory Capabilities

When parents hold their newborn babies, they often wonder what their babies can see and hear and what their newborns can process with their other sensory modalities. In this section, we cover the basic sensory capabilities of newborn babies and track how some of these capabilities change during the infancy period. We return to this topic again in Chapter 5, where we describe how researchers study perceptual development and summarize what researchers have learned about how well infants and toddlers coordinate information across different sensory modalities.

As you study this section, ask yourself these questions:

- How clearly do infants see? How well do they see colors and depth?
- How well can infants hear? How early can they distinguish different sounds?
- When do infants begin to recognize smells and react to different odors? Can they distinguish different flavors?

Basic Components of Vision

How Clear Is Their Vision? One of the fundamental questions in perception concerns visual acuity—the ability to see fine detail. You are probably familiar with the standard eye chart used to measure visual acuity. According to this chart, a person with normal, 20/20 vision can read a certain row of letters on the chart from 20 feet away. A person with 20/40 vision would need to be 20 feet away to read what someone with normal vision could read from 40 feet away. But how can researchers test acuity in young infants who do not know the alphabet? To do this, researchers presented infants with the striped patterns shown in Figure 4.8. Each striped pattern was paired with a uniform gray square. If an infant doesn’t have sufficient acuity to see the stripes, then the striped pattern blends to gray. (Back up several feet from your textbook, and the stripes will fade even more.) When infants can see the stripes, however, they tend to prefer to look at the stripes over the gray square. At a distance of 10 inches, 6-month-olds can see stripes as thin as 1/64 inch (and they prefer to look at those over the plain gray square), but 1-month-olds need the stripes to be at least 1/8 inch thick before they see them and prefer to look at them. Researchers estimate that visual acuity in newborns is somewhere between 20/150 and 20/600. Infants reach 20/20 vision by 6 to 12 months (Cohen, DeLoache, & Strauss, 1979). Even though acuity is poor in the first months, Hainline (1998) reminds us that when “development proceeds normally, infant vision seems perfectly adequate for the things that infants need to do” (p. 42), such as locate a caregiver, see a food source, or lock in on a smiling face.

Can They See Different Colors? It is unclear how well newborn infants are able to distinguish among various colors. Studies have found that newborns prefer to look at green, yellow, or red over gray (Adams, Maurer, & Davis, 1986). However, other evidence indicates that newborns can distinguish red from white but not blue, green, or yellow from white (Adams, Courage, & Mercer, 1994). Most of the evidence collected in the last few decades suggests that the photopigments in the eye that are necessary for normal color vision are present by at least 3 months, and it is safe to say that color vision is relatively mature by 6 months (Kellman & Arterberry, 2006; Suttle, Banks, & Graf, 2002).
How Deep Is That Drop? Early Depth Perception. When do infants first begin to perceive depth? Do they need to learn the dangers of deep drops, such as a set of stairs, through trial-and-error learning? The classic research on depth perception was Eleanor Gibson and Richard Walk’s (1960) visual cliff experiment. Similar to the photo in Figure 4.9, a heavy sheet of glass extended across a solid surface and a deep drop-off. Infants from 6 to 14 months of age were tested. The researchers placed each infant in the middle; then the baby’s mother called, first from one side and then the other. All of the 6-month-olds crawled out onto the solid side to reach their mothers, but they refused to crawl onto the deep side. Many cried, but still they didn’t venture over the visual cliff. Gibson and Walk concluded that depth perception is available by the time infants learn to crawl. A decade later, other researchers demonstrated that infants just under 2 months of age could see the difference between the deep and solid sides (Campos, Langer, & Krowitz, 1970). They placed infants face-down on each side of the visual cliff and measured their heart rates. Infants showed significantly more slowing of their heart rates on the deep side. In infants, heart rate deceleration indicates engrossed attention. Although it was clear that these young infants could perceive depth, it seems that they were more intrigued by than afraid of the “cliff.”

