Learning Objectives

4.1 Discuss neural development from infancy through older adulthood, including the role of experience.

4.2 Summarize patterns of gross and fine motor development and influences on motor development.

4.3 Describe age-related changes in vision, hearing, and other senses.

Digital Resources

- Infants, Young Children, and Technology
- Play and Brain Development
- Motor Development in Infancy
- Health in Older Adults
- Neonatal Sense of Touch
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One-year-old Sophia grunted and stared at her mother as she let go of the sofa and made her first independent steps toward her. A child’s first steps are a watershed moment for parents—and often the cause of waterworks on their part. But those first steps are the culmination of a year-long process that began with newborn Sophia struggling to control her flailing arms and legs. Learning to walk is a developmental milestone influenced by our sensory abilities and, especially, neurological development. In this chapter, we examine biological development, specifically brain and motor development and sensation and perception.

Brain Development

LO 4.1 Discuss neural development from infancy through older adulthood, including the role of experience.

The brain is made up of billions of cells called neurons. Like other cells in your body, neurons contain a cell body and nucleus, but they also have other structures that enable them to communicate with other cells. Neuronal communication makes it possible for people to sense the world, think, move their body, and carry out their lives.
THE NEURON

Neurons are specialized to process information and communicate with other neurons, sensory cells (including those responsible for vision and hearing), and motor cells (responsible for movement). As shown in Figure 4.1, neurons have distinct structures that set them apart from other cells and enable their communicative functions. Dendrites are branching receptors that receive chemical messages from other neurons that are translated into an electrical signal (Markant & Thomas, 2013). The axon is a long tube-like structure that extends from the neuron and carries electrical signals to other neurons. Neurons do not touch. Instead, there are gaps between neurons called synapses. Once the electrical signal reaches the end of the axon, it is translated to chemical messenger, called a neurotransmitter, and crosses the synapse to communicate with the dendrites of another neuron (Carson, 2014). This process of neural transmission is how neurons communicate with other neurons. Neurons also communicate with sensory and motor cells. Some axons synapse with muscle cells and are responsible for movement. The dendrites of some neurons synapse with sensory cells, such as those in the eyes or ears, to transfer sensory information, such as vision and hearing (Kolb, 2015). Finally, axons are often coated with a fatty substance called myelin, which speeds the transmission of electrical impulses and neurological function.

The first neurons form early in prenatal development, in the embryo’s neural tube, through a process called neurogenesis. We are born with more than 100 billion neurons, more than we will ever need—and more than we will ever have at any other time in our lives (Kolb, 2015). Over time, some of our neurons die, and new ones are formed. Neurogenesis continues throughout life, though at a much slower pace than during prenatal development (Stiles & Jernigan, 2010). As the brain develops, new neurons migrate along a network of glial cells, a second type of brain cell that outnumbers neurons 10 to 1 (Jessen, 2004; Nelson & Bloom, 1997). Glial cells nourish neurons and move throughout the brain to provide a physical structure to the brain (Klämbt, 2009). As shown in Figure 4.2, neurons travel along glial cells to the location of the brain.

neuron A nerve cell that stores and transmits information; billions of neurons comprise the brain.
neurogenesis The production of new neurons.
glial cell A type of brain cell that nourishes neurons and provides structure to the brain.

FIGURE 4.1: Neurons and Neural Transmission

FIGURE 4.2: Glial Cell–Neuron Relationship

Neurons migrate along thin strands of glial cells.

Source: Gasser and Hatten (1990).
where they will function (Nelson & Bloom, 1997; Zhang et al., 2010), such as the outer layer of the brain, known as the cortex, and glial cells instruct neurons to form synapses with other neurons (Ullian, Sapperstein, Christopherson, & Barres, 2001).

**EXPERIENCE AND BRAIN DEVELOPMENT**

Brain development is a multifaceted process that is not a result of maturational or environmental input alone. Much of what we know about brain development comes from studying animals. Animals raised in stimulating environments with many toys and companions to play with develop brains that are heavier and have more synapses than do those who grow up in standard laboratory conditions (Greenough & Black, 1992; Grossman, Churchill, McKinney, Kodish, & Otte, 2003; Rosenzweig, 1984). Likewise, when animals raised in stimulating environments are moved to unstimulating standard laboratory conditions, their brains lose neural connections (Grossman, Churchill, McKinney, Kodish, & Otte, 2003; Thompson, 1993).

This is true for humans, too. Infants who are understimulated, including those who experience child maltreatment or who are reared in deprivation, such as in poor understaffed orphanages, also show cognitive and perceptual deficits (Twardosz & Lutzker, 2009; Wilson, 2003). Experience influences the physical structure of our brains throughout life. Though infancy is a particularly important time for the formation and strengthening of synapses, experience shapes brain structure at all ages of life, even into adulthood (Rosenzweig, 2002; Zeana, 2009).

The powerful role that experience plays in brain development can be categorized into two types. First, the brain depends on experiencing certain basic events and stimuli at key points in time in order to develop normally (Fox, Levitt, & Nelson, 2010); this is referred to as **experience–expectant brain development**. Experience–expectant brain development is demonstrated in sensory deprivation research with animals. If animals are blindfolded and prevented from using their visual system for the first several weeks after birth, they never acquire normal vision because the connections among the neurons that transmit sensory information from the eyes to the visual cortex fail to develop; instead, they decay (DiPietro, 2000; Neville & Bavelier, 2001). If only one eye is prevented from seeing, the animal will be able to see well with one eye but will not develop **binocular vision**, the ability to focus two eyes together on a single object. Similarly, human infants born with a congenital cataract in one eye (an opaque clouding that blocks light from reaching the retina) will lose the capacity to process visual stimuli in the affected eye if they do not receive treatment. Even with treatment, subtle defects in facial processing may remain (Fox et al., 2010; Maurer, 2017).

Brain organization depends on experiencing certain ordinary events early in life, such as opportunities to hear language, see the world, touch objects, and explore the environment (Kolb, Mychasiuk, & Gibb, 2014; Maurer & Lewis, 2013). All infants around the world need these basic experiences in order to develop normally.

A second type of development, **experience–dependent brain development**, refers to the growth that occurs in response to learning experiences (Greenough & Black, 1992). For example, experiences such as learning to stack blocks or crawl on a slippery wood floor are unique to individual infants, and they influence what particular brain areas and functions are developed and reinforced. Experience–dependent development is the result of lifelong experiences that vary by individual based on contextual and cultural circumstances (Nelson & Luciana, 2008; Stiles & Jernigan, 2010; Kolb et al., 2014). Exposure to enriching experiences, such as interactive play with toy cars and other objects that move; hands-on play with blocks, balls, and cups; and stimulating face-to-face play, can all enhance children’s development (Fox et al., 2010). For example, a longitudinal study that followed more than 350 infants from 5 to 24 months of age found that the quality of mother–infant interactions at 5 months predicted greater brain activity in the prefrontal cortex at 10 and 24 months of age, suggesting that parenting quality may contribute to brain development in infancy (Bernier, Calkins, & Bell, 2016).
**BRAIN DEVELOPMENT IN INFANCY**

The newborn’s brain is about 25% of its adult weight, and it grows rapidly throughout infancy, reaching 80% of its adult weight by 2 years of age (Nelson & Luciana, 2008). At birth, the neural networks of axons and dendrites are simple, with few synapses (DiPietro, 2000). Early in infancy, major growth takes place. Neurons and glial cells enlarge. As the dendrites grow and branch out, neurons form synapses and thereby increase connections with others (Kolb, 2015; Markant & Thomas, 2013). Synaptogenesis, the formation of new synapses, peaks in different brain regions at different ages (Price, Jarman, Mason, & Kind, 2011). The most active areas of synaptogenesis during the first 5 weeks of life are in the sensorimotor cortex and subcortical parts of the brain, which are responsible for respiration and other essential survival processes. The visual cortex develops very rapidly between 3 and 4 months and reaches peak density by 12 months of age. The prefrontal cortex—responsible for planning and higher thinking—develops more slowly from infancy through early adulthood (Nelson & Luciana, 2008).

Throughout the lifespan, stimulation and experience are key components needed to maximize neural connections and brain development. In response to exposure to stimulation from the outside world, the number of synapses initially rises meteorically in the first year of life and the dendrites increase 500% by age 2 (Monk, Webb, & Nelson, 2001). By age 3, children have more synapses than at any other point in life, with at least 50% more synapses than in the adult brain (DiPietro, 2000; Monk et al., 2001). This explosion in connections in the early years of life has been called transient exuberance because the brain makes more connections than it needs, in preparation to receive any and all conceivable kinds of stimulation (Nowakowski, 1987). Those connections that are used become stronger and more efficient, while unused ones eventually shrink, atrophy, and disappear. This loss of unused neural connections is a process called synaptic pruning. The first 3 years of life have been identified as a particularly important time for neural development because stimulation during infancy and early childhood influences the number of connections among neurons and, by extension, the child’s cognitive potential (DiPietro, 2000).

**BRAIN DEVELOPMENT IN CHILDHOOD**

An increase in synapses and connections among brain regions causes the brain to reach 90% of its adult weight by age 5 (Dubois et al., 2013). Children’s brains tend to grow in spurts, with very rapid periods of growth followed by little growth or even reductions in volume with pruning (Gogtay & Thompson, 2010). Little-used synapses are pruned in response to experience, an important part of neurological development that leads to more efficient thought (Brown & Jernigan, 2012; Stiles & Jernigan, 2010). In addition, a process called myelination contributes to many of the changes that we see in children’s capacities. Myelination refers to the process by which glial cells produce and coat the axons of neurons with fatty myelin, which speeds the transmission of neural impulses (Markant & Thomas, 2013). Myelination predicts general cognitive function (Deoni et al., 2011). That is, with myelination, children’s thought and behavior becomes faster, more coordinated, and complex (Chevallier et al., 2015; Dubois et al., 2013; Mabbott, Noseworthy, Bouffet, Laughlin, & Rockel, 2006). Myelination proceeds most rapidly from birth to age 4, first in the sensory and motor cortex in infancy, and continues through childhood into adolescence and early adulthood (Jessen, 2004; Qiu, Mori, & Miller, 2015).

In addition to the changes just described, parts of the brain become specialized for different functions. The two halves of the brain, known as hemispheres, may look alike but are not identical. Each hemisphere of the brain (and the parts of the brain that comprise each hemisphere) is specialized for particular functions and become more specialized with experience. This process of the hemispheres becoming specialized to carry out different functions is called lateralization (Duboc, Dufourcq, Blader, & Roussigné, 2015). Lateralization (from the Latin lateralis, meaning “belonging to the side”) begins before
birth and is influenced both by genes and by early experiences (Friederici, 2006; Goymer, 2007). For example, in the womb, most fetuses face toward the left, freeing the right side of the body, which permits more movement on that side and the development of greater control over the right side of the body (Previc, 1991). In newborns, the left hemisphere tends to have greater structural connectivity and efficiency—more connections and pathways—than the right, suggesting that newborns are better able to control the right side of their bodies (Ratnarajah et al., 2013). Children display a preference for the right or left hand, and their subsequent activity makes the hand more dominant because experience strengthens the hand and neural connections and improves agility. In this way, one hemisphere becomes stronger and more adept, a process known as hemispheric dominance. Most people experience hemispheric dominance, usually with the left hemisphere dominating over the right (Duboc et al., 2015), so that about 90% of people in Western countries are right-handed.

Among right-handed people, the left hemisphere plays an important role in language and the right hemisphere influences spatial skills. In left-handed people, the right hemisphere is dominant, and language is influenced by both hemispheres (Szaflarski et al., 2002). In some cultures, left-handedness is discouraged. For example, less than 1% of adults in Tanzania are left-handed because left-handed children often are physically restrained and punished for using their left hand (Provins, 1997). When left-handed children are forced to use their right hands, they typically learn to write with their right hand but carry out most other activities with their left, and brain scans reveal that their brains remain right-dominant (Klöppel, Vongerichten, van Eimeren, Frackowiak, & Siebner, 2007).

