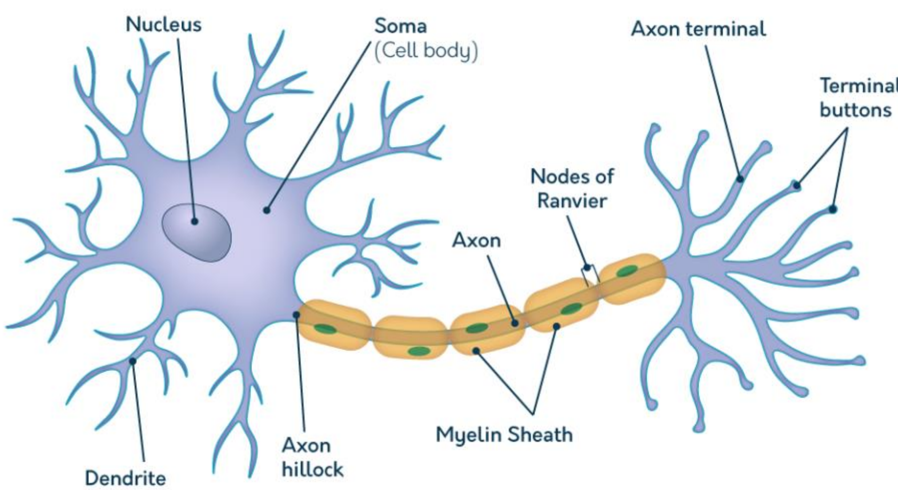
Module 3 – Biology and Neuroscience

3.1 - The Smart Conduit

- The nervous system is the main interpreter both the events in your body and those in the outer world.
- The brain and spinal cord are the ultimate problem solvers that send and receive information to and from all areas of the body
- The nervous system is a maze of complex cellular networks that relay and process information, and its overall purpose is to create behaviour
- This integrate set of networks Is composed of specialize cells called neurons and glial cells which provide support functions. These cells are arranged in all kinds of different configurations to perform different tasks.

3.2.1 - Cells of the Nervous System

- Neurons acts as the main communicators and send electrical impulses as messages to the brain. The glia cells perform support functions in the nervous system
- Dendrites are extensions of the membrane of the cell body and receive chemical messages from other neurons, as we grow, learn and experience the world around us, dendrites spread and form connections with new neurons. The more dendritic branches a neuron has, the greater the number of other neurons the cell communicates with.
    - Dendrites have proteins that are called receptors and these are embedded in their membranes. These receptors bind with molecules called neurotransmitters which are chemicals released by others cells that help to communicate with the rest of the nervous system.
    - When a neurotransmitter binds to a receptor, it has the potential to influence the behaviour of the cell. Generally, after receiving a chemical signal, cells will either send their own signal or reduce the signals that the send to other neurons.



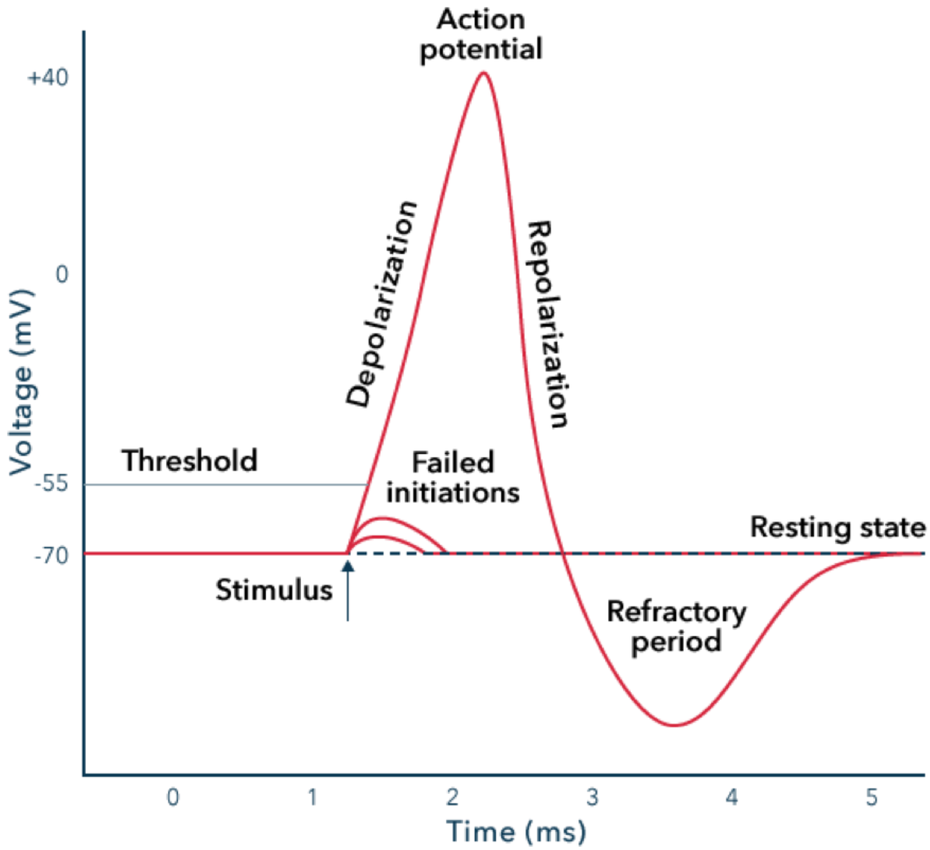
- Dendrites are attached to the membrane of the soma (cell body). The soma is where metabolic processing in the cell occurs and also contains the cell's organelles. Protruding form the cell membrane is the axon hillock which the beginning of the axon.

- Neurons have many dendrites that branch out from the some, however there is only one axon. The axon acts like a wire that transmits the signal from the soma to the end of the axon where the axon terminals and terminal buttons are located.
- The terminal buttons play an important role in neural communication. The terminal button houses vesicles which are little bubbles the contain the neurotransmitters. At the terminal buttons, the neuron will release neurotransmitters, which sends signals to other nearby dendrites. Since this portion of the cell sends signals into the space between neurons, its also called the presynaptic neuron.
- The vesicles release their contents into a space called the synapse or synaptic cleft.
- Once neurotransmitters are released from the vesicles, they float in the synaptic cleft until they are attracted by postsynaptic receptors on the dendrites of adjacent neurons.
- Some axons have a protein and fatty substance called myelin. This substance acts like the insulation that's wrapped around wires you see in everyday life. This keeps the electrical impulse flowing down the axon.
- There are also breaks in the myelin called nodes of Ranvier, these nodes play an important role in helping the signal travel down to the axon by allowing ions to enter and change the charge inside the cell. This allows for more efficient signal transmission. Structures in the neuron are optimized to transform and transfer energy at specific times.
- Electrical activity travels from the soma then to the axon hillock then through the axon and eventually reaching the axon terminal.

3.2.2 - How Neurons Transmit Messages: More Detail on the Action Potential

- Neurons share information within and between parts of the nervous system, but there must be control of when and how it happens. The main way of sharing messages happens through a burst of electrical energy in the neuron that signals it to release a neurotransmitter. This can be either triggered or shut down.
- The nervous system creates and uses bursts of electrical energy called action potential. Everyone has electrically charged particles in the body called ions. Electrical activity is possible because of the movement of the charged particles such as sodium (Na+) and chloride (Cl-),
- A large number negatively charged ions inside the cell causes the neuron to have a negative charge at around -70 millivolts (mV). This is called "polarized" because the charge is far away from 0, which is considered neutral.
- When cells are polarized, it is at rest and doesn't release neurotransmitters. The more positively charged a particle inside the cell is, the more positive the charge inside that cell will be. This is called "depolarization" because we are moving away from the state of being polarized.
- The more depolarized the neuron is, the more likely it is to activate (action potential) and send a neurotransmitter to message other neurons or organs.
- If we bring in Na+ into the cell, it gets closer to the action potential because we're depolarizing, but when we push K+ out of the cell, the cells gets more polarized and gets closer to deactivating because its losing the positive ions which makes the neuron more negative.
- The membrane of a neuron kind of has a barrier, some are locked and need a special key like a neurotransmitter, and some are waiting for a stimulus or the charge (voltage) to change inside the cell.