What visual cues can infants use to perceive depth in the visual cliff experiments? Infants are first sensitive to cues involving the motion of objects, such as motion parallax: As the head and eyes move, the elements on the solid side of the visual cliff move more rapidly across the field of vision. Other studies find that infants as young as 1 month old show avoidance (e.g., blinking their eyes) in the face of approaching objects (Náñez & Yonas, 1994). A little later, by 3 to 4 months of age, infants can judge depth using binocular disparity—the difference between the images projected on the two eyes (Fox et al., 1980). Finally, there are pictorial cues—the relative size and density of the pattern elements shown beneath the glass. Neurological development and experience both play important roles in facilitating depth perception. As Bornstein and Arterberry (1999) put it, “no matter how early in life depth perception can be demonstrated, the ability still rests on some experience, and no matter how late its emergence, it can never be proved that only experience has mattered” (p. 238).
How Well Do Infants Hear?

Research on young infants’ auditory capabilities lets us draw several conclusions (Aslin, 1987). First, the auditory system is functional several weeks before birth; researchers have found that auditory stimuli such as loud sounds produce changes in fetal heart rate and brain-wave activity. Second, by 6 months of age, infants are capable of responding to a broad range of sounds. Even the youngest infants easily distinguish among rattles, voices, songs, and many other environmental noises. Infants seem to prefer more complex sounds (Richard et al., 2004). However, infants cannot yet detect very faint sounds, such as the softest of whispers, and they need changes in loudness and frequency (pitch) to be greater before they can detect these changes. For example, infants 6 to 9 months of age can barely detect a frequency change of 2 percent, but adults can detect a 0.5 percent change.

If you listen to adults speaking to infants, you will notice that adults take these developmental differences into account in a special style of speech: child-directed speech. In child-directed speech adults move close to the infant, speaking slowly, clearly, and with exaggerated changes in intonation. The “singsong” quality of child-directed speech provides greater changes in loudness and frequency, inducing infants to be more attentive.

A third characteristic of early auditory perception is that infants and young children might in fact be more sensitive than adults to higher frequencies of sound (e.g., 20,000 Hz). Sensitivity to higher frequencies begins to decline around the age of 6 years. Fourth, infants are able to locate sounds in the environment by turning their head or eyes in the direction of the sound source. Interestingly, this ability declines from birth to 2 months of age; then it improves again around 4 months of age. This trend might be due to the loss of the orienting reflex, which is controlled by lower brain centers. Then, as the higher cortex develops, the lower brain centers are overridden; this results in greater voluntary search behaviors (Aslin, 1987).

Researchers have devoted extensive study to infant reactions to the human voice. Newborns prefer the voices of their own mothers to the voices of unfamiliar females (DeCasper & Fifer, 1980). By 2 months, infants show a preference for speech with the rising and falling inflections typical of child-directed speech (Sullivan & Horowitz, 1983). At 4 months, infants prefer to listen to human voices over silence or white noise (Colombo & Bundy, 1981). By 5 months of age, infants can recognize their own names being spoken amid other names but only if their name is spoken more loudly than the other words (Newman, 2005).

A particularly intriguing experiment was conducted by DeCasper and Spence (1986). These researchers asked pregnant women to read aloud a particular children’s story (e.g., The Cat in the Hat) twice each day during the last six weeks of pregnancy. Two to three days after birth, the experimenters tested the newborns for their recognition of the story. They connected a pacifier to an electronic switch that could activate one of two sound tracks. One sound track was a recording of the newborn’s mother reading the familiar story (The Cat in the Hat). The other track was a recording of the mother reading a new story (e.g., The King, the Mice, and the Cheese). Newborns could choose which story to activate by adjusting their rate of sucking on the pacifier.
For some, slower sucking would activate the familiar story; for others, this required faster sucking. In both cases, newborns adjusted their rate of sucking as required to activate the familiar story. Because both sound tracks were recordings of the mother’s voice, the infants must have been choosing on the basis of certain qualities (e.g., pace) they heard in the stories. Further, these infants still preferred the familiar story when the stories were recorded by unfamiliar female voices. These results indicate that auditory perception before birth was adequate to process and retain the acoustic qualities of the story and that the newborns’ perception and memory were sufficient to differentiate the two sound tracks and recognize which one was familiar. Quite a task for a baby only 2 to 3 days old!

