Chapter 2

Learning to Learn

Lesson 1

Brain Structure and Function

Chapter 2

Key Terms

axon
brain stem
cerebral hemispheres
cortex
dendrite
limbic system
neural plasticity
neurons
neurotransmitter
sensory flooding
sensory gating
synapse

What You Will Learn to Do

- Relate the structure and function of the brain to the learning process

Linked Core Abilities

- Build your capacity for lifelong learning
- Apply critical thinking techniques

Skills and Knowledge You Will Gain Along the Way

- Identify key areas and function of the midbrain/limbic system
- Associate major regions of the brain to their functions
- Explain the function of a neuron
- Explain the three elements involved in transmitting stimulus from outside the body to the brain
- Assess the process required to enhance brain power
- Define the key words contained in this lesson

Introduction

This lesson introduces you to the most marvelous and mysterious part of your anatomy—the human brain. Most humans never totally discover or exert the full potential of their brain. In this lesson you explore current research on what the brain is (structure) and how it works (function). You learn practical ways to apply complex concepts that put you in control of your own mind.

Evolution of the Human Brain

Key Note Terms

cortex – the highly wrinkled outer layer of the cerebrum and cerebellum (forebrain); also referred to as *grey matter*

limbic system – a group of subcortical structures (such as the hypothalamus, hippocampus, and amygdala) of the brain that are concerned especially with emotion and motivation

brain stem – the oldest part of the brain composed of the mesencephalon, pons, and medulla oblongata, and connecting the spinal cord with the forebrain and cerebrum; also referred to as the *reptilian brain*

One way to look at the brain's structure is based on the theory of evolution. Only 100,000 years ago, the ancestors of modern man had a brain weighing only about a pound, which is roughly one-third the weight of our current brain. Most of this increased weight is because of a much larger cerebral **cortex**. Here most of the thinking that makes human beings such unique mammals occurs. This tremendous growth is an important aspect of the evolution of the human brain.

The Triune Brain

An early description of the human brain was conceived by neurologist Dr. Paul MacLean who attempted to explain its structure in terms of how it had evolved. According to MacLean's theory, three separate and distinct brains exist, from oldest to more recent. As each brain evolved, the older brain was retained for its specialized functions, and the new brain simply formed around it.

Note

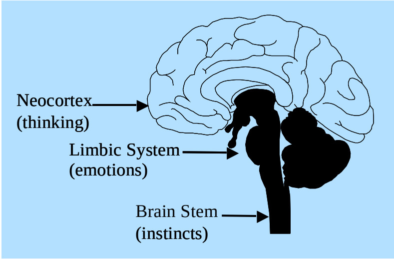
When this book was published, Dr. MacLean was serving as the director of the Laboratory of Brain Evolution and Behaviour in Poolesville, Maryland. He wrote *The Triune Brain in Evolution* (Plenum Press, 1990) and explains his triune brain theory in this book. For more information about his book and his theory, you can read a book review at *http://www.thymos.com/mind/maclean.html*.

MacLean's theory provides a simple, easy-to-understand concept of the human brain. This description relates directly to evidence about how the brain actually works, as you will see in the sections "Brain Function" and "Downshifting" later in this lesson.

The human brain (see Figure 2.1.1) has three parts: the neocortex (mushrooming out at the top), the **limbic system** (in the middle), and the **brain stem** (at the base).

Figure 2.1.1: The triune brain.

Courtesy of CACI and the U.S. Army.



Let's take a closer look at how the brain functions, from top to bottom, and how it interacts with the rest of the body.

Researchers believe the neocortex, sometimes called the *cerebral cortex,* grew out of the limbic system at some time in human evolution. Though not exclusively, the neocortex is where most higher-order and abstract thoughts are processed. The two hemispheres of the neocortex also handle input from our sensory systems, making connections between various stimuli, such as associating what we see with what we hear. This makes comprehension possible, and is how we make it all meaningful.

The neocortex, the most newly developed part of our brain, also attaches feeling and value to stimuli it receives. When humans learn, the structure and chemistry of nerve cells in the neocortex are changed.

The limbic system, once thought to be associated exclusively with emotion, is now known to process not only emotional response but also a number of higher-level thinking functions, including memory.