Although the left and right hemispheres are implicated for different functions, some researchers note that a strict right/spatial and left/language dichotomy is overly simplistic (Vilasboas, Herbet, & Duffau, 2017). Despite lateralization, the two hemispheres interact in a great many complex ways to enable us to think, move, create, and exercise our senses (Efron, 1990; Richmond, Johnson, Seal, Allen, & Whittle, 2016; Springer & Deutsch, 1998). Complex activities such as thinking and problem solving involve communication between both hemispheres of the brain (Turner, Marinsek, Ryhal, & Miller, 2015). The corpus callosum, a collection of 250 to 800 million neural fibers, connects the left and right hemispheres of the brain, permitting them to communicate and coordinate processing (Banich & Heller, 1998). During early childhood, the corpus callosum grows and begins to myelinate, permitting the two halves of the brain to communicate in more sophisticated and efficient ways and to act as one, enabling the child to execute large and fine motor activities such as catching and throwing a ball or tying shoelaces (Banich, 1998; Brown & Jernigan, 2012).

At all ages, the human brain has a capacity to change its organization and function in response to experience; this is known as plasticity (Kolb, Gibb, & Robinson, 2003). The brain is most plastic during the first few years of life (Nelson, Thomas, & de Haan, 2006; Stiles & Jernigan, 2010). The young child’s brain can reorganize itself in response to injury in ways that the adult’s brain cannot. Adults who suffered brain injuries during infancy or early childhood often have fewer cognitive difficulties than do adults who were injured later in life. The immature young brain, although offering opportunities for plasticity, is also uniquely sensitive to injury (Johnston et al., 2009; Uylings, 2006). If a part of the brain is damaged at a critical point in development, functions linked to that region will be irreversibly impaired (Luciana, 2003). How well a young child’s brain compensates for an...
Injury depends on the age at the time of injury, site of injury, and brain areas and capacities compromised. Generally speaking, plasticity is greatest when neurons are forming many synapses, and it declines with pruning (Kolb et al., 2003; Nelson, 2011). However, brain injuries sustained before age 2, and in some cases 3, can result in more global, severe, and long-lasting deficits than those sustained later in childhood (Anderson et al., 2014; Anderson et al., 2010), suggesting that a reserve of neurons is needed for the brain to show plasticity. Overall, the degree to which individuals recover from an injury depends on the injury; its nature and severity, age, experiences after the injury, and contextual factors supporting recovery, such as interventions (Anderson, Spencer-Smith, & Wood, 2011; Bryck & Fisher, 2012).

**Brain Development in Adolescence**

In early adolescence, the increase in sex hormones with puberty triggers a variety of neurological developments, including a second burst of synaptogenesis, resulting in a rapid increase of connections among neurons (Goddings, 2015; Vigil et al., 2011). Connections between the prefrontal cortex and various brain regions strengthen, permitting rapid communication, enhanced cognitive functioning, and greater behavioral control (Jolles, van Buchem, Crone, & Rombouts, 2011; Spear, 2013). Connections strengthen especially among areas associated with higher cognitive and emotional functions. These rapid changes and the corresponding shaping of the cortex make it likely that adolescence is a sensitive period for brain development (Fuhrmann, Knoll, & Blakemore, 2015); only in the first years of life are there as many rapid and significant changes.

The volume of the cerebral cortex increases, peaking at about 10.5 years of age in girls and 14.5 in boys, although this age difference provides no functional advantage to girls or boys (Giedd et al., 2009). Synaptic pruning in response to experience occurs at an accelerated rate during adolescence as compared with childhood and adulthood (Zhou, Lebel, Treit, Evans, & Beaulieu, 2015). Synaptic pruning decreases the volume of gray matter, thins and molds the prefrontal cortex, which is responsible for rational thought and executive function, and results in markedly more efficient cognition and neural functioning (Blakemore, 2012; Mills, Goddings, Clasen, Giedd, & Blakemore, 2014).

As shown in Figure 4.3, myelination continues throughout adolescence and leads to steady increases in the brain’s white matter, especially in the prefrontal cortex and the corpus callosum, which increases up to 20% in size, speeding communication between the right and left hemispheres (Barnea-Goraly et al., 2005; Luders, Thompson, & Toga, 2010). Increases in white matter are linked with improved performance on measures of working memory, executive functioning, and learning (Blakemore & Choudhury, 2006). Over the course of adolescence, adolescents’ brains become larger, faster, and more efficient (Richmond et al., 2016). However, different parts of the brain develop at different times, leaving adolescents with somewhat lopsided functioning for a time. The prefrontal cortex requires the most time to develop, continuing maturation into the 20s.

Pubertal hormones cause the limbic system, responsible for emotion, to undergo a burst of development in early adolescence, well ahead of the prefrontal cortex, responsible for judgment (Goddings et al., 2014; Strang, Chein, & Steinberg, 2013). According to the dual process model, the lag in development between

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**limbic system** A collection of brain structures responsible for emotion.

**dual process model** A model of the brain consisting of two systems, one emotional and the other rational, that develop on different timeframes, accounting for typical adolescent behavior.
the limbic system and prefrontal cortex is difference can account for many “typical” adolescent behaviors (Mills et al., 2014; Shulman et al., 2016). Full development entails the prefrontal cortex catching up. These changes influence adolescents’ thought and behavior in a myriad of ways. For example, parents often wonder whether they are speaking in a foreign language when their teens unexpectedly break off a conversation and storm away or when conflict arises over seemingly innocuous events. However, in a way, parents are speaking in a foreign language because adolescents’ brains do not always lead them to accurately assess situations. Adolescents have difficulty identifying emotions depicted in facial expressions. Performance on tasks measuring sensitivity to facial expressions improves steadily during the first decade of life but dips in early adolescence, increasing in late adolescence into young adulthood (Motta-Mena & Scherf, 2017; Thomas, De Bellis, Graham, & LaBar, 2007). Why? Blame the brain.

In studies in which both adults and adolescents are shown photographs of people’s faces depicting fear, adults correctly identify the emotion shown in the photograph, but many adolescents incorrectly identify the emotion as anger (Monk et al., 2003; Yurgelun-Todd, 2007). Moreover, fMRI scans indicate that when adults view facial expressions indicating fear, both their limbic system and prefrontal cortex are active. Scans of adolescents’ brains, however, reveal a highly active limbic system but relatively inactive prefrontal cortex relative to adults, suggesting that adolescents experience emotional activation with relatively little executive processing in response to facial stimuli indicating fear (Monk et al., 2003; Yurgelun-Todd, 2007). This often results in adolescents incorrectly labeling emotions, such as mistaking fear for anger. Research with people aged 7 to 37 reveals developmental changes in facial processing; activity in parts of the frontal cortex increases during childhood, dips in early adolescence, then increases in late adolescence into adulthood (Cohen Kadosh, Johnson, Dick, Cohen Kadosh, & Blakemore, 2013). In another study, older children and adolescents viewed images of fearful and happy faces while undergoing fMRI. As shown in Figure 4.4, in response to fearful stimuli, girls showed increases in bilateral prefrontal activity through mid-adolescence but in males, age-related increase in brain activity were

![Figure 4.4: Sex Differences in Face Processing During Adolescence](image-url)

limited to the right prefrontal cortex (Yurgelun-Todd & Kilgore, 2006). Given that girls begin puberty two years before boys, a lag in prefrontal maturation is expected.

Brain structure influences affective responses and interactions with others. For example, one part of the limbic system, the amygdala, is implicated in aggression. When faced with emotionally arousing contexts and stimuli, adolescents tend to show exaggerated amygdala activity relative to adults and fewer functional connections between the prefrontal cortex and amygdala, suggesting that adolescents experience more emotional arousal yet less cortical processing and control than adults (Blakemore & Mills, 2014; Hare et al., 2008). Generally, amygdala volume increases more in adolescent males than females (Blakemore, 2012; Giedd et al., 2009). It seems that adolescents are wired to experience strong emotional reactions and to misidentify emotions in others' facial expressions, which can make communication and social interactions difficult.

Most adults look back upon their own adolescence and recall engaging in activities that included an element of risk or were even outright dangerous, such as racing bikes off ramps to soar through the air or driving at fast speeds. Risk taking and adolescence go hand in hand, and the brain plays a large part in such behavior. In early adolescence, the balance of neurotransmitters shifts. At 9 to 10 years of age, the prefrontal cortex and limbic system experience a marked shift in levels of serotonin and dopamine, neurotransmitters that are associated with impulsivity, novelty seeking, and reward salience (Padmanabhan & Luna, 2014; Smith, Chein, & Steinberg, 2013; Van Leijenhorst et al., 2010). Sensitivity to rewards peaks at the same time as adolescents experience difficulty with response inhibition, the ability to control a response (Geier, 2013; Spear, 2013). A heightened response to motivational cues coupled with immature behavioral control results in adolescents being biased toward immediate goals instead of long-term consequences (Casey, Jones, & Somerville, 2011). The shift is larger for boys than girls and is thought to make potentially rewarding stimuli even more rewarding for teens (Steinberg, 2008). As a result, risky situations, those that entail an element of danger, become enticing. Risks become experienced as thrills (Spielberg, Olino, Forbes, & Dahl, 2014). Adolescents may find themselves drawn to extreme sports, for example, enjoying the high and element of the unknown when they direct their skateboard into the air for a daring turn.

Yet not all adolescents engage in the same risks. Contextual factors, such as adult supervision, exposure to stressors, and impoverished communities, for example, influence the direction that adolescents’ propensities for risk taking (Smith et al., 2013). One study examined adolescents in 11 countries in Africa, Asia, Europe, and the Americas and found that sensation seeking increased in preadolescence, peaked around age 19, and declined thereafter (Steinberg et al., 2017). Risky activity is thought to decline in late adolescence in part because of increases in adolescents’ self-regulatory capacities and their capacities for long-term planning that accompany maturation of the frontal cortex (Albert, Chein, & Steinberg, 2013; Casey, 2015).

**BRAIN DEVELOPMENT IN ADULTHOOD**

Brain development continues into emerging adulthood, maturing roughly in the mid-twenties (Dumontheil, 2016; Taber-Thomas & Perez-Edgar, 2015). As we age, the nervous system changes in predictable ways. Many neural fibers lose their coating of myelin, and communication among neurons slows accordingly. Declines are especially marked in the prefrontal cortex, responsible for executive functioning and judgment (Lu et al., 2013). Myelin losses contribute to cognitive declines with aging (Kohama, Rosene, & Sherman, 2012; Peters & Kemper, 2012). The last areas of the brain to myelinate are also the first to show reductions in myelin, a pattern some experts call the “last-in first-out” hypothesis of brain aging (Bender, Völkle, & Raz, 2016). The sensory regions of the brain, including the areas responsible for vision and hearing, and the motor cortex are the
Brain Growth in Older Adulthood

One of the most important findings in recent years about neurological development is that the brain retains some plasticity throughout life. The adult brain holds the potential to grow and change in response to experience. For example, older adults who are taught multiple cognitive strategies and problem-solving approaches show widespread positive effects on cognition that generalize to everyday tasks and last over time, often for years (Dunlosky, Kubat-Silman, & Hertzog, 2003; Schaie & Willis, 1986). Cognitive training does not simply influence older adults’ skills—it changes their brains. Cognitive training has consistently been associated with increases in volume in the brain structures thought to be critical to the trained task (Lustig et al., 2009). Moreover, expertise is associated with brain growth and changes in connectivity (Strenziok et al., 2014). Experts tend to have enlarged brain structures related to their type of expertise (Maguire et al., 2003).