- Opening each of the channels changes something different inside the cell. In scenarios where we are changing electrical activity to activate or deactivate a neuron, the channels are designed to allow ions to leave or enter the cell
- Action potential can be produced by the movement of Na+ into the neuron through a specific set of channels at the right time.

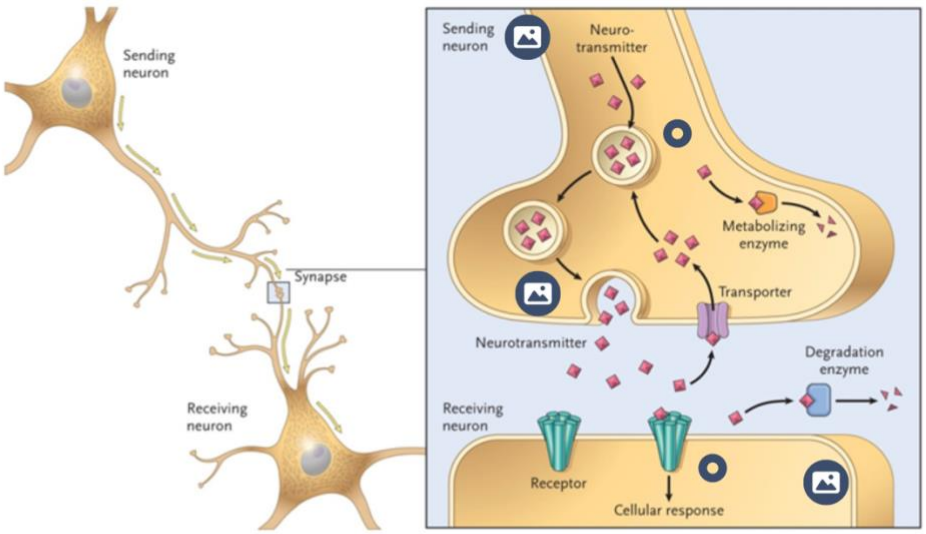


- There are multiple Na+ channels lined up strategically along the axon, this process causes the electrical impulse to continue in succession along the axon. As the gated channels in each successive section "sense" the positive shift in voltage, they pop open too, repeating the rush of Na+
- Propagation is the process by which electrical impulses get send to the end of a neuron. When this electrical impulse gets to the axon terminal, it triggers the release of neurotransmitters, which are the chemicals that neurons use to signal each other.
- It is not good for neurons to be fully active all the time, so at some point, it has to return to resting potential. In a normally functioning neuron, the opening of the K+ channels allow the neuron to return to and maintain resting potential. However, when the channel opens, K+ will rush out instead of in like Na+. Potassium channels respond to depolarization as well, but after the Na+ channels do.
- In a way, Na+ coming in triggers K+ to leave. This results in a quick repolarization of the neuron to negative resting potential. This also rests the neuron so that it can be activated again.

3.2.3 - How Neurotransmitters and Receptors Work

- There are over 100 different types of neurotransmitters in the body.

- Some neurotransmitters are excitatory which means they increase the probability of the neuron becoming electrically active. While other neurotransmitters are inhibitory which means they decrease the probability of the neuron becoming activated. Neurons can receive inputs from both excitatory and inhibitory neurotransmitters.
- The axon of the first (presynaptic) neuron releases neurotransmitters from its vesicles. When these neurotransmitters enter the synaptic space, they are attracted to receptors on the dendrites of the second (postsynaptic) neuron where they alter cellular activity. If enough neurotransmitters activate their receptors, we can get an action potential, however this is only true for certain neurotransmitters.



- Figure: Chemical communication between neurons. In this representation, vesicles in the presynaptic (sending) axon terminal fuse with the membrane to release neurotransmitters into the synaptic cleft, where they bind with receptors on the postsynaptic (receiving) dendrite. Neurotransmitters are synthesized and packaged in vesicles in the presynaptic neuron. After use, they are either transported back into the neuron or degraded by an enzyme in the synaptic cleft.
- Axons in the nervous system secrete many different kind of neurotransmitters, and each is for a particular receptor protein. The interaction of each neurotransmitter with a receptor produces a different kind of response in the neuron. Some interactions between neurotransmitters and receptors are inhibitory which causes hyperpolarization, (-), and some interactions are excitatory which causes (+).
    - For example: GABA, which is an inhibitory neurotransmitter, binds with its receptor to opens a chloride (Cl^-) channel. As a result of this the cell is negative, which means the cells is more likely to be inactivated (inhibited). Whereas acetylcholine (Ach) is normally an excitatory neurotransmitter, so when Ach binds to its appropriate receptor, a sodium (Na^+) channel is opened which makes the cell more positive (more excited)
- There are several factors that influence what kind of behaviors, feelings, or thoughts result from neurotransmitter release, including the receptor they bind with, where they are being released in the brain, the timing of the release, and the activity of other neurons in the same network.

3.2.3.1 - Your Brain on Drugs

- The interactions between neurotransmitters and receptors can also be artificially manipulated or affected in many ways through chemicals. Different neurotransmitters have different effects and depending on the location of the receptor, drugs can alter our experiences by acting like a neurotransmitter or stopping a neurotransmitter from finding the receptor site.
- Agonists, which are chemicals that come from outside the body, can mimic the actions of an endogenous neurotransmitter, which comes naturally inside the body. Antagonists which is a chemical that comes from outside the body can prevent the action of the endogenous neurotransmitters.
    - Both agonists or antagonists can be competitive, which means they will compete with the same binding site on the receptor as the neurotransmitter. However, some are non-competitive because they will bind at a different site. These non-competitive agonists or antagonists are referred to as passive-aggressive chemicals because they won't directly confront the neurotransmitter but instead will interfere with receptor function from hidden locations.
- Some drugs are referred to as partial agonists/antagonists. This means that they bind to and activate the receptor with less power than the endogenous neurotransmitter.
    - For example, a neurotransmitter like glutamate will bind to its receptor and cause a cell to depolarize. A partial agonist would bind to that same receptor, but for a shorter amount of time which results in less activation.

Neurotransmitter	Excitatory/Inhibitory	Function	Associated Drugs
Glutamate	Excitatory	Learning and movement	PCP (causes hallucinations), Ketamine (anesthetic)
GABA	Inhibitory	Learning, anxiety regulation through inhibition of neurons	Valium (used to treat anxiety), Flumazenil (used to reverse anesthesia)
Acetylcholine	Excitatory	Learning, muscle action	Botox (Botulinum toxin, inhibits release of acetylcholine)
Dopamine	Excitatory/ Inhibitory	Learning, Reward/Pleasure	Cocaine (prevents reuptake of dopamine, produces euphoria)
Serotonin	Excitatory/Inhibitory	Elevation / depression of mood	Prozac (prevents reuptake of serotonin, used to treat depression)
Norepinephrine	Excitatory/Inhibitory	Elevation / depression of mood	Doxepin (used for treating anxiety and depression)
Enkephalins/Endorphins	Excitatory	Regulation of pain responses	Opiates (Morphine, Heroin)

3.2.4 - Glial Cells

- Throughout the nervous system, glial cells support neurons and outnumber then 10-1. In certain ways, glial cells can be considered as the caretakers of the neuron. Glial cells perform vital roles in the nervous system, such as providing structural support for neurons, bringing nutrients, removing waste and dead neurons, and speeding up electrical impulses.