The brain stem, sometimes called the *reptilian brain* (R-complex), is considered to be the oldest part of the brain from an evolutionary standpoint. It follows then that much of the processing of basic survival needs (eating, breathing, and the fight-or-flight response) occurs here. Fight or flight is the common terminology for a complex set of reactions to a perceived threat—the organism's ability to go on red alert and respond quickly. Many of the body's systems respond automatically to increase the chance of survival when under attack.

Brain Function

The brain is vital to human understanding and the ability to learn. Perhaps you've heard of higher-level thinking skills. This phrase refers to the level of information processing and response required by a particular task. Some complicated tasks can require a higher level of information processing.

For example, when you touch a hot stove, you pull your hand away quickly. That activity does not take much thinking, and it had better not take a lot of time! In fact, your nervous system is designed to process information like that automatically, with little help from the neocortex.

Think about getting burned. What information would be helpful to store long term about that experience? Maybe the size, shape, and color of the heat source will help you to avoid the problem in the future. But the "how to" of pulling away your hand is best left to the quick reactions of nerves and muscles. Given the brain structure presented in triune brain theory, which of the three major regions is probably in charge of the burn response?

If you said the brain stem, you're pretty close. In fact, muscles can react to nerve impulses without those impulses ever traveling up the spinal cord to the brain. The withdrawal reflex, where the finger is pulled away from the pain as muscles contract, is the simplest act that the nervous system can perform. It is automatic and unconscious; it does not involve any higher-level thinking.

Downshifting

Now let's look at a process we call *downshifting*. From the top to bottom view described in the previous section, downshifting describes what occurs when information processing moves from the higher-level thinking regions of the brain, the neocortex and even the limbic system, down into the brain stem and even into the automatic responses of reflex. Why does this happen? Why give up the ability to ponder and reflect and instead revert back to instinct and involuntary reflexes? Fear and intimidation are two main reasons downshifting occurs.

In the presence of perceived threat, survival becomes important, and the brain discerns the need for speed. Like the burn example in the previous section, your nervous system is fine-tuned enough to automatically revert to more efficient processing methods to keep the organism safe and sound. In other words, the brain will downshift from neocortex involvement to rely more heavily on the survival and emotional processing of the brain stem and limbic system whenever the organism perceives a threat.

Psychological threats can produce the same kind of fight-or-flight response needed when an animal is under attack from a predator. And to be more efficient, the brain downshifts.

Perhaps you have a lot at stake in the outcome of an upcoming geometry test. Maybe you won't pass this year if you don't complete a major writing assignment. Or maybe you know someone who believes being tough helps motivate people to perform better. Sometimes tough comes out more like put-downs and threats, instead of inspiration, high standards, and a belief in your ability to succeed.

You need your whole brain involved, especially the neocortex, to solve these problems. Fight-or-flight reactions won't help. Notice when your emotions react and your mind seems to shift into an automatic mode of response. Being self-aware of a downshift gives you the chance to incorporate your higher-level thinking skills in evaluating the situation. Then your whole brain is in operation; ideas and creativity can flow to help you determine a better way to respond to the challenge at hand. This enhanced state of being fully engaged and aware is what we call whole brain activation. Taking in and processing information in many different ways activates the whole brain.

Major Brain Areas

The brain is composed of a number of different regions, each with specialized functions. Figure 2.1.2 shows a tripartite view of the brain's structure and function.

The brain's central core, which includes the brain stem and the midbrain, is quite different from the cerebral cortex that envelops it. The central core is relatively simple, and its activity is largely unconscious. In contrast, the cortex is highly developed and capable of the deliberation and associations necessary for complex thinking and problem solving. In humans, its size and function has increased rapidly; the older portions of the brain remain relatively static.

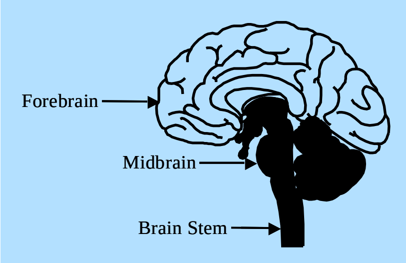


Figure 2.1.2: Another view of the brain, also showing three separate areas.
Courtesy of CACI and the U.S. Army.