Physical health is associated with neurological health and plasticity throughout adulthood and well into older adulthood. Recent research suggests that caloric restriction may hold potential for improving memory, improving connectivity among neurons, and increasing gray matter volume in parts of the brain implicated in memory (Lin, Parikh, Hoffman, & Ma, 2017; Prehn et al., 2016). Many cross-sectional and longitudinal studies have shown that aerobic exercise training in older adulthood is associated with increases in brain volume and cognitive function, especially executive function (Lang, Featherman, & Nesselroade, 1997; Stillman, Weinstein, Marsland, Gianaros, & Erickson, 2017). Aerobic exercise and activities that improve coordination are associated with increases in volume and connectivity in the frontal cortex, temporal lobe, and the hippocampus, areas responsible for memory, planning, and problem solving and prone to age-related deterioration (Erickson et al., 2011; Niemann, Godde, & Voelcker-Rehage, 2014; ten Brinke et al., 2015; Voss et al., 2013).

In one study (shown in Figure 4.5), greater amounts of physical activity were associated with greater gray matter volume in several areas of the brain, including the prefrontal cortex and hippocampus, over a 9-year period and a reduced risk for cognitive impairment (Erickson et al., 2010). Moreover, even sedentary older adults introduced to a long-term program of moderate physical activity showed increases in hippocampal volume over a 2-year period, suggesting that it is never too late to improve physical and neurological function (Rosano et al., 2017). These exercise experiments demonstrate that the brain remains modifiable throughout adulthood and that aerobic exercise offers important opportunities for neural plasticity (Hötting & Röder, 2013).

Although the phrase “use it or lose it” is often used in reference to cognitive function, recent research suggest that the aging brain can do more than just retain its functions; plasticity means that it can also grow. Perhaps the phrase should be changed to “use it to improve it.”

What Do You Think?

Identify three things that an adult of any age can do to promote positive brain development and functioning in older adulthood.
first brain areas to myelinate in infancy; they are also the last areas to show loss with age (Wu, Kumar, & Yang, 2016). Finally, some myelination continues throughout adulthood, but at a slower rate, permitting plasticity (Wang & Young, 2014).

Brain volume shrinks as dendrites contract and are lost, accompanied by a decrease in synapses and a loss of glial cells (Schuff et al., 2012). However, the reduction is, on average, less than half of 1% each year (Salthouse, 2011). For example, one study of men and women followed up from the early thirties to early forties found a 3% to 4% change in volume in men and women, respectively (Guo et al., 2016). Also, estimates of age-related changes in brain volume vary with measurement and across research studies. For example, some cross-sectional samples that compare adults of different ages at one time show greater age differences in brain volume than do longitudinal samples, which tend to show more continuous and gradual changes in brain volume that are less tied to age (Salthouse, 2011). A program of aerobic exercise has been shown to restore brain volume, especially in the hippocampus, a brain region closely involved with memory, supporting the role individuals have in their own development (see the Applying Developmental Science feature).

The brain retains plasticity and compensates for structural changes throughout older adulthood. Older adults’ brains compensate for cognitive declines by showing more brain activity and using different brain areas in solving problems than do younger adults (Turner & Spreng, 2012). Older adults often show brain activity that is spread out over a larger area, including both hemispheres, compensating for neural losses, as shown in Figure 4.6 (Daselaar & Cabeza, 2005; Reuter-Lorenz & Cappell, 2008). For example, in one study older adults compensated for lower levels of parietal and occipital activity with greater activity in the frontal lobes and performed better on a working memory task than did younger adults (Osorio, Fay, Pouthas, & Ballesteros, 2010).

Age-related brain changes are not always apparent in adults’ functioning. Adults’ brains naturally compensate for losses through cognitive reserve, the ability to make flexible and efficient use of available brain resources that permits cognitive efficiency, flexibility, and adaptability (Barulli & Stern, 2013; Nair, Sabbagh, Tucker, & Stern, 2014). Cognitive reserve is a type of plasticity cultivated throughout life from experience and environmental factors. Educational and occupational attainment and engagement in leisure activities allows some adults to cope with age-related changes better than others and show more successful aging (Barulli & Stern, 2013; Scarmeas & Stern, 2003). For example, bilingualism is associated with cognitive benefits throughout life. Adults who have daily experiences in using two languages, such as determining when to use one and inhibit another, show enhanced cognitive control abilities, more mental flexibility as well as being better able to handle tasks involving switching, inhibition, and conflict monitoring (Barac & Bialystok, 2012; Grant, Dennis, & Li, 2014). In addition, bilingual older adults show preserved white matter integrity, especially in the frontal lobe, as compared with their monolingual peers (Olsen et al., 2015; Pliatsikas, Moschopoulou, & Saddy, 2015).

A particularly exciting finding is that neurogenesis, the creation of new neurons, continues throughout life. New neurons are created in the hippocampus and striatum (a subcortical part of the brain responsible for coordinating motivation with body movement)
and the olfactory bulb throughout life but at a much slower rate than prenatally (Ernst et al., 2014; Gonçalves, Schafer, & Gage, 2016; Sailor, Schinder, & Lledo, 2017). Most of these neurons die off, but some survive, especially if exposed to experiences that require learning (Shores, 2014). As with neurogenesis early in life, surviving neurons migrate to the parts of the brain where they will function and create synapses with other neurons (Braun & Jessberger, 2014), permitting lifelong plasticity (Obemier, Tong, & Alvarez-Buylla, 2014). It is estimated that about 2% of neurons are renewed each year (Spalding et al., 2013). The corresponding synaptogenesis is associated with learning and plays a role in cognition and in stress and emotional responses, contributing to plasticity and the maintenance of cognitive abilities and advances in psychosocial maturing in the adult years (Cameron & Glover, 2015; Gonçalves et al., 2016; Nelson & Alkon, 2015; Sailor et al., 2017).

### Thinking in Context 4.1

1. What do parents need to know about their children’s brain development? What advice might you give to parents of infants, children, and adolescents on how to promote brain development? Would you give similar advice at all ages? Why or why not?

2. Children who suffer brain injuries often regain some, and sometimes all, of their capacities. Adults sometimes, but not always, show this resilience as well. How might you explain this, given what you have learned about brain development?

3. Most adults blame puberty for much of adolescent behavior. Researchers, however, point to the dual process model’s role in influencing adolescent behavior. Explain.

4. How are cultural, contextual, and lifestyle factors, such as neighborhood, socioeconomic status, ethnicity, and interactions with family and peers, reflected in brain development and change from infancy through older adulthood?

### MOTOR DEVELOPMENT

**L0 4.2 Summarize patterns of gross and fine motor development and influences on motor development.**

Newborns are equipped to respond to the stimulation they encounter in the world. The earliest ways in which infants adapt are through the use of their reflexes, involuntary and automatic responses to stimuli such as touch, light, and sound. Each reflex has its own developmental course (Payne & Isaacs, 2016). Some disappear early in life, and others persist throughout life, as shown in Table 4.1. Infants show individual differences in how reflexes are displayed, specifically the intensity of the response. Preterm newborns, for example, show reflexes suggesting a more immature neurological system than full-term newborns (Barros, Mitsuhiro, Chalem, Laranjeira, & Guinsburg, 2011). The absence of reflexes, however, may signal neurological deficits (Gabbard, 2012).

### GROSS MOTOR DEVELOPMENT

**Gross motor development** refers to the ability to control the large movements of the body, which are the actions that help us move around in our environment. Like physical development, motor skills evolve in a predictable sequence. By the end of the first month of life, most infants can reach the first milestone, or achievement, in motor development: lifting their heads while lying on their stomachs. After lifting the head, infants progress through an orderly series of motor milestones: lifting the chest, reaching for objects, rolling over, and sitting up with support (see Table 4.2). Notice that these motor achievements reflect a cephalocaudal progression of motor control, proceeding from the head downward (Payne & Isaacs, 2016). Success at initiating forward motion, or crawling (6–10 months), is particularly significant for both infants and parents. Infants vary in how they crawl. Some use...
their arms to pull and legs to push, some use only their arms or only their legs, and others scoot on their bottoms. Once infants can pull themselves upright while holding on to a chair or table, they begin “cruising,” moving by holding on to furniture to maintain their balance while stepping sideways. In most Western industrialized countries, most infants walk alone by about 1 year of age.

Once babies can walk, their entire visual field changes. Whereas crawling babies are more likely to look at the floor as they move, walking babies gaze straight ahead at caregivers, walls, and toys (Kretch, Franchak, & Adolph, 2014). Independent walking holds implications for cognitive, social, and emotional development, as it is associated not only with more attention and manipulation of objects but also with more sophisticated social interactions with caregivers, such as directing mothers’ attention to particular objects and sharing. These behaviors, in turn, are associated with advanced language development relative to non-walkers in both U.S. and Chinese infants (Clearfield, 2011; Ghassabian et al., 2016; He, Walle, & Campos, 2015; Karasik, Tamis-LeMonda, & Adolph, 2011).

Between the ages of 3 and 6, children become physically stronger, with increases in bone and muscle strength as well as lung capacity. Children make gains in coordination as the parts of the brain responsible for sensory and motor skills develop, permitting them to play harder and engage in more complicated play activities that include running, jumping, and climbing (see Table 4.3). Young children practice using their large motor skills to jump, run, and ride tricycles, pedal cars, and other riding toys. Coordinating complex

### Table 4.1 • Newborn Reflexes

<table>
<thead>
<tr>
<th>NAME OF REFLEX</th>
<th>RESPONSE</th>
<th>DEVELOPMENTAL COURSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palmar grasp</td>
<td>Curling fingers around objects that touch the palm</td>
<td>Birth to about 4 months, when it is replaced by voluntary grasp</td>
</tr>
<tr>
<td>Rooting</td>
<td>Turning head and tongue toward stimulus when cheek is touched</td>
<td>Disappears over first few weeks of life and is replaced by voluntary head movement</td>
</tr>
<tr>
<td>Sucking</td>
<td>Sucking on objects placed into the mouth</td>
<td>Birth to about 6 months</td>
</tr>
<tr>
<td>Moro</td>
<td>Giving a startle response in reaction to loud noise or sudden change in the position of the head, resulting in throwing out arms, arching the back, and bringing the arms together as if to grasp something</td>
<td>Birth to about 5 to 7 months</td>
</tr>
<tr>
<td>Babinski</td>
<td>Fanning and curling the toes in response to stroking the bottom of the foot</td>
<td>Birth to about 8 to 12 months</td>
</tr>
<tr>
<td>Stepping</td>
<td>Making stepping movements as if to walk when held upright with feet touching a flat surface</td>
<td>Birth to about 2 to 3 months</td>
</tr>
<tr>
<td>Swimming</td>
<td>Holding breath and moving arms and legs, as if to swim, when placed in water</td>
<td>Birth to about 4 to 6 months</td>
</tr>
</tbody>
</table>

### Table 4.2 • Early Gross Motor Milestones

<table>
<thead>
<tr>
<th>AVERAGE AGE ACHIEVED</th>
<th>MOTOR SKILL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 months</td>
<td>Lifts head and holds head steady when held upright</td>
</tr>
<tr>
<td>3 months</td>
<td>Pushes head and chest up with arms and rolls from stomach to back</td>
</tr>
<tr>
<td>4 months</td>
<td>Grasps cube</td>
</tr>
<tr>
<td>6 months</td>
<td>Sits without support</td>
</tr>
<tr>
<td>7 months</td>
<td>Rolls from back to stomach and attempts crawling. Uses opposable thumb to grasp objects</td>
</tr>
<tr>
<td>8 months</td>
<td>Achieves sitting position alone and pulls to a stand</td>
</tr>
<tr>
<td>9 months</td>
<td>“Cruises” by holding on to furniture</td>
</tr>
<tr>
<td>10 months</td>
<td>Plays patty-cake</td>
</tr>
<tr>
<td>11 months</td>
<td>Stands alone</td>
</tr>
<tr>
<td>12 months</td>
<td>Walks alone</td>
</tr>
<tr>
<td>14 months</td>
<td>Builds tower of two cubes and scribbles</td>
</tr>
<tr>
<td>17 months</td>
<td>Walks up steps</td>
</tr>
<tr>
<td>18 months</td>
<td>Runs</td>
</tr>
</tbody>
</table>
movements, like those entailed in riding a bicycle, is challenging for young children as it requires controlling multiple limbs, balancing, and more. As they grow and gain competence in their motor skills, young children become even more coordinated and begin to show interest in skipping, balancing, and playing games that involve feats of coordination, such as throwing and catching a ball. By age 5, most North American children can throw, catch, and kick a ball; climb a ladder; and ride a tricycle. Some 5-year-olds can even skate or ride a bicycle (Gabbard, 2012).