- Myelin is made of protein and fat, and it is wrapped around the axons of some neurons in the brain and spinal cord by glial cells called oligodendrocytes. By creating the myelin sheath, these cells speed up communication in the central nervous system. Schwann cells do the same thing but for the nerves outside of the brain and spinal cord.
- Cells called astrocytes and microglia help form the immune system of the brain. These cells help fight off infections and clean up debris that could lead to dangerous inflammation in the brain. In fact, dysfunctional astrocytes are linked to neurodegenerative diseases which are disorders in which neurons die over time and cause an increasing loss of a particular ability.

3.3 - Brain Anatomy: How to Build a Sophisticated Network

- Neural networks are complex connections between the dendrites and axons of many neurons. A nerve is a bundle of axons from many neurons bundled into a tube that extends a large distance. These axons extend from cell bodies that are housed in the central nervous system, which consists of the brain and spinal cord.
- Some of these axons are called efferent, which carry electrical impulses away from the CNS to trigger neurotransmitter or hormone release in an organ or muscle. Others, can be called afferents, and these carry impulses back to the CNS from the organs and muscles.
- The nervous system is able to respond to changing environments through a process called neuroplasticity. This process allows for the ability of neurons and their networks to change. At birth, we have an excess of neurons. As we grow, we lose more neurons than we gain; however, this is not necessarily a bad thing. We need to get rid of neurons that are inefficient, damaged, or unnecessary. Our nervous system can also grow new branches on dendrites and change amounts of receptors and neurotransmitters. All of these processes are part of the neuroplasticity that changes how networks are organized.
- However, many of the processes that occur in our brains and bodies are automatic and below the level of consciousness. There are other neural networks dedicated to those tasks. For example, it would be difficult if you had to consciously remember to breathe while you were studying, or to digest your dinner, or pump blood into and out of your heart
- Conscious thinking and high level processing is done in the neocortex, which is the outer layer of the brain. This outer layer contains billions of neurons that are arranged in circuits, and uses sensory information, memories, and thoughts to form plans.
- Circuits in the medulla which is a structure in the brain stem, help control basic life support functions like breathing, heart rate, and reflexes.
    - However, we do have some conscious control over these functions. Thoughts, and fears that we are aware of can shift or modulate the function of the heart and lungs. We can think about things that calm us down or make us angry, and this can either slow down or speed up our heartbeat. Stressful situations activate the same mechanisms that help us enter our fight or flight when we are in danger. This modulation of neural networks in the lower-brain centers like the medulla and spinal cord is made possible by axons that extend from the cortex to connect with neurons in the medulla.

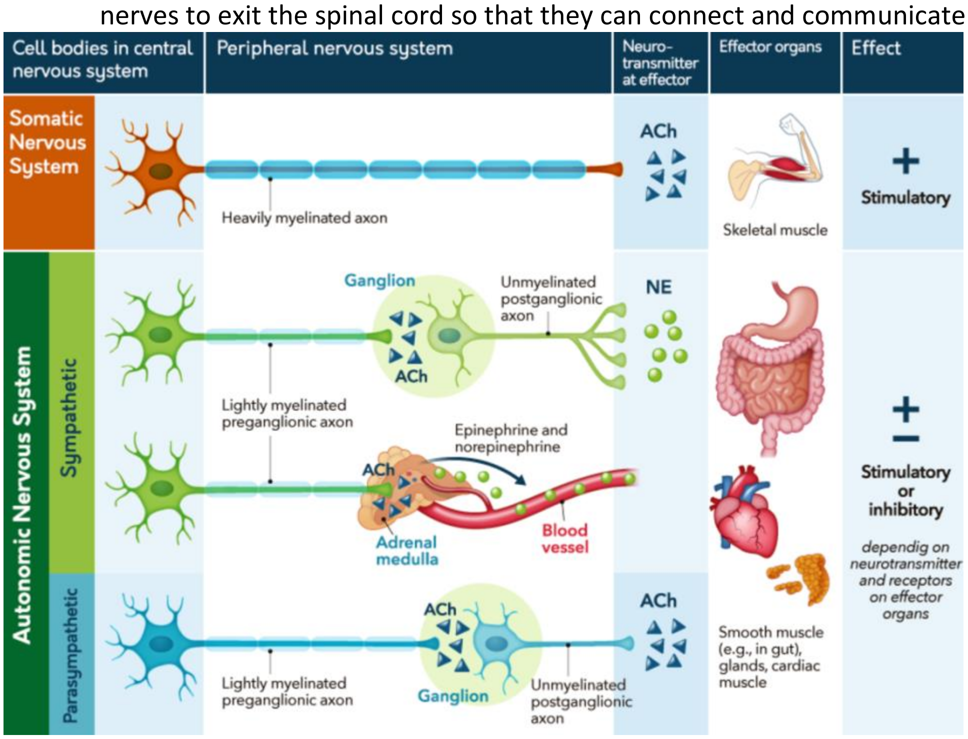
3.4 - Central versus Peripheral Nervous Systems

- Effective communication happens in all direction, not just in one direction. The central nervous system is all the cells supporting structures inside the skull and vertebral column. In short, the CNS is the brain and the spinal cord. The nerves outside of the skull and vertebral column, as well as the specialized sensory endings comprise of the peripheral nervous system.

- The spinal cord conducts simple reflex-level processing and communication with peripheral nerves in the body. Neurons in the spinal cord and the nerves that exit the spinal cord to connect to the muscles must be coordinated. The neurons in the spinal cord are arranged in circuits that do that.
- The central nervous system contains both grey matter (neurons and glia) and white matter which consists of bundles of myelinated axons. In fact, myelin is what makes it appear white. The grey matter does local processing of information, and the white matter helps make different areas of the brain share information by connecting neurons via axons and dendrites.

3.4.1 - The Peripheral Nervous System: Bridge between Brain, Body, and World

- Once nerves leave the spinal cord or brain, they are in the peripheral nervous system. The information in the brain is no good if its not shared with the body. No action would happen without this connection. The peripheral nervous system is split into somatic (voluntary) and autonomic (automatic) divisions. The peripheral nervous system is a large part of what makes our brain a conduit and processor between the world and the self.
- In the previous section we said that the vertebrae are individual joints that make up your vertebral column. This arrangement allows for two things: (1) the ability to flex (think bending over), extend (reaching high), and twist the spine; and (2) space for peripheral nerves to exit the spinal cord so that they can connect and communicate with the body.



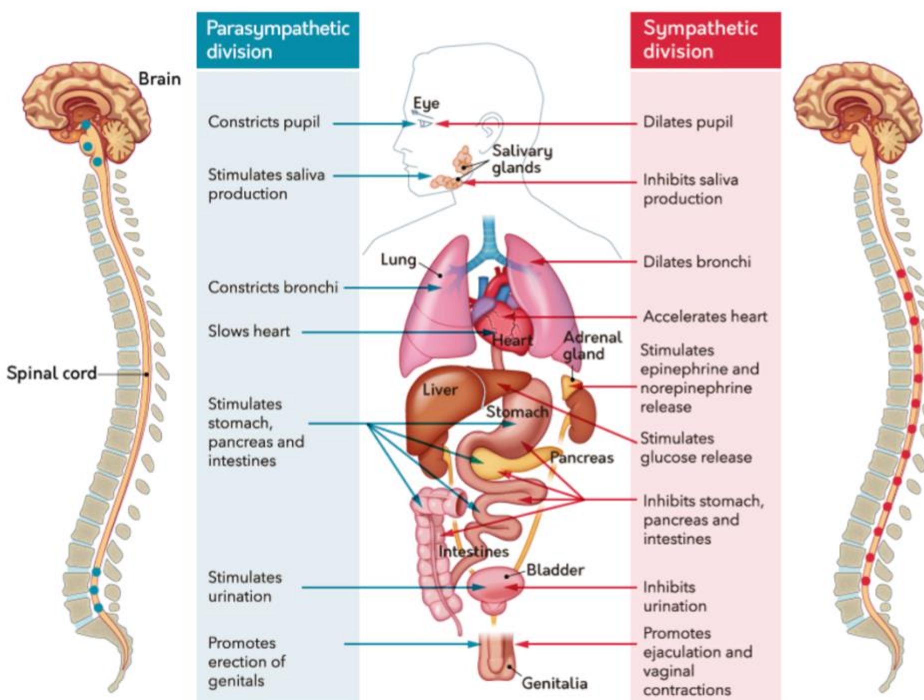
- Figure: Divisions of the peripheral nervous system. The peripheral nervous system is split into two divisions. The somatic nervous system directly controls voluntary movement, while the automatic division regulates functions we do not control consciously. The automatic division is further split into the sympathetic (common known as “fight or flight”) and the parasympathetic (“rest and restore”).