**Smell and Taste**

Immediately after birth, their facial expressions show that that newborn babies react to certain odors in a manner similar to adults. Newborns show positive facial expressions in response to the aromas of bananas and butter, positive or indifferent responses to vanilla, some rejection to fishy odors, and complete disgust to rotten eggs (Bornstein & Arterberry, 1999; Steiner, 1979). In other experiments, Richard Porter and his colleagues studied newborns’ recognition of their parents’ smells. For example, parents in one study wore gauze pads under their arms for several hours; then researchers used the pads in a smelling test with the parents’ newborn babies (Cernoch & Porter, 1985). At the age of 2 weeks, breastfed babies turned their heads toward the smell of their mothers more than to the smell of unfamiliar females (mothers of other babies). The newborns did not show recognition of the smell of their fathers, however. Also, bottle-fed newborns did not show a preference for the smell of their mothers. These results demonstrate that infants are capable of discerning small differences in complicated odors, at least when they have close and repeated contact with the odor—as breastfed infants would have with the smell of their mothers. But the perception of smell might become functional even before this time. Infants as young as 3 to 4 days of age prefer the smell of breast milk to that of formula milk, regardless of whether they are breastfed or bottle-fed (Marlier & Schall, 2005). There is also intriguing evidence that, just as for audition, the fetal system is well enough developed sometime near the end of gestation to sense and store information about odors encountered before birth. For example, newborns prefer the smell of their own amniotic fluid over that of other infants (Schall, Marlier, & Soussignan, 1998).

Infants show taste preferences immediately after birth, even before their first feedings (Steiner, 1979). When given a sweet solution, newborns smile and make sucking movements. Infants will suck longer to obtain a solution that is sweeter as opposed to one that is less sweet (Crook, 1987). With a sour taste, they purse their lips and wrinkle their noses. A bitter taste causes newborns to spit and make a face that indicates disgust and rejection. These early taste preferences seem to be governed by areas in the lower brain, because they appear even in infants who are born without a cerebral cortex (Steiner, 1979). Reaction to salty flavors develops later, usually by 4 months of age (Beauchamp et al., 1994).
Motor Development

When babies are born, they can turn their heads in the direction of interesting sounds, and they move their eyes to track the movements of some objects. Even in the first weeks, they are beginning to gain control over muscles in the head and neck area, but it will still be a while before they can coordinate muscles in the rest of their bodies. With some trial and error, newborns may be able to get their hands to their mouths to suck their fingers or thumbs, but they still can’t control their arm and hand muscles well enough to reach out and grasp an object. They are months away from being able to stand up, walk, and run.

In this section, we trace the typical patterns of motor development—gains that infants and children make in the ability to control their muscle movements. We begin with the muscle reflexes that infants show in the early months. Next we move to the ability of infants to coordinate voluntary muscle movements involved in actions such as sitting, standing, and walking. We look at the role of early experience and other factors that govern these patterns of development. We end the section with a discussion of toilet training.

As you study this section, ask yourself these questions:

- What kinds of reflexes do infants have soon after birth, and what functions do these reflexes serve?
- What patterns are seen as infants and toddlers learn to control their movements? What factors govern this phase of motor development?
- Can motor development be accelerated with early experience, or is the rate of development limited by the growth and maturation of the brain?
- When are toddlers ready for toilet training? What is the best approach for parents to use in toilet training?
Reflexes: The Infant’s First Coordinated Movements

Human infants are equipped at birth with several interesting reflexes. **Reflexes** are involuntary movements that are elicited by environmental stimuli such as sound, light, touch, and body position. If you touch a newborn’s cheek, the infant’s head will turn in the direction of the touch. This is called the *rooting reflex*. If anything touches an infant’s lips, the infant automatically begins to suck—the *sucking reflex*. As you read earlier in this chapter, the cerebral cortex (the upper part of the brain), which governs voluntary muscle movements, is not well developed at birth. So at first, it is the lower brain centers (spinal cord, brain stem, and midbrain) that control infants’ involuntary reflexes. What purposes do these reflexes serve? Some help the infant to find nourishment, some help the infant to exercise muscles, and still others may be protective mechanisms. Let’s consider three classes of reflexes: *primitive, postural, and locomotor* (Gabbard, 1992).

