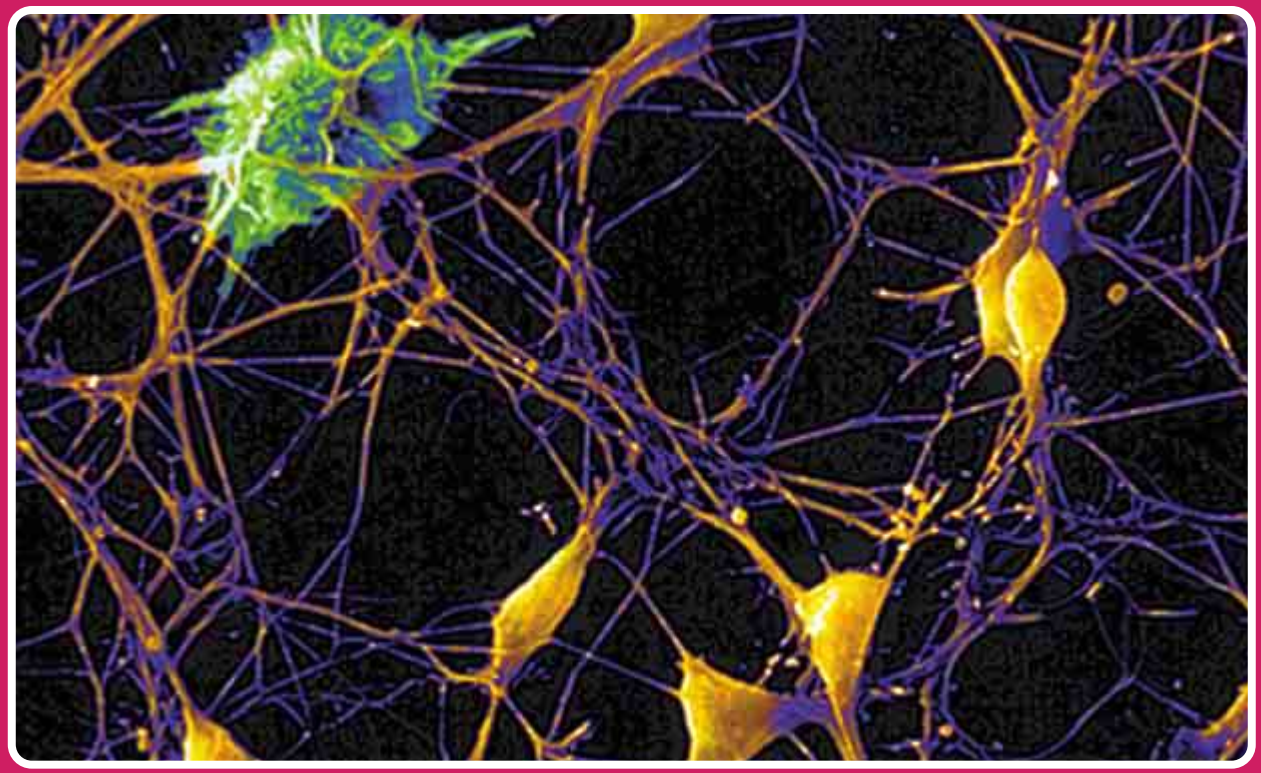
Module 3: Brain's Building Blocks

Power Study 2.0™ Complete Module



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Losing One's Mind

Why does 71-year-old Ina think the baby is hers?

Her children had always called their mother, Ina, "the Rock of Gibraltar." Ina could fix the plumbing, hang wallpaper, and prepare a full dinner from scratch every night, while keeping her six children out of trouble. She could swim faster than anyone, she wanted to be a basketball player, and her late husband called her the most beautiful woman he had ever seen.

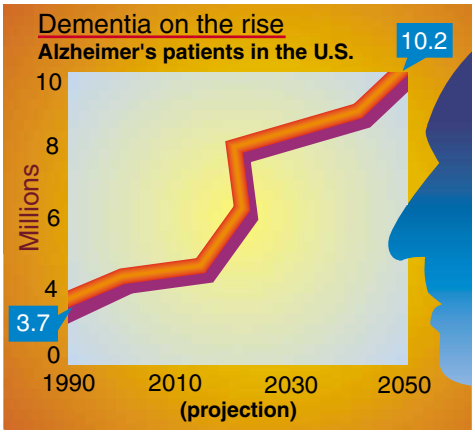
But that was before she started to forget things and repeat herself, which could just be part of getting old. But how to explain her mopping the kitchen floor at 2:00 in the morning and refusing to go to bed? Or wearing the same dirty clothes day after day, something she had never done in her entire life? Or being confused at housework? Or thinking that her granddaughter (right photo) is her own child?

She was the family's "Rock of Gibraltar" until she developed Alzheimer's.

Because Ina had always been so healthy, her six grown children thought she must have suffered a stroke or be depressed. When they took Ina in for a checkup, a neurologist confirmed their worst fears. Ina had Alzheimer's (*ALTS-hi-mers*) disease.

In 10% of the cases, *Alzheimer's disease* begins after age 50, but in 90% of the cases, it begins after age 65. Its initial symptoms are problems with memory, such as forgetting and repeating things, getting lost, and being mildly confused. There are also cognitive deficits, such as problems with language, difficulties in recognizing objects, and inability to plan and organize tasks. Over a period of five to ten years, these symptoms worsen and result in profound memory loss, lack of recognition of family and friends, deterioration in personality, and emotional outbursts. There is widespread damage to the brain, especially the hippocampus, which is involved in memory. At present, there is no cure for Alzheimer's, which is always fatal (American Psychiatric Association, 2000).

In the United States, Alzheimer's is the fourth leading cause of death among adults. In 2002, approximately 5 million people—or 5% of adults over age 65—had Alzheimer's disease, and the number of patients is projected to rise dramatically in the coming decades (graph on right) as people are expected to live longer (Cowley, 2002).



Ina's condition worsened through the coming months. She had trouble completing even the simplest tasks, and the day after having a big Thanksgiving celebration with her family, she asked where she had spent the holiday. At times, she recognized her grown children; at other times, she thought they were her cousins. Ina must now be watched almost every minute so that she does not hurt herself or wander off and get lost (adapted from *Newsweek,* December 18, 1989).

For Ina, the worst is yet to come. Her memory will totally disintegrate, she will be completely bedridden, and she will not know who she is or recognize the family she has lovingly raised. When she dies—for Alzheimer's has, at present, no cure—Ina will have lost her memory, her wonderful personality, and all signs of humanity.

Diagnosis and Causes

In Ina's case as well as all cases of individuals with memory and cognitive difficulties, Alzheimer's is diagnosed by identifying a combination of behavioral symptoms and by eliminating other physical problems. Recently, researchers were successful in diagnosing Alzheimer's by injecting chemical markers and identifying brain damage from pictures of living brains (PET scans, p. 71) (Shoghi-Jadid et al., 2002).

Researchers now believe they are very close to figuring out the causes of Alzheimer's disease, which involve genetic, neurological, and possible environmental factors (Bower, 2002b). For example, Alzheimer's incidence is three times higher among individuals who have one parent with Alzheimer's and five times higher if both parents have the disease (Tanzi, 2000). Researchers have also identified several chemicals (proteins and peptides) that occur naturally in all brains but, for some reason, begin to multiply and are believed to cause Alzheimer's. These chemicals seem to act like glue that eventually destroys brain cells (Hardy & Selkoe, 2002). With these new leads, researchers are optimistic about finding the causes of and developing treatments for Alzheimer's. New treatments are needed because current drugs are only moderately effective and short acting in treating early symptoms of Alzheimer's disease (Wilkinson & Muray, 2001).

What's Coming

The reason Alzheimer's disease eventually destroyed Ina's memory, personality, and humanity is that this disease gradually destroys the building blocks that form the brain's informational network. We'll explain the two groups of brain cells—glial cells and neurons—that make up this network. We'll discuss how the cells in one group—neurons—have a remarkable ability to receive and send information. You'll discover how brain cells communicate with chemicals that have the ability to start or stop the flow of information. Finally, we'll explain an experimental treatment of implanting neurons to treat brain diseases. We'll use the story of Ina and Alzheimer's disease to illustrate the brain's building blocks.

A. Overview: Human Brain

As Alzheimer's disease slowly destroys Ina's brain, she is also slowly losing her mind. In Ina's case, Alzheimer's disease has progressed to the point that she can no longer recognize her own children or remember her family gathering on Thanksgiving day.

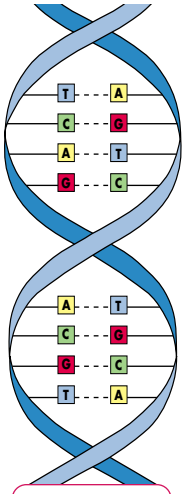
We'll use Ina's brain and her current problems with Alzheimer's disease to answer four related questions: Why isn't the brain a nose? What's in the brain? Can a brain grow new neurons? Can you take a picture of the mind?

Development of the Brain

Why isn't the brain a nose?

The fact that your brain does not develop into a nose is because of instructions contained in your genes.

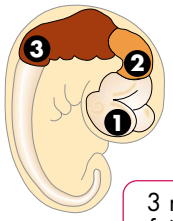
Genes **are chains of chemicals that are arranged like rungs on a twisting ladder (right figure). There are about 30,000 genes that contain chemical instructions that equal about 300,000 pages of written instructions (N. Wade, 2003a). The chemical instructions in the genes program the development of millions of individual parts into a complex body and brain.**



Chemical instructions

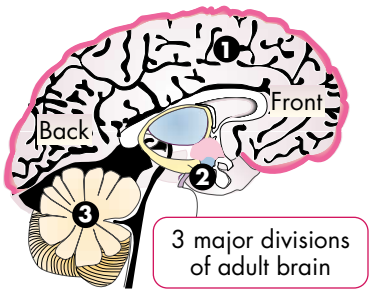
An amazing feature of the 30,000 genes is that they are contained in a fertilized egg, which is a single cell about the size of a grain of sand. We'll explain more about the genes and their chemical instructions in the next module (p. 68).

In the brain's early stages of development, it looks nothing like the final product. For example, the figure below looks more like some strange animal than what it really is, a six-week-old human embryo with a developing brain.



3 major divisions of 6-week-old brain

Six-Week-Old Brain. This drawing represents a greatly enlarged six-week-old human embryo. The 3 labeled areas (in 3 colors) will eventually develop into the 3 major divisions of the mature human brain that is shown below.



3 major divisions of adult brain

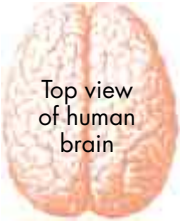
Mature Brain. The 3 labeled areas represent the 3 major divisions of the mature brain that we'll discuss in the next module. The mature human brain (side view) weighs almost 3 pounds and contains about 1 trillion cells (Fischbach, 1992).

In the case of Ina, who developed Alzheimer's disease, researchers think that some of her genetic instructions were faulty. The faulty instructions resulted in an abnormal buildup in the brain of a gluelike substance that gradually destroys brain cells (Cowley, 2000b). Next, we'll explain the two different kinds of brain cells and which ones are destroyed by Alzheimer's disease.

Structure of the Brain

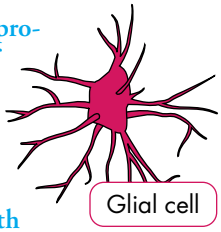
What's in your brain?

On the left is a top view of a human brain. It is shaped like a small wrinkled melon, weighs about 1,350 grams (less than 3 pounds), has a pinkish-white color, and has the consistency of firm Jell-O. Your brain is fueled by sugar (glucose) and has about 1 trillion cells that can be divided into two groups—glial cells and neurons.


Top view of human brain

Glial Cells. The most numerous brain cells, about 900 billion, are called glial (*GLEE-all*) cells.

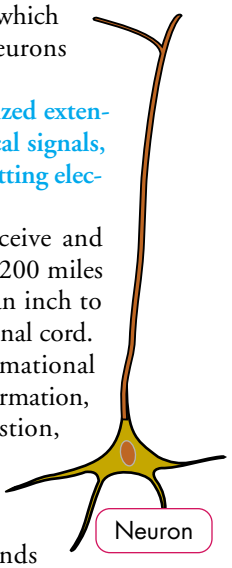
Glial cells **have at least three functions: providing scaffolding to guide the growth of developing neurons and support mature neurons; wrapping around neurons to form a kind of insulation to prevent interference from other electrical signals; and releasing chemicals that influence a neuron's growth and function (Fields & Stevens-Graham, 2002).**


Glial cell

A star-shaped glial cell (astrocyte) is shown above. Glial cells grow throughout one's lifetime. If something causes the uncontrolled growth of glial cells, the result is brain cancer. Alzheimer's disease does not usually destroy glial cells, but it does destroy the second kind of brain cells, which are called neurons.