3.4.1.1 - The Somatic Nervous System: Voluntary Movement

- The somatic nervous system contains the neurons and nerves that control the muscles for voluntary movement and bring sensory information from the body to the brain. This system includes nerves that connect to muscles and joints in the neck, arms, legs, and torso.
- When an individual throws a ball, the brain is sending commands that activate somatic neurons in the spinal cord. This creates action potentials in nerves that exit the spinal cord. In this case of a voluntary movement like this, command impulses have been sent from the brain to neurons in the spinal cord. This stimulates neurons, whose axons are bundled into nerves that connect with muscles.
- You're also getting signals back from muscles and joints all through the body and skin. These signals travel back along nerves from the body to provide information to reflex circuits in the spinal cord and to synapse with neurons that send signals back to the brain.
- If the spinal cord is injured, any body parts that are controlled by the nerves from the spinal cord segments below that point can no longer be controlled voluntarily. The brain will also be unable to perceive sensory information from those parts of the body.

3.4.1.2 - The Autonomic Nervous System: Automatic Movement

- The other subdivision of the peripheral nervous system is called the autonomic nervous system. Below the level of consciousness, the autonomic nervous system regulates all of the automatic functions that keep the human body alive, functional and healthy.
- The autonomic system is then further divided into sympathetic and parasympathetic connections to organs and endocrine system structures.



- The sympathetic and parasympathetic nervous divisions comprise the autonomic nervous system and exert control over functions that do not require conscious control, including digestion, heart rate, respiration, and sexual functions. These nerves are also modulated by the endocrine system.

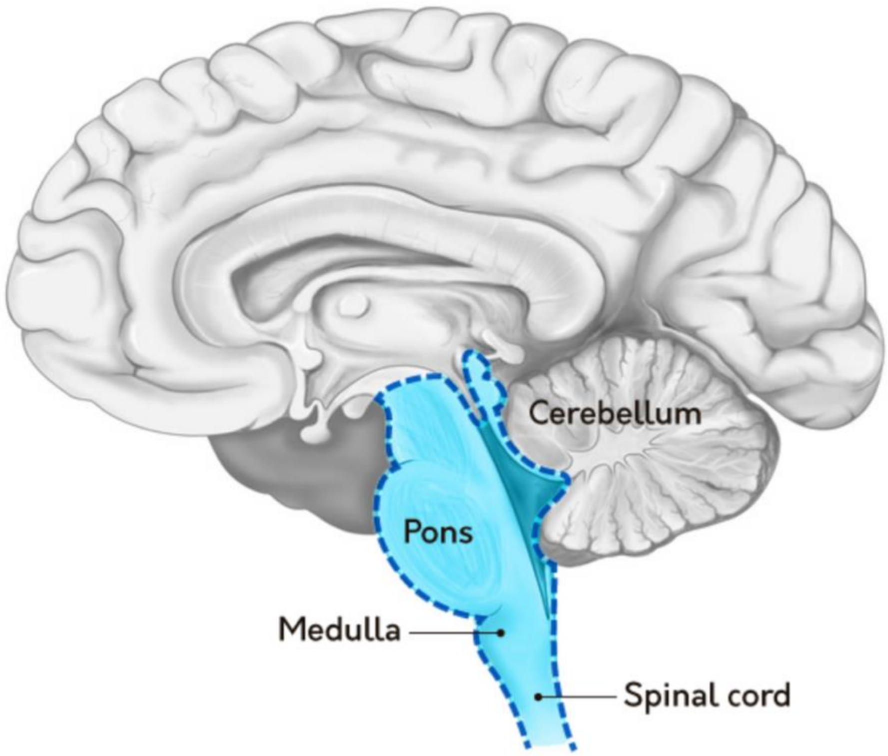
- The neurons and nerves of the parasympathetic nervous system originate in the lower brain and sacral spinal cord. When activated, parasympathetic nerves transmit commands to the organs that help with recovery, digestion, and sexual arousal. The sympathetic nerves mostly achieve the exact opposite. We sympathetic nerves are stimulated, we get increases in heart rate and breathing, as well as an inhibition of digestive activity.
- If an individual is in a situation where they were nervous or frightened, the sympathetic nervous system was activated. In a life or death situation, an individual's heart rate would be beating in overdrive to pump blood to their muscles. Their visual field would be narrowed for focus. They would produce sweat because their body temperature rises. Blood flow is routed toward all systems that would help them fight or escape away from systems involved in digestion or growth repair. This means that while the sympathetic nervous system is activated, the parasympathetic system is deactivated.
- Yoga or a good meal is a good example of things that will activate circuits in the parasympathetic nervous system. During this, your heart rate and respiration will slow down, and more blood will be routed your digestive system. The parasympathetic nervous system helps us to rest, recover, and repair.
- Sex is an example of an activity that stimulated both sympathetic and parasympathetic divisions. The excitement of attraction will activate the sympathetic nervous system, which results in increased heart rate and respiration. But the parasympathetic system increases blood flow to genitals, resulting in erection for both male and female.

3.5 - Sections of the Brain: The Central Command Center

- The brain is considered the command center, where neurons are organized into complex circuits that are dedicated to different functions and integrated with other circuits.
- We view the brain and its organization according to function. We have grouped neural networks together that share function and purpose. However, some prefer to view the brain from an anatomical view according to how structures develop in the fetus.
- The basic idea is that as the fertilized egg divides into many cells, it eventually forms a structure called the neural tube. The cells and supporting structures in this tube become the prosencephalon (forebrain), mesencephalon (midbrain), and rhombencephalon (hindbrain, or lower brain). During this critical time, cells in these areas are differentiating, meaning they are becoming specialized in structure and function.
    - The prosencephalon further differentiates into the telencephalon and diencephalon. The mesencephalon continues along the same path to become the midbrain. The rhombencephalon becomes the metencephalon and myelencephalon.

3.5.1 - Life Functions and Basic Reflexes

- The medulla and the pons are critical for sustaining basic life functions. These rudimentary structures are found in all animals. Part of their job is to regulate basic life functions in the background. However, they also have another job in connecting the peripheral and central nervous systems to regulate what we do and pay attention to.



- The medulla and pons help to regulate a lot of the basic functions we don't have to think about, including our heartbeat, level of awareness, and turning our head suddenly to look at something.