The Brain Stem

The brain stem seems to be inherited almost "as is" from the reptilian brain. It consists of structures such as the medulla (which controls breathing, heart rate, and digestion) and the cerebellum (which coordinates sensory input with muscle movement).

The Midbrain

The midbrain includes features that appear intimately connected to human emotion and to the formation of long-term memory via neural connections to the lobes of the neocortex. The structures contained here also link the lower brain stem to the thalamus—for information relay from the senses, to the brain, and back to muscles—and to the limbic system.

The limbic system, essentially alike in all mammals, lies above the brain stem and under the cortex. It consists of a number of interrelated structures. Researchers have linked the limbic system to hormones, drives, temperature control, and emotion. One part is dedicated to memory formation, thus explaining the strong link between emotion and long-term memory.

The limbic system includes the following parts and functions:

- **The hypothalamus is instrumental in regulating drives and actions. Neurons affecting heart rate and respiration are concentrated here. These neurons direct most of the physical changes that accompany strong emotions, such as the flight-or-fight response.**
- **The amygdala appears connected to aggressive behavior.**
- **The hippocampus plays a crucial role in processing various forms of information to form long-term memories. Damage to the hippocampus will produce global retrograde amnesia.**

One important feature of the midbrain and limbic system is the reticular activating system (RAS). It is this area that keeps us awake and aware of the world. The RAS acts as a master switch that alerts the brain to incoming data—and to the urgency of the message.

The Forebrain or Neocortex

The forebrain, which appears as a mere bump in the brain of a frog, balloons out into the cerebrum of higher life forms and covers the brain stem like the head of a mushroom. This, the newest part of the human brain, is called the neocortex, or cerebral cortex, and is shown in Figure 2.1.3.

Key Note Term

neurons – a grayish or reddish granular cell with specialized processes that is the fundamental functional unit of nervous tissue in the brain

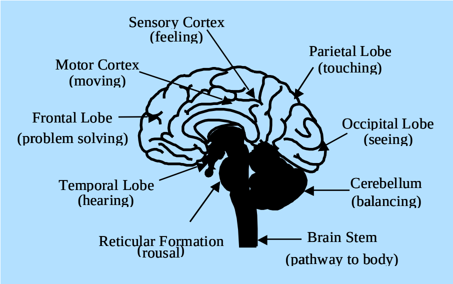


Figure 2.1.3: The forebrain and all of its components.
Courtesy of CACI and the U.S. Army.

The structure of the neocortex is complicated. Most of the higher-level functions associated with human thought are enabled here.

In humans, the neocortex has evolved further than in other mammals, into two **cerebral hemispheres**. The wrinkled surface of the hemispheres is about two millimeters thick and has a total surface area the size of a desktop (about 1.5 square meters).

Key Note Term

cerebral hemisphere – when looked at from the top, the brain is composed of two interconnected spheres or lobes and is the seat of higher-level thinking

Note

For more information about the two hemispheres and how they work together, refer to the next lesson, "Left-Brain/Right-Brain."

Remember that there is symmetry between hemispheres; however, not every specialized region is found on both sides. For example, highly specialized language centers exist only in the left hemisphere. The brain coordinates information between the two hemispheres and does so with startling speed and skill.

The following is a brief description of the four lobes that make up the cerebral hemispheres.

Frontal Lobes

The frontal lobes occupy the front part of the brain and are associated with making decisions, planning, and voluntary muscle movement. Speech, smell, and emotions are processed here as well. The frontal lobes control our responses and reactions to input from the rest of the system. The saying "get your brain in gear" refers to activity in the frontal lobes.

Parietal Lobes

The parietal lobes are most closely associated with our sense of touch. They contain a detailed map of the whole body's surface. More neurons are dedicated to some regions of surface area than others. For example, the fingers have many more nerve endings than the toes, and therefore they have more associated areas in the brain for processing.

The parietal lobe of the right hemisphere appears to be especially important for perceiving spatial relationships. The recognition of relationships between objects in space is important to activities such as drawing, finding your way, construction, and mechanical or civil engineering.

Temporal Lobes

The temporal lobes are associated with emotions and also contain the primary auditory cortex, which processes sound. Doesn't this provoke wonder at the profound connection between music and strong emotion?

