LESSON 4: BRAIN STRUCTURE AND FUNCTION

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

INTRODUCTION

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

EVOLUTION OF THE HUMAN BRAIN

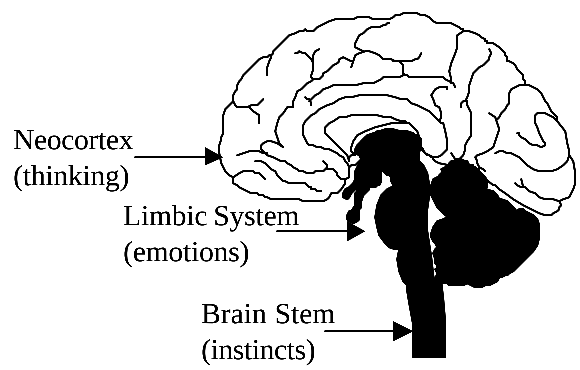
One way to look at the brain's structure is based on the theory of evolution. Only 100,000 years ago, the ancestors of modern man had a brain weighing only about a pound, which is roughly a third of the weight of our current brain. Most of this increased weight is because of a much larger cerebral **cortex.** 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 MacLean that attempted to explain its structure in terms of how it has 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.

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 on Brain Function and Downshifting.

The human brain, top to bottom, has three parts: the neocortex mushrooming out at the top, the **limbic system** (below that), and the **brain stem** (at the base).



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, really the organism's ability to go on red alert and respond quickly. Many of the body's systems respond in automatically in order to increase the chance of survival when under attack.

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 high-level thinking functions, including memory.

The neocortex, sometimes called the cerebral cortex, is believed by researchers to have grown 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.

This newest part of our brain, the neocortex, 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 concept of "making meaning" is explored further as we delve into learning styles and processing preferences in other lessons. But first let's take a closer look at how the brain functions, this time from top to bottom, and how it interacts with the rest of the body.

BRAIN FUNCTION (TOP TO BOTTOM)

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 high level of information processing.

Here's an 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 figured 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 just described, 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 above, your nervous system is fine tuned enough to automatically revert to more efficient processing methods in order 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.

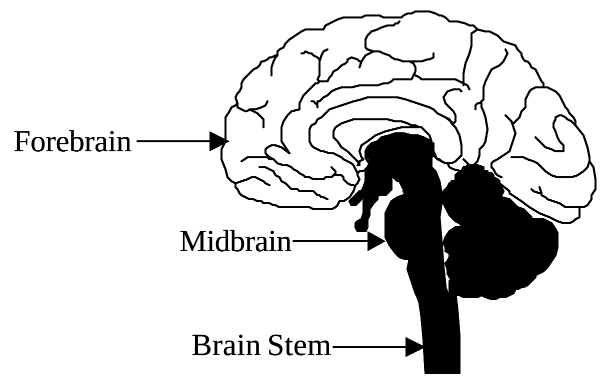
Perhaps you have a lot at stake in the outcome of that upcoming geometry test. Maybe you won't pass this year if you don't complete a major writing assignment. Or maybe you know someone who believes being tough helps motivate people to perform better. Sometimes tough comes out more like put-downs and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

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

Trouble is, you need your whole brain involved, *especially* the neocortex, in order to solve these problems. Fight or flight reactions won't help. One thing you *can* do is 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 comprised of a number of different regions, each with specialized functions. Here is another view of the brain's structure and function, also with roughly three separate parts.



The brain's central core, which includes the brain stem and the midbrain, is quite different than the cerebral cortex that envelops it. The central core is relatively simple, older 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. While the older portions of the brain remain relatively static.

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 (controlling 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 out 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 these parts:

- The hypothalamus is instrumental in regulating drives and actions. **Neurons** affecting heart rate and respiration are concentrated here. These 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 very 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 also called the neocortex, or cerebral cortex.

The Neocortex

The structure of the neocortex is very complicated. Here most of the higher level functions associated with human thought are enabled.

Brain Hemisphere

In humans, the neocortex has evolved further than in other mammals, into the 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).

For more information about the two hemispheres and how they work together, refer to the next lesson called *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.

Here is a brief description of the four lobes that make up the cerebral hemispheres, or neocortex.

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.