3.5.1.1 - The Medulla

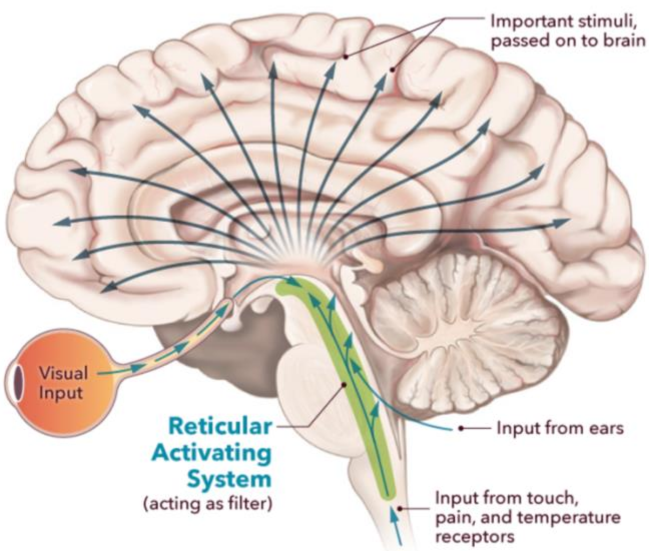
- The medulla, or medulla oblongata, is the lowest anatomical portion of the brain and the transition point between the brain and the spinal cord.
- Without the medulla, we could not breathe, our heart would not beat, and we would be incapable of swallowing (which is vital in obtaining nourishment).
- Significant damage to the medulla is fatal. Upper spinal cord injuries are fatal because they involve neurons in the medulla/cervical spinal cord area that perform life functions.
- People can die from alcohol overdoses because the large amount of ethanol present in alcohol depresses the activity in the medulla, causing it to be unable to sustain the heart rate and respiration required to keep the human body alive.

3.5.1.2 - Pons

- Information that enters the medulla is then transferred to the pons and to higher-order brain functions. This occurs so that information can be useful at each level of processing.
- The pons are responsible for regulating arousal (level of excitement/energy), coordinate the sense with the cerebellum, and serves as a bridge for tracts from the upper brain to the lower brain/spinal cord.
- The pons also house several clusters of neurons that control facial expressions and movements of the eye. Furthermore, the vestibulocochlear nerve enters the brain here, this is the nerve that originates from the inner ear, and helps the brain sense the body's orientation and regulate left-right coordination.

3.5.1.3 - Reticular Activating System

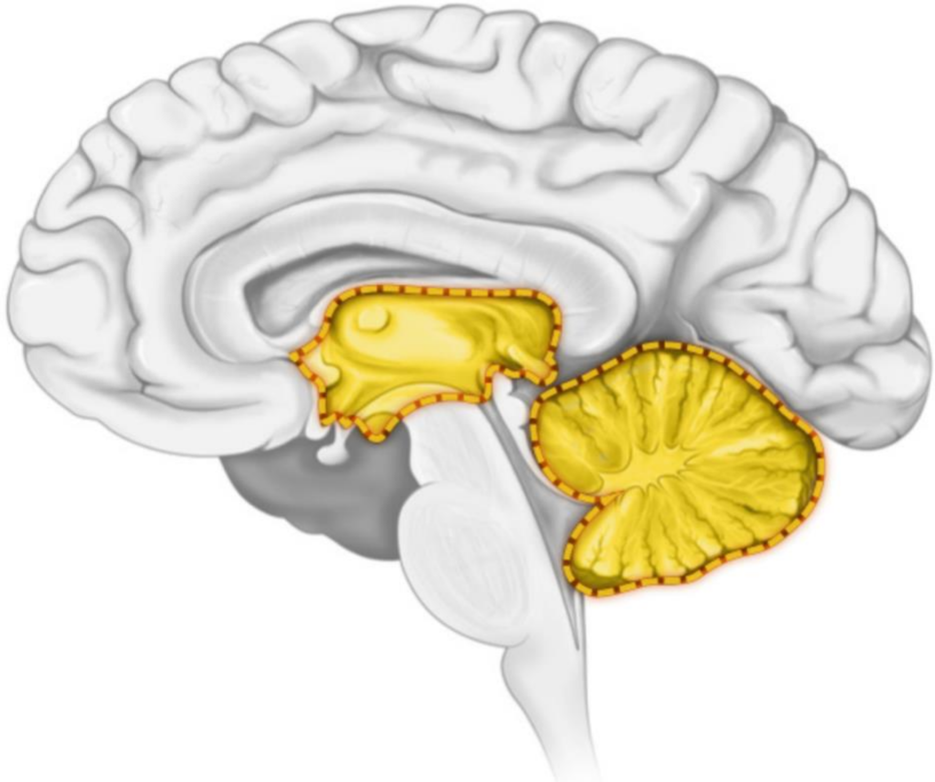
- The reticular activating system is a network of neurons spanning the center of the medulla and pons. The RAS bridges the functions of the body and brain via connections to the spinal cord and thalamus.
- There are two intertwined functions that the RAS helps to regulate, our level of arousal (excitement/energy) and the focus of out attention on tasks, people, or objects
    - Example: If you're a party and there's lots of people and lots of things happening around you, but you want to talk to your friend, the RAS will allow you to focus on just talking your friend rather than all of the other stuff that may be happening around.
- In normal situations, the RAS filters irrelevant stimuli on a constant and daily basis. In fact, dysfunction in the RAS system has been linked to be a possible contributor to ADHD.



- The reticular activating system connects to the spinal cord and cortical circuits to regulate arousal/level of attention. It receives sensory input and packages this information into coded messages that help networks in the cortex refine decisions.

3.5.2 - The Coordinators

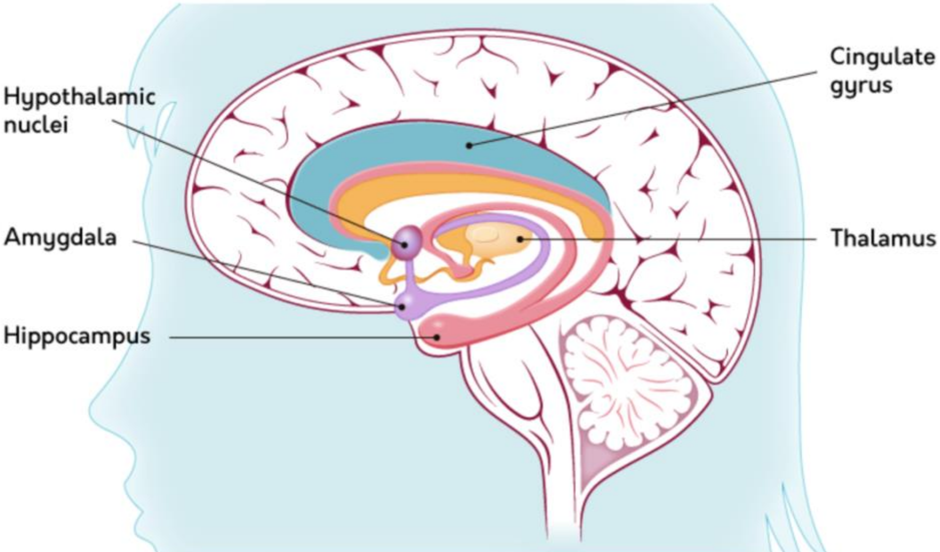
- The networks of neurons and glia are often referred to as nuclei or ganglia, and are located in the limbic system, basal ganglia, and cerebellum, and are designed to be modifiers of action and thought. They collect information encoded by impulses from other areas of the central nervous system and help cortical circuits modify high-level commands. These areas of the brain help us adjust on the fly after areas like the prefrontal cortex make decisions. Structures like the limbic system also help us feel emotions and remember.



- The midbrain (diencephalon) and cerebellum coordinate several different functions to make sense of sensory information, regulate emotional responses, form memories, and coordinate movement/cognition.

3.5.2.1 - The Limbic System

- The limbic system includes circuits in the cortex and the midbrain, and helps regulate the endocrine system as well as our emotions and emotional memory.
- The limbic system contains the prefrontal cortex, the olfactory (smell) cortex, the amygdala, the hippocampus, the cingulate gyrus, and the hypothalamus.
- The main function of the limbic system is to integrate more primitive functions with higher-order thought.