Like growth, children’s motor development proceeds continuously, advancing gradually throughout childhood (Kit, Akinbami, Isfahani, & Ulrich, 2017), so that motor skills from birth to age 4 predict children’s motor abilities later, when children enter school (Piek, Dawson, Smith, & Gasson, 2008). During the school-age years, the gross motor skills developed in early childhood refine and combine into more complex abilities, such as running and turning to dodge a ball, walking heel to toe down the length of a balance beam and turning around, or creating elaborate jump rope routines that include twisting, turning, and hopping by quickly alternating their feet (Gallahue & Ozmun, 2006). Increases in body size and strength contribute to advances in motor skills, which are accompanied by advances in flexibility, balance, agility, and strength (Broude, 1995; Gabbard, 2012). Now children can bend their bodies to more easily kick a ball, do a somersault, or carry out a dance routine; balance to jump rope or throw a ball; demonstrate agility to run and change speed and direction rapidly; and have the strength to jump higher and throw a ball farther than ever before (Gallahue & Ozmun, 2006; Haywood & Getchell, 2005).

FINE MOTOR DEVELOPMENT

Fine motor development refers to the ability to control small movements of the fingers such as reaching and grasping. Voluntary reaching plays an important role in cognitive development because it provides new opportunities for interacting with the world. Like other motor skills, reaching and grasping begin as gross activity and are refined with time. Newborns begin by engaging in prereaching, swinging their arms and extending them toward nearby objects (Ennouri & Bloch, 1996; von Hofsten & Rönnqvist, 1993). Newborns use both arms equally and cannot control their arms and hands, so they rarely succeed in making contact with objects of interest (Lynch, Lee, Bhat, & Galloway, 2008). Prereaching stops at about 7 weeks of age.

Voluntary reaching appears at about 3 months of age and slowly improves in accuracy. At 5 months, infants can successfully reach for moving objects. By 7 months, the arms can reach independently, and infants are able to reach for an object with one arm rather than both (Spencer, Vereijken, Diedrich, & Thelen, 2000). By 10 months, infants can reach for moving objects that change direction (Fagard, Spelke, & von Hofsten, 2009). As they gain experience with reaching and acquiring objects, infants develop cognitively because they learn by exploring and playing with objects—and object preferences change with experience. In one study 4- to 6-month-old infants with less reaching experience spent more time looking at and exploring larger objects, whereas 5- to 6-month-old infants with more reaching experience spent more time looking at and touching smaller objects. The older infants did this despite first looking at and touching the largest object (Libertus et al., 2013). With experience, infants’ attention moves away from the motor skill (like the ability to coordinate their movement to hit a mobile), to
the object (the mobile), as well as to the events that occur before and after acquiring the object (how the mobile swings and how grabbing it stops the swinging or how batting at it makes it swing faster). In this way, infants learn about causality and how to solve simple problems.

As children grow older their fine motor skills improve. The ability to button a shirt, pour milk into a glass, assemble puzzles, and draw pictures all involve eye–hand and small muscle coordination. As children get better at these skills, they are able to become more independent and do more for themselves. Young children become better at grasping eating utensils and become more self-sufficient at feeding. Many fine motor skills are very difficult for young children because they involve both hands and both sides of the brain. With short, stubby fingers that have not yet grown and a cerebral cortex that is not yet myelinated, a challenging task such as tying a shoelace is frustrating for young children. Tying a shoelace is a complex act requiring attention, memory for an intricate series of hand movements, and the dexterity to perform them. Though preschoolers struggle with this task, by 5 to 6 years of age most children can tie their shoes (Payne & Isaacs, 2016). During the school years, children become adept at using pencils to write words and sentences. They become able to control their hands independently and many subsequently learn to play musical instruments. Many children now show interest in activities that require fine motor coordination, such as drawing, building model cars, and sewing. By 12 years of age children show fine motor skills comparable to those of adults.

Not only are older children better at running, jumping, and other physical activities than young children, but they also show advances in fine motor control that allow them to develop new interests. School-age children build model cars, play with yo-yos, braid friendship bracelets, weave potholders, and learn to play musical instruments—all tasks that depend on fine motor control. Fine motor development is particularly important for children’s school performance, specifically penmanship. Most 6-year-old children can write the alphabet, their names, and numbers in large print, making strokes with their entire arm. With development, children learn to use their wrists and fingers to write. Uppercase letters are usually mastered first; the lowercase alphabet requires smaller movements of the hand that require much practice. By third grade, most children can write in script, or cursive writing. Girls tend to outperform boys in fine motor skills (Junaid & Fellowes, 2006; Nyiti, 1982). Success in fine motor skills, particularly writing skills, may influence academic skills as children who write with ease may be better able to express themselves in writing, for example.
Motor development illustrates the complex interactions that take place between maturation and contextual factors. Maturation plays a very strong role in motor development. Preterm infants reach motor milestones later than do full-term infants (Gabriel et al., 2009). Cross-cultural research also supports the role of maturation because around the world, infants display roughly the same sequence of motor milestones. Among some Native Americans and other ethnic groups around the world, it is common to follow the tradition of tightly swaddling infants to cradleboards and strapping the board to the mother’s back during nearly all waking hours for the first 6 to 12 months of the child’s life. Although this might lead one to expect that swaddled babies will not learn to walk as early as babies whose movements are unrestricted, studies of Hopi Indian infants have shown that swaddling has little impact on when Hopi infants initiate walking (Dennis & Dennis, 1991; Harriman & Lukosius, 1982). Such research suggests that walking is very much maturationally programmed. Other evidence for the maturational basis of motor development comes from twin studies. Identical twins, who share the same genes, share more similarities in the timing and pace of motor development than do fraternal twins, who share half of their genes (Fogel, 2007; Wilson & Harpring, 1972). Samples of young children in the United States show no ethnic or socioeconomic status differences in gross motor skill such as running, hopping, kicking, and catching (Kit et al., 2017).

Advancements in motor skill are influenced by body maturation and especially brain development. The pruning of unused synapses contributes to increases in motor speed and reaction time so that 11-year-old children tend to respond twice as quickly as 5-year-olds (Kail, 2003). Growth of the cerebellum (responsible for balance, coordination, and some aspects of emotion and reasoning) and myelination of its connections to the cortex contribute to advances in gross and fine motor skills and speed (Baillieux, De Smet, Paquier, De Deyn, & Mariën, 2008; Diamond, 2000; Tiemeier et al., 2010). Brain development improves children’s ability to inhibit actions, which enables children to carry out more sophisticated motor activities that require the use of one hand while controlling the other, such as throwing a ball, or that require both hands to do different things, such as playing a musical instrument (Diamond, 2013). As infants and children gain experience coordinating their motor skills, activity in the areas of the brain responsible for motor skills becomes less diffuse and more focused, consistent with the lifespan principle that domains of development interact (Nishiyori, Bisconti, Meehan, & Ulrich, 2016).

Much of motor development is driven by maturation, yet opportunities to practice motor skills are also important. In a classic naturalistic study of institutionalized orphans in Iran who had spent their first two years of life lying on their backs in their cribs and were never placed in sitting positions or played with, none of the 1- to 2-year-old infants could walk, and fewer than half of them could sit up; the researchers also found that most of the 3- to 4-year-olds could not walk well alone (Dennis, 1960). Recent research suggests that infants raised in orphanages score lower on measures of gross motor milestones at 4, 6, and 8 months of age and walk later as compared with home-reared infants (Chaibal, Bennett, Rattanathanthong, & Siritaratiwat, 2016). While maturation is necessary for motor development, it is not sufficient; we must also have opportunities to practice our motor skills.

In fact, practice can enhance motor development (Lobo & Galloway, 2012). For example, when infants from 1 to 7 weeks of age practice stepping reflexes each day, they retain the movements and walk earlier than babies walk at about a year of age, but cultural and contextual circumstances can speed or delay motor development.
infants who receive no practice (Vereijken & Thelen, 1997; Zelazo, 1983). Even newborns show improvement in stepping when given treadmill practice (Siekerman et al., 2015). Practice in sitting has a similar effect (Zelazo, Zelazo, Cohen, & Zelazo, 1993). Even 1-month-old infants given postural training showed more advanced control of their heads and necks than other infants (Lee & Galloway, 2012). Similarly, infants who spend supervised playtime prone on their stomachs each day reach many motor milestones, including rolling over and crawling, earlier than do infants who spend little time on their stomachs (Fetters & Hsiang-han, 2007; Kuo, Liao, Chen, Hsieh, & Hwang, 2008). In one study, over a two-week period, young infants received daily play experience with “sticky mittens”—Velcro-covered mitts that enabled them to independently pick up objects. These infants showed advances in their reaching behavior and greater visual exploration of objects, while a comparison group of young infants who passively watched an adult's actions on the objects showed no change (Libertus & Needham, 2010). Sticky mittens training in reaching at 3 months of age predicts object exploration at 15 months of age (Libertus, Joh, & Needham, 2016).

Practice contributes to cross-cultural differences in infant motor development. Different cultures provide infants with different experiences and opportunities for development. For example, in many cultures, including several in sub-Saharan Africa and in the West Indies, infants attain motor goals like sitting up and walking much earlier than do North American infants. Among the Kipsigi of Kenya, parents seat babies in holes dug in the ground and use rolled blankets to keep babies upright in the sitting position (Keller, 2003). The Kipsigis help their babies practice walking at 2 to 3 months of age by holding their hands, putting them on the floor, and moving them slowly forward. Notably, Kipsigi mothers do not encourage their infants to crawl; crawling is seen as dangerous as it exposes the child to dirt, insects, and the dangers of fire pits and roaming animals. Crawling is therefore virtually nonexistent in Kipsigi infants (Super & Harkness, 2015). Infants of many sub-Saharan villages, such as the !Kung San, Gusii, and Wolof, are also trained to sit using holes or containers for support and are often held upright and bounced up and down, a social interaction practice that contributes to earlier walking (Lohaus et al., 2011). Caregivers in some of these cultures further encourage walking by setting up two parallel bamboo poles that infants can hold onto with both hands, learning balance and stepping skills (Keller, 2003). Similarly, mothers in Jamaica and other parts of the West Indies use a formal handling routine to exercise their babies' muscles and help them to grow up strong and healthy (Dziewolska & Cautilli, 2006; Hopkins, 1991; Hopkins & Westra, 1989, 1990).

Although practice can speed development and caregivers in many cultures provide their infants with opportunities for early practice of motor skills, sometimes survival and success requires continued dependence on caregivers and delaying motor milestones. For example, crawling may not be encouraged in potentially dangerous environments, such as those with many insects, rodents, and/or reptiles on the ground. For example, the nomadic Ache of eastern Paraguay discourage their infants from crawling or moving independently. Ache infants walk at 18 to 20 months, as compared with the 12-month average of North American infants (Kaplan & Dove, 1987).