Neurons. The second group of brain cells, which number about 100 billion, are called neurons (*NER-ons*); one is shown on the right.

A *neuron* is a brain cell with two specialized extensions. One extension is for receiving electrical signals, and a second, longer extension is for transmitting electrical signals.


Neuron

Depending upon their size, neurons receive and transmit electrical signals at speeds of up to 200 miles per hour over distances from a fraction of an inch to over 3 feet, such as from your toe to your spinal cord.

Neurons form a vast, miniaturized informational network that allows us to receive sensory information, control muscle movement, regulate digestion, secrete hormones, and engage in complex mental processes such as thinking, imagining, dreaming, and remembering.

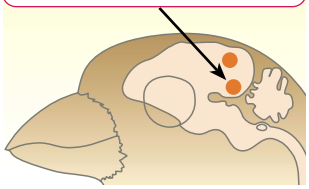
Ina's brain was constructed from two kinds of building blocks—glial cells and neurons. However, it is the neurons that Alzheimer's disease gradually destroys; the result is that Ina's brain is losing its ability to transmit information, causing memory and cognitive difficulties. Why neurons do not usually repair or replace themselves is our next topic.

Growth of New Neurons

Can a brain grow new neurons?

If you had a bird's brain, you could grow new neurons every spring. A male canary learns to sing a breeding song in the spring, but when breeding season is over, the ability to sing the song disappears. However, come next spring, an adult canary's brain begins growing about 20,000 new neurons a day, and, during this short period, the bird relearns the breeding song. These new neurons result in a 50% or more increase in two areas of the canary's brain (left figure) that control singing (G. Miller, 2003). Without a doubt, an adult canary's brain can regularly grow new neurons (Barinaga, 2003a).

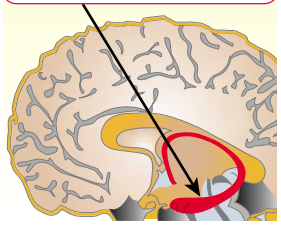
The two red dots show two areas of the mature canary's brain that increase by 50% with the growth of new neurons.



Primate Brains. Does the fact that adult canaries as well as adult mice, rats, and other animals can grow new neurons also hold true for adult human brains (Barinaga, 2003a)? Researchers believe that, with few exceptions, the brains of adult primates, such as humans and chimpanzees, develop almost all their neurons at birth and adult brains do not grow new neurons (Kornack & Rakic, 2001).

The few exceptions to the finding that new neurons do not grow in adult brains were found in two areas of the brain—hippocampus (p. 80) and olfactory bulb (p. 107). Researchers concluded that adult monkey and human brains are capable of growing a relatively limited number of new neurons throughout adulthood and that some of these new neurons play an important role in our continuing ability to learn and remember new things (van Praag et al., 2002).

Growth of new neurons is found in this area of mature human brain (hippocampus).



Repairing the Brain. Besides having a limited capacity to grow new neurons throughout adulthood, mature human brains also have a limited capacity to replace, rewire, or repair damaged neurons, such as after a stroke, gunshot wound, or blow to the head (Horner & Gage, 2000). For instance, after the brain is accidentally injured, healthy neurons have the ability to send out very short extensions to make some new connections with neurons whose normal connections were damaged. One reason neurons have only a limited capacity to be repaired or rewired after damage is that there is a genetic program that turns off regrowth when neurons become fully grown (McKerracher & Ellezam, 2002). This limited capacity of the adult brain to rewire itself by forming new connections helps explain why people may recover some, but rarely all, of the functions initially lost after brain damage (Gage, 2003).

The reason Alzheimer's disease is so destructive and eventually leads to death is that this disease destroys neurons many times faster than the brain's limited capacity for regrowth, repair, or rewiring. As Alzheimer's destroys Ina's brain, what is happening to her mind?

Brain Versus Mind

Can you take a picture of the mind?

As Alzheimer's destroys Ina's brain, she is also losing her mind, which brings us to the mind-body question.

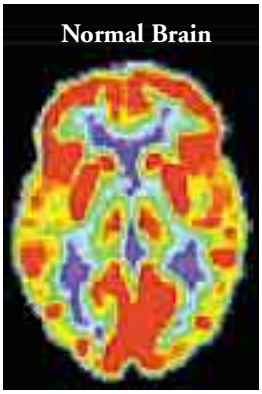
The *mind-body question* asks how complex mental activities, such as feeling, thinking, and learning, can be explained by the physical, chemical, and electrical activities of the brain.

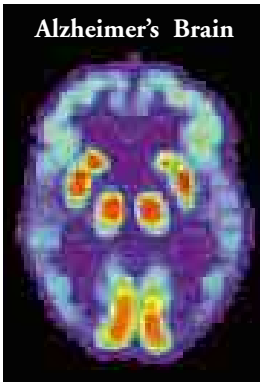
Through the centuries, philosophers and scientists have given different answers to the mind-body question, some believing the mind and brain are separate things and others saying the mind and brain are one and the same (Hiltzik, 2002).

For example, Nobel Prize winner and geneticist Francis Crick (2002) believes the mind ***is*** the brain: "You, your joys and your sorrows, your memories and your ambition, your sense of personal identity and free will, are in fact no more than the behavior of a vast assembly of nerve cells and their associated molecules." Although some agree with Crick's answer, that the mind and brain are the same, others reply that mental activities cannot be reduced to the physical activities of the brain (Gold & Stoljar, 1999).

Another answer comes from Nobel Prize winner and neurophysiologist Roger Sperry (1993), who said that the brain is like a coin with two sides. One side consists of physical reactions, such as making chemicals that neurons use for communicating. The other side consists of all of our mental functions, such as thinking, imagining, and deciding. According to Sperry, the brain's chemicals (physical side) influence consciousness and mental activities, which, in turn, influence the production of more or different brain chemicals. There is considerable support for Sperry's idea of continuous interaction between the physical and mental sides (Wakefeld, 2001).

Alzheimer's. In Ina's case, as Alzheimer's disease destroys her brain, she also loses more and more of her mental activities, such as knowing, thinking, and deciding. Researchers can now study a person's mental activities by taking pictures or brain scans of the neural activities going on inside the living brain (brain scans are discussed on pp. 70–71). For example, the top right brain scan shows a great amount of neural activity occurring inside a normal brain (red/yellow indicate most neural activity, blue/green indicate least activity). In comparison, the bottom right brain scan shows relatively little neural activity and thus relatively little mental activity occurring inside an Alzheimer's brain. These kinds of brain scans show that neural activities and mental activities are closely linked, and researchers are studying how these links occur (Gold & Stoljar, 1999).





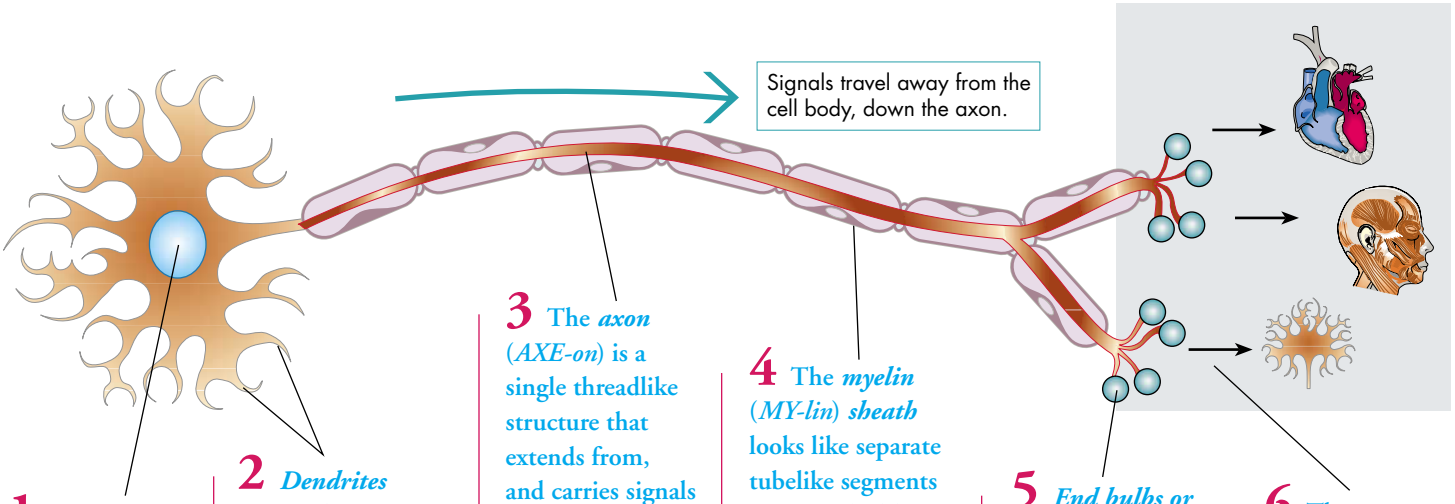
Knowing now how important neurons are to your mental and physical functions, we next examine them in more detail.

B. Neurons: Structure & Function

Parts of the Neuron

Why could Ina think, move, and talk?

Before Ina developed Alzheimer's disease, she was able to engage in an incredible variety of cognitive and physical behaviors. She was able to think, remember, walk, smile, and speak—all because of the activity of millions of microscopic brain cells called neurons. We'll examine the neuron, which comes in many wondrous shapes and sizes and has only three basic structures—cell body, dendrites, and axon.



1 The ***cell body*** (or soma) is a relatively large, egg-shaped structure that provides fuel, manufactures chemicals, and maintains the entire neuron in working order.

In the center of the cell body is a small, oval shape representing the nucleus, which contains genetic instructions (in the form of DNA) for both the manufacture of chemicals and the regulation of the neuron.

2 ***Dendrites*** (*DEN-drites*) are branchlike extensions that arise from the cell body; they receive signals from other neurons, muscles, or sense organs and pass these signals to the cell body.

At the time of birth, a neuron has few dendrites. After birth, dendrites undergo dramatic growth that accounts for much of the increase in brain size. As dendrites grow, they make connections and form communication networks between neurons and other cells or organs.

3 The ***axon*** (*AXE-on*) is a single threadlike structure that extends from, and carries signals away from, the cell body to neighboring neurons, organs, or muscles.

Here the axon is indicated by an orange line inside the tube composed of separate gray segments. Axons vary in length from less than a hair's breadth to as long as 3 feet (from your spinal cord to your toes). An axon conducts electrical signals to a neighboring organ (heart), a muscle, or another neuron.

4 The ***myelin*** (*MY-lin*) ***sheath*** looks like separate tubelike segments composed of fatty material that wraps around and insulates an axon. The myelin sheath prevents interference from electrical signals generated in adjacent axons.

The axons of most large neurons, including motor neurons, have myelin sheaths. You may have heard the brain described as consisting of gray and white matter. Gray is the color of cell bodies, while white is the color of myelin sheaths.

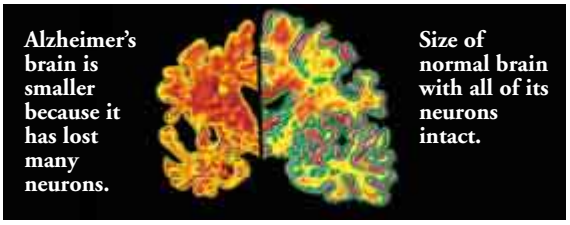
5 ***End bulbs or terminal bulbs*** look like tiny bubbles that are located at the extreme ends of the axon's branches. Each end bulb is like a miniature container that stores chemicals called neurotransmitters, which are used to communicate with neighboring cells.

End bulbs reach right up to, but do not physically touch, the surface of a neighboring organ (heart), muscle (head), or another cell body.

6 The ***synapse*** (*SIN-apse*) is an infinitely small space (20–30 billionths of a meter) that exists between an end bulb and its adjacent body organ (heart), muscles (head), or cell body.

