11.15 — Hormones & Neuron Regeneration

endorphins [en-DOR-ins] Chemical substances in the nervous system that are similar in structure and action to opiates; they are involved in pain reduction, pleasure, and memory and are known technically as *endogenous opioid peptides*.

hormones Chemical substances, secreted by organs called glands, that affect the functioning of other organs.

endocrine glands Internal organs that produce hormones and release them into the bloodstream.

melatonin A hormone, secreted by the pineal gland, that is involved in the regulation of daily biological rhythms.

oxytocin A hormone, secreted by the pituitary gland, that stimulates uterine contractions during childbirth, facilitates the ejection of milk during nursing, and seems to promote, in both sexes, attachment and trust in relationships.

adrenal hormones Hormones that are produced by the adrenal glands and that are involved in emotion and stress.

can interact with other medications and can be harmful in high doses. Even ordinary foods can influence the availability of neurotransmitters in the brain, as we discuss in "Taking Psychology with You."

Endorphins: The Brain's Natural Opiates

Another intriguing group of chemical messengers is known collectively as *endogenous opioid peptides*, or more popularly as **endorphins**. Endorphins have effects similar to those of opiate drugs; that is, they reduce pain and promote pleasure. They are also thought to play a role in appetite, sexual activity, blood pressure, mood, learning, and memory. Some endorphins function as neurotransmitters, but most act primarily by altering the effects of neurotransmitters—for example, by limiting or prolonging those effects.

Endorphins were identified in the early 1970s. Candace Pert and Solomon Snyder (1973) were doing research on morphine, a pain-relieving and mood-elevating opiate derived from heroin, which is made from poppies. They found that morphine works by binding to receptor sites in the brain. This seemed odd. As Snyder later recalled, "We doubted that animals had evolved opiate receptors just to deal with certain properties of the poppy plant" (quoted in Radetsky, 1991). Pert and Snyder reasoned that if opiate receptors exist, then the body must produce its own internally generated, or *endogenous*, morphinelike substances, which they named "endorphins." Soon they and other researchers confirmed this hypothesis.

Endorphin levels seem to shoot up when an animal or a person is afraid or under stress. This is no accident; by making pain bearable in such situations, endorphins give a species an evolutionary advantage. When an organism is threatened, it needs to do something fast. Pain, however, can interfere with action: A mouse that pauses to lick a wounded paw may become a cat's dinner; a soldier who is overcome by an injury may never get off the battlefield. But, of course, the body's built-in system of counteracting pain is only partly successful, especially when painful stimulation is prolonged.

"PSST—ENDORPHINS. AND THEY'RE PERFECTLY LEGAL."

In Chapter 14, we will see that a link also exists between endorphins and the pleasures of social contact. Research with animals suggests that in infancy, contact with the mother stimulates the flow of endorphins, which strengthens the infant's bond with her. Some researchers now think that this "endorphin rush" also occurs in the early stages of passionate love between adults, accounting for the feeling of euphoria that "falling" for someone creates (Diamond, 2004).

Hormones: Long-Distance Messengers

Hormones, which make up the third class of chemical messengers, are produced primarily in **endocrine glands**. They are released directly into the bloodstream, which carries them to organs and cells that may be far from their point of origin. Hormones have dozens of jobs, from promoting bodily growth to aiding digestion to regulating metabolism.

Neurotransmitters and hormones are not always chemically distinct; the two classifications are like clubs that admit some of the same members. A particular chemical, such as norepinephrine, may belong to more than one classification, depending on where it is located and what function it is performing. Nature has been efficient, giving some substances more than one task to perform.

The following hormones, among others, are of particular interest to psychologists:

1. **Melatonin**, which is secreted by the *pineal gland* deep within the brain, helps to regulate daily biological rhythms and promotes sleep, as we will discuss further in Chapter 5.

2. **Oxytocin**, which is secreted by another small gland within the brain, the *pituitary gland*, enhances uterine contractions during childbirth and facilitates the ejection of milk during nursing. Psychologists are interested in this hormone because recent research suggests that it also contributes to relationships in both sexes by promoting attachment and trust (see Chapter 14).