Occipital Lobes

The occipital lobes are the primary visual cortex. This area at the back of the brain, just above the cerebellum, processes stimuli from eyes, via the optic nerve, and associates that information with other sensory input and memories.

Recall that areas crucial to long-term memory also reside at the back of the brain. These association areas interpret sensory data by relating it to existing knowledge, and are essential to memory formation. More information on memory is included in later sections of the text.

Sensory Cortex and Motor Cortex

Regions called the sensory cortex and the motor cortex are sandwiched between the frontal and parietal lobes at the top of the head. These areas specialize in the control of movement and in receiving information from the body's primary sensory systems (vision, smell, taste, touch, and sound).

Awareness of Time

According to some researchers, the lobes to the front and the back of the brain seem to be aware of the passage of time; thus the frontal lobe of the neocortex, shown in Figure 2.1.4, appears to be responsible for planning, decision making, and risk taking, while the back of the brain stores memories.

The middle section is focused on experiencing the present moment because it houses the primary sensory and motor cortex. It is busily processing information from our five senses and sending controlled signals back out to our muscles.

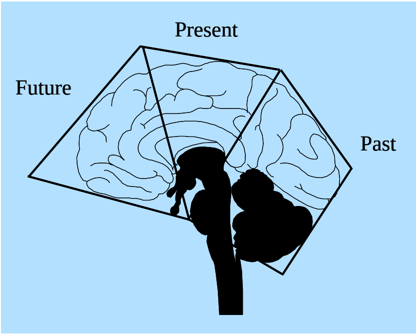


Figure 2.1.4: The lobes to the front and back of the brain are aware of the passage of time.
Courtesy of CACI and the U.S. Army.

The Nervous System

The nervous system links the body to the external environment through sensory organs, permitting us to see, hear, taste, smell, or feel and to respond to stimuli. Through your five senses you know when the air is cold, it's early morning, and someone has a fire burning. The hot chocolate smells wonderful, and the birds are singing. But how do you know?

Sensory Systems

The five most commonly known sensory channels—our eyes, ears, skin, nose, and tongue—all rely on specialized receptor cells to take in data from the external world.

For example, mechanical, chemical, and electrical processes transform the glow of the sun in your eyes and its heat on your skin into electrical impulses and send them sparking along nerve fibers (called sensory neurons). Traveling at speeds up to 290 miles per hour, jumping microscopic gaps (called **synapses**) along the way, these messages make their way to nerve processing centers (called interneurons) in the spinal cord and brain. They then connect back out to your muscles and glands (called motor neurons), causing you to sweat in response to the sun's heat.

Key Note Terms

synapse – the space between nerve cells; the point at which a nervous impulse passes from one neuron to another

sensory gating – also called the neuron spike point, regulates the transmission of stimuli to the brain

sensory flooding – occurs when too much data are getting through to the brain

axon – long fibers that send electrical impulses and release neurotransmitters

dendrite – any of the usually branching protoplasmic processes that conduct impulses toward the body of a nerve cell

neurotransmitter – a chemical molecule (such as norepinephrine or acetylcholine) that transmits nerve impulses across a synapse, within and between brain cells

Sensory Flooding and Gating

A large amount of data comes into the brain all the time. We can't and don't pay attention to all of it. A "go or no go" signal occurs to regulate the transmission of stimuli. This is called the neuron spike point, or **sensory gating**. Without this monitoring, sensory overload, or flooding, would occur. This automatic physical process is a key aspect of what we actually process on a conscious level.

Sensory flooding occurs when too much data are getting through. There is some indication that disorders such as autism are, in part, caused by this type of physiological data transmission problem.

Neuron Structure

The arm and hand in Figure 2.1.5 are used to illustrate a *neuron.* The arm represents the **axon**, long fibers that send electrical impulses and release **neurotransmitters**. The hand is like the cell body and the fingers are like **dendrites**.

Messages are transmitted as electrical impulses from the senses, muscles, or other neurons. The neuron processes the impulse and then sends the message to other neurons via axons. When the impulse reaches the end of the axon, the dendrites pick up the signal as a chemical neurotransmitter synapse.

Neurotransmitters

Neurotransmitters are chemical in nature and are used to accept an electrical impulse from the axon at a synapse and relay it to the dendrites.