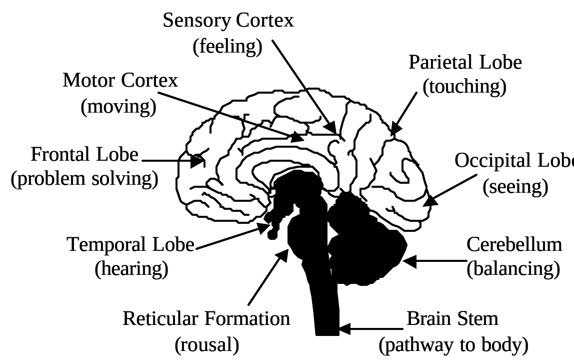
Temporal Lobes

The temporal lobes are concerned 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 our 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.

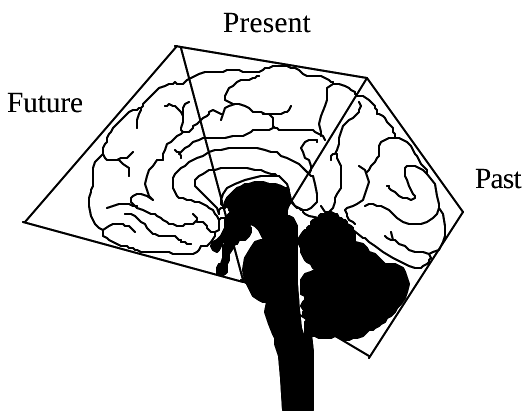


Sensory Cortex And Motor Cortex

Regions called the sensory cortex and the motor cortex are sandwiched between the frontal and parietal lobes, right 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 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, since it houses the primary sensory and motor cortex. It is busily processing information from our five senses and sending control signals back out to our muscles.

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 that 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.

Then, 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. Then they connect back out to your muscles and glands (called motor neurons), causing you to sweat in response to the sun's heat.

SENSORY FLOODING AND GATING

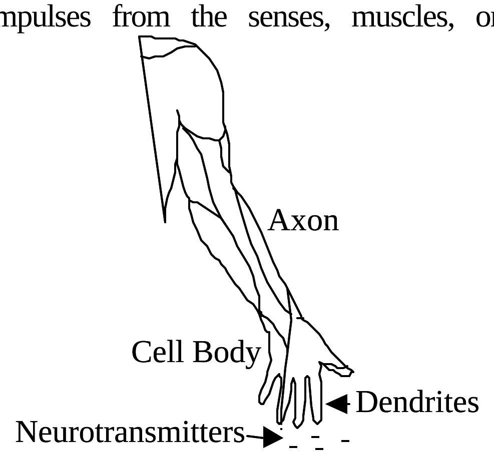
Lots of data comes in, all the time. We can't and don't pay attention to all of it. A "go or no go" signal occurs to regulate the transmission of stimuli. This is called the neuron spike point, or **sensory gating**. Without this monitoring, sensory overload, or flooding, would occur. This automatic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

Sensory flooding is what happens when too much data is 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 graphic of the arm and hand below is 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.

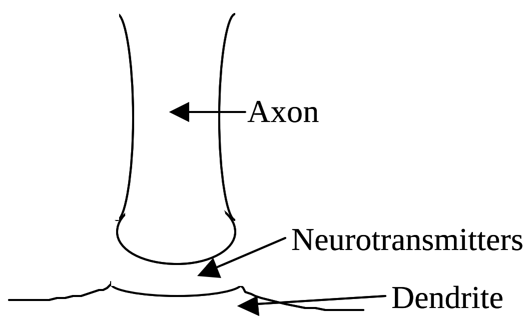
NEUROTRANSMITTERS

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 effect behavior patterns such as pain and pleasure.

AMAZING FACTS ABOUT NEURONS

- 50 to 100 billion nerve cells act as information specialists in the brain and spinal cord.



- Tens of billions of messages travel as electro-chemical 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, sparking with electro-chemical 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, and understanding how these things occur, can bring further advantages. For 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 function for another critical use when called upon to do so.

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 for sight, and sight alone.

The brain's amazing adaptive ability has been demonstrated through the research of many scientists. Neural plasticity is an important adaptation. Like other tissue plasticities, it tends to occur when called upon for special skill development, or fine-tuning existing capabilities. So, 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 (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, 1993.

INTERESTING FACTS ABOUT BRAIN GROWTH

- We produce no new nerve cells after roughly the time of birth. These cells must be nurtured since 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-term and short-term memory. That's one way to categorize memory systems, 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 has indicated 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 upon to do those things, 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 and locale memories.

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 they are 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. For example, 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 the *Multiple Intelligences* lesson.

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 she or he brings to bear on the "problem" of 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.

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 the lesson on *Multiple Intelligences*.

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 is completely different ways. Knowing how your brain works may make it easier for you to learn, communicate, and resolve conflict.