When stimulated by electrical signals from the axon, the end bulbs eject neurotransmitters into the synapse. The neurotransmitters cross the synapse and act like switches to turn adjacent cells on or off. We'll explain this switching process a little later.

Alzheimer's Disease and Neurons



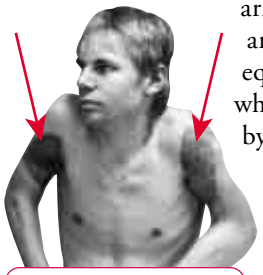
In Alzheimer's disease there is an excessive buildup of gluelike substances, which gradually destroy neurons (Cowley, 2002). In Ina's case, these gluelike substances will destroy more and more of her neurons, causing her brain to actually shrink, as shown by the very deep creases in the Alzheimer's brain (left photo). Researchers are searching for ways to stop the buildup of these gluelike, killer substances.

We have discussed the structure and function of neurons, but it is important not to confuse neurons (in your brain and spinal cord) with nerves (in your body).

Reattaching Limbs

What's unusual about John's arms?

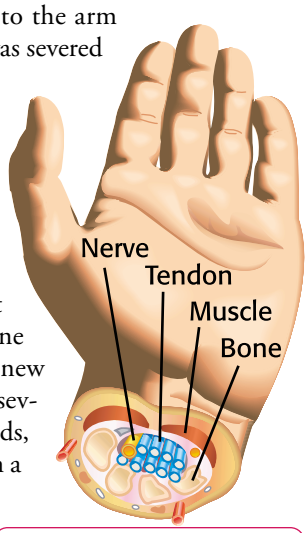
John Thomas was 18 when a farm machine ripped off both of his arms just below his shoulders. Since he was home alone, he had to walk to the farmhouse, kick open the front door, and with a pencil clenched in his teeth, dial the phone for help. When paramedics arrived, he reminded them to get his two arms, which were still stuck in the farm equipment. John was taken to the hospital, where doctors reattached both arms (indicated by red arrows in left photo).



Both his arms were torn off and then reattached.

Three months later, John could raise his arms up in the air but could not move them below his elbows. After three years of physical therapy and 15 operations, John could raise both of his reattached arms over his head, make fists, and grip with his hands. Surgeons believe that John will recover additional movement and feelings in his arms, but that may require 2–5 years of physical therapy (*USA Today*, January 12, 1995).

More recently, doctors have taken a hand from a donor body and reattached the hand to the arm (stump) of a person whose own limb was severed or damaged (Horowitz, 2000). During this operation, nerves, blood vessels, and muscles from a donor's hand (right figure) are reattached to those in the patient's remaining limb. Four years after surgery, patients with reattached donor's hands can feel hot and cold, write, turn a faucet, tie shoe laces, insert coins in vending machines, and put one checker on top of another using their new hands (P. Smith, 2003). The fact that severed nerves in limbs, such as arms, hands, or legs, can be reattached but neurons in a severed spinal cord are very difficult to reattach illustrates a major difference between the peripheral and central nervous systems.



A donor's hand was attached to a different arm.

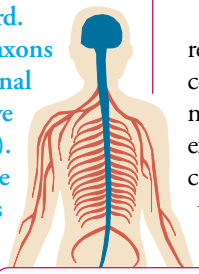
Peripheral Nervous System

Why can limbs be reattached?

Severed limbs can be reattached and regain movement and sensation because their nerves are part of the peripheral nervous system.

The ***peripheral nervous system*** is made up of nerves, which are located throughout the body except in the brain and spinal cord.

Nerves are stringlike bundles of axons and dendrites that come from the spinal cord and are held together by connective tissue (shown in red in right figure). Nerves carry information from the senses, skin, muscles, and the body's organs to and from the spinal cord. Nerves in the peripheral nervous system have the ability to regrow or reattach if severed or damaged.



Peripheral nerves can be reattached.

The fact that nerves can regrow means that severed limbs can be reattached and limb transplants are possible. However, limb transplants are risky because a person must take drugs long-term to suppress his or her own immune system, whose normal job is to destroy "foreign" things, such as a donor's transplanted limb. By suppressing his or her own immune system, a person is at risk for getting serious infectious diseases (J. W. Jones et al., 2000).

The remarkable ability of nerves to regrow and be reattached distinguishes them from neurons.

Central Nervous System

Why wheelchairs?

People may find themselves in wheelchairs after damage to their spinal cords because of what neurons cannot easily do.

The ***central nervous system*** is made up of neurons located in the brain and spinal cord (shown in blue in left figure). The adult human brain has a limited capacity to grow new neurons and a limited ability to make new connections. Once damaged, neurons usually die and are not replaced.

Because neurons have such a limited capacity for repair or regrowth, people who have an injured or damaged brain or spinal cord experience some loss of sensation and motor movement, depending upon the severity of the damage. For example, Christopher Reeve (right photo) injured his spinal cord in the upper neck and, as a result, has regained only very limited movement and feeling in his hands and feet (Vergano, 2002). Reeve has been confined to a wheelchair because neurons usually have a very limited capacity for regrowth or repair (McKerracher & Ellezam, 2002).

It is most unlikely that Reeve will ever walk.

Currently, one of the most exciting areas of research involves techniques that stimulate the regrowth or repair of damaged neurons. For example, axons, which carry information up and down the spinal cord, normally wither and die after injury, as happened to Reeve. Two methods for promoting the regrowth of axons are providing tubes that guide their growth and injecting growth-producing chemicals (Schwab, 2002). Positive findings in animals offer hope of developing similar methods to treat humans who have suffered brain or spinal cord injury (Seppa, 2000). The newest approach for treating brain damage is to replace damaged neurons by transplanting fetal tissue or stem cells (taken from embyros) into the damaged area. This method has great potential for treating brain diseases, such as Alzheimer's (Begley, 2001c). We'll discuss fetal tissue transplants in the Application section.

Now that you know the structure of the neuron, we'll explain one of its amazing functions: sending information at speeds approaching 200 miles per hour.

D. Sending Information

Sequence: Action Potential

1 Feeling a Sharp Object

When you step on a sharp object, you seem to feel the pain almost immediately because neurons send signals at speeds approaching 200 mph. To feel the pain involves the following series of electrochemical events:

A. Some stimulus, such as a tack, causes a change in physical energy. The tack produces mechanical pressure on the bottom of your foot.

B. Your skin has sensors that pick up the mechanical pressure and transform it into electrical signals. (We'll discuss various kinds of sensors in Module 5.)

C. The sensors' electrical signals are sent by the neuron's axon to various areas in the spinal cord and brain.

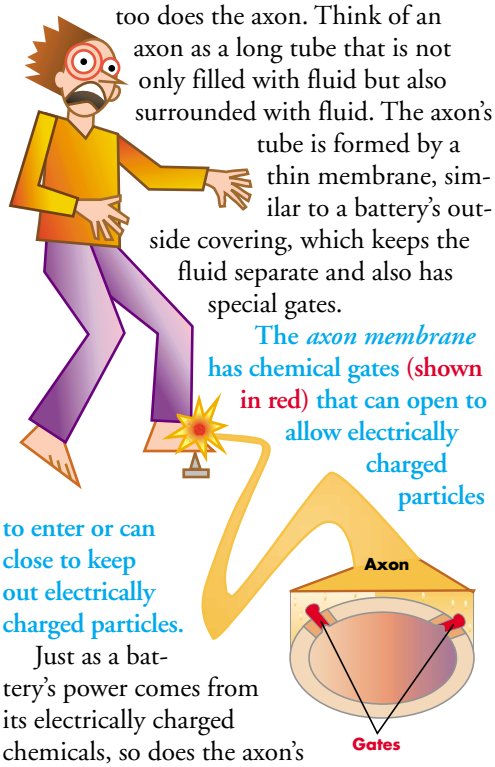
D. Finally, your brain interprets these electrical signals as "pain."

We're going to focus on step C and explain how axons send electrical signals by using the analogy of a battery. We'll begin by enlarging the inside of an axon.

2 Axon Membrane: Chemical Gates

Just as a battery has a protective covering, so too does the axon. Think of an axon as a long tube that is not only filled with fluid but also surrounded with fluid. The axon's tube is formed by a thin membrane, similar to a battery's outside covering, which keeps the fluid separate and also has special gates.

The *axon membrane* has chemical gates (shown in red) that can open to allow electrically charged particles to enter or can close to keep out electrically charged particles.

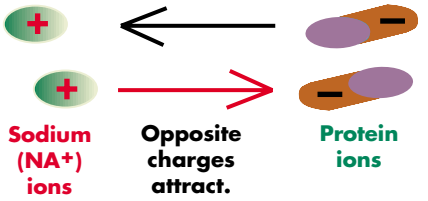


Just as a battery's power comes from its electrically charged chemicals, so does the axon's power to send information. In fact, the axon's electrically charged particles are the key to making it a living battery.

3 Ions: Charged Particles

The fluid inside and outside the axon contains ions.

Ions are chemical particles that have electrical charges. Ions follow two rules: Opposite charges attract (figure below), and like charges repel.



The fluid contains several different ions, such as sodium, potassium, chloride, and protein. The axon's function is often explained by discussing sodium and potassium ions. However, it is simpler and easier to focus on just sodium ions, which have positive charges and are abbreviated Na^+, and large protein ions, which have negative charges and are labeled protein$^-$. Because they have opposite charges, Na^+ ions will be attracted to protein$^-$ ions (figure above).

Because the axon's membrane separates the positive sodium ions from the negative protein ions, we have the makings of a living battery, as shown in section 4 on the next page.

Sequence: Nerve Impulse

6 Sending Information

One mistake students make is to think that the axon has ONE action potential, similar to the bang of a gunshot. However, unlike a gunshot, the axon has numerous individual action potentials that move down the axon, segment by segment; this movement is called the nerve impulse.

The *nerve impulse* refers to the series of separate action potentials that take place segment by segment as they move down the length of an axon.

Thus, instead of a single bang, a nerve impulse goes down the length of the axon very much like a lit fuse. Once lit, a fuse doesn't go off in a single bang but rather burns continuously until it reaches the end. This movement of a nerve impulse all the way down to the end of an axon is actually a natural law.

7 All-or-None Law

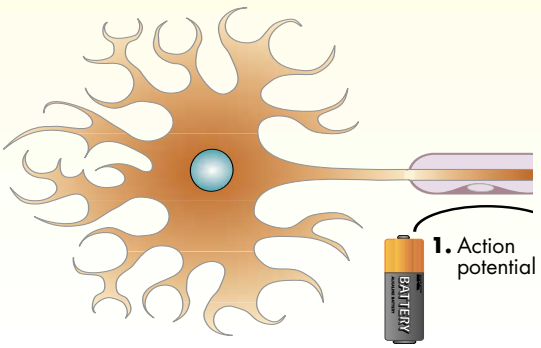
Why does a nerve impulse travel down the axon's entire length? The answer is the all-or-none law.

The *all-or-none law* says that, if an action potential starts at the beginning of an axon, the action potential will continue at the same speed, segment by segment, to the very end of the axon.

You'll see how the all-or-none law works in the next figure.

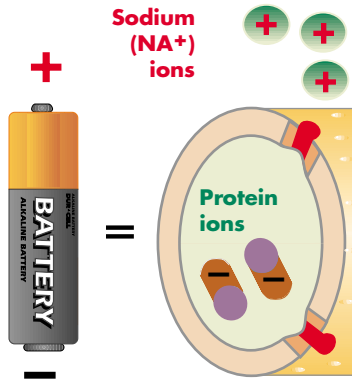
8 Nerve Impulse

Notice in this drawing, which continues on the next page, that the nerve impulse is made up of a sequence of six action potentials, with the first action potential occurring at the beginning of the axon.



4 Resting State: Charged Battery

The axon membrane separates positively charged sodium ions on the outside from negatively charged protein ions on the inside. This separation produces a miniature chemical battery that is not yet discharging and, thus, is said to be in its resting state.



The *resting state* means that the axon has a charge, or potential; it resembles a battery. The charge, or potential, results from the axon membrane separating positive ions on the outside from negative ions on the inside (left figure).

The axon membrane has a charge across it during the resting state because of several factors, the primary one being the sodium pump. (To simplify our explanation of the resting state, we won't discuss other pump or transport systems.)