**Primitive reflexes** include rooting and sucking. As we have described, both of these reflexes help infants to find nourishment. When the breast or bottle touches their cheek, infants turn their head to the source of nutrition. When the nipple touches their mouth, they begin to suck. Other primitive reflexes are most likely remnants from earlier evolutionary forms in which the reflexes might have served protective functions. The Moro reflex (or startle reflex), for example, occurs when an infant is startled by a loud noise or begins to fall. A sharp bang on the crib will cause infants to extend their arms and legs outward, spread their fingers and toes, then bring their limbs back to their bodies. You will see the same response if you hold an infant in your arms, face upward, and then drop your arms suddenly a few inches. *(Be sure to catch the baby!)* The grasping reflex occurs when an object touches an infant’s palm; the baby’s fingers will automatically wrap around the object and grip strongly. These reflexes might have helped our ancestors grab onto their mothers or catch hold of support when falling. Most primitive reflexes are functional in the later months of prenatal development; for example, fetuses suck their thumbs by the fourth prenatal month. These reflexes tend to disappear by about four months after birth as the higher cortical centers in the brain begin to take over voluntary control of muscle movements.

Several **postural reflexes** help infants to keep their heads upright, maintain their postural balance, and roll their heads in the direction of their body motion. One interesting example is the parachute reflex. If infants are held upright and then quickly tilted face down, they will reflexively extend their arms outward as if to balance and brace against the movement. Postural reflexes emerge by the age of 2 to 4 months and then disappear by 12 months.

During the first few months of life, infants will show crawling motions if they are lying on their stomaches and their feet are stroked. If they are upright with their feet touching a surface such as a tabletop or the floor, they take small steps. If held horizontal in water with their heads up, infants make swimming motions with their arms and legs. These crawling, stepping, and swimming reflexes are examples of **locomotor reflexes**. The locomotor reflexes tend to emerge during the first month or so after birth and then disappear again by 4 months of age.

There has been much debate about the functional significance of infant reflexes. Some theorists have argued that with practice, early reflexes will evolve into coordinated voluntary movements. Infants who are given regular practice with the stepping reflex, for example, tend to maintain the reflex longer and tend to show voluntary walking about a month earlier than infants who are not given extra practice (Zelazo, 1983; Zelazo, Zelazo, & Kolb, 1972). Reflexes may provide valuable exercise that strengthens the muscles and helps the nervous system to make connections between the brain and the muscle groups. Other researchers contend that the lag between the disappearance of most reflexes and the onset of similar voluntary movements shows that these two phases of motor development are independent. Some even claim that the early reflexes must be suppressed so that the brain can take voluntary control of the muscles (Pontius, 1973).

**your perspective**

Which reflexes have you observed in infants you have known? What purposes are served by these reflexes?
Either way, pediatricians have long used the existence and disappearance of reflexes as early indicators of nervous system function. Remember from Chapter 3 that the Apgar test includes a measure of “reflex irritability” as part of the assessment of early functioning in newborns. The Brazelton Neonatal Behavioral Assessment Scale, designed to assess the health of infants, measures some 20 different reflexes. A lack of reflexive response, or a delay in the emergence or disappearance of certain reflexes, can signal a problem with neurological development.

Voluntary Movements: The Motor Milestones

When our children were newborn babies, we loved the way they wiggled and squirmed when we held and played with them. Many of their movements were jerky and somewhat erratic, but it was a joy to watch them stretch and exercise their tiny muscles. Newborns can typically move their eyes and turn their heads to find one’s face or track the sound of one’s voice. Put your finger in the palm of a newborn’s hand, and the strength of the infant’s grip (from the grasping reflex) will surprise you. When newborn babies are awake, their arms and legs seem to be constantly stretching and flexing, their fingers gripping and extending. These early arm and leg movements are spontaneous and involuntary, not directed at reaching at or holding particular objects. It will be several months before the infant can coordinate voluntary and purposeful behaviors like reaching for a toy or dumping out a box of blocks. Over the next months, babies’ reflexes, spontaneous movements, and later voluntary movements gradually strengthen the babies’ muscles and stimulate neurological development in their brains and nervous systems.

Figure 4.10 illustrates the major milestones in gross motor development across the first year of life. Gross motor development refers to the process of coordinating movements with the large muscles in the body.
movements with the large muscles in the body. These muscles control the larger parts of the body such as the head, neck, torso, arms, and legs. Later, we will discuss fine motor development, the development of the smaller muscles that control our more intricate movements (e.g., finger movements).