The neurotransmitters carry excitatory or inhibitory messages and affect behavior patterns such as pain and pleasure.

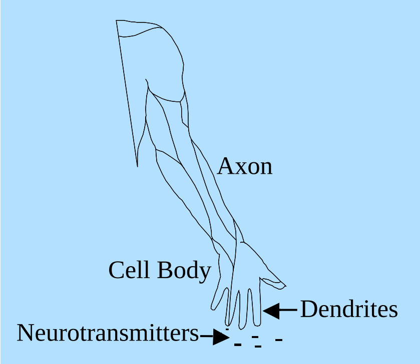


Figure 2.1.5: An arm and hand can show how a neuron works.
Courtesy of CACI and the U.S. Army.

Amazing Facts About Neurons

- Fifty to 100 billion nerve cells act as information specialists in the brain and spinal cord.
- Tens of billions of messages travel as electrochemical impulses every few seconds of every day of your entire lifetime.
- Some single nerve cells, such as the sciatic nerve in your leg, contain dendrite branches 3 feet long.
- Along these large nerve fibers, impulses travel up to 290 miles per hour.

Brain Growth

The human brain has evolved over time to a three-pound mass of tissue sparked with electrochemical interactions. Our jaws and teeth have grown smaller, infancy and childhood last longer, and we physically mature and reproduce at an older age. All these evolutionary adaptations have reserved both time and energy to devote to brain development.

Human Thought

With the advantages of a larger brain and more processing power, humans now are able to solve problems, make decisions, and generate options. Emotions are now rich and complex, giving us the ability to fall in love, nurture each other, and hope for a better future. The wonder of a more highly developed limbic system and neocortex is lived out each day in processes we often take for granted.

Looking closely at complex processes such as learning, you can see how these processes can bring further advantages. With understanding comes the ability to make choices to improve our lives. And these choices can literally make our physical body work better by increasing the size, number, and connections between neurons, the basic cellular building block of the human nervous system.

Growing Dendrites, Making Connections

The billions of nerve cells connect to each other in billions of combinations, forming trillions of pathways for nerve signals to follow. This results in dendritic growth. The dendrites continue to grow throughout your lifetime.

Neural Plasticity

In addition to adding and refining neural networks through the growth of dendrites, the human brain is capable of adapting specialized nerve functions for another critical use when called on to do so.

Key Note Term

neural plasticity – concerns the property of neural circuitry to potentially acquire (given appropriate training) nearly any function

Neural plasticity concerns the property of neural circuitry to potentially acquire (given appropriate training) nearly any function. For example, the connections between the eye and primary visual cortex suggest that neural circuits are wired by evolution exclusively for sight.

The brain's amazing adaptive ability has been demonstrated by the research of many scientists. Neural plasticity is an important adaptation. Similar to other tissue plasticity, neural plasticity tends to occur when called on for special skill development or fine-tuning existing capabilities. For example, when a musician makes special demands for left-hand skills in the process of learning how to play the piano, the brain adapts by increasing the number of neural circuits in the right primary motor cortex.

Similarly, the area of the brain devoted to the right index fingertip (what's known as the reading finger) is larger in Braille readers compared to that for their non-reading fingertips, or for sighted readers, according to researchers Pascual-Leone & Torres in 1993.

Interesting Facts About Brain Growth

- We produce no new nerve cells after roughly the time of birth. These cells must be nurtured because they must work for the next 80 years or so.
- Our infant brain demonstrates on-the-job training; the brain is being used at the same time it is being assembled.
- We are fairly helpless at birth. Less than 1 percent of the portion of our brain circuitry that will be dedicated to receiving sensory information needed for perception and cognition is functional at that point.
- At birth, 100 billion nerve cells in our cerebral cortex set about wiring incredibly complex circuits (some 5,000 to 10,000 connections to each nerve cell).
- Through learning mechanisms in the brain, the brain continues to rewire and change its circuitry throughout our lives.

Memory Systems

Researchers have identified different types of neural systems that store memories, each with their own focus and purpose. Perhaps you've heard of long- and short-term memory. One way to categorize memory system is in terms of how the brain intends to use the information: for short-term processing needs or as a reference that will be useful to solve problems in the future.