Even simple aspects of the child-rearing context, such as choice of clothing, can influence motor development. In the 19th century, 40% of American infants skipped crawling, possibly because the long, flowing gowns they wore impeded movement on hands and knees (Trettien, 1990). One study of 13- and 19-month-old infants compared their gait while wearing a disposable diaper, a thicker cloth diaper, and no diaper (Cole, Lingeman, & Adolph, 2012). When naked, infants demonstrated the most sophisticated walking with fewer missteps and falls. While wearing a diaper, infants walked as poorly as they would have done several weeks earlier had they been walking naked. In sum, motor development is largely maturational, but subtle differences in context and cultural emphasis play a role in its timing.
MOTOR DEVELOPMENT AS A DYNAMIC SYSTEM

Motor milestones, such as the ability to crawl, might look like isolated achievements, but they actually develop systematically and build on each other, with each new skill preparing an infant to tackle the next (Thelen, 1995, 2000). As shown in Figure 4.7, motor development reflects an interaction among developmental domains, maturation, and environment in which we acquire increasingly complex dynamic systems of action (Thelen, 1995, 2000). Simple motor skills are combined in increasingly complex ways, permitting advances in movement including a wider range and more precise movements that enable babies to more effectively explore and control their environments. Separate abilities are blended together to provide more complex and effective ways of exploring and controlling the environment. For example, the abilities to sit upright, hold the head upright, match motor movements to vision, reach out an arm, and grasp are all combined into coordinated reaching movements to obtain a desired object (Corbetta & Snapp-Childs, 2009; Spencer et al., 2000).

Motor skills also reflect the interaction of multiple domains of development. All movement relies on the coordination of our senses and cognitive abilities to plan and predict actions. Social and cultural influences provide context to our movements. Motor behavior influences what we sense and our opportunities to engage our world, advance cognition, and interact with others. Motor skills do not develop in isolation; rather, they are influenced by the physical and social context in which they occur (Adolph & Franchak, 2017). Motor skills become more specialized, coordinated, and precise with practice, permitting infants to reach for an object with one hand without needlessly

FIGURE 4.7: Dynamic Systems Theory

The infant’s abilities to reach out an arm, stretch, and grasp combine into coordinated reaching movements to obtain desired objects. Motor development progresses to sitting, crawling, walking, and eventually running; all reflections of infants’ blending and coordinating abilities to achieve self-chosen goals, such as obtaining toys, and all tailored by environmental supports and challenges. (photos: iStock and CanStock/Harishmarnad.)

dynamic systems A framework describing motor skills as resulting from ongoing interactions among physical, cognitive, and socioemotional influences and environmental supports in which previously mastered skills are combined to provide more complex and effective ways of exploring and controlling the environment.
flailing the other, for example (D'Souza, Cowie, Karmiloff-Smith, & Bremner, 2016). With experience in a given task, infants' brain activity shifts from diffuse activity spread through large regions of the brain to functioning that is more refined and localized to the motor cortex (Nishiyori et al., 2016).

Motor development reflects goal-oriented behavior because it is initiated by the infant's or child's desire to accomplish something, such as picking up a toy or moving to the other side of the room. Infants' abilities and their immediate environments (e.g., whether they are being held, lying in a crib, or lying freely on the floor) determine whether and how the goal can be achieved (Spencer et al., 2000). The infant tries out behaviors and persists at those that enable him or her to move closer to the goal, practicing and refining the behavior. For example, infants learn to walk by taking many steps and making many falls, but they persist even though, at the time, crawling is a much faster and more efficient means of transportation (Adolph et al., 2012). Why? Perhaps because upright posture leads to many more interesting sights, objects, and interactions. The upright infant can see more and do more, with two hands free to grasp objects, making walking a very desirable goal (Adolph & Tamis-LeMonda, 2014). New motor skills provide new possibilities for exploration of the environment and new interactions with caregivers that influence opportunities. Differences in caregiver interactions and caregiving environments affect children's motor skills, the form they take, the ages of onset, and the overall developmental trend (Adolph & Franchak, 2017).

Therefore, from a dynamic systems perspective, motor development is the result of several processes: central nervous system maturation, the infant's physical capacities, environmental supports, and the infant's desire to explore the world (see Figure 4.7). It is learned by revising and combining abilities and skills to fit the infant's goals. In this way, motor development is highly individualized as each infant has goals that are particular to his or her specific environment. For example, an infant might respond to slippery hardwood floors by crawling on her stomach rather than all fours or by shuffling her feet and hands rather than raising each. Infants attain the same motor tasks, such as climbing down stairs, at about the same age, yet differ in how they approach the task. Some, for example, might turn around and back down, others descend on their bottoms, and others slide down face first (Berger, Theuring, & Adolph, 2007). By viewing motor development as dynamic systems of action produced by an infant's abilities, goal-directed behavior, and environmental supports and opportunities, we can account for the individual differences that we see in motor development.

**Motor Development and Aging**

Motor skills change in predictable ways over the lifespan. One study of fine and gross motor performance found that performance showed a pattern of improvement with age up until early adulthood and a decline with age thereafter. Specifically, performance improved from 7- to 9-year-old children through 19- to 25-year-old young adults and then declined from young adulthood into older adulthood, in 66- to 80-year-old adults (Leversen, Haga, Sigmundsson, Rebollo, & Colom, 2012). We have seen that physical activity can compensate for age-related declines in muscle and strength. A lifetime of regular physical activity is associated with greater mobility in older adulthood (Boyer et al., 2012).

Changes in *balance*, the ability to control the body's position in space, is a particularly important influence on older adults' mobility (Payne & Isaacs, 2016). Balance involves integrating sensory information with awareness of the position of one's body in space and in the surrounding environment (Payne & Isaacs, 2016). As we will see later in this chapter, sensory abilities tend to decline in function, and these declines make balance more difficult to achieve and sustain. However, just as muscle strength can be improved, so can balance. Interventions that encourage exercise and promote strength and balance, such as tai chi, can increase balance and strength and offset loss
(Granacher, Muehlbauer, & Gruber, 2012; Lesinski, Hortobágyi, Muehlbauer, Gollhofer, & Granacher, 2015; Peterson, Rhea, Sen, & Gordon, 2010). With age, balance requires more attention and taps more cognitive resources. In one study, researchers administered four challenging balance tasks to a large sample of healthy 50- to 64- and 65- to 75-year-old participants (Aslan et al., 2008). Balance tasks included a forward reach that required participants to stand with their feet together and reach forward as far as they could without losing balance; a timed task that recorded how quickly the adults could stand from a chair, walk 10 feet, return, and sit back down; standing from a seated position in a chair five times, fully straightening the legs each time before sitting back down; and a timed task in which participants stepped up on a 4-inch step five times. Balance performance declined with age. Tasks that ask older adults to multitask and perform cognitive tasks (such as counting backwards by threes) show even greater decrements, suggesting that age-related changes are influenced by the ability to allocate attention, and that neurological change plays a role in motor performance (Granacher et al., 2012).

Walking is the result of many integrated functions, including neurological, muscular, and sensory systems (Holtzer, Epstein, Mahoney, Izzetoglu, & Blumen, 2014; Sorond et al., 2015). As muscle strength, bone density, and flexibility declines, people walk more slowly (Shumway-Cook et al., 2007), yet many adults compensate by taking longer steps (Jerome et al., 2015).

Gait (the manner in which people walk) speed naturally declines with age (Payne & Isaacs, 2016). However, rapid or steep decline in gait speed may indicate overall physiological declines that predict mortality because motor function, specifically gait speed, is a marker of overall health and is used in geriatric assessment in addition to measures of blood pressure, respiration, temperature, and pulse (Kuys, Peel, Klein, Slater, & Hubbard, 2014; Studenski, 2011).

**Thinking in Context 4.2**

1. Carmen is concerned because her 14-month-old baby is not yet walking. All of the other babies she knows walked by 12 months of age. What would you tell Carmen?

2. How might a fine motor skill, such as learning to use a spoon, reflect the interaction of maturation and sociocultural context? How might contextual factors such as neighborhood, family, school, and culture influence the development of motor skills? Do these factors become more influential over the childhood years? Why or why not?

3. Consider your own development. What do you recall about the development of your motor skills? For example, when did you learn to tie your shoelaces or ride a bike? How did your motor skills influence other aspects of development, such as your relationships with others or your cognitive skills?

4. How do motor skills illustrate the interaction of domains of development in infancy? Adulthood?

**SENSATION AND PERCEPTION**

**LO 4.3 Describe age-related changes in vision, hearing, and other senses.**

We have seen that individuals are embedded in and interact dynamically with their context. James and Eleanor Gibson studied perceptual development from an ecological
perspective, emphasizing that perception arises through interactions with the environment. Rather than collecting small pieces of sensory information and building a representation of the world, the Gibsons argued that the environment itself provides all the information needed and we perceive the environment directly, without constructing or manipulating sensory information.

Perception arises from action. Infants actively explore their environment with their eyes by moving their heads and, later, reaching with their hands and, eventually, crawling. Through these activities infants perceive affordances—the nature, opportunities, and limits of objects (Gibson & Pick, 2000). The features of objects tell infants about possible actions, such as whether an object is squeezable, mouthable, catchable, or reachable. Infants explore their environment systematically, searching to discover the properties of the things around them (Savelsbergh, van der Kamp, & van Wermeskerken, 2013). From this perspective, perception arises from action, just as it influences action (Gibson, 1979). Exploration and discovery of affordances depends on the infant's capacities for action, which is influenced by their development, genetics, and motivation (Miller, 2016). For example, a large pot might offer a 10-year-old the possibility of cooking because the child has developed this capacity and can perceive this affordance of the pot. An 18-month-old infant may perceive very different affordances from the pot based on her capacities, such as a drum to bang or a bucket to fill. We naturally perceive affordances, such as knowing when a surface is safe for walking, by sensing information from the environment and coordinating it with our body sensations, such as our sense of balance, for example (Kretch et al., 2014).

**SENSORY AND PERCEPTUAL DEVELOPMENT**

Visiting the doctor's office for the first time in her young life, Kerry followed the doctor's finger with her eyes as he passed it over her face. "I think she sees it!" says her surprised mother. "She most certainly does," said the doctor. "Even as a newborn, your Kerry can sense the world. She can see, hear, and smell better than you know." Developmental researchers draw a distinction between sensation and perception. Sensation occurs when our senses detect a stimulus. Perception refers to the sense our brain makes of the stimulus and our awareness of it. Newborns can both detect and perceive stimuli, but many of their abilities are immature relative to those of adults. Yet infants' sensory abilities develop rapidly, achieving adult levels within the first year of life (Courage & Adams, 1990; Northern, 2014). The Applying Developmental Science feature describes some of the methods researchers use to study sensation and perception in infants.

**Vision**

At birth, vision is the least developed sense, but it improves rapidly. Newborn visual acuity, or sharpness of vision, is approximately 20/400 (Farroni & Menon, 2008). Studies of infants' looking preferences—what the infant looks at and for how long (see Chapter 6)—show that infants reach adult levels of visual acuity between 6 months and 1 year of age (Courage & Adams, 1990; Gwiazda & Birch, 2001; Mercuri, Baranello, Romeo, Cesarini, & Ricci, 2007). Improvement in vision is due to the increasing maturation of the structures of the eye and the visual cortex, the part of the brain that processes visual stimuli.

Newborns are born with preferences for particular visual stimuli. Newborns prefer to look at patterns, such as a few large squares, rather than a plain stimulus such as a black or white oval shape (Fantz, 1961). Newborns also prefer to look at faces, and the preference for faces increases with age (Frank, Vul, & Johnson, 2009; Gliga, Elsabbagh, Andrvizou, & Johnson, 2009). How infants explore visual stimuli changes with age (Colombo, Brez, & Curtindale, 2015). Until about 1 month of age, infants tend to scan along the outer perimeter of stimuli. For example, when presented with a face, the infant's gaze will scan along the hairline and not move to the eyes and mouth. By 6 to 7 weeks of age, infants
How do researchers study infant perception? The simplest method is through preferential looking tasks, which are experiments designed to determine whether infants prefer to look at one stimulus or another. For example, consider an array of black and white stripes. As shown in Figure 4.8, an array with more stripes (and therefore, many more narrow stripes) tends to appear gray rather than black and white because the pattern becomes more difficult to see as the stripes become more narrow. Researchers determine infants' visual acuity by comparing infants' responses to stimuli with different frequencies of stripes because infants who are unable to detect the stripes lose interest in the stimulus and look away from it.