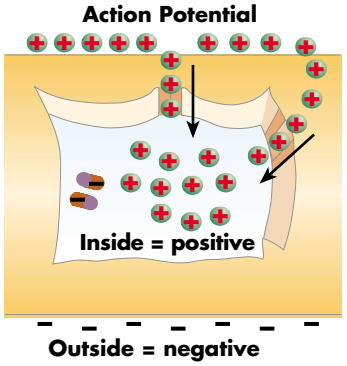
The *sodium pump* is a transport process that picks up any sodium ions that enter the axon's chemical gates and returns them back outside. Thus, the sodium pump is responsible for keeping the axon charged by returning and keeping sodium ions outside the axon membrane.

In the resting state, the axon is similar to a fully charged battery. Let's see what happens when the resting state is disrupted and the battery discharges.

5 Action Potential: Sending Information

If a stimulus, such as stepping on a tack, is large enough to excite a neuron, two things will happen to its axon. First, the stimulus will eventually open the axon's chemical gates by stopping the sodium pump. Second, when the stoppage of the sodium pump causes the gates to open, thousands of positive sodium ions will rush inside because of their attraction to the negative protein ions. The rush of sodium ions inside the axon is called the action potential.

The *action potential* is a tiny electric current that is generated when the positive sodium ions rush inside the axon. The enormous increase of sodium ions inside the axon causes the inside of the axon to reverse its charge. The inside becomes positive, while the outside becomes negative.



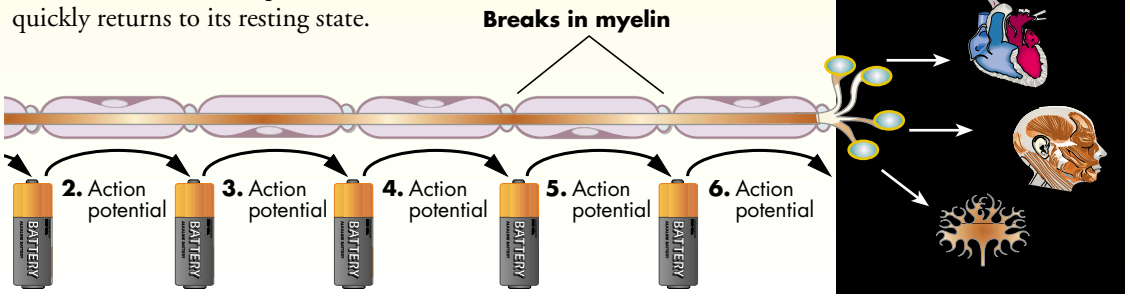
5a Just as a current flows when you connect the poles of a battery, current also flows when sodium ions rush through the opened gates of the axon membrane.

5b During an action potential, the inside of the axon changes to positive and the outside changes to negative. Immediately after the action potential, the sodium pump starts up and returns the axon to the resting state.

At this point, imagine that an action potential has started at the beginning of an axon. How action potentials whiz at race-car speeds down the entire length of an axon is what we'll examine next in the section below, Sequence: Nerve Impulse.

8a According to the all-or-none law, once a nerve impulse begins, it goes to the end of the axon. This means that when action potential 1 occurs, it will be followed in order by potentials 2, 3, 4, 5, and 6. After the occurrence of each action potential, the axon membrane at that point quickly returns to its resting state.

8b Notice that the *myelin sheath* has regular breaks where the axon is bare and uninsulated. It is at these bare points that the axon's gates open and the action potential takes place.



9 End Bulbs and Neurotransmitters

Once the nerve impulse reaches the end of the axon, the very last action potential, 6, affects the end bulbs, which are located at the very end of the axon. This last action potential triggers the end bulbs to release their neurotransmitters. Once released, neurotransmitters cross the synapse and, depending upon the kind, they will either excite or inhibit the function of neighboring organs (heart), muscles (head), or cell bodies.

As you can now see, neurotransmitters are critical for communicating with neighboring organs, muscles, and other neurons. We'll examine transmitters in more detail and show you how they excite or inhibit.

E. Transmitters

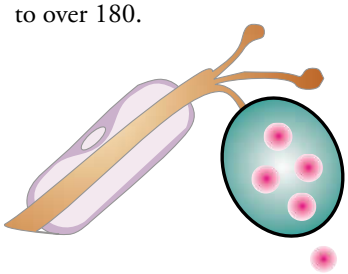
Excitatory and Inhibitory

What makes your heart pound?

There's no doubt that you have felt your heart pounding when you are afraid, stressed, or angry. One reason for your pounding heart has to do with transmitters.

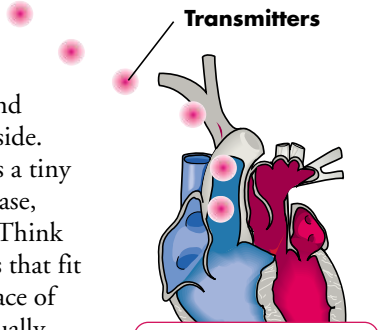
A ***transmitter*** is a chemical messenger that transmits information between nerves and body organs, such as muscles and heart.

Everything you do, including thinking, deciding, talking, and getting angry, involves transmitters. For example, imagine seeing someone back into your brand new car and then just drive away. You would certainly become angry and your heart would pound. Let's see why getting angry can increase your heart rate from a normal 60 to 70 beats per minute to over 180.



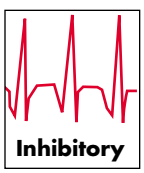
1 In the figure on the left, you see the end of an axon with 3 branches. At the end of the bottom branch is a greatly enlarged ***end bulb.*** Inside the bulb are 4 colored circles that represent transmitters.

2 When the action potential hits the ***end bulb,*** it causes a miniature explosion, and the transmitters are ejected outside. Once ejected, transmitters cross a tiny space, or synapse, and, in this case, reach the nearby heart muscle. Think of transmitters as chemical keys that fit into chemical locks on the surface of the heart muscle. End bulbs usually hold either excitatory or inhibitory transmitters, which have opposite effects.



Transmitters can increase or decrease heart rate.

3 Strong emotions cause the release of ***excitatory transmitters,*** which open chemical locks in the heart muscle and cause it to beat faster (left figure). When you get very angry, excitatory transmitters may cause your heart rate to double or even triple its rate. When you start to calm down, there is a release of ***inhibitory transmitters,*** which block chemical locks in the heart muscle and decrease its rate (right figure). Think of transmitters acting like chemical messengers that either excite or inhibit nearby body organs (heart), neurons, or muscle fibers. One special class of transmitters that are made in the brain are called neurotransmitters.

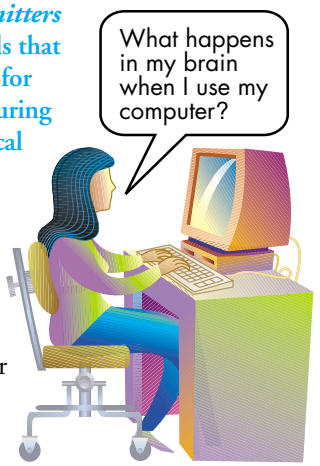


Neurotransmitters

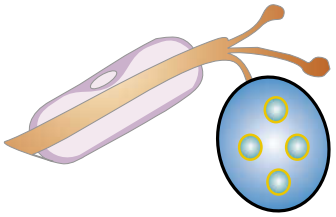
What makes your brain work?

Writing a paper on a computer requires your brain to use millions of neurons that communicate with one another by using chemicals called neurotransmitters.

Neurotransmitters are about a dozen different chemicals that are made by neurons and then used for communication between neurons during the performance of mental or physical activities.

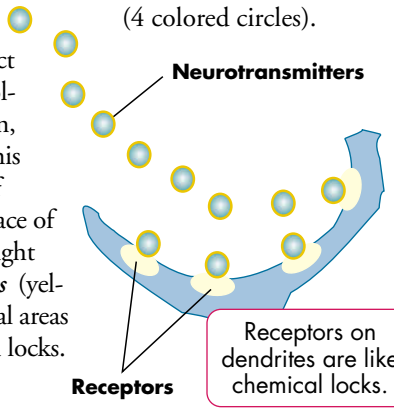


Since billions of neurons that are packed tightly together use different neurotransmitters for eating, sleeping, talking, thinking, and dreaming, why don't neurotransmitters get all mixed up? The answer is that neurotransmitters are similar to chemical keys that fit into only specific chemical locks.



1 The figure on the left again shows the end of an axon with 3 branches. We have again enlarged one ***end bulb*** to show that it contains neurotransmitters (4 colored circles).

2 The action potential causes the end bulbs to eject their neurotransmitters (colored circles), which, in turn, cross the synapse and, in this case, land on the surface of nearby dendrites. The surface of one dendrite is enlarged (right figure) to show its ***receptors*** (yellow ovals), which are special areas that function like chemical locks.



Receptors on dendrites are like chemical locks.

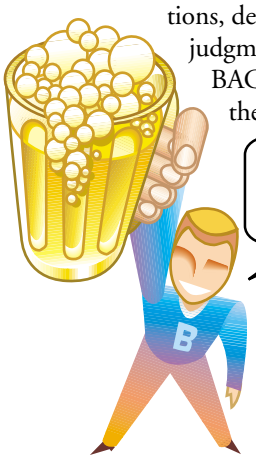
3 Although there are many different neurotransmitters, each one has a unique chemical key that fits and opens only certain chemical locks, or receptors. Thus, billions of neurons use this system of chemical keys that open or close matching locks to communicate and to participate in so many different activities. Also, remember that some neurotransmitters are ***excitatory***—they open receptor locks and turn on neurons—while others are ***inhibitory***—they close locks and turn off neurons.

Since neurons use neurotransmitters to communicate, any drug that acts like or interferes with neurotransmitters has the potential to change how the brain functions and how we feel, think, and behave. For example, here's what alcohol does.

Alcohol

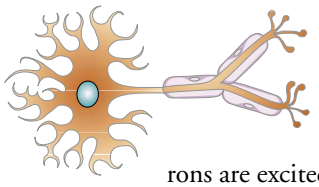
What does alcohol do?

Drinking alcoholic beverages usually raises the level of alcohol in the blood, which is measured in terms of blood alcohol content (BAC). For example, at low to medium doses (0.01–0.06 BAC), alcohol causes friendliness, loss of inhibitions, decreased self-control, and impaired social judgment; after 3 or 4 drinks, the average person's BAC will range from 0.08 to 0.1, which meets the legal definition of drunkenness in most states. (Alcohol is discussed more fully in Module 8.)



Alcohol **(ethyl alcohol) is a psychoactive drug that is classified as a depressant, which means that it depresses the activity of the central nervous system.**

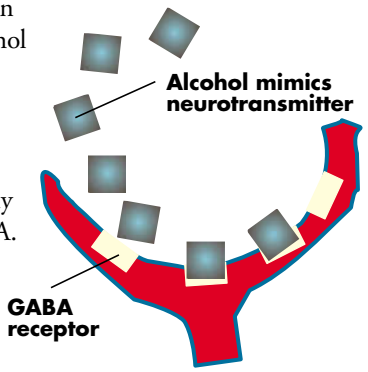
Although alcohol has been around for 3,000 years, it is only recently that researchers have determined its effects on the brain. The effects of alcohol have proved difficult to pin down since it has so many. We'll discuss one of its major effects on the brain.



GABA neurons. Alcohol affects the nervous system in a number of ways, blocking some neural receptors and stimulating others. For example, some neurons are excited by a neurotransmitter called GABA (*GAH-bah*), which the brain normally manufactures. This means that GABA neurons (figure above) have chemical locks that can be opened by chemical keys in the form of the neurotransmitter GABA (Tsai et al., 1995).

GABA keys. Now here's the interesting part. Alcohol molecules so closely resemble those of the GABA neurotransmitter that alcohol can function like GABA keys and open GABA receptors (figure below right). Opening GABA receptors excites GABA neurons.

Although it seems backward, when GABA neurons are *excited*, they *decrease* neural activity and overall produce inhibitory effects, such as reduction in anxiety and tension, loss of inhibitions and self-control, and often an increase in friendliness. Thus, one reason alcohol is such a popular drug is that it reduces tension and anxiety (Stritzke et al., 1996).



One way that alcohol affects the brain is by imitating a naturally occurring neurotransmitter, GABA. Other drugs have different effects on the brain's neurotransmitters, several of which have been recently discovered.

