CHAPTER XII

The Nervous System: Hitting A Nerve

LEARNING OBJECTIVES

By the end of this class you should be able to:

- List functions of the nervous system
- Describe the divisions of the nervous system
- Explain how neurons communicate.
- Identify the parts of the human and sheep brain and state their functions.
- Explain what neurodegenerative diseases are and provide examples.
- Describe the different types of neurons and their functions.
- Describe the anatomy of the spinal cord.
- Define and describe gray and white matter.
- Describe a spinal reflex arc.
- Discuss the distribution of sensory receptors in the skin and sense of touch and temperature detection

Introduction

The nervous system is a very complex organ system. In Peter D. Kramer's book Listening to *Prozac,* a pharmaceutical researcher is quoted as saying, "If the human brain were simple enough for us to understand, we would be too simple to understand it" (1994). That quote is from the early 1990s; in the two decades since, progress has continued at an amazing rate within the scientific disciplines of neuroscience. But our current level of understanding is probably nowhere close to completely unraveling it.

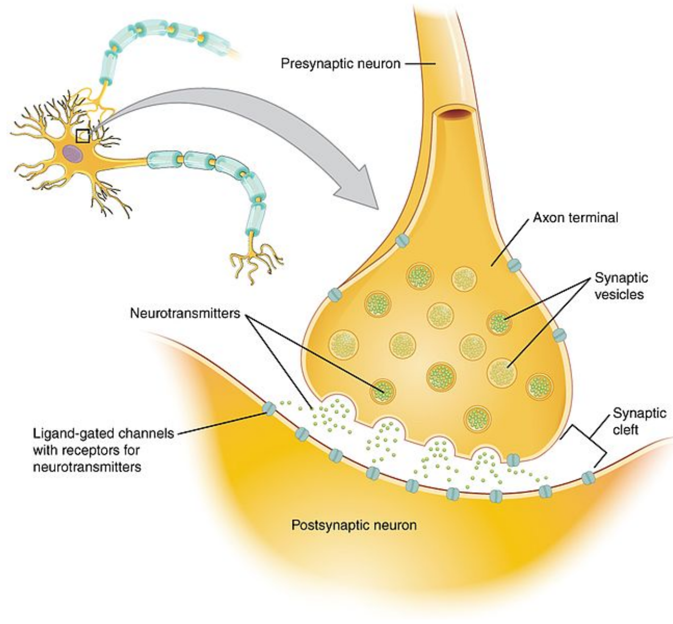
Human Nervous System. A toddler engaging his nervous system as he sits, reads, holds a book, breathes, etc … (Public Domain).

As you read this, your nervous system is performing several functions simultaneously. The visual system is processing what is seen on the page; the motor system controls your eye movements and the turn of the pages (or click of the mouse); the prefrontal cortex maintains attention. Even fundamental functions, like breathing and regulation of body temperature, are controlled by the nervous system. The nervous system is one of two systems that exert control over all the organ systems of the body; the other is the endocrine system. The nervous system's control is much more specific and rapid than the hormonal system. It communicates signals through cells and the tiny gaps between them rather than through the circulatory system as in the endocrine system. It uses a combination of chemical and electrochemical signals, rather than purely chemical signals used by the endocrine system to cover long distances quickly. The nervous system acquires information from sensory organs, processes it and then may initiate a response either through motor function, leading to movement, or in a change in the organism's physiological state. A nervous system is an organism's control center: it processes sensory information from outside (and inside) the body and controls all behaviors—from eating to sleeping to finding a mate.

Maybe you have heard the claim that humans only use 10 percent of their brains and/or seen an advertisement on a website saying that there is a secret to unlocking the full potential of your mind—as if there were 90 percent of your brain sitting idle, just waiting for you to use it. It isn't true. some evidence suggests that about 80 percent of the brain is using energy—based on blood flow to the tissue—during well-defined tasks similar to the one suggested above. This task does not even include all of the vital functions the brain performs in the background.