Another method of studying infant perception relies on infants' capacity for habituation, which is a gradual decline in the intensity, frequency, or duration of a response to an unchanging stimulus. For example, to examine whether an infant can discriminate between two stimuli, a researcher presents one until the infant habituates to it. Then a second stimulus is presented. If dishabituation, or the recovery of attention, occurs, it indicates that the infant detects that the second stimulus is different from the first. If the infant does not react to the new stimulus by showing dishabituation, it is assumed that the infant does not perceive the difference between the two stimuli. The habituation method is very useful in studying infant perception and cognition, and underlies many of the findings discussed in this chapter.

Operant conditioning is the basis for a third method researchers use to study perception in infants. Recall from Chapter 1 that operant conditioning entails learning behaviors based on their consequences—whether they are followed by reinforcement or punishment. Behaviors increase when they are followed by reinforcement and decrease when they are followed by punishment. Research employing this method has shown that newborns will change their rate of sucking on a pacifier, increasing or decreasing the rate of sucking, in order to hear a tape recording of their mother's voice, a reinforcer (Moon, Cooper, & Fifer, 1993). Other research shows that newborns will change their rate of sucking to see visual designs or hear human voices that they find pleasing (Floccia, Christophe, & Bertoncini, 1997). Researchers have found that premature infants and even third-trimester fetuses can be operantly conditioned (Dziewolska & Cautilli, 2006; Thoman & Ingersoll, 1993). For example, a 35-week-old fetus will change its rate of kicking in response to hearing the father talk against the mother's abdomen, suggesting that hearing begins in the womb (Dziewolska & Cautilli, 2006).

What Do You Think?
Provide examples of how parents and caregivers can apply habituation and operant conditioning to promote infants' development.
study the eyes and mouth, which hold more information than the hairline (Hunnius & Geuze, 2004). Similarly, the ability to follow an object's movement with the eyes, known as visual tracking, is very limited at birth but improves quickly. By 2 months of age, infants can follow a slow-moving object smoothly, and by 3 to 5 months, their eyes can dart ahead to keep pace with a fast-moving object (Agyei, van der Weel, & van der Meer, 2016; Richards & Holley, 1999; Teller, 1997). The parts of the brain that process motion in adults are operative in infants by 7 months of age (Weaver, Crespi, Tosetti, & Morrone, 2015).

Like other aspects of vision, color vision improves with age. Newborns see color, but they have trouble distinguishing between colors. That is, although they can see both red and green, they do not perceive red as different from green. Early visual experience with color is necessary for normal color perception to develop (Colombo et al., 2015; Sugita, 2004). Habituation studies show that by 1 month of age, infants can distinguish among red, green, and white (Teller, 1997). By 2 to 3 months of age, infants are as accurate as adults in discriminating the basic colors of red, yellow, and blue (Matlin & Foley, 1997; Teller, 1998). By 3 to 4 months of age, infants can distinguish many more colors as well as distinctions among closely related colors (Bornstein & Lamb, 1992; Haith, 1993). Seven-month-old infants detect color categories similar to those of adults; they can group slightly different shades (e.g., various shades of blue) into the same basic color categories as adults do (Clifford, Franklin, Davies, & Holmes, 2009).

Depth perception is the ability to perceive the distance of objects from each other and from ourselves. Depth perception is what permits infants to successfully reach for objects and, later, to crawl without bumping into furniture. By observing that newborns prefer to look at three-dimensional objects rather than two-dimensional figures, researchers have found that infants can perceive depth at birth (Slater, Rose, & Morison, 1984). Three- to 4-week-old infants blink their eyes when an object is moved toward their face, as if to hit them, suggesting that they are sensitive to depth cues (Kayed, Farstad, & van der Meer, 2008; Náñez & Yonas, 1994). Infants learn about depth by observing and experiencing motion.

**FIGURE 4.9: Visual Cliff**

Three-month-old infants show a change in heart rate when placed face down on the glass surface of the deep side of the visual cliff, suggesting that they perceive depth, but do not fear it. Crawling babies, however, show a different response. In a classic study of visual perception, crawling babies moved to the shallow side of the visual cliff, even if called by their mothers. The more crawling experience infants had, the more likely they were to refuse to cross the deep side of the visual cliff.

Source: Levine and Munsch (2010).
A classic series of studies using an apparatus called the visual cliff demonstrated that crawling influences how infants perceive depth. The visual cliff, as shown in Figure 4.9, is a Plexiglas-covered table bisected by a plank so that one side is shallow, with a checkerboard pattern right under the glass, and the other side is deep, with the checkerboard pattern a few feet below the glass (Gibson & Walk, 1960). In this classic study, crawling babies readily moved from the plank to the shallow side, but not to the deep side, even if coaxed by their mothers, suggesting that they perceive the difference in depth (Walk, 1968). The more crawling experience infants have, the more likely they are to refuse to cross the deep side of the visual cliff (Bertenthal, Campos, & Barrett, 1984).

Does this mean that babies cannot distinguish the shallow and deep sides of the visual cliff until they crawl? No, because even 3-month-old infants who are too young to crawl distinguish shallow from deep drops. When placed face down on the glass surface of the deep side of the visual cliff, 3-month-old infants became quieter and showed a decrease in heart rate as compared with when they were placed on the shallow side of the cliff (Campos, Langer, & Krowitz, 1970; Dahl et al., 2013). The young infants can distinguish the difference between shallow and deep drops but do not yet associate fear with deep drops.

As infants gain experience crawling, their perception of depth, the meaning they associate with it, changes. Newly walking infants avoid the cliff’s deep side even more consistently than do crawling infants (Dahl et al., 2013; Witherington, Campos, Anderson, Lejeune, & Seah, 2005). A new perspective on the visual cliff studies argues that infants avoid the deep side of the cliff not out of fear but simply because they perceive that they are unable to successfully navigate the drop; fear might be conditioned through later experiences, but infants are not naturally fearful of heights (Adolph, Kretch, & LoBue, 2014).

**Hearing**

The capacity to hear develops in the womb; in fact, hearing is the most well-developed sense at birth. Newborns are able to hear about as well as adults (Northern, 2014). Shortly after birth, neonates can discriminate among sounds, such as tones (Hernandez-Pavon, Sosa, Lutter, Maier, & Wakai, 2008). By 3 days of age, infants will turn their head and eyes in the general direction of a sound, and this ability to localize sound improves over the first 6 months (Clifton, Rochat, Robin, & Berthier, 1994; Litovsky & Ashmead, 1997).

The process of learning language begins at birth, through listening. Newborns are attentive to voices and can detect their mothers’ voices. Newborns only 1 day old prefer to hear speech sounds over acoustically comparable nonspeech sounds. Newborns can perceive and discriminate nearly all sounds in human languages, but from birth, they prefer to hear their native language (Moon et al., 1993). Brain activity in the temporal and left frontal cortex in response to auditory stimuli indicates that newborns can discriminate speech patterns, such as differences in cadence among languages (Gervain, Macagno, Cogoi, Peña, & Mehler, 2008; Gervain & Mehler, 2010). In one study, 4-month-old Japanese infants showed increased brain activity in the left hemisphere of the brain, responsible for language in adults, in response to hearing their native language as compared with nonnative speech, emotional voices (human vocalizations with no linguistic content), monkey calls, and scrambled versions of each vocalization (Minagawa-Kawai et al., 2011). Infants show not only the ability to hear sounds, but clear preferences for their native language, suggesting an early developing neurological specialization for language.

**Touch**

As compared with vision and hearing, we know much less about the sense of touch in infants. In early infancy, touch, especially with the mouth, is a critical means of learning about the world (Piaget, 1936/1952). The mouth is the first part of the body to show sensitivity to touch prenatally and remains one of the most sensitive areas to touch after birth.
Neonatal circumcision, removal of the foreskin of the penis, is the oldest known planned surgery (Alanis & Lucidi, 2004). Although it is uncommon throughout much of the world, the United States leads Western nations in rates of infant circumcision (Elder, 2007). As shown in Figure 4.10, circumcision rates declined from 65% of male newborns in 1979 to 57% in 2010, but there are regional differences, with nearly twice as many infant circumcisions in the Midwest as in the West (Owings, Uddin, & Williams, 2013). In recent years circumcision has come under increasing scrutiny within the United States as some charge that it places the newborn under great distress and confers few medical benefits.

For decades many scientists and physicians believed that newborns did not feel pain, leading many to perform circumcision without pain management techniques such as anesthesia or analgesia (Alanis & Lucidi, 2004). We now know that even the fetus feels pain (Benatar & Benatar, 2003). Newborns show many indicators of distress during circumcision, such as a high-pitched wail, flailing, grimacing, and dramatic rises in heart rate, blood pressure, palm sweating, pupil dilation, muscle tension, and cortisol levels (Paix & Peterson, 2012; Razmus, Dalton, & Wilson, 2004). According to the American Academy of Pediatrics (1999), analgesia (pain relief in which the newborn remains conscious) is safe and effective in reducing the pain associated with circumcision. The American Society for Pain Management Nursing has issued a position statement that when circumcision is chosen, it must be accompanied by pain management before, during, and after the procedure (O’Connor-Von & Turner, 2013).

The medical benefits of circumcision are debated (Freedman, 2016; Frisch & Earp, 2016). Benefits include reduced risk of urinary tract infections, developing penile cancer, and acquiring HIV (American Academy of Pediatrics Task Force on Circumcision Policy, 1999; American Medical Association, 1999; Morris et al., 2017). Yet urinary tract infections and penile cancer are relatively rare even among men who are uncircumcised. Evidence regarding HIV transmission comes from research with adult males in Africa; whether the same effects apply to infants in Western industrialized countries is uncertain (Alanis & Lucidi, 2004; Benatar & Benatar, 2003). Moreover, behavior is a more important factor in preventing HIV infection than is circumcision.

In 1999, both the American Medical Association and American Academy of Pediatrics joined medical associations in Canada, Europe, and Australia in concluding that the benefits of circumcision are not large enough to recommend routine circumcision; instead it is a parental decision. However, in 2012 the American Academy of Pediatrics modified its view to note that although it is a parental decision, the benefits of circumcision justify providing access to the procedure (by insurance companies) to families who choose it. A critical commentary by physicians and representatives of medical associations and societies in countries in Europe, Canada, and Australia countered that the revised recommendation was not based on medical evidence but instead reflected cultural bias on the part of the AAP to support social practices common in the United States (Frisch et al., 2013).

Regardless, formal recommendations by medical associations may ultimately have little sway on parents (Freedman, 2016). Education about the risks and benefits of circumcision, especially the controversy over the medical necessity of circumcision, generally does not influence parental decisions regarding circumcision (Binner, Mastrobattista, Day, Swaim, & Monga, 2013).
A stroke to the newborn's cheek elicits the rooting reflex (see Table 4.1 above), which acts as a powerful survival mechanism by enabling the infant to reflexively attach to the mother's breast.

Touch, specifically a caregiver's massage, can reduce stress responses in preterm and full-term neonates and is associated with weight gain in newborns (Diego et al., 2007; Hernandez-Reif, Diego, & Field, 2007). Skin-to-skin contact with a caregiver, as in kangaroo care (see Chapter 2), has an analgesic effect, reducing infants' pain response to being stuck with a needle for blood testing (de Sousa Freire, Santos Garcia, & Carvalho Lamy, 2008; Ferber & Makhoul, 2008). Although it was once believed that newborns were too immature to feel pain, we now know that the capacity to feel pain develops even before birth; by at least the 30th week of gestation a fetus responds to a pain stimulus (Benatar & Benatar, 2003). The neonate's capacity to feel pain has influenced debates about infant circumcision, as discussed in the Lives in Context feature.