- Amygdala
    - The structures of the limbic system are specialized but varied neutral networks that coordinate to bridge higher-order thought and primitive emotional responses.
    - The amygdala increases electrical activity in its neurons when we are under threat. It also involves aggression responses to threats and even romantic love.
    - The amygdala is also responsible for the increased secretion of norepinephrine (adrenaline) in the body during our flight or fight response.
    - The amygdala is also active in forming memories associated with events that are tied to strong emotions.
    - An amygdalotomy is a procedure that involved the experimental destruction of amygdala in animals, which makes animal docile. They will even snuggle up to things that they would normally find scary.
    - Humans that have damaged the amygdala lose awareness of their own emotions and thus often respond inappropriately in situations that normally trigger emotional responses.
    - Overactivity in the amygdala has been observed to cause anxiety and phobias in patients.
- Hippocampus
    - The hippocampus is a circular structure medial to the temporal lobes, is set up as a loop of neurons that are activated when we are forming memories.
    - The hippocampus synapses strengthen, making more receptors and neurotransmitters, when exposed to high-frequency stimulation over time.
    - The unique structure of the hippocampus is essential for the formation of new memories, and even the imagination of new possibilities.
    - Even though the hippocampus is not our entire memory system, repeatably activating its neurons is necessary for the cataloging of new experiences. It also helps us remember what we want to return to or avoid.
    - The relationship between the hippocampus and amygdala to the memory of new and emotionally important events and objects is crucial for our survival.
- Cingulated Gyrus

    - The cingulated gyrus, which is ventral to the neocortex, is an interesting set of neurons. Increased activity in this area is observed when people experience physical pain and when they are excluded socially.
    - The cingulated gyrus neural network helps focus our attention on thoughts and things that are unpleasant to us. The reason we perceive experiences as unpleasant is because we associate them with potential damage or death.
- The Hypothalamus
    - The hypothalamus helps control several functions in the automatic and endocrine systems. It is responsible for regulating hunger responses, sexual behavior, temperature, and aggression.
    - The hypothalamus can both bring about life and death in this way.

3.5.2.2 - Coordinating Movement

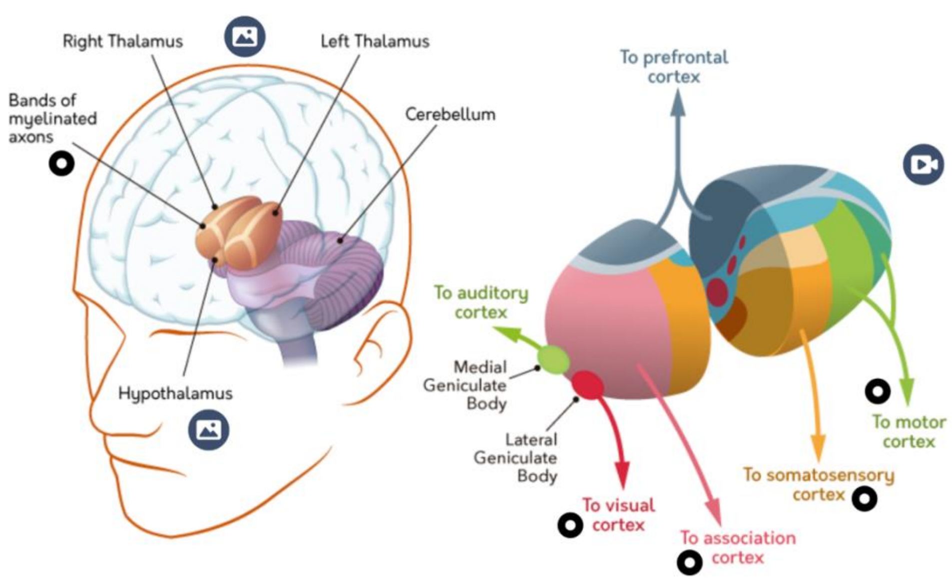
- The Basal Ganglia

  The basal ganglia are interconnected groups of neurons that serve to modulate movement commands in the brain before they reach the spinal cord. There will be an increased blood flow and electrical activity in this area when someone is initiating or terminating a movement. Also, the basal ganglia are heavily involved in helping us learn to make complex movements more automatic.
- The Cerebellum
    - The cerebellum is the part of the brain that is basically a rhythm and timing machine. The neuronal circuits in the layers of the cerebellum are strategically connected with other parts of the brain to modify what they do, especially for movements in cognitive tasks. The circuits in the cerebellum are set up to simultaneously receive and organize input from multiple central nervous system networks.
    - Functionally, the cerebellum is separated into three major divisions: spinocerebellar, vestibulocerebellar, and cerebrocerebellar. The spinocerebellar division helps to match sensory input with motor plans in order to fine-tune movement patterns. The vestibulocerebellar division processes information from the inner ear to help adjust your posture and balance. The cerebrocerebellar (lateral hemispheres and dentate nuclei) division manages connections with the pons and thalamus to adjust the timing and planning of movements.
    - Sometimes, the circuits in the cerebellum are injured or don't develop properly, in this case the patient will present to a neurologist with symptoms such as loss of balance or an uncoordinated gait (walking). Unlike severe damage to the motor cortex or spinal cord, problems in the cerebellum don't result in paralysis. Instead, the person's timing, planning, and balance is staggered.

3.5.2.3 - Thalamus: The Relay Station

- The brain is set up to create packaged experiences. The way the thalamus is arranged and connected helps us do that. Each cluster of neurons in the thalamus corresponds to a particular set of functions and locations in some parts of the brain. While the reticular activating system determines level of arousal and amount of attention, the thalamus is what the cortex uses to choose which thing we pay attention to.

- In Figure 3.22, we can see the thalamus (diencephalon). It operates like Grand Central Station, the hub through which all train routes pass. All senses, with the exception of smell (which is routed directly to the temporal lobes), must pass through the thalamus before it is relayed to the neocortex for interpretation, organization, and action plans. This means that axons from spinal and cranial nerves that carry impulses from the eyes, ears, skin, muscles, and joints first synapse in the thalamus. In turn, these neurons have axons that project to areas of the cortex that make decisions governing our next set of thoughts and responses. The thalamus is arranged as a series of nuclei (remember, these are clusters of neurons, not like the nucleus of a cell). Each nucleus receives a specific kind of sensory information or sends that information to another part of the brain.



- The thalamus serves as a sensory relay. Observe that the thalamus is in the center of the brain, which is no mistake. Clusters of neurons in the thalamus are responsible for routing sensory information to the cortex so that cortical circuits can integrate the information.

3.5.3 - Neocortex (New Brain): Higher-Level Processing

- Humans share a lot of characteristics with primates, but there are two main differences: the number of connections in the neocortex and the area dedicated to the frontal lobes, which govern personality, context, and decision making. This region of the brain has the distinctive "wrinkled" or "tree bark" appearance that we are used to seeing on the outside of the brain. Part of what makes humans capable of abstract thought may be the thickness of our neocortex. There are four basic sections of the neocortex, called lobes.
- The neocortex looks the way it does because of three distinct features: the gyri, sulci, and fissures. This kind of structure allows us to fit more brain into a small space like a human skull. The neocortex has six layers.
- Each lobe of the neocortex receive sensory information in primary areas. Adjacent to these primary processing networks are areas called association cortex which further process the information and help to integrate it with other sensory information.