3. **Adrenal hormones**, which are produced by the *adrenal glands* (organs that are perched right above the kidneys), are involved in emotion and stress (see Chapter 13). These hormones also rise in response to nonemotional conditions, such as heat, cold, pain, injury, burns, and physical exercise, and in response to some drugs, such as caffeine and nicotine. The outer part of each adrenal gland produces *cortisol*, which increases blood-sugar levels and boosts energy. The inner

part) produces *epinephrine* (popularly known as adrenaline) and *norepinephrine*. When adrenal hormones are released in your body, activated by the sympathetic nervous system, they increase your arousal level and prepare you for action.

Adrenal hormones also enhance memory. If you give people a drug that prevents their adrenal glands from producing these hormones, they will remember less about emotional stories than a control group will (Cahill et al., 1994). Conversely, if you give epinephrine to animals right after learning, their memories will improve (McGaugh, 1990). The link between emotional arousal and memory makes evolutionary sense: Arousal tells the brain that an event or piece of information is important enough to encode and store for future use. Very high levels of adrenal hormones, however, sometimes impair memory for learned tasks; a moderate level may be optimal. To remember material for a test, therefore, you should probably aim for an arousal level somewhere between "hyper" and "laid back."

4 **Sex hormones**, which are secreted by tissue in the *gonads* (testes in men, ovaries in women) and also by the adrenal glands, include three main types, all occurring in both sexes but in differing amounts and proportions in males and females after the onset of puberty. *Androgens* (the most important of which is *testosterone*) are masculinizing hormones produced mainly in the testes but also in the ovaries and the adrenal glands. Androgens set in motion the physical changes males experience at puberty—for example, a deepened voice and facial and chest hair—and cause pubic and underarm hair to develop in both sexes. Testosterone also influences sexual arousal in both sexes. *Estrogens* are feminizing hormones that bring on physical changes in females at puberty, such as breast development and the onset of menstruation, and that influence the course of the menstrual cycle. *Progesterone* contributes to the growth and maintenance of the uterine lining in preparation for a fertilized egg, among other functions. Estrogens and progesterone are produced mainly in the ovaries but are also produced in the testes and the adrenal glands.

Researchers are now studying the possible involvement of sex hormones in behavior not directly related to sex and reproduction. For example, some researchers believe that the body's natural estrogen may contribute to improved learning and memory by promoting the formation of synapses in certain areas of the brain (Maki & Resnick, 2000; Sherwin, 1998a; Wickelgren, 1997). But the most common belief about the nonsexual effects of sex hormones—that fluctuating levels of estrogen and progesterone make most women "emotional" before menstruation—has not been borne out by research, as we will see in Chapter 5.

sex hormones Hormones that regulate the development and functioning of reproductive organs and that stimulate the development of male and female sexual characteristics; they include androgens, estrogens, and progesterone.

QUICK quiz

Get your glutamate going by taking this quiz.

A. Which word in parentheses better fits each of the following definitions?
   1. Basic building blocks of the nervous system (*nerves, neurons*)
   2. Cell parts that receive nerve impulses (*axons, dendrites*)
   3. Site of communication between neurons (*synapse, myelin sheath*)
   4. Opiatelike substance in the brain (*dopamine, endorphin*)
   5. Chemicals that make it possible for neurons to communicate (*neurotransmitters, hormones*)
   6. Hormone closely associated with emotional excitement (*epinephrine, estrogen*)

B. *True or false:* To remember the material in this chapter well, you should be as relaxed as possible while studying.

C. Imagine that you are depressed, and you hear about a medication for depression that affects the levels of several neurotransmitters thought to be involved in the disorder. Based on what you have learned, what questions would you want to ask before deciding whether to try the treatment?

Answers:

A 1. neurons 2. dendrites 3. synapse 4. endorphin 5. neurotransmitters 6. epinephrine B. false (Can you say why?) C. You might want to ask, among other things, about side effects (each neurotransmitter has several functions, all of which might be affected by the treatment); about evidence that the treatment works; about whether there is any reason to believe that your own neurotransmitter levels are abnormal; and about whether there could be other reasons for your depression.

called the **myelin sheath**, which is made up of glial cells. Constrictions in this covering, called *nodes*, divide it into segments, which make it look a little like a string of link sausages (see Figure 4.4 again). One purpose of the myelin sheath is to prevent signals in adjacent cells from interfering with each other. Another, as we will see shortly, is to speed up the conduction of neural impulses. In individuals with multiple sclerosis, loss of myelin causes erratic nerve signals, leading to loss of sensation, weakness or paralysis, lack of coordination, or vision problems.