Smell and Taste

Smell and taste are well developed at birth. Classic experiments demonstrate that newborns can discriminate between smells (Goubet et al., 2002). Just hours after birth, newborns display facial expressions signifying disgust in response to odors of ammonia, fish, and other scents that adults find offensive (Steiner, 1979). Within the first days of life, newborns detect and recognize their mother’s odor (Macfarlane, 1975; Porter, Varendi, Christensson, Porter, & Winberg, 1998; Schaal et al., 1980). Infants are calmed by their mother’s scent. Newborns who smelled their mother’s odor displayed less agitation during a heel-stick test and cried less afterward than infants presented with unfamiliar odors (Rattaz, Goubet, & Bullinger, 2005). Familiar scents are reinforcing and can reduce stress responses in infants (Goubet, Strasbaugh, & Chesney, 2007; Nishitani et al., 2009; Schaal, 2017).

Infants show innate preferences for some tastes (Beauchamp & Mennella, 2011; Ross, 2017). For example, both bottle- and breast-fed newborns prefer human milk—even milk from strangers—to formula (Marlier & Schaal, 2005). Newborns prefer sugar to other substances, and a small dose of sugar can serve as an anesthetic, distracting newborns from pain (Gradin, Eriksson, Schollin, Holmqvist, & Holstein, 2002). Experience can modify taste preferences, beginning before birth: Fetuses are exposed to flavors in amniotic fluid that influence their preferences after birth (Beauchamp & Mennella, 2011; Forestell, 2016). In one study, the type of formula fed to infants influenced their taste preferences at 4 to 5 years of age (Mennella & Beauchamp, 2002). Infants who were fed milk-based formulas and protein-based formulas were more likely to prefer sour flavors at 4 to 5 years of age as compared with infants who were fed soy-based formulas, who,

What Do You Think?

1. In your view, what are the most important considerations in making a decision about whether to circumcise a newborn boy?

2. Imagine that you had a newborn boy. Would you choose to circumcise your son? Why or why not?
in turn, were more likely to prefer bitter flavors. In addition, mothers reported that the infants fed protein- or soy-based formulas were more likely to prefer broccoli than those fed milk-based formulas. Touch, taste, and smell further illustrate infants' amazing capacities to sense and respond to the world around them.

**Intermodal Perception**

Though we have discussed the senses separately in this chapter, in everyday life when people attend to the environment they combine information from our various sensory systems to understand the world. This process is called *intermodal perception*. Not only are infants able to sense in multiple modalities; they are able to coordinate their senses. Most of the stimuli we experience are intermodal because they provide more than one type of sensory information (Slater, Quinn, Brown, & Hayes, 1999). Research on intermodal perception supports the finding that infants expect vision, auditory, and tactile information to occur together (Hyde, Flom, & Porter, 2016; Sai, 2005). For example, newborns coordinate visual and auditory senses, turning their heads and eyes in the direction of a sound source, suggesting that they intuitively recognize that knowledge about spatial location is provided by both visual and auditory information (Clifton, Morrongiello, Kulig, & Dowd, 1981; Muir & Clifton, 1985; Newell, 2004; Wertheimer, 1961). By 6 months of age, infants who explore an object with their hands alone can recognize it by sight alone and vice versa, a finding that supports the integration of vision and touch (Pineau & Sterri, 1990; Rose, Gottfried, & Bridger, 1981; Ruff & Kohler, 1978). Intermodal matching of visual and auditory stimuli shows similar patterns as visual and tactile. By 4 months of age, infants coordinate visual stimuli with expectations about auditory stimuli (Spelke, 1976).

Sensitivity to intermodal relations among stimuli is critical to perceptual development and learning—and this sensitivity emerges early in life (Bahrick, 2002; Gibson & Pick, 2000; Lewkowicz, 2000; Lewkowicz & Lickliter, 1994; Newell, 2004). But just how early? Newborns show a preference for viewing their mother's face at 78, 72, 12, and even just 4 hours after birth (Bushnell, Sai, & Mullin, 1989; Field, Cohen, Garcia, & Greenberg, 1984; Pascalis, Dechene, Morton, Duruelle, & Grenet, 1995). Because 4-hour-old neonates prefer their mother's face, it was once believed that infants' preference for their mother's face was innate. However, infants are not born knowing their mother's face. Instead, they quickly learn to identify their mother. How? In one study, neonates were able to visually recognize their mother's face only if the face was paired with their mother's voice at least once after birth (Sai, 2005). Thus, intermodal perception is evident at birth because neonates can coordinate auditory and visual stimuli in order to associate their mother's face with her voice. They quickly remember the association and demonstrate a preference for her face even when it is not paired with her voice.

Newborns are equipped with remarkable capacities for sensing and perceiving stimuli. Their senses, although well developed at birth, improve rapidly over the first year of life. Moreover, capacities for intermodal perception mean that infants can combine information from various sensory modalities to construct a sophisticated and accurate picture of the world around them.

**SENSORY CHANGES IN ADULTHOOD**

Suddenly aware that he holds the newspaper at arm's length and still squints to read, 45-year-old Dominic wonders to himself, “When did this happen? I can't see like I used to.” Like much of physical development, the changes that take place in our senses represent continuous change. Over the adult years, vision and hearing capacities gradually decline. Like Dominic, most adults notice changes in vision during their 40s and changes in hearing at around age 50. The use of corrective lenses aids vision problems, and hearing aids amplify sounds, permitting better hearing.
Vision Changes in Adulthood

Dominic’s need to hold the newspaper at a distance in order to read is not unusual and is related to changes in the eye that occur throughout the adult years. The cornea flattens; the lens loses flexibility; and the muscle that permits the lens to change shape, or accommodate, weakens. The result is that most adults in their 40s develop presbyopia, also known as farsightedness—the inability to focus the lens on close objects, such as in reading small print (Hermans, Dubbelman, van der Heijde, & Heethaar, 2008; Strenk, Strenk, & Koretz, 2005). Presbyopia is largely caused by the stiffening of the lens in the eye, related to the loss of collagen that contributes to stiffening of tissues throughout the body (Laughton, Sheppard, & Davies, 2016). By age 50, virtually all adults are presbyopic and require reading glasses or other corrective options (Gil-Cazorla, Shah, & Naroo, 2015; Truscott, 2009). Most also require corrective lenses for distance. Bifocals that combine lenses for nearsightedness and farsightedness are helpful.

In addition to changes in the accommodative ability of the lens, the ability to see in dim light declines because, with age, the lens yellows, and the size of the pupil shrinks. In addition, by middle age most adults have lost about one half of the rods (light receptor cells) in the retina, which reduces their ability to see in dim light and makes adults’ night vision decline twice as fast as their day vision (Jackson & Owseley, 2003; Lin, Tsubota, & Apte, 2016; Owseley, 2016). As rods are lost, so too are cones (color receptive cells) because rods secrete substances that permit cones to survive (Bonnel, Mohand-Said, & Sahel, 2003). Color discrimination, thus, becomes limited with gradual declines beginning in the 30s (Kraft & Werner, 1999; Paramei & Oakley, 2014). Night vision is further reduced because the vitreous (transparent gel that fills the eyeball) becomes more opaque with age, scattering light that enters the eye (creating glare) and permitting less light to reach the retina (Owseley, 2011). In middle adulthood, about one third more light is needed to compensate for these changes that reduce vision (Owseley, McGwvin, Jackson, Kallies, & Clark, 2007). All of these changes in vision make driving at night more challenging as headlights from other cars become blinding (Gruber, Mosimann, Müüri, & Nef, 2013; Owseley, 2016).

Many adults develop cataracts, a clouding of the lens resulting in blurred, foggy vision that makes driving hazardous and, if untreated, can lead to blindness (Kline & Li., 2005). Cataracts are the result of a combination of hereditary and environmental factors associated with oxidative damage, including illnesses such as diabetes and behaviors such as smoking (David, Nancy, & Ying-Bo, 2010; Lin et al., 2016; Tan et al., 2008). By age 80, more than half of adults have cataracts (American Academy of Ophthalmology, 2011). Cataracts are commonly corrected through a surgical procedure in which the lens is replaced with an artificial lens.

In addition to the lens, other parts of the eye show structural changes (see Figure 4.11). Cells in the retina and optical nerve are lost with aging (Owseley, 2011). Some older adults experience macular degeneration, a substantial loss of cells in the center area of the retina, the macula, causing blurring and eventual loss of central vision (Chakravarthy, Evans, & Rosenfeld, 2010; Owseley, 2016). Hereditary and environmental factors, such as smoking and atherosclerosis, influence the onset of macular degeneration (Myers et al., 2014). A healthy diet, including green leafy vegetables high in vitamins A, C, and E; as well as vegetables rich in carotenoids, such as carrots; may protect the retina and offset damage caused by free radicals (Rhone & Basu, 2008; Sin, Liu, & Lam, 2013). Laser surgery, medication, and corrective eyewear can sometimes restore some vision and treat the early stages of macular degeneration. However, macular degeneration is the leading cause of blindness (Chakravarthy et al., 2010; Jager, Mieler, & Miller, 2008).
Most of these changes in vision are so gradual that they may go unnoticed in people who do not receive regular ophthalmological examinations (Owsley, 2011). Substantial vision loss, however, can have a serious effect on adults’ daily lives as it interferes not only with driving but also with reading, watching television, and doing a variety of daily activities from cooking to banking. Not surprisingly, older adults with vision loss participate less than their peers in recreational and sports activities (Alma et al., 2011) and are likely to be depressed (Tabrett & Latham, 2010), especially when vision loss interferes with their day-to-day functioning and independence (van Nispen, Vreeken, Comijs, Deeg, & van Rens, 2016). In a sample of adults from 10 European countries, vision loss was associated with concentration difficulty; losing interest and enjoyment in activities; feeling fatigued, irritable, and tearful; having less hope for the future; and even wishing for death (Mojon-Azzi, Sousa-Poza, & Mojon, 2008).

As with all of our senses, our ability to see depends on not just our sensory organs (in this case, our eyes) but also our brain. We might assume that everyone processes visual stimuli the same way, but the emerging field of cultural neuroscience shows how different the visual experience can be from one person or cultural group to another (see the Cultural Influences on Development feature).

### Hearing

In addition to vision changes, 45-year-old Dominic also noticed that he has difficulty hearing, at least in some situations. When he plays with his 4-year-old nephew, Dominic finds that he has to lean in close to hear the boy's speech. Sometimes he finds himself watching his teenage daughter's lips while she speaks, especially when they are having dinner in a crowded restaurant. Age-related hearing loss, **presbycusis** (“old hearing”), becomes apparent in the 50s and is caused by natural cell death that results in the deterioration of the ear structures that convert sound into neural impulses (Quaranta et al., 2015). The loss is first limited to high-pitched sounds, which enable us to distinguish between consonants such as f versus s and p versus t; as a result, the person often can hear most of a message but may misinterpret parts of it, such as names. Middle-aged adults tend to experience more difficulty hearing in settings with background noise, such as at a dinner party or restaurant, and perform more poorly under that condition than do young adults (Leigh-Paffenroth & Elangovan, 2011). Presbycusis increases in older adulthood, with cell losses in the inner ear and cortex (Gates & Mills, 2005). Older adults experience difficulty distinguishing high-frequency sounds, soft sounds of all frequencies, and complex tone patterns (Gordon-Salant, 2005) and show less activation of the auditory cortex in response to speech as compared with younger adults (Hwang, Li, Wu, Chen, & Liu, 2007).

About two-thirds of older adults experience hearing loss (Lin, Thorpe, Gordon-Salant, & Ferrucci, 2011), which can greatly diminish quality of life and poses health risks. The inability to hear car horns and other street sounds or to hear the telephone or doorbell is a risk not only to safety but also to self-esteem. Turning up the volume to hear a television or radio program and then being asked by others to turn it down can be frustrating to older adults and their loved ones. Difficulty hearing others’ speech can socially isolate older adults, reducing their social network, increasing feelings of loneliness and depression, and reducing life satisfaction (Gordon-Salant, 2005).

Much hearing loss is preventable, the result of exposure to noise in the workplace, at concerts, and through the use of headphones (Tremblay & Ross, 2007). Generally, men's hearing declines occur earlier and more rapidly than women's, perhaps up to twice as quickly (Cruickshanks et al., 2010; Helzner et al., 2005). Men's rapid hearing decline can be traced to exposure to intense noise (e.g., headphones and concerts);
Cultural Influences on Development

Cultural Neuroscience

Do people of Eastern and Western cultures process this image differently?