3.5.3.1 - Frontal Lobes: Executive Decisions

- The frontal lobes are primarily tasked with decision making and movement. This means that the neurons in these areas are active during times that we have to make decisions about how to act or what to do.
- These circuits seem to encode our personalities. It is the consequence of the interaction between the neural networks in the frontal lobes and the rest of the CNS that comprises executive function.
- Decision making in the brain is a team effort. The frontal lobe is necessary for maintaining our ability to regulate our behavior and thought. The output of the frontal lobe tends to be inhibitory.
- The most posterior structure (towards the back of the head) in the frontal lobes is the motor cortex, which houses the primary neurons that initiate voluntary movement. The primary motor cortex gives rise to two major pathways: the motor axons of the corticospinal and corticobulbar tracts. These bundles of axons control movement of the muscles in the body (spinal) and head/face (cobulbar), respectively.
- The prefrontal cortex helps us decide when, why and how we do things. In this one important are, we house about 14%-17% of the neurons in the brain. The prefrontal cortex has both inhibitory (hyperpolarizing) and excitatory (depolarizing) connections. This is what makes this area able to integrate information and act as a coordinator, because it is a set up as a series of on/off switches that make what we call "if, then" decisions.
    - These decisions are not just "go" and "stop" like in the case of simple spinal circuits. These multilevel connections in the PFC allow it to make decisions based on several different sources of information, whereby it will say "if this happens, then we can do that". Neural dysfunction in the prefrontal cortex seems to correlate with the presence of "negative symptoms" in schizophrenic patients, which include social withdrawal.
- There are also parts of the prefrontal cortex that are even further specialized to make decisions based on specific criteria or input. Two examples include the ventromedial prefrontal cortex (vmPFC) and the dorsolateral prefrontal cortex (DLPFC). The vmPFC (closer to the bottom inside part of the cortex) helps to modulate behavior based on fear. The DLPFC (closer to the top and side of the head) helps us maintain information in our working memory and change how we do things depending on what task we are trying to complete. For example, the DLPFC might change the sequence and groups of muscles your motor cortex activates while you hammer a nail based on whether you are sitting on the edge of a roof or comfortably in your apartment.
- The prefrontal cortex is one of the last regions to undergo the process of myelination, where oligodendrocytes wrap myelin around axons to speed up the transmissions of impulses. The implications are huge. This is a contributing factor to the high degree of impulsiveness and lack of consideration of context in adolescents. Like any human behavior or thought pattern, there is a large degree of variability in that tendency. Some adolescents are less impulsive and seem to make better executive decisions than others.

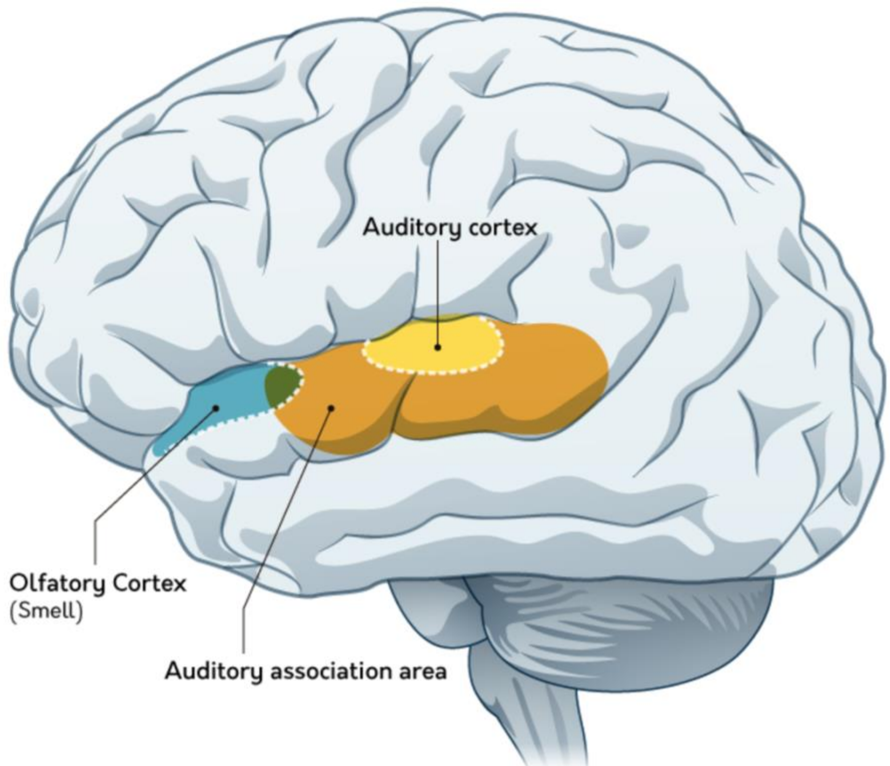
3.5.3.2 - Parietal Lobes: Space, Time and Numbers

- Circuitry within the parietal lobe seems to be heavily in functions like processing numbers and performing calculations. There are even differences between the left and right sides, if the right side of the parietal lobe is injured severely, we end up with problems like not navigating the space around us well (spatial relations) or misinterpreting sensation from our left side.

- The sensory cortex in the anterior portion (closer to the frontal lobe) of the parietal lobe receives input from the contralateral (opposite) side of the body. This is because the nerves that carry sensation from the body, and motor commands from the brain of the body, cross at the level of the brainstem. This allows the information carried from sensory receptors in the skin, muscles, and joints to integrate with other areas of the brain via circuits in the brainstem and thalamus. This decussation, or crossing, also helps us coordinate both sides of the body, as we do in most movements.
- Humans do a lot of cross-lateral movements, where we have to coordinate both sides to reach across the midline of the body. Activities such as throwing a ball, eating, dancing, are all examples of movements that require crossing the midline of the body.

3.5.3.3 - Temporal Lobes: Listen to the Memories

- The temporal lobe is part of the brain that is right above the ear. Neurons in this are of the cortex assist us with tasks like forming memories, and processing sound input from the auditory nerves.
- Temporal lobe lesions, which are focused areas where cells have died, result most often in memory loss, and especially the loss of the ability to form new memories.

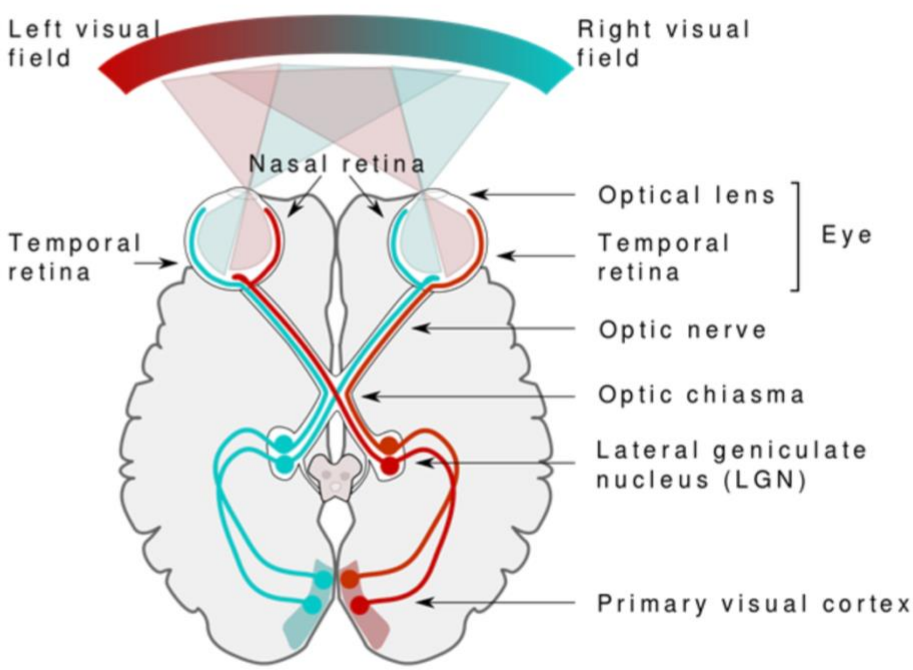


- The temporal lobes interpret auditory information, help to form and store new memories, and process language.
- The temporal lobe is also important for hearing. When someone sustains an injury to the primary auditory cortex, the caudal part of the temporal lobe, they might lose all ability to perceive sound if the injury is serious, without any damage or alteration to the ear itself or the cochlear nerve. This means that the person can still "hear" because the circuits in the temporal lobes code the information they receive through specific frequencies of action potential originating in axons of the cochlear nerve, but the person is unable to use the information effectively.