Gross motor development follows the cephalocaudal pattern that we discussed before (Frankenburg et al., 1992). By 1 month of age, the muscles in infants’ necks are strong enough to allow the infants to hold their heads upright. Next, the muscles in the trunk become more coordinated. Infants can roll over by 3 months and sit upright without support by 6 months. Around 7 months the legs are strong enough to allow infants to crawl—pushing with their legs and dragging their bodies along the floor. At 7 months, babies also can stand by holding onto a table or other form of support.

For many parents, the most significant of the early motor milestones is the baby’s first step. Most infants take their first unaided steps sometime around their first birthday. But it is important to know that these ages are averages, and the rates of development for individual babies vary considerably. For example, 25 percent of infants are walking well at 11 months; another 25 percent begin walking well at 13 months; and 10 percent do not walk proficiently until 15 months (Frankenburg et al., 1992). Individual genetics, different rates of neurological development, and opportunities to practice muscle movements all contribute to this variability. Pediatricians will, however, see serious delays in motor development as a potential indication of neurological or muscular deficits. To learn more about how to identify and treat developmental delays in motor development, read the Professional Perspective box entitled “Career Focus: Meet a Physical Therapist.”

A proximodistal, or nearer-to-farther (from the body’s midline), pattern can be seen in the progress infants make in reaching and grasping. At first, they reach with their arms; next come the fine motor skills of grasping with the hands and fingers (Gabbard, 1992). In Figure 4.11, you can see that voluntary control over the upper arm is shown by 4 to 5 months. The infant has voluntary control over the upper arm
Part Two: Infants and Toddlers

and can reach out and pull an object in with both arms. At this age, infants wrap all four fingers and the thumb around the object in what is referred to as the palmar grasp. By 10 months, infants show the more advanced pincer grasp, using the thumb and the opposite forefinger. At 15 months, they can hold a writing implement (although they begin again with the palmar grasp) and make scribbles by using the large muscles in the upper arm. Later, children begin using the more precise “tripod” grasp for holding pencils and other writing implements: They hold the writing tool between the forefinger and...
and thumb, and they steady the bottom of their hand on the writing surface. As you can see, control over the fine motor movements of the hands and fingers comes much later than control over the gross motor movements of the elbows, arms, and shoulders.

The cephalocaudal and proximodistal patterns in motor development mirror the progressive maturation of centers in the brain. Cells and connections in the part of the brain that controls muscle movements in the head and upper body tend to mature first. Neurological development then spreads, allowing control and coordination of muscles to proceed both downward and outward through the body. Of course, there are exceptions to every rule, and we point one out here. When young infants first start reaching for toys and other objects, they actually tend to reach with their feet first and do not try to reach with their hands until they are several weeks older (Galloway & Thelen, 2004). In general, however, motor development does tend to follow the head-to-tail and midline-out patterns of development.

Brain maturation also influences the appearance and disappearance of infant reflexes. The reflexes that are seen in early infancy are controlled mainly by pathways in the spinal cord, and the actions of these nerve pathways become inhibited once the higher cortical centers develop. The stepping reflex, for example, disappears as the motor area of the cortex matures enough to allow coordinated and voluntary movements of the legs. But is brain maturation the only factor driving motor development? Obviously not. For example, the disappearance of the stepping reflex is also related to weight gain during infancy. Infants who gain weight more rapidly tend to lose the stepping reflex earlier.

One group of researchers demonstrated this effect with 1-month-old infants. When they fitted these infants with leg weights that mimicked the amount of weight the infants would gain in the next few weeks, the stepping reflex diminished (Thelen, Fisher, & Ridley-Johnson, 1984). And when the researchers held other infants in water, the infants showed a more vigorous stepping reflex. The fatty leg tissue was more buoyant under water, so the reflex revived when the muscles were relieved of the extra weight load. Esther Thelen hypothesized that the normal disappearance of the stepping reflex is affected by the biomechanical load placed on the limbs and not caused entirely by maturation of the higher brain centers.

As we mentioned earlier, Philip Zelazo and his colleagues demonstrated that daily practice could strengthen the stepping reflex (Zelazo, Zelazo, & Kolb, 1972). Zelazo has even suggested that motor development may be subservient to cognitive development (Zelazo, 1983). Independent walking, for example, may occur only after infants develop certain information-processing and memory skills. According to this view, babies need to associate balance with stepping and to remember how to coordinate different body movements to walk successfully. So when it comes to motor development, cognitive practice may be as important as physical exercise and the strengthening of muscles.