A critical theme in lifespan developmental science is the central relevance of cultural context in influencing development. Our interactions with our culture influence not simply social development, such as our ways of interacting with others, but our neurological development as well, including patterns of brain activity (Chiao & Immordino-Yang, 2013; Kitayama & Uskul, 2011). Cultural neuroscience is an emerging field that studies how cultural values, practices, and beliefs influence and are influenced by neurological processes and translate to behavior (Han et al., 2013; Sasaki & Kim, 2017).

For example, collectivism, the East Asian cultural valuing of the community over the individual, and individualism, the Western cultural value emphasizing individualism and independence, influence how cultural group members view their worlds, including visual perception itself. People from East Asian and Western cultures show reliable differences in aspects of visual perception and processing. East Asians tend to process visual information in a more holistic manner, attending to and recalling the salient object and surroundings, whereas Westerners tend to process visual information in an analytic manner, paying attention and recalling the salient object independent of the scene in which it is embedded, a context-independent mode of perception (Nisbett & Miyamoto, 2005; Nisbett, Peng, Choi, & Norenzayan, 2001). These differences in object-context attention and recall are supported by different patterns of brain activation across cultural groups. In one study, U.S. and Chinese participants viewed pictures consisting of a focal object (e.g., a deer, a television) superimposed upon a background scene that was congruent (e.g., a deer in the woods) or incongruent (e.g., a television in the desert) with the target object (Jenkins, Yang, Goh, Hong, & Park, 2010). The Chinese but not the U.S. participants showed greater neural activity in both the right and left lateral visual cortex in response to incongruent scenes as compared with congruent scenes, suggesting greater cortical sensitivity and adaptation to incongruence, likely reflecting more holistic processing among Chinese participants.

Other research examining face processing supports a similar cultural difference in holistic processing. When viewing faces, Westerners show greater activity in the left visual cortex, as compared with Easterners, which is involved in analytic processing of facial features, such as the eyes and lips, perhaps reflecting the cultural value of individualism that tends to emphasize differences between individual identities (Jenkins et al., 2010). East Asians show greater activity in the right visual cortex, as compared with the left, which is implicated in holistic processing of faces where the facial components and their spatial configuration are processed as a whole.

Although visual processing itself is universal, socially transmitted cultural traits, such as an emphasis on analytic versus holistic processing, influence how visual stimuli are perceived, recognized, and interpreted (Chiao & Immordino-Yang, 2013; Han et al., 2013). Culture thereby influences how we view the world, not just metaphorically but also neurologically (Sasaki & Kim, 2017).

loud work environments (e.g., construction, military, and transportation work); and, in later adulthood, illnesses such as cerebrovascular disease (a disease of the blood vessels that supply the brain, often caused by atherosclerosis), which can lead to a stroke that damages the auditory cortex (Ecob et al., 2008; Helzner et al., 2005). Hearing declines are evident in some men as early as 30 years of age and these may also entail a genetic component (Gordon-Salant, 2005; Wingfield, Tun, & McCoy, 2005). Hearing loss can be prevented by wearing protective equipment, such as earplugs, and by lowering the volume on music players and other audio equipment. It is recommended that adults have periodic screening to identify risk for hearing loss and early signs of hearing loss, as early diagnosis can help in preventing or delaying further loss (Chou, Dana, Bougatsos, Fleming, & Beil, 2011).
Many older adults compensate for their hearing loss by reducing background noise, when possible, and paying attention to nonverbal cues such as lip movements, facial expressions, and body language to optimize their ability to hear and participate in conversations. Hearing aids are widely available, but research suggests they are underused for several reasons: social attitudes that undervalue the importance of hearing; stigma associated with being seen wearing hearing aids; and their cost, which is typically not covered by health insurance (Laplante-Lévesque, Hickson, & Worrall, 2010). Quality of life for older adults can be improved with successful hearing loss management, which may include education about communication effectiveness, hearing aids, assistive listening devices, and cochlear implants for severe hearing loss. When hearing aids no longer provide benefit, cochlear implantation is the treatment of choice with excellent results even in octogenarians (Quaranta et al., 2015).

**Smell and Taste**

Sensitivity to smell declines throughout adulthood beginning as early as the twenties (Margran & Boulton, 2005), but is usually not noticeable until late in midlife (Finkelstein & Schiffman, 1999; Hawkes, 2006). By the sixties olfaction tends to decline markedly (Wang, Sun, & Yang, 2016). About one third of adults experience disruptions in their ability to smell (Shu et al., 2009) and more than two thirds of adults experience significant olfactory dysfunction by age 80 (Attems, Walker, & Jellinger, 2015). In a classic study, young, middle, and older adults were asked to identify 40 different smells, such as peanut butter and gas (Doty et al., 1984). Young and middle adults performed at similar levels but performance declined rapidly at age 60, more rapidly for men than women (Morgan, Covington, Geisler, Polich, & Murphy, 1997). However, individuals vary. Some show marked declines and others more gradual change. The odor itself might matter in determining adults’ performance on olfactory tasks. Research suggests that older adults are as able as younger adults to identify and remember unpleasant odors, but they show decline in their abilities to identify and remember pleasant odors (Larsson, Oberg-Blåvarg, & Jonsson, 2009).

Recent research with over 1,100 Swedish adults age 40 to 90 has suggested that poor olfactory performance predicts mortality over a 10-year period (Ekström et al., 2017). Similar findings occurred with a U.S. sample of 2,400 adults age 53–97 followed for 17 years (Schubert et al., 2016), suggesting that olfactory loss might indicate deteriorating health.

Smell and taste are linked such that declines in olfactory abilities hold implications for their abilities to taste. Older adults are generally less sensitive to taste as compared with young and middle-aged adults (Schubert et al., 2012). They also produce less saliva with age, resulting in a dry mouth that interferes with taste (Abrams, 2014). There are also large individual differences, similar to other aspects of development. Some individuals show marked declines while others retain ability. Most older adults report that food seems more bland, and they tend to prefer more intense flavors, especially sweetness (de Graaf, Polet, & van Staveren, 1994). They may lose interest in eating or, alternatively, may overuse salt and spicy seasonings with poor health consequences. A poor sense of taste can even be a health hazard by making it more difficult for an older adult to detect spoiled food.

Developmental changes in both smell and taste are influenced by many factors, such as general health, chronic disease, medications, and smoking (Imoscopi, Ínnelmen, Sergi, Miotto, & Manzato, 2012; Roberts & Rosenberg, 2006; Schiffman, 2009). Most men show greater deficits with age than do women. This is likely the result of different work environments, since men are more likely to work in factories and other environments that expose them to chemicals that can damage sensory abilities (Corwin, Loury, & Gilbert, 1995; Schiffman, 2009; Ship & Weiffenbach, 1993). Changes in smell and taste, like other physical capacities, are influenced by our lifelong interactions within our contexts.
Thinking in Context 4.3

1. How might parents and caregivers design caregiving environments that stimulate infants’ early sensory capacities and development? What advice would you give on how to design such an environment for a newborn? For a 6-month-old infant? For a 3-year-old child?

2. How might the age-related changes that adults experience in vision and hearing influence their day-to-day functioning and interactions with others? Consider adults’ roles in the workplace and at home, as employees, parents, spouses, and friends. What are the practical implications of these developmental changes?

3. Contextual factors, such as socioeconomic status, influence all aspects of physical aging, including the rate and form that aging takes. How might contextual factors influence the sensory changes that occur over the adult years?

Apply Your Knowledge

“Some of the fine details seem so muddy!” 65-year-old artist Lupita thought to herself as she turned on the light and stood back from her artwork. “Once I loved to work in a studio with nothing more than sunlight to brighten the room, but no longer.” As a student Lupita used to paint live theater performances, sketching and coloring images of ballerinas as she sat in the dark theater. Now she watches theater intently, etching images into her mind to paint later.

As an art student, Lupita created many detailed pieces of art with little effort. After retiring from a career in nursing, Lupita rediscovered her love of painting. Recently she decided to repaint one of her favorite pieces of art to create “then vs. now” comparison artwork. Lupita was surprised to find herself struggling to recreate her work. Controlling the paintbrush seemed much more difficult than it did in college. As Lupita finished a simpler version of the painting, her son, Jesse, arrived and commented that a green does not match. “It’s much more yellow,” he said. Lupita protested, “It looks identical; I don’t see it.” “Mom, it’s not the same color at all,” replied Jesse, “and anyway, I’m here to ask your advice about Nico.” “What about my favorite 11th grader?” asked Lupita. “Your grandson is grounded for driving recklessly. Nico was caught racing cars around the high school parking lot. No one was hurt, fortunately, but Nico doesn’t understand why I’m upset. Sometimes it’s like I’m speaking a different language.” Lupita smiles, “You were the same way, son.”

1. Discuss normative changes in vision over the adult years. What might Lupita expect regarding her artistic talents and how can she compensate for these changes?

2. What other sensory changes might Lupita expect over time?

3. How might neurological development account for adolescent behavior, such as Nico’s?

4. What neurological changes can Nico expect as he becomes an adult? As he progresses through adulthood?

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4.1 Discuss the process of neural development over the lifespan, including the role of experience.

**SUMMARY**

The brain develops through several processes: neurogenesis, synaptogenesis, pruning, and myelination, and both expects and depends on environmental input at different points in time. Increases in the volume of the cortex, interconnections among neurons, and myelination influence the speed, efficiency of thought, and capacity for executive function. Different parts of the brain develop at different times, as illustrated by the dual process model, which can account for many typical adolescent behaviors. The brain is most malleable during the first few years of life but retains some plasticity through adulthood. The loss of neurons and brain volume over the course of adulthood leads to slower communication among neurons. Adults’ brains naturally compensate for losses through cognitive reserve and more diffuse activation.

**KEY TERMS**

- neurons
- neurogenesis
- glial cells
- experience-expectant brain development
- experience-dependent brain development
- synaptic pruning
- myelination
- lateralization
- hemispheric dominance
- corpus callosum
- plasticity
- dual process model
- limbic system
- amygdala
- cognitive reserve

**REVIEW QUESTIONS**

1. What are 4 processes of neural development?
2. How can brain development explain adolescent behavior?
3. How does the brain change over adulthood?
4. How do adults compensate for neurological change?

4.2 Summarize patterns of gross and fine motor development and influences on motor development.

**SUMMARY**

Infants are born with reflexes, each with their developmental course. Infant and children progress through an orderly series of motor milestones. Motor development illustrates the complex interactions that take place between developmental domains, maturation, and contextual supports. Motor skills change in predictable ways over the lifespan, with changes in muscle strength, bone density, and flexibility. Physical activity can compensate for age-related declines in muscle and strength.

**KEY TERMS**

- reflexes
- gross motor development
- fine motor development
- dynamic systems

**REVIEW QUESTIONS**

1. What are some milestones in gross and fine motor development?
2. Identify biological and contextual influences on motor development?
3. What motor changes can adults expect and how can they influence motor change?

4.3 Describe age-related changes in vision, hearing, and other senses.

**SUMMARY**

Neonates are born with all senses. Vision is most poor but improves rapidly over the first year of life. Newborns show adult-like hearing and perceive and discriminate nearly all sounds in human languages. Smell and taste are also well developed at birth. Intermodal perception, the ability to coordinate sensory stimuli, is evident at birth and develops quickly. Vision declines over adulthood with most midlife adults experiencing presbyopia and changes in night vision. Presbycusis becomes more common over midlife into older adulthood and most adults experience reductions in sensitivity to taste and smell.

**KEY TERMS**

- affordances
- intermodal perception
- presbyopia
- cataracts

**REVIEW QUESTIONS**

1. What senses are we born with?
2. How do vision and hearing develop in infancy?
3. What sensory changes can adults expect?
4. What are some ways adults compensate for sensory changes?

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