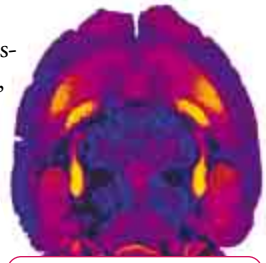
New Transmitters

What are the latest discoveries?

There are a number of well-known neurotransmitters, such as acetylcholine, GABA, norepinephrine, epinephrine, dopamine, and serotonin. However, researchers continue to discover new ones to add to the list of neurotransmitters.

Endorphins. In the 1970s, researchers discovered that the brain makes its own painkiller, very similar to morphine. They called this neurotransmitter endorphin, which is secreted to decrease the effects of pain during great bodily stress, such as an accident (J. Hughes et al., 1975). We'll discuss the effects of endorphins on page 113.

Anandamide. In the early 1990s, researchers discovered a somewhat surprising neurotransmitter, called anandamide, which is similar in chemical makeup to THC, the active ingredient in marijuana (discussed on p. 186) (Fackelmann, 1993). The figure on the right shows a horizontal section of a rat brain that has been treated with a radioactive version of anandamide. The yellow areas, which were most affected by anandamide, are involved in memory, motor coordination, and emotions (Herkenham, 1996). Researchers speculate that anandamide may help humans deal with stress and pain (Fackelmann, 1993).



Yellow areas show where marijuana-like anandamide acts.

Nitric oxide. In the mid-1990s, researchers discovered that a gas, nitric oxide, functions like a neurotransmitter and may be involved in regulation of emotions. For example, mice genetically altered to lack nitric oxide were six times more likely to pick a fight (right figure) compared to normal mice (R. J. Nelson et al., 1995). Based on these results, researchers think that nitric oxide may be involved in turning off aggression in mice and perhaps in humans.

Changing neurotransmitter levels in rats causes increased aggression.

Other chemicals. Currently, researchers have identified over a dozen chemicals that have all the characteristics of neurotransmitters and up to 100 chemicals that influence communication between neurons but do not have all the characteristics of more traditional neurotransmitters (Synder, 2002). The important point to remember about neurotransmitters is that their system of chemical keys and locks permits very effective communication among billions of neurons, which allow us to move, sense, think, feel, and perform hundreds of other functions.

Now that you are familiar with the structure and function of the neuron and the importance of neurotransmitters, we'll use this knowledge to explain a response that many of you have experienced—what happened when you touched a hot object.

F. Reflex Responses

Definition and Sequence

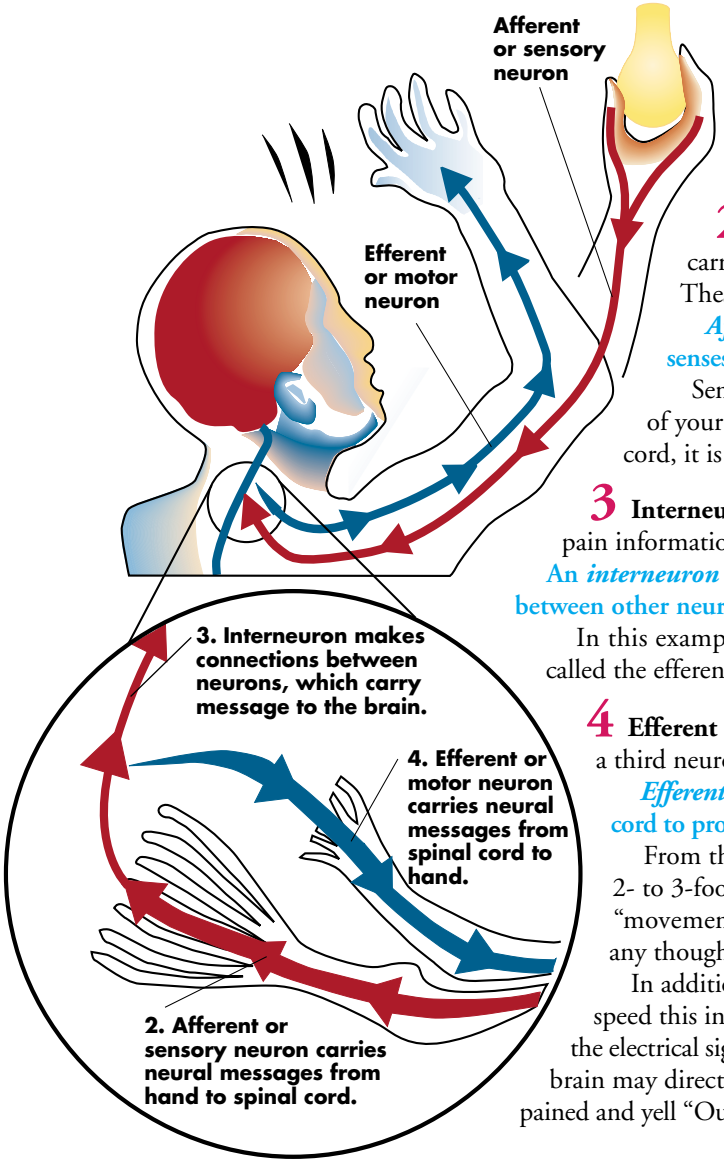
Can you move without thinking?

If you accidentally touched a hot light bulb, your hand would instantly jerk away, without any conscious thought or effort on your part. This is an example of a reflex.

A ***reflex*** is an unlearned, involuntary reaction to some stimulus. The neural connections or network underlying a reflex is prewired by genetic instructions.

In some cases, such as when a doctor taps your knee, the knee-jerk reflex is controlled by the spinal cord. In other cases, such as when someone shines a bright light into your eye, the pupillary reflex causes the pupil to constrict. We are all born with a number of programmed reflexes, and all reflexes share the same two or three steps, depending upon how they are wired in the nervous system.

One reason reflexes occur so quickly is that they are genetically programmed and involve relatively few neural connections, which saves time. Here's the sequence for how a reflex occurs:



1 Sensors. The skin of your fingers has specialized sensors, or receptors, that are sensitive to heat. When you touch a hot light bulb, these skin sensors trigger neurons that start the withdrawal reflex.

2 Afferent neuron. From the receptors in your skin, long dendrites carry "pain information" in the form of electrical signals to the spinal cord. These dendrites are part of sensory, or afferent, neurons (red arrows).

Afferent *(AFF-er-ent)*, **or *sensory, neurons* carry information from the senses to the spinal cord.**

Sensory neurons may have dendrites 2 to 3 feet long, to reach from the tips of your fingers to the spinal cord. When the pain information enters the spinal cord, it is transmitted to a second neuron.

3 Interneuron. Once the afferent neuron reaches the spinal cord, it transmits the pain information to a second neuron, called an interneuron.

An *interneuron* is a relatively short neuron whose primary task is making connections between other neurons.

In this example, an interneuron transmits the pain information to a third neuron, called the efferent, or motor, neuron.

4 Efferent neuron. Inside the spinal cord, an interneuron transfers information to a third neuron, called an efferent, or motor, neuron (blue arrows).

Efferent *(EFF-er-ent)*, **or *motor, neurons* carry information away from the spinal cord to produce responses in various muscles and organs throughout the body.**

From the spinal cord, an efferent (motor) neuron sends electrical signals on its 2- to 3-foot-long axon to the muscles in the hand. These electrical signals contain "movement information" and cause the hand to withdraw quickly and without any thought on your part.

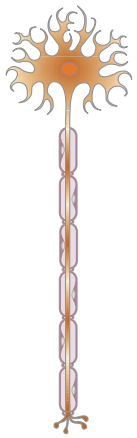
In addition, an interneuron will send the pain information to other neurons that speed this information to different parts of the brain. These different parts interpret the electrical signals coming from your hand as being hot and painful. At this point your brain may direct motor neurons to move your facial and vocal muscles so that you look pained and yell "Ouch!" or something much more intense.

Functions of a Reflex

The primary reason you automatically withdraw your hand when touching a hot object, turn your head in the direction of a loud noise, or vomit after eating tainted food has to do with survival. Reflexes, which have evolved through millions of years, protect body parts from injury and harm and automatically regulate physiological responses, such as heart rate, respiration, and blood pressure. One primitive reflex that is no longer useful in our modern times is called piloerection, which causes the hair to stand up on your arms when you are cold. Piloerection helped keep heat in by fluffing hair for better insulation, but clothes now do a better job.

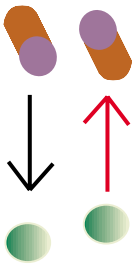
After the Concept Review, we'll discuss a very strange neural phenomenon that you may have heard of—phantom limb.

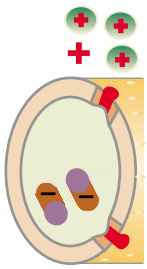
Concept Review



1. The structure that nourishes and maintains the entire neuron is the (a)_____. Branchlike extensions that receive signals from senses and the environment are called (b)_____. A single threadlike extension that speeds signals away from the cell body toward a neighboring cell is the (c)_____. A tubelike structure that insulates the axon from interference by neighboring signals is the (d)_____. Tiny swellings at the very end of the axon are called (e)_____, which store neurotransmitters.

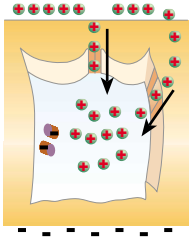
2. Chemicals that have electrical charges are called (a)_____. They obey the rule that opposite charges attract and like charges repel. Although the fluid of the axon contains a number of ions, we have focused on only two, a positively charged (b)_____ ion whose symbol is Na^+ and a negatively charged (c)_____ ion.

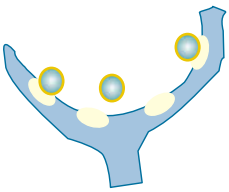




3. If an axon membrane has a potential similar to a charged battery, the axon is in the (a)_____. During this state, the ions outside the membrane are positively charged (b)_____ ions; the ions inside the membrane are negatively charged (c)_____ ions.

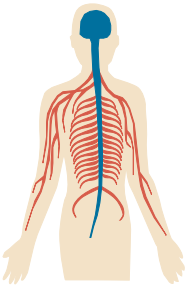
4. If an axon membrane is in a state similar to a discharging battery, the axon is generating an (a)_____. During this potential, the chemical gates open and positively charged (b)_____ rush inside, changing the inside of the membrane to a (c)_____ charge, while the outside of the membrane has a (d)_____ charge. As the action potential moves down the axon, it is called an (e)_____. Once it is generated, the impulse travels from the beginning to the end of the axon; this phenomenon is referred to as the (f)_____.





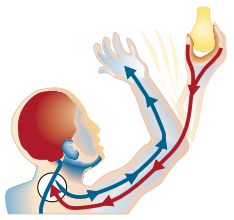
5. The end bulbs of one neuron are separated from the dendrites of a neighboring neuron by an extremely small space called the (a)_____. Into this space, end bulbs release chemicals, called (b)_____, which open/excite or block/inhibit neighboring receptors.

6. From end bulbs, chemical keys or (a)_____ are secreted into the synapse. These chemical keys open matching locks called (b)_____, which are located on the surface of neighboring dendrites, muscles, or organs. Neurotransmitters that open a receptor's lock are called (c)_____; neurotransmitters that block a receptor's lock are called (d)_____.



7. Neurons in the brain and spinal cord make up the (a)_____. If neurons are damaged, they have little ability to (b)_____ and usually die. The mature human brain has a limited ability to regrow (c)_____ throughout adulthood. Information from the body's senses, skin, organs, and muscles is carried to and from the spinal cord by nerves that make up the (d)_____. If this nervous system is damaged, (e)_____ in this system have a remarkable ability to regrow and make new connections. If your finger were accidentally cut off, it could be (f)_____ and there is a good chance that your finger would regain most of its sensory and motor functions.

8. If you touch a sharp object, your hand automatically withdraws because of a prewired reflex response. Neurons that carry "pain information" to the spinal cord are called (a)_____ neurons. Inside the spinal cord, there are short neurons, called (b)_____, that make connections between other neurons that carry information to the brain. Neurons that carry information away from the spinal cord to muscles or organs are called (c)_____ neurons.