Esther Thelen and her colleagues have proposed a dynamic systems theory (see Chapter 1) to describe the myriad interactive processes that are involved in motor development (Gershkoff-Stowe & Thelen, 2004; Thelen, 1989; Thelen & Smith, 2006). In this theory, coordinated movements such as reaching, crawling, walking, and throwing are dynamic actions that emerge from the complex interplay of individual muscles, nerve pathways, physical growth, learning, and motivation:
Part Two: Infants and Toddlers

Neurological development gives infants the ability to exert voluntary control over their muscles.

Parental encouragement and interesting objects in the environment motivate infants to raise their heads, turn their bodies, crawl, and take their first steps.

Opportunities to exercise give babies the muscle strength they need to lift and control their growing limbs.

Maturation of cognitive systems helps babies to remember where interesting objects are located and figure out how to coordinate their movements to get them.

The brain, the body, and the environment all work in concert to propel the child toward increased strength and coordination. Without the brain, the muscles won’t move. Without muscular exercise, the brain won’t develop. Without motivation, the child won’t exercise. The important question is not which part of the system develops first, but rather how the various components work together to move the infant and child toward higher levels of development.

Cultural Differences in Early Experience

Because parenting practices differ across cultures, babies in some cultures receive more vigorous physical stimulation than do babies in other cultures. In Mali, for example, mothers often suspend babies by their arms or legs (which stretches the babies’ muscles) and encourage babies to sit and stand at an early age (Bril & Sabatier, 1986). Researchers have also noted that some African cultures emphasize physical stimulation, and babies who are raised in these cultures are typically ahead of North American babies in the major motor milestones (Ainsworth, 1967; Rabain-Jamin & Wornham, 1993; Super, 1976).

In contrast, in some South American cultures, mothers are more protective of young infants and tend to limit their babies’ opportunities to explore and exercise their motor skills. In Brazil, for example, researchers find that mothers carry their babies or hold the babies in their laps for a large part of the day. Many Brazilian mothers reportedly believe that sitting and standing positions can cause damage to the legs and spines of young infants, so they rarely allow their babies to sit or play on the floor by themselves (Santos, Gabbard, & Goncalves, 2001). During the first six months of infancy, these Brazilian babies lag behind their North American age-mates in motor skills such as sitting up and reaching for objects. By 8 months of age, however, they gain more physical exercise and catch up with babies raised in other cultures. Studies have found similar trends in babies in Chile (Andraca et al., 1998).

Infants among the Hopi tribe in Arizona and the Tewa of New Mexico take their first steps at about 14 months of age, or one to two months later than most other infants in North America (Dennis & Dennis, 1939/1991). For their classic study on cultural differences in motor development, Wayne and Marsena Dennis spent two summers living among the Hopi. In some villages, they found that Hopi mothers used the traditional practice of strapping their infants to cradle boards.
that the mothers then carried on their backs. For the first nine months of life, these infants spent most of their days restrained tightly on these boards, and they remained on the cradle boards even when they were nursing and when sleeping at night. Other Hopi villages were more “Americanized,” and mothers in these villages had given up use of the cradle boards. Did the infants in these villages walk at an earlier age than the cradle board babies? Interestingly, the answer was no, not really: Use of the cradle board delayed the onset of walking by only two days on average (Dennis & Dennis, 1939/1991). Whether confined to the board or allowed to play and exercise more freely, all the Hopi infants took their first steps at about 14 months of age. As you can see, studies that investigate different cultures do not agree completely about the roles of physical practice and exercise in motor development.

### Toilet Training

Watching infants and toddlers move through the motor milestones is thrilling. Parents celebrate the first time their infants sit up, crawl, and stand on their own. And who can forget the excitement of those first few wobbly steps the toddler takes? For practical reasons, parents also celebrate a much less glamorous milestone: when their toddlers become toilet trained. As with crawling, walking, and other developmental milestones, toilet training develops from an interaction of physical maturity, cognitive understanding, cues and feedback from the environment, and motivation. Toilet training isn’t solely a matter of motor development. This is a lesson that can be learned from the dynamic systems theory discussed earlier in the chapter.