- The temporal lobe also has a third role that is related to audition: the left temporal lobe houses Wernicke's area, which is an important area for the processing of language. People who have had strokes or injuries that involve the neural networks in this area have trouble hearing or comprehending speech.
- The temporal lobe also houses the cortical site of smell (olfactory) and taste synapses. In fact, olfactory information is the only sensory information that does not pass through the thalamic relay synapses but instead goes straight to the temporal lobes.

3.5.3.4 - Occipital Lobes: Visions of the Present

- The occipital lobes are primarily concerned with processing light stimuli.
- The optic nerves originate in the retina of the eye and decussate partially at the optic chiasma. The goal here is to make sure that the nerve fibers (bundles of axons) that start in the retina end in the designated part of the occipital cortex in order to organize information.
    - When light comes from the left visual field to contact the medial portion of the left eye and the lateral part of the right eye retina, after a short time neurons will depolarize and activate in the right thalamus (the lateral geniculate nucleus, LGN) and the right occipital cortex. You know that you just saw something on your left side, because neurons on the right side of the brain initiate electrical impulses.



- The optic nerves that represent the left and right sides of your visual field (what you can see) cross over to the opposite side of the brain. This helps you integrate what you see into a whole picture.
- There are neurons so specialized in the occipital cortex that some of them only fire when you seen an object or feature in a particular angle or position. Damage to the neurons of the occipital lobe through stroke, seizure, or trauma can rob us completely of sight, or the ability to see something specific like faces. However, we can "remap" the brain to

prioritize another sense (ie. Some people who are blind "see" the world by sounds that are around.

3.5.3.5 - Brain Laterality

- In visual processing, the right brain sees things globally, while the left brain typically responds to detail and specificity. Language tends to be processed and produced on the left side of the brain, but some activity on the right side is necessary to maintain a complete sense of what we are hearing and saying.
- Some people try to predict careers or interests by making assumptions that a person is "left-brained" or "right-brained". However, this is not a valid assumption or conclusion to make because whether someone is a scientist or an artist, they could be left-brained or right-brained. Some people create great art through analysis and detail, and some scientists conduct great science because they have vivid imaginations. Furthermore, no one is completely lateralized. In reality, we use both sides of our brains quite a bit.

3.5.3.6 - The Corpus Callosum

- The corpus callosum is a thick bundle of fibers whose purpose is to connect to the two hemispheres and allow them to share information. Things like the sensory information, with the exception of olfaction (smell), crosses from one side to the other. The corpus callosum helps to make sense of these crossing messages.
- A treatment used on some patients with severe epilepsy is to transect (cut) the corpus callosum. This helps calm seizures, but as you can imagine, it produces some other problems in these "split-brain" patients. Split-brain patients have trouble seeing an object in their left visual field and naming it (Sperry, 1979). But the patient should be able to name this object because language output is regulated by Broca's area on the left, right? Remember that visual information from the left visual field is processed in the right visual cortex. So now, this information is basically "stuck" in the right hemisphere. If the patient is allowed to view the object with the right visual field or with both, they can name the object easily.

3.6 - Endocrine System

- The endocrine system consists of a series of glands throughout the body that release hormones. These hormones have a profound influence on our behavior. The endocrine system serves as a secondary control system that assist and gives valuable feedback to the nervous system about what is happening in the body. Hormones secreted by the endocrine glands can also act as neurotransmitters
- There are three major endocrine control centers that rest within the central nervous system: the hypothalamus, which secretes hormones and controls the pituitary gland via direct nerve stimulation/chemicals, the pineal gland, which secretes melatonin to regulate sleep cycles, and the pituitary gland which secretes a host of hormones that affect sexual behavior, reproduction, circulatory function, hunger, and responses to aggression.
- The hypothalamus secretes a hormone called oxytocin, which functions as a bonding hormone. The release of oxytocin is a component of love, but is not love itself. Oxytocin is released during orgasms.

3.8 - Summary

- The human nervous system is a product of both genetics as well as the environment; genetics provide the blueprint, while the environment helps shape it through a process called neuroplasticity.
- Neurons are the basic building blocks of the nervous system; they send, receive, and relay messages to and from various parts of the body using electrical and chemical processes.
- Neurons are made up of many parts, with the most important for neural transmission being the dendrites, the soma, the axon, and the terminal buttons.
- Action potentials travel along the length of a neuron, allowing for electrical messages to be sent quickly; myelin speeds this transmission along.
- When an action potential reaches the terminal buttons, neurotransmitters are released into the synaptic cleft and act on the postsynaptic cell.
- Despite neurons' critical role in communication, glial support cells like astrocytes, microglia, and oligodendrocytes are every bit as important to the function of the nervous system.
- Neurons control the flow of electrical activity and produce action potentials by regulating the presence of ions on either side of the cell membrane; this is accomplished through the use of ion channels.
- Neurotransmitters are the chemical component of the electrochemical "language of the brain"; they play important roles in regulating mood, pleasure, movement, memory, and more.
- There are many different kinds of neurotransmitters; they can be excitatory or inhibitory, and psychoactive drugs act primarily to modulate the effectiveness of neurotransmitters.
- The nervous system can be divided into central and peripheral components, and the peripheral nervous system can be further subdivided into somatic and autonomic components. The autonomic nervous system is divided once more into sympathetic and parasympathetic components.
- Neural signals can be afferent or efferent, depending on whether they move toward or away from the central nervous system.
- The somatic nervous system controls voluntary muscle movement, whereas the autonomic nervous system handles automatic bodily functions that keep us alive and allow us to prepare for and recover from arousing situations like emergencies and exciting activities.
- The medulla controls basic life-support processes, while the pons regulates arousal and transfers information to other portions of the brain from the spinal cord.
- The limbic system is a part of the brain heavily involved in collecting, organizing, and modifying information for the rest of the brain; it is made up of many individual networks of neurons located medially in the brain.
- The functions of the amygdala, hippocampus, cingulate gyrus, and hypothalamus are particularly important for regulating emotion, memory, perception of pain, as well as motivation.
- The basal ganglia and cerebellum are important for learning, regulating, and producing skilled movement.
- The thalamus can be thought of as a "relay station," directing sensory information to and from other parts of the brain.
- The neocortex is the home of higher-level processing and is made up of four lobes (frontal, parietal, temporal, and occipital), and these lobes contain various gyri and sulci.
- Decision making, impulse control, and movement are controlled by the frontal lobes; Broca's area is also contained in the left frontal lobe.
- Our parietal lobes contralaterally process the sense of touch, process numbers, as well as help situate us in time and space.
- Our senses of hearing and smell are processed by the temporal lobes, which have a close association with the hippocampus and memory formation; Wernicke's area is located in the left temporal lobe.

- Visual information is contralaterally processed by the occipital lobes (right visual input is processed by the left occipital lobe and vice versa), creating our sense of sight.
- The two hemispheres of our brains are connected by the corpus callosum—the largest bundle of white matter axons in the brain. Because of this strong connection, it is incorrect to assert that people are “left-brained” or “right-brained.”
- The endocrine system is a messaging system like the nervous system, but it uses the bloodstream rather than neurons to enact its effects.
- The major methods of studying the nervous system include structural imaging (CT, MRI), functional imaging (PET/SPECT, fMRI, DTI), recording neuronal activity (EEG, single cell recording), and dissection.
- By studying the nervous system, we can determine whether an individual brain structure is necessary or sufficient to produce specific behaviors.