How Neurons Communicate

The nervous system is made up of neurons, specialized cells that can receive and transmit chemical or electrical signals, and glia, cells that provide support functions for the neurons. There is great diversity in the types of neurons and glia that are present in different parts of the nervous system. All functions performed by the nervous system—from a simple motor reflex to more advanced functions like making a memory or a decision—require neurons to communicate with one another. Neurons communicate between the axon of one neuron and the dendrites, and sometimes the cell body, of another neuron across the gap between them, known as the **synaptic cleft**. When an action potential reaches the end of an axon it stimulates the release of **neurotransmitter molecules** into the synaptic cleft between the synaptic knob of the axon and the post-synaptic membrane of the dendrite or soma of the next cell. The neurotransmitter diffuses across the synaptic cleft and binds to receptors in the post-synaptic membrane. If sufficient neurotransmitter has been released an electrical impulse may be initiated in the next cell, but this is not guaranteed. If insufficient neurotransmitter is released the nerve signal will die at this point. There are a number of different neurotransmitters that are specific to neuron types that have specific functions. Examples of neurotransmitters are dopamine, serotonin, adrenaline (epinephrine), oxytocin.



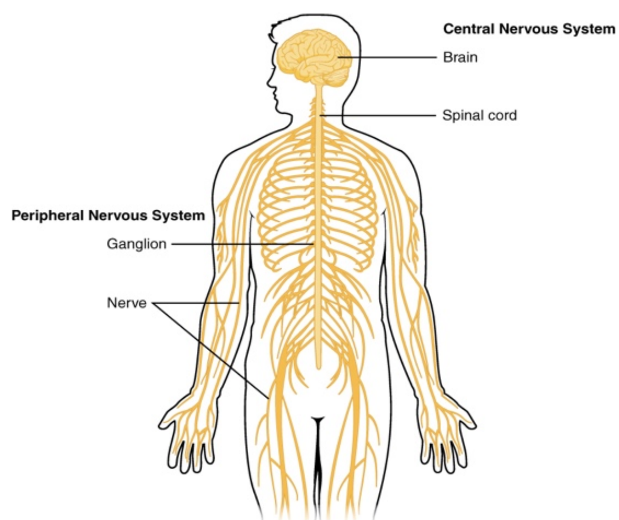
The Synapse. The synapse is a connection between a neuron and its target cell (which is not necessarily a neuron). The neurotransmitter diffuses across the synaptic cleft to bind to its receptor (credit: OpenStax Anatomy & Physiology CC BY 4.0).

The Components of Our Nervous System

Our nervous system includes a well-developed brain, a spinal cord (both forming the **central nervous system**, CNS) and peripheral nerves and ganglia constituting the **peripheral nervous system** (PNS). The PNS is the connection between the central nervous system and the rest of the body. Nerves of the PNS fall into two functional categories:

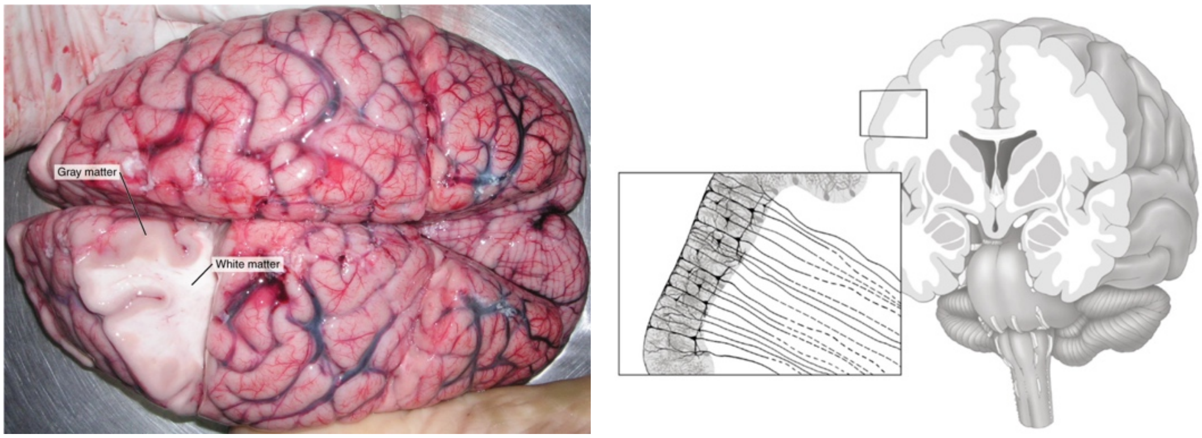
- **somatic** which controls voluntary functions,
- **autonomic** in control of involuntary functions.