Most toddlers gain voluntary control and coordination over the muscles that control their bladder and bowel movements by the time they are 18 to 24 months old. By this time, the toddlers are also walking well enough that they can get through the house and to the potty as the need arises. Once these physical developments have occurred, parents next need to assess their child’s emotional and cognitive readiness. Can the child approach toilet training in a way that is positive and fairly relaxed? This is not the time to engage in a major power struggle with a testy 2-year-old, and children are not ready if they show fear of the potty or fear of bodily functions. Cognitive readiness is indicated when the child shows awareness of having soiled diapers, requests to be changed, asks to wear underwear, or shows a positive interest in the bathroom and toilet. It helps if the child is able to follow simple instructions and can stay dry for at least two or three hours during the day.

When the child seems ready for training, it’s time to introduce the child to his or her own special potty (usually a child-sized potty chair), demonstrate or teach the basic skill, and be ready with lots of praise and rewards for a job well done. Most experts recommend a child-oriented approach to training, allowing the child to set the pace according to his or her own schedule of readiness (Brazelton, 1962; Stadtler, Gorski, & Brazelton, 1999).

Researchers studying a group of toddlers in the Milwaukee area found that at least half of girls showed an interest in using the toilet by 24 months of age and stayed dry during the day and night by 34 months (Schum et al., 2002). Boys achieved these milestones about two months later than girls. It is possible, however, for children to be trained at an even earlier age. In their review of other studies on this topic, the researchers conducting the Milwaukee study noted that the average age of daytime dryness was about 24 months during the 1950s (when parents tended to push children harder and use stricter methods). They also noted that children in some other countries
are trained earlier than most U.S. children and that many of the African American toddlers in their Milwaukee sample began training before 15 months of age. Although children can be pushed to train at an earlier age, most experts believe that there are psychological and emotional benefits to using a more child-oriented approach with most toddlers, even though it might delay training success by several months.

Let’s Review . . .

1. What should you conclude about a 1-month-old infant who does not show the Moro reflex?
   a. This reflex normally does not emerge until 4 months, so the infant is developing normally.
   b. This reflex disappears by 3 weeks of age, so the infant is developing normally.
   c. Most infants do not show the Moro reflex, so there is no reason to be concerned.
   d. The infant may have a neurological problem or immaturity.

2. Which is the correct sequence of motor development for most infants?
   a. roll over, sit up, hold head up, walk
   b. hold head up, sit up, roll over, walk
   c. hold head up, roll over, sit up, walk
   d. hold head up, roll over, walk, sit up

3. Which of the following statements provides the best summary of the dynamic systems theory of motor development?
   a. Motor skills emerge from the combination of physical growth, learning, and motivation.
   b. Motor development is governed primarily by neurological development as maturation in the brain allows more coordinated motor movements.
   c. Motor development is governed primarily by experience as physical exercise stimulates the formation of neural circuits in the brain.
   d. Cognitive development precedes motor development; infants must first understand how to coordinate individual movements before they can execute complex motor skills.

4. True or False: Like most infants, Kelli learned to sit upright on her own before she learned to walk. This is an example of the proximodistal pattern of motor development.

5. True or False: Overall, children are being toilet trained at an earlier age today than they were 50 years ago.

Answers: 1. d, 2. c, 3. a, 4. f, 5. f

Thinking Back to Beverly . . .

Like most expectant parents, Beverly is concerned about how to stimulate her baby’s development. With all the excitement generated by popular press reports about research on brain development, parents are eager to learn how experience helps to shape the communication pathways in the brain. During pregnancy, neurons will grow in the baby’s brain, and synapses will begin to form to connect the neurons. The brain grows an overabundance of neurons, and half of the baby’s neurons will die off in programmed cell death.
neurons survive and which will die is determined partly by experience and the relative activity of the neurons, but this neuron loss is normal. Babies’ brains use the variety of sights, sounds, and other sensations stimulated by the environment to govern brain growth and development, but Beverly should understand that stimulation is important throughout childhood, not just during the first year or two.

What about playing classical music during infancy? There is some slight evidence that classical music can stimulate spatial-reasoning and mathematics skills in preschool children and college students, but there is no evidence yet that this “Mozart effect” lasts over the long term or has the same impact on infants. At this point, we can say only that it probably won’t hurt. The same goes for yoga and other exercise for infants. For example, practicing reflexes speeds the emergence of motor skills only slightly, so such classes probably do more for the social interaction between parent and baby than for the motor skills. The infant’s nervous system and motor skills will develop well if the typical sources of stimulation are on hand: objects to manipulate, friendly voices and faces, hugs, things to climb on, and encouragement to explore a varied environment.