Answers: *1. (a) cell body or soma, (b) dendrites, (c) axon, (d) myelin sheath, (e) end bulbs; 2. (a) ions, (b) sodium, (c) protein; 3. (a) resting state, (b) sodium, (c) protein; 4. (a) action potential, (b) sodium ions, (c) positive, (d) negative, (e) impulse, or nerve impulse, (f) all-or-none law; 5. (a) synapse, (b) neurotransmitters; 6. (a) neurotransmitters, (b) receptors, (c) excitatory, (d) inhibitory; 7. (a) central nervous system, (b) regrow, repair, or reconnect, (c) neurons, (d) peripheral nervous system, (e) nerves, (f) reattached; 8. (a) sensory, or afferent, (b) interneurons, (c) motor, or efferent*

G. Research Focus: What Is a Phantom Limb?

Case Study

Why did Donald cut off his leg?

An interesting and puzzling question for researchers to answer is "How can someone feel a phantom limb?"

This question especially applies to Donald Wyman, who was a bulldozer driver working alone on trees in a remote forest. A giant oak tree accidentally fell and pinned him to the ground. With no one close enough to hear his shouts for help, Donald realized his only hope to get out from under the tree and survive was to cut off his leg, which he did with a 3-inch pocket knife. Although bleeding badly, he dragged himself to his truck and drove a mile and a half to get help. Even though his leg was recovered, it was too damaged to be reattached. Donald is now learning to walk with an artificial leg (left photo) that is fitted to the stump.

Donald is recovering but he says, "The toughest part since the accident is dealing with phantom pain. It feels like somebody's holding an electrical shock to your foot that's not there. It makes you jump around" (*USA Today,* August 31, 1993, p. 2A). Donald's case introduces you to the strange phenomenon of phantom limb.

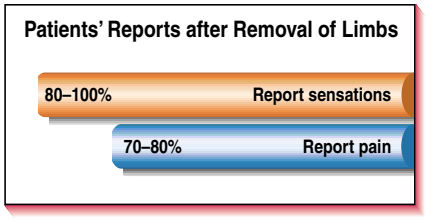
Definition and Data

What is phantom limb?

Very few symptoms have so surprised doctors as when patients reported feeling strange sensations or movements in arms or legs that had been amputated, a phenomenon called phantom limb.

Phantom limb refers to feeling sensations or movements coming from a limb that has been amputated. The sensations and movements are extremely vivid, as if the limb were still present.

As the figure on the right shows, the vast majority of individuals felt sensations ("pins and needles") or intense pain coming from their removed limbs. Patients insist that the phantom limb pain is real pain and not merely memories of previous pain (A. Hill et al., 1996). In other cases, amputees felt that their removed limbs were not only still present but stuck in certain positions, such as straight out from their bodies, so they felt they had to be very careful not to hit their phantom limbs when going through doorways (Katz, 1992).



From 1866 to the present, there have been at least three answers for what causes the feelings of sensations and movements coming from phantom limbs.

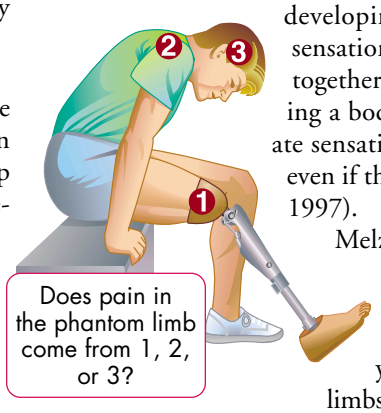
Answers: Old and New

1 Sensations come from cut nerves in the stump.
Early researchers thought that the phantom limb sensations come from cut nerves remaining in the stump. However, when these nerves were cut near the spinal cord, phantom limb should have been prevented; but the sensations still remained, so this early answer has been rejected (Melzack, 1997).

2 Sensations come from the spinal cord.
If sensations from phantom limbs do not come from the stump, perhaps they originate in the spinal cord. However, even individuals whose spinal cords have been severed above the stump report phantom limb sensations. Since a severed spinal cord prevents sensations (electrical signals) from reaching the brain, this answer too has been rejected (Melzack, 1997).

3 Sensations come from a body image stored in the brain.
Researchers now have enough data to indicate that the origin of phantom limb sensations must be the brain itself (Melzack, 1997). But having said that, researchers are puzzled about how the brain generates sensations from phantom limbs.

This newest and most creative answer to the origin of phantom limb sensations comes from researcher Ronald Melzack, who has been studying this problem for about 40 years (Melzack, 1989, 1997). A simplified version of his theory is that each of us has a genetically programmed system of sensations that results in our knowing where our body parts are and in our developing an image of our body. Based on sensations from body parts, the brain pieces together a complete body image. Thus, having a body image, the brain itself can generate sensations as coming from any body part, even if that part is a phantom limb (Melzack, 1997).



Melzack admits that some of his theory must still be tested, but many researchers agree that it is so far one of the best answers to the 40-year-old question involving phantom limbs (Flor et al., 1995).

The phantom limb phenomenon points out that the brain sometimes functions in mysterious ways. Less mysterious is how certain drugs affect the functioning of the brain and the body.

H. Cultural Diversity: Plants & Drugs

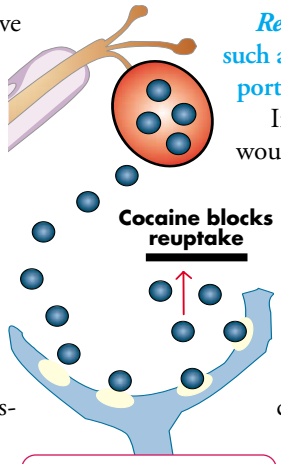
Where did the first drugs come from?

The very first drugs that affected neurotransmitters came from various plants, which people used long before researchers knew what those plants contained. We'll discuss three such drugs—cocaine, curare, and mescaline—which come from plants found in different parts of the world. We'll explain what these plants contain and their actions on the nervous systems.

Cocaine: Blocking Reuptake

For almost 3,500 years, South American Indians have chewed leaves of the coca plant. Following this ancient custom, adult Indians habitually carry bags of toasted coca leaves, which contain cocaine. Throughout the day, they chew small amounts of coca leaves to relieve fatigue and feelings of hunger. Here's how cocaine affects neurotransmitters.

The drawing on the right shows a neuron's end bulb containing the neurotransmitter dopamine (*DOPE-ah-mean*). Once released, dopamine (colored blue circles) reaches the dendrite's receptors, opens their chemical locks, and activates the neuron. However, after a short period of time, the neurotransmitter is normally removed by being transported back into the end bulb through a process called reuptake.



Cocaine works by blocking reuptake.

Reuptake **is a process through which some neurotransmitters, such as dopamine, are removed from the synapse by being transported back into the end bulbs.**

If reuptake does not occur, the released neurotransmitter would continually affect the neuron by remaining longer in the synapse. What cocaine does is block reuptake so that dopamine remains longer in the synapse (Stahl, 2000). Because cocaine blocks reuptake, neurons are stimulated longer, resulting in the physiological arousal and feelings of euphoria that are associated with cocaine usage. Researchers now understand why South American Indians chewed coca leaves. The cocaine released from chewing coca leaves blocked the reuptake of dopamine, which in turn caused physiological arousal that relieved fatigue and feelings of hunger.

Curare: Blocking Receptors

When hunting animals, the Indians of Peru and Ecuador coat the ends of blowdarts with the juice of a tropical vine that contains the paralyzing drug curare.

Curare **(*cure-RAH-ree*) is a drug that enters the bloodstream, reaches the muscles, and blocks receptors on muscles. As a result, the neurotransmitter that normally activates muscles, which is called acetylcholine, is blocked, and muscles are paralyzed.**

Once hit by a curare-tipped blowdart, an animal's limb muscles become paralyzed, followed by paralysis of chest muscles used to breathe.

Why did Indians coat blowdarts with curare?

Curare is an example of a drug that stops neural transmission by blocking the muscles' receptors. Today, the purified active ingredient in curare (tubocurarine chloride) is used to induce muscle paralysis in humans, such as when doctors insert a breathing tube down a patient's throat. Curare doesn't easily enter the brain because the body's blood must go through a filtering system before it can enter the brain. This filtering system, called the ***blood-brain barrier,*** prevents some, but not all, potentially harmful substances in the body's blood supply from reaching the brain.

Mescaline: Mimicking a Neurotransmitter

A golf-ball-sized, gray-green plant (right photo) called peyote cactus grows in Mexico and the southwestern United States. Peyote contains mescaline (Stahl, 2000).

Mescaline **(*MESS-ka-lin*) is a drug that causes physiological arousal as well as visual hallucinations. Mescaline's chemical keys are similar to those of the neurotransmitter norepinephrine (*nor-epee-NEFF-rin*).**

Because mescaline's chemical keys open the same chemical locks (receptors) as norepinephrine, mescaline produces its effects by mimicking the actions of norepinephrine.

In 1965, an estimated 250,000 members of the Native American Church in the United States and Canada won a Supreme Court case that permits them to be the only group legally authorized to use peyote in their religious services. To enhance meditation, members may eat from 4 to 12 peyote buttons, which results in visual sensations, euphoria, and sometimes nausea and vomiting.

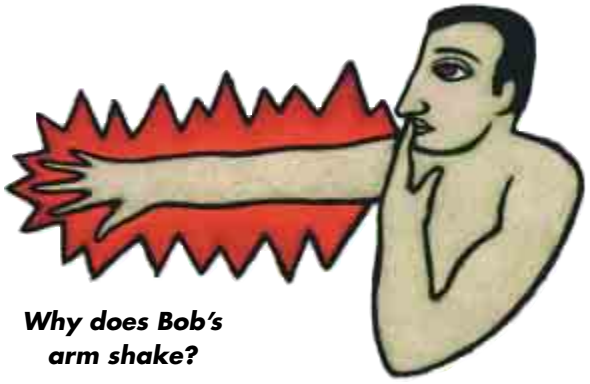
Mescaline comes from peyote cactus.

Conclusion. These three plants—cocaine, curare, and mescaline—contain potent drugs that illustrate three different ways of affecting the nervous system. Researchers have discovered numerous plants, including the opium poppy, marijuana, and "magic" mushrooms, which contain drugs that in turn affect neurotransmitters (discussed in Module 8).

Neurotransmitters are the keys that turn the brain's functions on or off. For example, Alzheimer's disease interferes with neurons and neurotransmitters and turns off the brain's functions. Such is the case with another terrible disease, called Parkinson's, which we'll discuss next.

I. Application: Experimental Treatments

Parkinson's Disease



Why does Bob's arm shake?

Part of Bob's job was to climb poles and make electrical repairs. He was good at his job until he began to notice that, for no apparent reason, his hands would shake or become rigid. The shakes and tremors in his arms grew worse until he couldn't hold his tools. When his symptoms forced him to stop working, his tremors were so bad that he was too embarrassed to eat out or be seen in public. Many days he had trouble walking because his legs would suddenly become stiff and rigid and he couldn't move. It was like being frozen in space.

Bob had all the symptoms of Parkinson's disease.

Parkinson's disease includes symptoms of tremors and shakes in the limbs, a slowing of voluntary movements, and feelings of depression. As the disease progresses, patients develop a peculiar shuffling walk and may suddenly freeze in space for minutes or hours at a time. Parkinson's is caused by a destruction of neurons that produce the neurotransmitter dopamine (*DOPE-ah-mean*).

Like most Parkinson's patients, Bob was placed on a medication called L-dopa, which boosts the levels of dopamine in the brain. However, patients must take ever-increasing amounts of L-dopa, until the drug itself causes involuntary jerky movements that may be as bad as those produced by Parkinson's. Thus, L-dopa controls but does not cure the symptoms of Parkinson's, and after prolonged use, L-dopa's beneficial effects may be replaced by unwanted jerky movements.

In spite of taking L-dopa, Bob's symptoms were getting worse. He had heard about an experimental treatment in which fetal brain tissue that contained dopamine-producing neurons was transplanted into an area of the brain called the basal ganglia (*Los Angeles Times,* November 26, 1992).

The ***basal ganglia*** are a group of structures located in the center of the brain and are involved in regulating movements. To function properly, neurons in the basal ganglia must have a sufficient supply of the neurotransmitter dopamine.

Bob's Parkinson's symptoms had worsened because neurons in his basal ganglia were running out of dopamine. Similarly, when TV actor Michael J. Fox's Parkinson's symptoms worsened, he had to leave his hit sitcom, "Spin City" (Weinraub, 2000). In the United States, about 1.5 million adults, usually over age 50, have Parkinson's disease (Fox was only 34). The causes of Parkinson's disease include genetic and possible environmental factors (Schmid, 2002). To date, Parkinson's has no cure but, as you'll see, several experimental treatments are under study.