There are two divisions of the autonomic nervous system that often have opposing effects: the **sympathetic** nervous system and the **parasympathetic** nervous system. The sympathetic nervous system is responsible for the immediate responses an animal makes when it encounters a dangerous situation. One way to remember this is to think of the "fight-or-flight" response a person feels when encountering a snake ("snake" and "sympathetic" both begin with "s"). Examples of functions controlled by the sympathetic nervous system include an accelerated heart rate and inhibited digestion. These functions help prepare an organism's body for the physical strain required to escape a potentially dangerous situation or to fend off a predator. While the sympathetic nervous system is activated in stressful situations, the parasympathetic nervous system allows an animal to "rest and digest." One way to remember this is to think that during a restful situation like a picnic, the parasympathetic nervous system is in control ("picnic" and "parasympathetic" both start with "p"). Parasympathetic preganglionic neurons have cell bodies located in the brainstem and in the sacral (toward the bottom) spinal cord. The parasympathetic nervous system resets organ function after the sympathetic nervous system is activated including slowing of heart rate, lowered blood pressure, and stimulation of digestion.



Human Nervous System. (Credit: OpenStax CC BY 4.0).

Our nervous system can also be divided into **gray matter** and **white matter**. Gray matter (which can appear pink or brown on fresh preparations) is composed of proportion of cell bodies of neurons. White matter consists mainly of **myelinated axons**, and takes its color from the myelin. The brain and spinal cord contain all parts of neurons and will display clusters of gray matter (called **nuclei**) surrounded by white matter. As nerves only contain axons, they display white matter only.



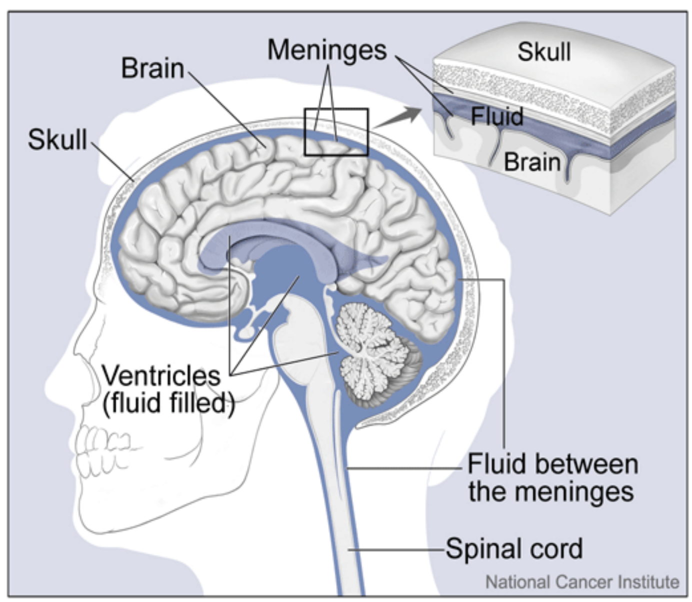
White and Gray Matter. Fresh human brain with a portion of the left frontal lobe removed to show gray and white matter (left; Credit: OpenStax CC BY 4.0). Artistic representation of grey and white matter in the human brain with insert showing the neurons cell bodies and axons arrangement (right; credit: Ms. Emma Vougt CC BY 4.0).

The Brain

The brain is the enlarged anterior end of the spinal cord. It is contained in and protected by the skull (also called **cranium**) and covered by **meninges** (sing, *meninx*), layers of protective membranes (three in mammals and birds). **Cerebrospinal fluid** within the meninges provides cushioning by absorbing shocks. Ten to tawelve pairs of nerves (PNS) are attached to the brain.