Unless there are conditions that prevent Beverly from breastfeeding, the expert advice is that Beverly should breastfeed her baby for at least the first year. Breast milk is all that her baby will need for the first six months, and then other foods and supplements can be introduced gradually. Experts also recommend that parents such as Beverly follow their children’s pace when it comes to toilet training: toddlers learn this task relatively easily once they are physically and cognitively ready for the chore. These are some of the concepts and research findings that you might share with Beverly. Studying the chapter more closely, you can find even more helpful information.
death. Synaptogenesis (formation of synapses between neurons) begins after 23 weeks of gestation. Myelination of axons improves the neurons’ capability to transmit information.

**What is known about visual acuity, color vision, and depth perception in infants?**

Newborn acuity is somewhat limited, with estimates ranging from 20/150 to 20/600. Normal 20/20 vision is achieved by 6 to 12 months of age. It is not clear how well newborns are able to distinguish various colors. Evidence suggests that color vision is adultlike by 3 to 6 months. Experiments with the visual cliff indicate that 2-month-olds can see the difference between the deep and shallow sides, and babies avoid the deep side by the time they can crawl (around 6 months). By 3 to 4 months, infants use binocular disparity to judge depth, and 1-month-olds show avoidance of approaching objects, indicating some sensitivity to depth and distance information.

**What are the main conclusions about auditory capabilities of infants?**

The auditory system is functional before birth, but young infants still need sounds to be louder; and to detect these changes, they need changes in intensity and frequency to be greater in comparison to the needs of adults. Infants might be more sensitive than adults to higher frequencies. Newborns prefer the voices of their own mothers, and they can recognize sounds that they heard while in the womb.

**Can newborns differentiate between major odors and flavors?**

Yes. For example, newborns react positively to the aromas of bananas and butter, but they reject the odors of fish and rotten eggs. Newborns prefer sweeter solutions but reject sour and bitter flavors.

**What reflexes do infants have, and what is their significance?**

Newborns show primitive reflexes (rooting, sucking, Moro, grasping, and Babinski) that normally disappear by 4 months of age. Rooting and sucking help newborns to obtain nourishment, but the other primitive reflexes are probably remnants from times earlier in evolution. Postural reflexes that help the baby to maintain balance and head direction emerge by 2 to 4 months of age and disappear by 12 months. Locomotor reflexes (crawling, stepping, swimming) emerge after birth and disappear by 4 months. These and other reflexes may provide exercise that helps to form connections between the muscles and brain; these connections will later support voluntary movements. When reflexes do not appear or disappear according to the usual timetable, neurological problems might be present.

**What are the main patterns in the development of voluntary movements? What factors influence progress through the motor milestones?**

Motor development generally proceeds according to cephalocaudal (head-to-tail) and proximodistal (near-to-far) patterns. Infants hold their heads up before they can sit alone, and they sit before they walk. They coordinate large muscles in the arms before gaining dexterity in the hands and fingers. Neurological development and opportunities to exercise muscle both contribute. According to dynamic systems theory, motor skills emerge from complex interactions among neurological development, physical growth, learning, and motivation. Cultural differences in exercise and stimulation can lead to small differences in attainment of motor milestones. Toilet training usually begins around age 2 years, and most toddlers can stay dry during the day by the time they are 3 years of age.

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**Key Terms**

- child-directed speech (138)
- colostrum (128)
- fine motor development (143)
- gross motor development (142)
- infant mortality (124)
- locomotor reflexes (141)
- low birth weight (123)
- myelination (134)
- neurons (132)
- postural reflexes (141)
- preterm birth (123)
- primitive reflexes (141)
- programmed cell death (135)
- reflexes (141)
- small for gestational age (123)
- synaptogenesis (134)
- very low birth weight (123)
- visual acuity (136)
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The Synapse
The Limbic System
Dendritic Spreading: Forming Interconnections in the Brain
Infant’s Perceptual and Cognitive Milestones

**Simulate**
The Visual Cliff
Physiological Bases of Behavioral problems

**Watch**
Brain Development and Nutrition
Breast-Feeding

**Practice**
Sensory Capabilities
Motor Development

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