Issues Involving Transplants

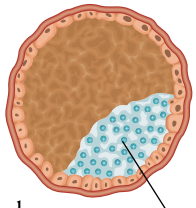
Why not just use drugs?

Human cells. The majority of patients, like Bob, have found that using L-dopa for 10 years or more to treat Parkinson's disease produces unwanted side effects, such as involuntary movements, as well as the return of some of the original symptoms described above (Troster, 2000).

Because of the disappointing long-term results of using L-dopa to treat Parkinson's disease, researchers are trying alternative treatments, such as fetal brain tissue transplants.

Previously, researchers had shown that when fetal rat brain tissue was transplanted into older rats, the fetal neurons lived, grew, functioned, and allowed brain-damaged older rats to relearn the solutions to mazes (Shetty & Turner, 1996). Following successful fetal transplants in rats and monkeys, researchers have transplanted human fetal brain tissue into patients with Parkinson's disease (Kolata, 2001).

The primary reason for using 6- to 8-week-old fetal tissue for transplants is that this fetal tissue has a unique ability to survive and make connections in a patient's brain or body. Because fetal brain tissue is primed for growth, it has a far greater chance of survival after transplantation than does tissue from mature brains (Barinaga, 2000b). More recently, researchers are exploring the use of stem cells to treat Parkinson's disease and spinal cord injuries.



Embryonic stem cells have the ability to form new brain cells.

Stem cells. About four days after a sperm has fertilized an egg, the resulting embryo, which is about the size of the period in this sentence (p. 379), has divided and formed embryonic stem cells (shown on left).

Stem cells, not discovered until 1998, have the amazing capacity to change into and become any one of the 220 cells that make up a human body, including skin, heart, liver, bones, and neurons.

The discovery of stem cells creates new possibilities for treating various body and neurological diseases. For example, when embryonic animal stem cells were transplanted into rats and mice with spinal cord injuries, the stem cells imitated the neighboring neurons and developed into new neurons that, in turn, helped the animals regain their lost functions (N. Wade, 2002). However, the use of human embryonic stem cells is controversial for ethical and political reasons. That's because these embryos, which are fertilized in laboratories and have the potential to develop into humans, are destroyed when the stem cells are removed. On moral grounds, President George W. Bush has limited federal funds for stem cell research. Because stem cell research has such potential, it has received wide support and funding from private and state sources (Perez-Pena, 2003).

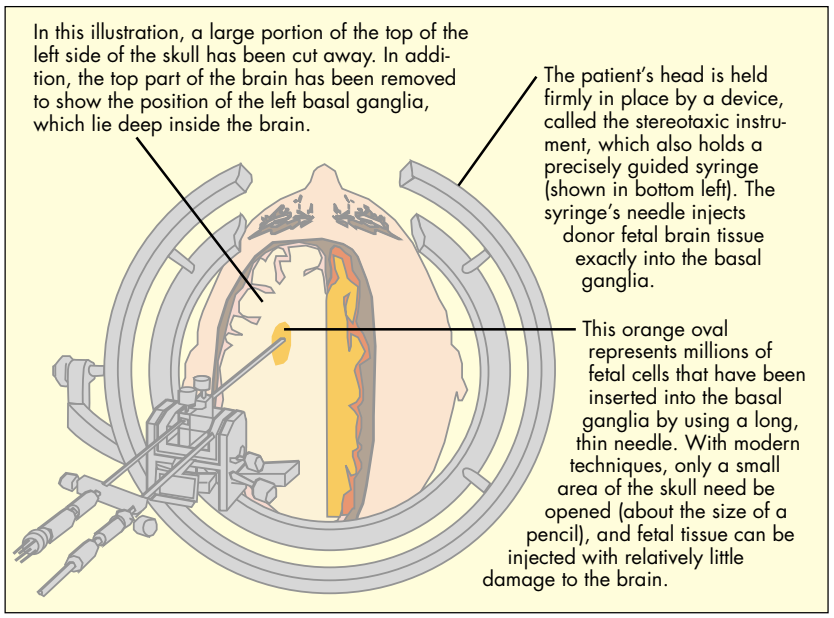
The possibility of using stem cells was unknown in the early 1990s, when Bob was thinking about a new treatment for his Parkinson's symptoms. At that time, he chose the newest experimental treatment available, which was having fetal tissue transplanted into his brain.

Placing tissue in the brain. A neurosurgeon can transplant fetal cells or stem cells into a precise location in either animal or human brains by using the stereotaxic procedure.

The *stereotaxic procedure* (below figure) involves fixing a patient's head in a holder and drilling a small hole through the skull. The holder has a syringe that can be precisely guided to inject cells into a predetermined location in the brain.

As shown below, Bob's head has been fixed in the stereotaxic holder. In this figure, a large part of the skull has been removed to show the brain, but in actual surgery, only a small, pencil-sized hole is drilled in the patient's skull. A long needle from the syringe (lower left in the figure) extends from the holder into the patient's brain area that is involved with regulating movement, the basal ganglia. The surgeon will slowly inject fetal or stem cells into the designated brain area.

The advantages of the stereotaxic procedure are that a thin syringe can be placed in precise locations in the brain and that it causes relatively little damage to the brain. The stereotaxic procedure can be used to either inject solutions or destroy diseased brain tissue.



Results. After surgery, Bob said that he still has his ups and downs but that his symptoms are more controllable. However, because this is a single case study, we do not know whether his improvement is due to the tissue transplants or to the placebo effect—namely, Bob's hopes and expectations.

To control for the placebo effect, a more recent study tested 40 patients with Parkinson's disease. They were randomly assigned to one of two groups: The experimental group had holes drilled in their skulls and fetal tissue was implanted into an area of the brain that controls movement (basal ganglia); the control group (sham operation) had holes drilled in their skulls but nothing was injected into their brains. This procedure, which kept patients from knowing whether or not they had received the transplants, helped prevent the patients' beliefs or expectations from biasing their evaluations and controlled for possible placebo effects.

A year after fetal tissue transplant, researchers asked patients to rate their improvement. There was no significant difference between the ratings of the experimental and control groups, meaning the fetal tissue transplants had not produced any significant improvement compared to the control group (sham operation). In addition, five patients developed serious side effects that involved exaggerated, uncontrollable wiggling and writhing movements, indicating that the fetal tissue transplants were making too much neurotransmitter (dopamine). The only slightly positive finding was that ten patients, all under the age of 60, showed slightly less rigidity in their movements (Freed et al., 2001).

This experiment was controversial from the beginning because some patients were given sham operations (holes drilled in their skulls but no transplants—these patients were given the option of having the actual transplants a year later) and because of religious and ethical objections to having obtained the fetal tissue from abortions. However, researchers believed that this study was necessary because in previous fetal tissue transplant operations (cost: $40,000 per patient), some Parkinson's patients had reported improvements, which encouraged other patients with this fatal disease, who were desperate for a cure, to seek this experimental treatment (Kolata, 2001). The study suggests that previously reported improvements after fetal tissue transplant, such as reported by Bob, may have, to varying degrees, been due to placebo effects.

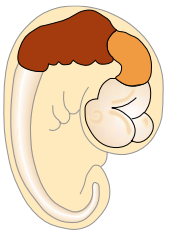
From the above study, researchers have learned that fetal tissue does survive and function in adults' brains. But, before more fetal tissue transplants are attempted, critics suggest that researchers need to identify the best location for injecting the tissue into the brain and to prevent the unwanted motor side effects by determining the optimum number of fetal cells to inject.

Another possibility. A more recent study has reported on a new type of cell implant that produced promising results. In the eyeballs (retinas) of cadavers, researchers found cells that make dopamine and can be grown in the laboratory. These dopamine-producing cells were injected into areas of the brain (basal ganglia) that were similar to areas in which fetal tissue was transplanted. Researchers reported that a year after receiving these cell implants, six patients, all of whom had moderate Parkinson's disease, reported a 50% reduction in their symptoms (Maugh, 2002a). However, as you have just learned from the fetal tissue transplant study, even though preliminary studies such as this may seem promising, their promise must be confirmed with better-designed studies using many more patients.

Future. As of this writing, stem cell research is still in its infancy, but already, remarkable success has been reported in using stem cells to treat animals with spinal cord or brain injury (McKay, 2002). Based on animal research, researchers are currently studying how to use stem cells to treat human spinal cord injury and diseases such as Alzheimer's and Parkinson's (Kim et al., 2002).

Summary Test

A. OVERVIEW: HUMAN BRAIN

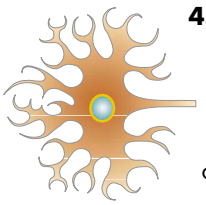


1. The brain is composed of a trillion cells that can be divided into two groups. One group of cells has specialized extensions for receiving and transmitting information. These cells, which are called (a)_____, are involved in communicating with other neurons, receiving sensory information, and regulating muscles, glands, and organs. The other group of cells provide the scaffolding to guide and support neurons, insulate neurons, and release chemicals that influence neuron functions. These cells are much more numerous than neurons and are called (b)_____.

2. There is a major difference between the growth of neurons in the brains of humans and in the brains of birds. A mature human brain is normally not capable of developing new (a)_____, which are almost totally present at the time of birth. In contrast, a mature (b)_____ brain has the capacity to develop new neurons.

3. The age-old question of how the brain's membranes, fluids, and chemicals are involved in generating complex mental activities, such as thoughts, images, and feelings, is called the _____ question.

B. NEURONS: STRUCTURE & FUNCTION

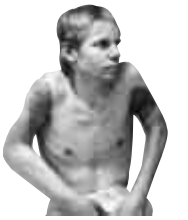


4. Although neurons come in wondrous shapes and sizes, they all share three structures. The structure that maintains the entire neuron in working order, manufactures chemicals, and provides fuel is called the (a)_____. The structure with many branchlike extensions that receive signals from other neurons, muscles, or organs and conduct these signals to the cell body is called a (b)_____. The single threadlike extension that leaves the cell body and carries signals to other neurons, muscles, or organs is called the (c)_____. At the very end of this structure are individual swellings called (d)_____, which contain tiny vesicles filled with (e)_____.

5. Surrounding most axons is a fatty material called the (a)_____. This material acts like (b)_____ and diminishes interference from electrical signals traveling in neighboring axons.

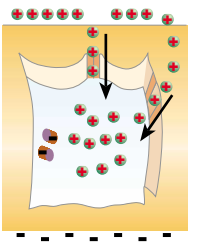
6. Neurons do not make physical contact with one another or with other organs. Instead, there is an infinitely small space between a neuron's end bulbs and neighboring dendrites, cell bodies, or other organs. This space is called the (a)_____. When an axon's end bulbs secrete a neurotransmitter, it flows across this space and affects the (b)_____ on the neighboring membrane.

C. NEURONS VERSUS NERVES



7. There are major differences between neurons and nerves. Cells with specialized extensions for conducting electrical signals are called a)_____. These cells, which are located in the brain and spinal cord, make up the (b)_____ nervous system. Stringlike bundles of neurons' axons and dendrites, which are held together by connective tissue, are called (c)_____. These stringlike bundles, which are located throughout the body, make up the (d)_____ nervous system. Nerves carry information back and forth between the body and the spinal cord. If a neuron in the central nervous system is damaged, it normally does not have the capacity to (e)_____. In comparison, a nerve in the (f)_____ nervous system has the capacity to regrow or reattach if cut or damaged. The mature human brain has a limited ability to regrow (g)_____ throughout adulthood.

D. SENDING INFORMATION



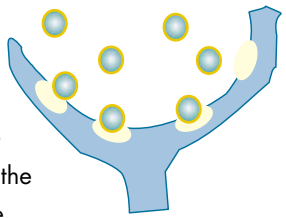
8. The axon membrane has (a)_____ that can be opened or closed. These gates keep some ions inside the membrane and other ions outside. If the axon is ready to conduct but not actually conducting an impulse, the axon is said to be in the (b)_____ state. In this state, most of the positively charged (c)_____ ions are on the outside of the membrane and all the negatively charged (d)_____ ions are trapped inside. In the resting state, the outside of the membrane has a (e)_____ charge compared to the (f)_____ charge on the inside. The process responsible for picking up and transporting sodium ions from the inside to the outside of the axon membrane is called the (g)_____.