During development, the brain, forming from the neural tube, becomes organized as three functional regions:

- the **forebrain**; sorts out sensory input and initiates motor responses. It contains the **olfactory bulbs** and **cerebrum** and is responsible for memory and intelligence.
- the **midbrain**, reduced in birds and mammals but well developed in fishes and amphibians, it relays sensory input to the forebrain. It contains the **optic lobes** which increase with the visual acuity and role of vision in the animal's survival.
- the **hindbrain,** continuous with the spinal cord, largely responsible for reflexes and coordination. It contains the **cerebellum** which is associated with agility.

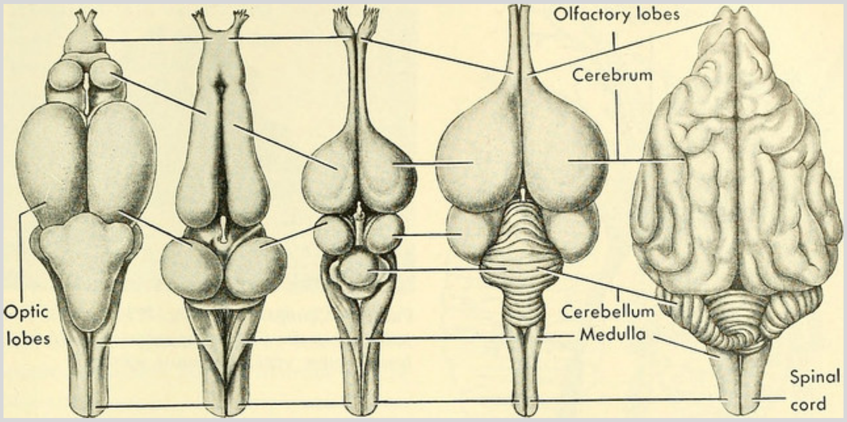


The Brain and Nearby Structures. (Credit: Alan Hoofring, National Cancer Institute, Public Domain)

The brain of mammals is characterized by a large cerebrum, the part of the brain related to sensory and motor integration. It is believed that as vertebrates became more agile and inquisitive, the cerebrum increased. As it did so, it affected many other brain regions and folded back on itself at its evolution and enlargement outpaced that of the cranium housing it.

Activity 1. Comparison of Vertebrates Brains

1.1 - Choosing a color for each of the labeled brain structures, color the illustration below:



Comparison of Vertebrate Brains. Left to right: dorsal view of the brain of a fish (trout), amphibian (frog), reptile (alligator), bird (sparrow) and mammal (dog). Sketches are not to the same scale. (Credit: Public Domain).

1.2 - Which structure appears to have undergone the greatest change? How does it relate to the different animals' lifestyles and behavior?

1.3 - Which animal would you predict to be the most agile? The least agile?

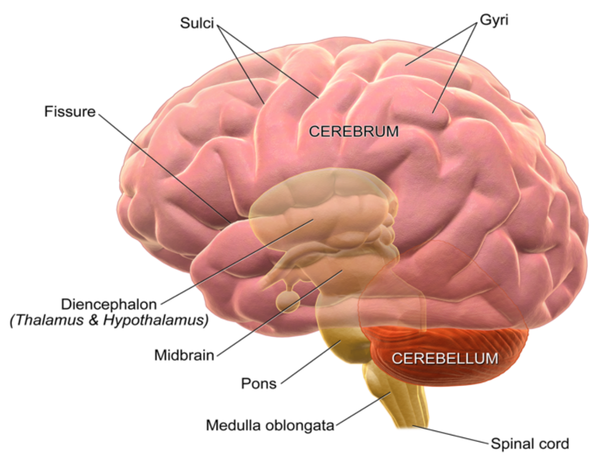
1.4 - Which areas of the human brain would you expect to be particularly large? Small?