Have you ever heard of the term *muscle memory*? Perhaps you're aware that people can ride a bike, swim, play the piano, or demonstrate a dance step after not doing those activities for many years. Recent research indicates that nerve fibers in the muscles, and not just the brain, are actually involved in some of this long-term memory storage. It's as though, with enough repetition, the body will store signals to make body parts move in certain ways. That way, when the body is called on to do those things, the processing time is faster. You literally can do things "without even thinking about it."

Memory Storage

Recall the idea that both sides of the brain are processing sensory data about the same thing at the same time, but in different ways. This theory regarding how the brain hemispheres both specialize and synchronize was presented in the previous textbook section.

The research indicates that one system handles the detail work while the other creates a framework. The two systems are called *taxon memory* and *locale memory*.

Taxon memory handles rote memorization of data. Multiplication tables, spelling words, and the bones of the hand are examples of data that use the taxon memory system. It requires effort, such as repetition and practice, to store taxon memories (rote learning).

The locale memory system, on the other hand, stores mental maps. These are configurations of information connected to events or associated information (map learning).

Memory Retrieval

The brain has the ability to withdraw information stored in taxon memory more readily when information is stored as part of one of the locale memory system's mental maps. Anything you can do to increase the creation of a mental map, or schema, is critical to long-term memory storage.

For example, continuous, repeated practice is one way to aid memory and retrieval capacity. Another method is to create associations with things you already know, to take your understanding to a new level and enable application of the information in more complex ways.

Involving additional sensory systems is helpful to increase retrieval possibilities. Some people find using body movements will aid long-term storage and retrieval. These "kinesthetic/tactile learners" will recall a telephone number by repeating the movements needed to press the phone keys. Others might recall a rhythm or sound pattern formed when saying the numbers out loud. We'll further explore these interesting differences in Lesson 4, "Multiple Intelligences," later in this chapter.

Intelligence Defined

The ability to solve a problem is one way to define intelligence. Another way to describe intelligence is to talk about the ability to create something or to contribute in a tangible way to one's social system or culture.

These words describe a great deal of human activity. In fact, problem solving is one way experiments are designed to test the intelligence of other species. Researchers present a task to the animal and observe what resources the animal brings to bear on the problem for task completion. For example, monkeys have been known to use sticks to access food or playthings.

The ability to solve a problem—from “the food is out of reach” to “how do we get to the moon”—or the capacity to create a product is how Howard Gardner defines intelligence in his theory of multiple intelligences. These capabilities are considered distinguishing characteristics of intelligent life. For Gardner to include a specific problem-solving style as a defined intelligence, the activity must meet additional criteria. For example, to make Gardner’s list, each particular intelligence must have specific regions of the brain specialized to support that function.

Note

Howard Gardner is the John H. and Elisabeth A. Hobbs Professor in Cognition and Education at the Harvard Graduate School of Education. He also holds positions as Adjunct Professor of Psychology at Harvard University, Adjunct Professor of Neurology at the Boston University School of Medicine, and Chair of the Steering Committee of Project Zero. To learn more about Gardner and his theory of multiple intelligences, go to *http://www.infed.org/thinkers/gardner.htm*.

Organisms that do not take in sensory information, process that information, and make decisions about what action to take based on that information are, by definition, less intelligent. The amoeba that takes in nutrients as it drifts around in the water is not solving problems. Its biological processes support food intake in that environment. Without a food source, it would die. It would not be capable of generating any options to enhance survival.

You, on the other hand, are capable of resourceful ingeniousness when it comes to solving problems in order to survive. For more information on this exciting subject, take a look at Lesson 4, “Multiple Intelligences,” later in this chapter.

Conclusion

Knowing how the brain functions should give you a better understanding for how we humans are so much alike yet can behave and react to similar stimuli in completely different ways. Knowing how your brain works may make it easier for you to learn, communicate, and resolve conflict.

In the following lesson, you will learn about the left- and right-brain activity. You will learn which side of the brain controls creative activity, and which controls analytical thought.

Lesson Review

1. **Which section of the brain makes humans different than animals?**
2. **Name the three parts of the brain.**
3. **Which part of the brain senses time?**
4. **Explain how both sides of the brain process sensory data differently.**