In the peripheral nervous system, the fibers of individual neurons (axons and sometimes dendrites) are collected together in bundles called **nerves**, rather like the lines in a telephone cable. The human body has 43 pairs of peripheral nerves; one nerve from each pair is on the left side of the body, and the other is on the right. Most of these nerves enter or leave the spinal cord, but the 12 pairs that are in the head, the *cranial nerves*, connect directly to the brain. In Chapter 6, we will discuss cranial nerves that are involved in the senses of smell, hearing, and vision.

myelin sheath A fatty insulation that may surround the axon of a neuron.

nerve A bundle of nerve fibers (axons and sometimes dendrites) in the peripheral nervous system.

Neurons in the News

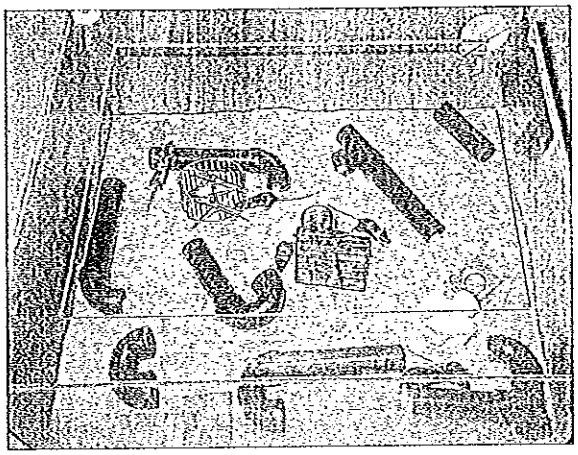
Until recently, neuroscientists assumed that if neurons in the central nervous system were injured or damaged, they could never regenerate (grow back). But then the conventional wisdom got turned upside down. Animal studies showed that severed axons in the spinal cord *can* regrow when treated with certain nervous system chemicals (Schnell & Schwab, 1990). Researchers are now working to fine-tune this process and are exploring other approaches as well. Many are hopeful that regenerated axons will eventually enable people with spinal cord injuries to use their limbs again (Kraft, 2005).

Scientists have also had to rethink another entrenched assumption, which was accepted for most of the twentieth century despite some contradictory evidence: that mammals produce no new CNS cells after infancy. In the early 1990s, Canadian neuroscientists, working with mice, immersed immature cells from the animals' brains in a growth-promoting protein and showed that these cells could give birth to new neurons. Even more astonishingly, the new neurons then continued to divide and multiply (Reynolds & Weiss, 1992). One of the researchers, Samuel Weiss, said that this result "challenged everything I had read; everything I had learned when I was a student" (quoted in Barinaga, 1992).

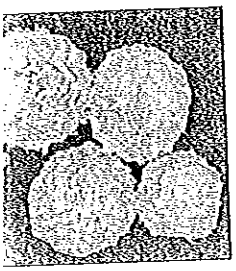
Since then, scientists have discovered that the human brain and other body organs also contain such cells, which are now referred to as **stem cells**. These, too, give rise to new neurons when treated in the laboratory. Stem cells involved in learning and memory seem to divide and mature throughout adulthood—a discovery that holds tremendous promise for human well-being (Eriksson et al., 1998; Gage et al., 1998; Gould et al., 1998; Gould, Reeves, et al., 1999). We may even have some control over that process: In animal studies, physical exercise and mental activity promote the production and survival of these new cells (Gould, Beylin, et al., 1999; Kempermann, Brandon, & Gage, 1998; van Praag, Kempermann, & Gage, 1999). On the other hand, stress can inhibit the production of new cells, and nicotine can kill them (Berger, Gage, & Vijayaraghavan, 1998; Gould et al., 1998).

Stem-cell research is one of the hottest areas in biology and neuroscience and also one of the most hotly debated. In the United States, federal funding for stem-cell research has faced strong resistance by antiabortion activists. The reason: Scientists prefer working with cells from aborted fetuses and from embryos that are a few days old, which consist of just a few cells. (Fertility clinics store many such embryos because several "test tube" fertilizations are created for every patient who hopes to become pregnant; eventually, the extra embryos are destroyed.) Embryonic stem (ES) cells are especially useful because they can differentiate into any type of cell, from

stem cells Immature cells that renew themselves and have the potential to develop into mature cells; given encouraging environments, stem cells from early embryos can develop into any cell type.