In the next activity, you will dissect a preserved sheep brain and use human brain models to observe and learn to identify the different parts of the brain:

Brain Stem: this is the part that joins the brain to the spinal cord and relays impulses from the higher brain centers to the spinal cord. It contains centers for the functioning of internal organs and consists of:

- The **midbrain** is very reduced in birds and mammals. It helps coordinate eye movements, pupil reflexes and body movements.
- The **pons**, with a ventral rounded bulge helps regulating breathing and swallowing.
- The **medulla oblongata** is the lowest part of the brain. It controls the heart rate, blood pressure, and is also involved in breathing and swallowing. It also contains centers for the functioning of internal organs.

Cerebellum: located under the cerebrum and below the occipital lobes, it is divided into right and left hemispheres by a shallow fissure. It is involved in muscle tone, posture and coordination (spatial orientation) to produce smooth movements. In a cross section, the typical tree-like appearance of the cerebellum is sometimes called *arbor vitae*.



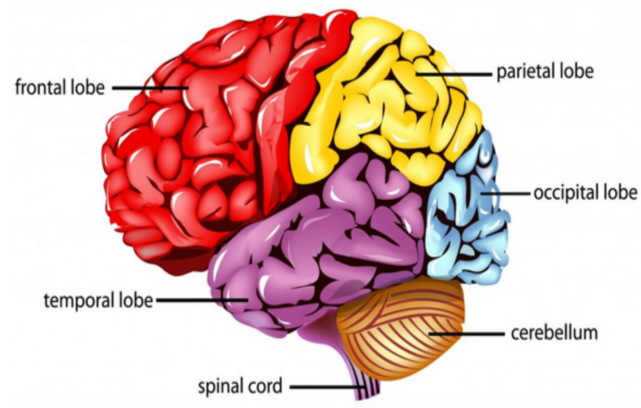
The Human Brain. (Credit: BruceBlaus CC BY 3.0)

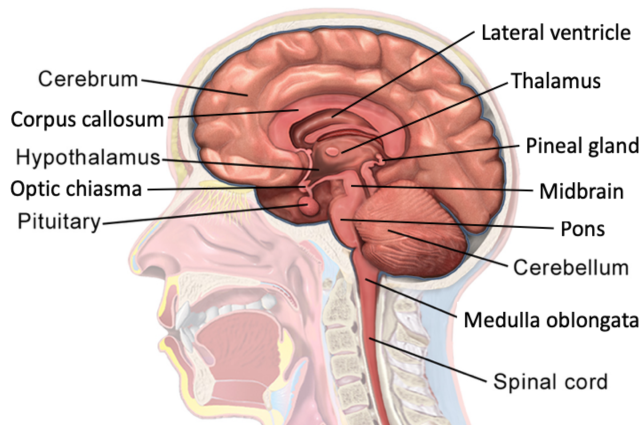
Cerebrum: the largest part of the brain and it is responsible for higher mental capabilities and unique capacities such as language and abstract thought. It is divided into right and left **cerebral hemispheres** separated by the **longitudinal fissure**. The **corpus callosum**, a mass of axons (white matter), joins the two hemispheres allowing impulses to pass from one side to another. The outer part of the cerebrum is the **cerebral cortex**. It is composed of gray matter (neuron cell bodies and unmyelinated processes). Its surface area is increased by **gyri** (ridges) and **sulci** (grooves) and divided into lobes:

- **Frontal lobes**: the most anterior parts of the brain, they control voluntary muscular movements and are involved in thinking, problem solving, speaking and smelling.
- **Parietal lobes**: situated between the frontal and occipital lobes, these parts of the cerebral cortex allow interpretation of sensations coming from the skin and taste, understanding speech.
- **Occipital lobes**: the posterior parts of the cerebellum, these are involved in vision, visual sensations and interpretation.
- **Temporal lobes**: situated by the temples (above the ears), these lobes interpret and hearing and smelling sensations.

Diencephalon: between the brain stem and cerebrum, it contains the **thalamus** and **hypothalamus**. The thalamus consisting of two globular masses, acts as a gatekeeper as it eventually relays impulses between the cerebrum and lower brain centers. It also allows awareness of pain and pleasure. Posterior to and above the thalamus, the **pineal gland** is a small endocrine gland that produces melatonin and regulates sleep patterns. The hypothalamus as its name indicates, is located under the thalamus. It plays major roles in homeostasis controlling appetite, body temperature, and water balance. It is also involved in pleasure, pain, reproductive behavior and hostility. The **pituitary gland** (or hypophysis), attached to the inferior wall of the hypothalamus, is described as the master gland of the body. It produces many hormones and regulates several processes such as growth, reproduction, lactation.