9. If a stimulus is strong enough to excite a neuron, two things happen to its axon. First, the stimulus will eventually open the axon's (a)_____. Second, after the gates are opened, the (b)_____ pump is stopped, and all the positive (c)_____ ions rush inside because they are attracted to the negatively charged protein ions. The rush of sodium ions inside generates a tiny electric current that is called the

(d)_____. When this current is generated, the inside of the axon membrane changes to a (e)_____ charge and the outside changes to a (f)_____ charge.

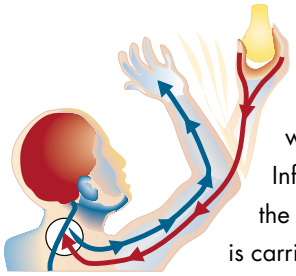
10. Once an action potential starts in the axon, it continues, segment by segment, down the entire length of the axon, creating the (a)_____. Once an action potential is triggered in the segment at the beginning of the axon, other action potentials will be triggered in sequence down the entire length of the axon; this phenomenon is called the (b)_____.

E. TRANSMITTERS



11. Once started, the action potential will reach the end bulbs at the end of the axon. The action potential excites the end bulbs and causes them to secrete (a)_____ that were stored in the end bulbs. Neurotransmitters function like chemical keys that unlock chemical locks or (b)_____, which are located on neighboring neurons, muscles, or other organs. If neurotransmitters open the receptors' locks on neighboring cells, they are said to be (c)_____. If neurotransmitters block the receptors' locks, they are said to be (d)_____. Because of these different actions, neurotransmitters can cause different and even opposite responses in neurons, muscles, or organs. There are about a dozen well-known neurotransmitters. One of the newly discovered neurotransmitters that has a chemical makeup similar to THC in marijuana is called (e)_____ and is involved in emotions and motor coordination.

F. REFLEX RESPONSES

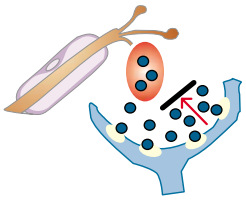


12. The movement of automatically withdrawing your hand after touching a hot object is called a (a)_____, which involves several or more neurons. Information is carried to the spinal cord by the (b)_____ neuron. Information is carried from the spinal cord to the muscle by the (c)_____ neuron. Connections between efferent (motor) and afferent (sensory) neurons are made by relatively short (d)_____, which also send signals to the brain. The functions of reflexes include protecting body parts from (e)_____ and automatically regulating the (f)_____ responses of the body.

G. RESEARCH FOCUS: WHAT IS A PHANTOM LIMB?

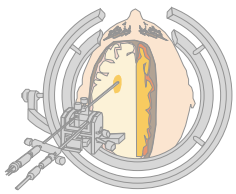
13. The experience of sensations from a limb that has been amputated is called the (a)_____ phenomenon. About 70–80% of patients report sensations of intense pain coming from limbs that have been amputated. A recent explanation of phantom limb sensations is that they arise from the brain's genetically programmed system of sensations that allows the brain to know the locations of all the body's (b)_____.

H. CULTURAL DIVERSITY: PLANTS & DRUGS



14. One of cocaine's effects on the nervous system is to block the process of (a)_____ so that the neurotransmitter remains longer in the synapse, which causes physiological arousal. A drug that blocks receptors on muscles and causes muscle paralysis is (b)_____. A drug that mimics the naturally occurring neurotransmitter norepinephrine and can produce visual hallucinations is (c)_____.

I. APPLICATION: EXPERIMENTAL TREATMENTS



15. The tremors and rigidity of Parkinson's disease result when a group of structures that regulate movement, called the (a)_____, lose their supply of dopamine. In experimental treatment, fetal brain cells or stem cells can be transplanted into a precise location of a patient's brain by a technique called the (b)_____ procedure. Cells that have the amazing capacity to develop into any of the 220 cells that make up the human body are called (c)_____. These cells can be used to treat spinal cord injuries and diseases like Alzheimer's and Parkinson's because stem cells can develop into (d)_____.

Answers: *1. (a) neurons, (b) glial cells; 2. (a) neurons, (b) bird; 3. mind-body; 4. (a) cell body, or soma, (b) dendrite, (c) axon, (d) end bulbs, (e) neurotransmitters; 5. (a) myelin sheath, (b) insulation; 6. (a) synapse, (b) receptors; 7. (a) neurons, (b) central, (c) nerves, (d) peripheral, (e) regrow, (f) peripheral, (g) neurons; 8. (a) chemical gates, (b) resting, (c) sodium, (d) protein, (e) positive, (f) negative, (g) sodium pump; 9. (a) chemical gates, (b) sodium, (c) sodium, (d) action potential, (e) positive, (f) negative; 10. (a) nerve impulse, (b) all-or-none law; 11. (a) neurotransmitters, (b) receptors, (c) excitatory, (d) inhibitory, (e) anandamide; 12. (a) reflex, or reflex response, (b) sensory, or afferent, (c) motor, or efferent, (d) interneurons, (e) injury or harm, (f) physiological; 13. (a) phantom limb, (b) parts; 14. (a) reuptake, (b) curare, (c) mescaline; 15. (a) basal ganglia, (b) stereotaxic, (c) stem cells, (d) neurons*

NEWSPAPER ARTICLE

Would You Want a Head Transplant?

Questions

1. From what you know about the central nervous system, what's the major problem in transplanting a head?

2. Why do researchers first develop new medical procedures in animals before trying them on humans?

3. Why do damaged neurons usually wither and die instead of regrowing?

Everyone knows the story of Dr. Frankenstein, who transplanted a brain into a dead body and brought this creature to life with a jolt from a lightning bolt. As a serious and respected researcher, Dr. Robert J. White, Harvard Medical School graduate and professor of neurosurgery at Case Western Reserve University, believes that a complete head (including brain) transplant is becoming increasingly possible.

Dr. White has been working for the past 40 years on the possibility of transplanting a head. In the 1960s, he succeeded in removing brains from monkeys and keeping the brains alive in special solutions for up to 22 hours. In the 1970s, he successfully removed the complete head from one rhesus monkey and transplanted it onto the body of another monkey. He reports that this "new" monkey with the transplanted head regained consciousness, tried to bite the researchers, moved its eyes, and lived for eight days—dying of lung failure. Although transplanting a head has a number of practical applications, it also raises ethical, religious, and moral questions.

As to practical applications, a head transplant would mean that if quadriplegics' bodies developed life-threatening problems, they could have their healthy heads (and brains) transplanted onto healthy donor bodies and thus keep on living. (Quadriplegics have damaged spinal cords that prevent all movement and sensations from the neck down and often develop life-threatening lung problems.) Because researchers have not yet solved the problem of how to reconnect spinal cords, the quadriplegic's head could not send or receive information from the donor's body. But if you were a quadriplegic with a diseased and dying body, would you want the choice and chance of living a little longer by having your healthy head transplanted onto a donor's healthy body?

Among the ethical and moral questions are whether someone with a healthy head should be allowed to live on top of a stranger's body. Or, how would a family react to knowing that their dead son's or daughter's body is still alive? Among the religious questions are what happens to a person's mind or soul when the person's head is now transplanted onto a different body. Or, is it right to separate the head from the body for any reason?

Dr. White answers these questions by saying that defining death is a medical and not a religious issue. He believes the body is essentially an "energy pack" and concludes by saying, "If a procedure can help somebody live longer, I think most doctors and patients are willing to do what they can, particularly if the alternative is death." (Adapted from S. LaFee, At hand and ahead, *San Diego Union-Tribune,* March 8, 2000, p. E-1)

4. What advances have been made in getting damaged neurons to regrow and in developing new neurons?

5. How do many neuroscientists view the mind-brain distinction?

6. How does Dr. White answer questions about the mind and soul?

Try these InfoTrac search terms: **organ transplant; neurosurgery; quadriplegia; mind-brain.**

SUGGESTED ANSWERS

1. Surgeons can transplant many body organs (hearts, lungs, kidneys, even hands) because peripheral nerves regrow. However, the major problem in transplanting a complete head involves reconnecting the head's spinal cord to the spinal cord in the donor's body. That's because damaged or severed neurons that are in the central nervous system do not usually reconnect or regrow.
2. This raises the ethical question of whether animals should be used in research. The major reason researchers first use animals to develop complicated medical procedures, such as heart or future head transplants, is to work out problems and avoid life-threatening risks to humans (see p. 41).
3. Damaged neurons (central nervous system) usually wither and die because of a built-in genetic program that turns off future regrowth or repair once a neuron is fully grown (see p. 49).
4. Researchers are stimulating damaged neurons to regrow by providing tubes to guide regrowth and by injecting growth-producing chemicals. Experimental treatments include injecting stem cells or fetal tissue into the brain (see pp. 51, 61, and 62).
5. As discussed on page 49, the age-old mind-body (brain) question has several answers. Some philosophers believe that the mind (spirit or soul) and brain are separate things. In contrast, many researchers believe that the mind and the brain are either the same thing or like two sides of a coin.
6. Dr. White seems to believe that the mind (soul, spirit) and brain are one and the same since he defines death as being a medical rather than a spiritual problem.

Links to Learning

Key Terms/Key People

action potential, 53
afferent, 56
alcohol, 55
all-or-none law, 52
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anandamide, 55
axon, 50
axon membrane, 52
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bird's brains, 49
cell body, 50
central nervous system, 51
cocaine, 59
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Parkinson's disease, 60
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repair of neurons, 51
repairing the brain, 49
resting state, 53
reuptake, 59
six-week-old brain, 48
sodium pump, 53
stem cells, 60
stereotaxic procedure, 61
synapse, 50
transmitter, 54

Learning Activities

- *POWERSTUDY CD-ROM 2.0* by Tom Doyle and Rod Plotnik

Check out the "Brain's Building Blocks" **SuperModule** (disk 1) on PowerStudy. This is a completely self-paced module that is fully narrated. Don't want the narration? It is easy to turn off! This module includes:

- Videos—Ina's daughter discusses the impact of Alzheimer's on her mother and the family. Other imbedded videos discuss the apparent Alzheimer's boom, Alzheimer's and the brain, as well as Parkinson's disease.
- A multitude of animations designed to help you understand each section of your text—for example, an overview of the brain and coverage of difficult concepts like the action potential.
- A test of your knowledge using an interactive version of the Summary Test on pages 62 and 63. Also access related quizzes—true/false, multiple choice, and matching.
- An interactive version of the Critical Thinking exercise "Would You Want a Head Transplant?" on page 64.
- Key terms, a chapter outline including chapter abstract, and a list of hotlinked Web sites that correlate to this module.

- *SELF-STUDY ASSESSMENT*

Want help studying? For your customized Study Plan go to **http://psychology.wadsworth.com/plotnik7e/**. This program will automatically generate pretests and posttests to help you determine what concepts you have mastered and what concepts you still need work on.

- *STUDY GUIDE and WEBTUTOR*

Check the corresponding module in your Study Guide for effective student tips and help learning the material presented.

- *INFOTRAC COLLEGE EDITION ONLINE LIBRARY*

To find interesting and relevant articles go to **http://www.infotrac-college.com**, use your password, and then type in search terms such as the ones listed below.

Human brain	Neurons	Central nervous system
Cocaine	Reflexes	Nerves

Study Questions

Use InfoTrac to search for topics mentioned in the following questions (e.g., neurotransmitters, phantom limb, fetal tissue transplant).

*A. **Overview: Human Brain**—Why is it really smart to drive a car only if it is equipped with driver- and passenger-side airbags? (**Suggested answer page 620**)

B. Neurons: Structure & Function—How would you decide if a piece of tissue came from the brain or from a muscle?

C. Neurons Versus Nerves—Headline—"Chimp Brain Transplanted into Human Skull." Is this possible?

*D. **Sending Information**—How are the structure and function of the axon like those of a battery? (**Suggested answer page 620**)

E. Transmitters—What are some of the ways that nerve gas could cause death?

F. Reflex Responses—How might the reflexes of professional tennis players differ from those of amateurs?

G. Research Focus: What Is a Phantom Limb?—What problems might you have after your hand was amputated?

*H. **Cultural Diversity: Plants & Drugs**—What are the different ways that drugs can affect neurotransmitters? (**Suggested answer page 620**)

I. Application: Experimental Treatments—Would you recommend that a family member with Parkinson's be treated with a fetal transplant?

*These questions are answered in Appendix B.