In an area associated with learning and memory, new cells develop from immature stem cells, and physical and mental stimulation promotes their production and survival. These mice, which have toys to play with, tunnels to explore, wheels to run on, and other mice to share their cage with, will grow more cells than mice living alone in standard cages.



y stem cells like these egnified 1,200 times in s photo) have pro- ked both excitement d controversy.

neurons to kidney cells, whereas those from adults are far more limited and are also harder to keep alive.

Scientists are now working to develop methods for extracting ES cells while avoiding destruction of the embryo (Chung et al., 2005). Some scientists have also reported success in coaxing stem cells from adult organs, such as bone marrow and skin, to transform themselves into brain cells (e.g., Brazelton et al., 2000; Toma et al., 2001). A team in Germany, working with mice, recently reported success in turning cells that produce sperm into cells with many characteristics of ES cells (Guan et al., 2006). However, other attempts at finding alternatives to ES cells have been unsuccessful, and we still do not know whether adult stem cells can develop reliably into more than one kind of tissue in human beings.

In 2001, an executive order by President George W. Bush required American researchers who rely on federal funding (which is most of them) to get their cells from only a few, already established sources; new cell lines cannot be developed. Unfortunately, for technical reasons the existing cells can never be transplanted into human beings. Scientists and patient-advocacy groups, however, have been pressing for the ban to be lifted because transplanted stem cells may eventually help people recover from diseases of the brain (such as Alzheimer's) and from damage to the spinal cord and other parts of the body. Scientists have recently had some success in animals. For example, in one study, mice with recent spinal cord injuries regained much of their ability to walk normally after being injected with stem cells derived from human fetal brain tissue. Microscopic analysis showed that most of the cells had turned into either neurons or a particular type of glial cell (Cummings et al., 2005).

Each year brings more incredible findings about neurons, findings that only a short time ago would have seemed like science fiction. A long road lies ahead, and many daunting technical hurdles remain to be overcome before these findings yield practical benefits for human patients. Eventually, however, new treatments for medical and psychological disorders may be among the most stunning contributions of this line of basic biological research.

synapse The site where transmission of a nerve impulse from one nerve cell to another occurs; it includes the axon terminal, the synaptic cleft, and receptor sites in the membrane of the receiving cell.

How Neurons Communicate

Neurons do not directly touch each other, end to end. Instead, they are separated by a tiny space called the *synaptic cleft*, where the axon terminal of one neuron nearly touches a dendrite or the cell body of another. The entire site—the axon terminal, the cleft, and the covering membrane of the receiving dendrite or cell body—is called a **synapse**. Because a neuron's axon may have hundreds or even thousands of terminals, a single neuron may have synaptic connections with a great many others. As a result, the number of communication links in the nervous system runs into the trillions or perhaps even the quadrillions.

When we are born, most of these synapses have not yet formed, but during infancy, new synapses proliferate at a great rate (see Figure 4.5). Axons and dendrites continue to grow, and tiny projections on dendrites, called *spines*, increase in size and in number, producing more complex connections among the brain's nerve cells. Just as new learning and stimulating environments promote the production of new neurons, they also produce the greatest increases in synaptic complexity (Diamond, 1993; Greenough & Anderson, 1991; Greenough & Black, 1992; Rosenzweig, 1984). During childhood, unused synaptic connections are also "pruned away" as cells or their branches die and are not replaced, leaving behind a more efficient neural network. Such pruning may be as important as synaptic growth (Kolb, Gibb, & Robinson, 2003). But these changes—pruning and increases in synaptic density—are not confined to the early years; they continue all through life.

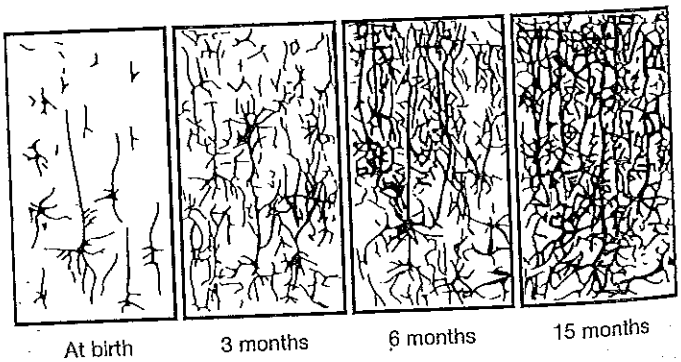


FIGURE 4.5
Getting Connected
Neurons in a newborn's brain are widely spaced, but they immediately begin to form new connections. These drawings show the marked increase in the number of connections from birth to age 15 months.