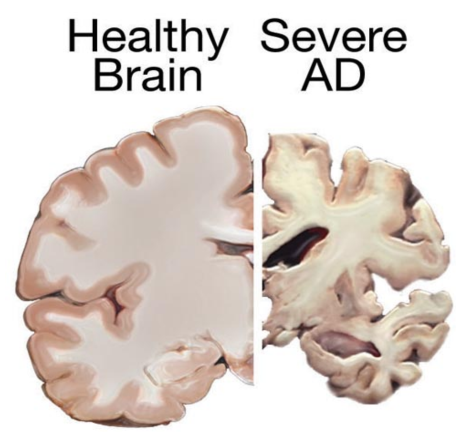
Ventricles: each of the four ventricles of the brain are spaces that secrete and store cerebrospinal fluid. The fluid circulates through the ventricles and within the meninges covering the brain and spinal cord. The **lateral ventricles** are partly surrounded by the corpus callosum.





The Human Brain. Top: The lobes of the cerebral cortex are shown in different colors (credit: BruceBlaus CC BY 3.0); bottom: sagittal section of the brain showing the inner structures on the right cerebral hemisphere (credit: modified from BruceBlaus CC BY-SA 4.0).

Neurodegenerative disorders are illnesses characterized by a loss of nervous system functioning that are usually caused by neuronal death. These diseases generally worsen over time as more and more neurons die. The symptoms of a particular neurodegenerative disease are related to where in the nervous system the death of neurons occurs. Spinocerebellar ataxia, for example, leads to neuronal death in the cerebellum. The death of these neurons causes problems in balance and walking. Neurodegenerative disorders include **Huntington's disease**, **amyotrophic lateral sclerosis** (ALS), **Alzheimer's disease** and other types of dementia disorders, and **Parkinson's disease**. Alzheimer's disease is the most common cause of dementia in the elderly. In 2012, an estimated 5.4 million Americans suffered from Alzheimer's disease, and payments for their care are estimated at $200 billion. Roughly one in every eight people age 65 or older has the disease. Due to the aging of the baby-boomer generation, there are projected to be as many as 13 million Alzheimer's patients in the United States in the year 2050. Unfortunately, there is no cure for Alzheimer's disease. Current treatments focus on managing the symptoms of the disease. Symptoms of Alzheimer's disease include disruptive memory loss, confusion about time or place, difficulty planning or executing tasks, poor judgment, and personality changes. Problems smelling certain scents can also be indicative of Alzheimer's disease and may serve as an early warning sign. Unfortunately, there is no cure for Alzheimer's disease. Current treatments focus on managing the symptoms of the disease. Smoking, obesity, and cardiovascular problems may be risk factors for the disease, so treatments for those may also help to prevent Alzheimer's disease. Some studies have shown that people who remain intellectually active by playing games, reading, playing musical instruments, and being socially active in later life have a reduced risk of developing the disease.



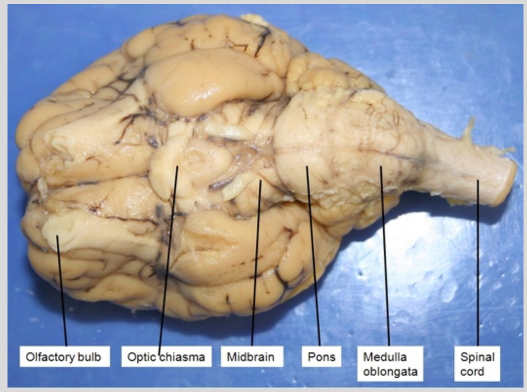
Alzheimer's Disease Compared to a normal brain (left), the brain from a patient with Alzheimer's disease (AD) (right) shows a dramatic neurodegeneration (credit: National Institutes of Health, NIH, [Public Domain]).

Activity 2. Sheep Brain Dissection

For this activity, you will dissect a preserved sheep brain as a model of mammalian brain. Sheep brains are easily available and large enough to observe different parts. As you follow your instructor's directions, you should be able to identify the structures listed above as well as additional ones.

2.1 - Obtain a sheep brain and note the following structures before you begin your dissection:

☐ Cerebellum ☐ Cerebrum ☐ Longitudinal fissure ☐ Medulla oblongata ☐ Midbrain ☐ Olfactory bulb ☐ Optic chiasma ☐ Optic nerve
☐ Pituitary gland* ☐ Pons ☐ Spinal cord



Sheep Brain (ventral view). (Credit: Michael J. Gregory, Ph.D., Clinton Community College, CC BY-SA-NC 3.0)

2.2 - Gently separate the two cerebral hemispheres to see the top of the **corpus callosum** joining the two hemispheres.

2.3 - Using human brain models, list differences and similarities between the human and sheep brains.

2.4 - With a scalpel, cut the brain in half from the frontal lobe to the spinal cord (sagittal plan), so that each half so that a left and right half are produced. Identify the following structures:

☐ Cerebellum (arbor vitae) ☐ Cerebrum ☐ Corpus callosum ☐ Hypothalamus ☐ Lateral ventricle ☐ Medulla oblongata
☐ Midbrain ☐ Optic chiasma ☐ Pineal gland ☐ Pituitary gland* ☐ Pons ☐ Spinal cord ☐ Thalamus

2.5 - How do you explain the appearance of the inside of the cerebellum?

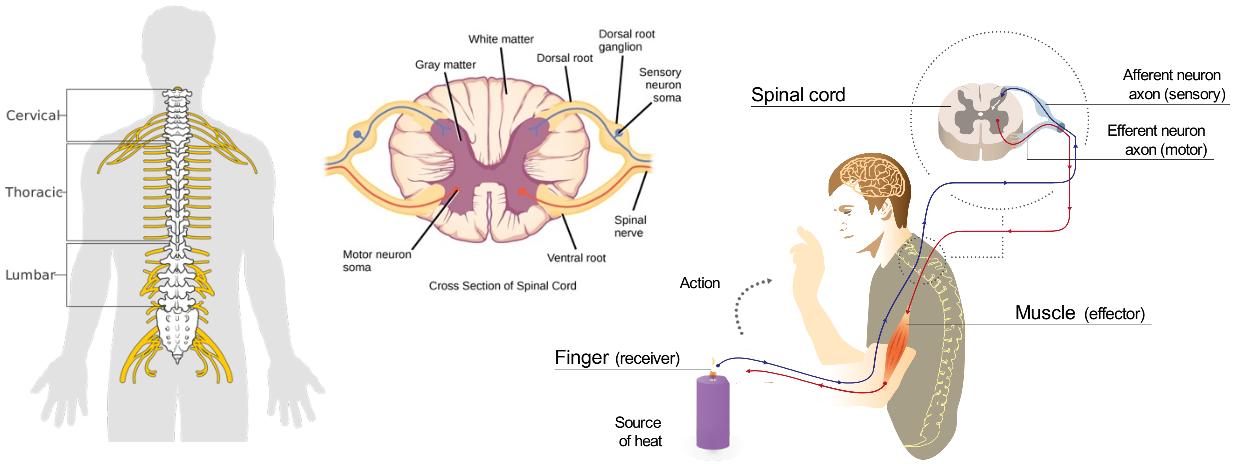
**Note: the pituitary gland was probably removed with the dura mater, one of the 3 meninges*

The Spinal Cord and Spinal Nerves

The spinal cord is located in the vertebral canal. Like the brain, it is covered by the meninges. It serves as a pathway between the brain and the spinal nerves (PNS) that lead to all parts of the body (except the head). Most mammals have between 34 and 44 pairs of spinal nerves; humans only have 31 pairs of spinal nerves due to their lack of caudal (tail) nerves. Each spinal nerve contains long fibers of **sensory nerves** forming the **dorsal roots** of the spinal cord, and **motor nerves** forming the **ventral roots**.

- **Sensory neurons** have their cell bodies in the dorsal root, forming **dorsal root ganglions**, and their axons extending to form the spinal nerves. Sensory neurons take impulses from a receptor to the spinal cord. Motor neurons have their cell body in the spinal cord and their axon extend outside of the spinal cord to form motor nerves.
- **Motor neurons** take impulses from the spinal cord to an effector such as a muscle or a gland.
- In the spinal cord, **interneurons** transmit nerves impulses from the sensory to the motor neurons. Some interneurons carry nerves impulses from and to the brain.

Reflexes are involuntary responses, *i.e.* they do not require conscious act to stimuli and are usually predictable. They are important in maintaining the well-being of the organism. Some reflexes such as the photopupil reflex, sneezing or coughing are controlled by the brain but **spinal reflexes**, such as withdrawal reflexes, do not require communication with the brain and allow faster action. With spinal reflexes, the brain will receive the sensory input while the reflex is being carried out and the analysis of the signal takes place after the reflex action. Simple reflexes do not require more than 3 neurons to produce a reaction to a stimulus. A **reflex arc** consists of (1) a receptor that is stimulated and generates an impulse, (2) a sensory neuron that carries the impulse to the brain or spinal cord (afferent neuron), (3) an interneuron that receives the impulse and relays it to the motor neuron, (4) a motor neuron that transmits the impulse to an effector (efferent neuron) and (5) An effector that performs the action.



The Human Spinal Cord and Nerves. Left: a diagram of the spinal cord showing the insertion of the spinal nerves (credit: Cancer Research UK CC BY-SA 4.0); center: cross section of the spinal cord showing the dorsal and ventral roots of spinal nerves (credit: CNX OpenStax CC BY 4.0); right: a withdrawal reflex arc. (credit: MartaAguayo CC BY-SA 3.0).

Activity 3. Patellar Reflex

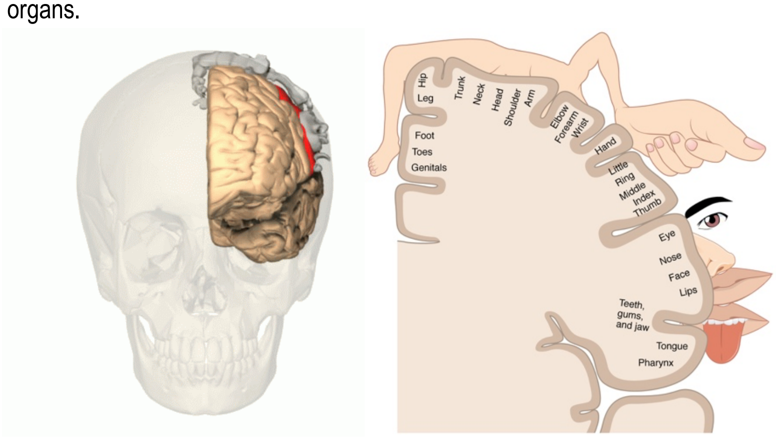
Physicians use reflex tests to assess the condition of the nervous system. In this activity, you will perform the **knee jerk or patellar reflex** working in groups and using a reflex hammer.

3.1 - The subject should sit on a stool or edge of a table with her/his legs over the edge and hanging freely (not touching the floor).
3.2 - Strike the patellar tendon with the small end of the reflex hammer and observe and describe the response.
3.3 - Test both legs. Do they respond the same way? Explain.
3.4 - Divert the subject's attention by asking them to interlock the fingers of both hands and pull the hands against each other. Test the patellar tendons again. Is the response the same? Explain.
3.5 - Draw a quick reflex arc to describe the knee jerk reflex.
3.6 - What part of the nervous system does this test assess?

The Patella-Tendon Reflex or Knee Jerk
(credit: Public Domain)

Senses

Sensations result from the interaction of three components of the nervous system: i) **stimulation**, *i.e.* **receptors** that detect specific stimuli and generate impulses ii) **sensory neurons** which carry the impulses to the brain or spinal cord where **interneurons** relay the impulses to the brain regions that assess the stimuli and, iii) **perception**, *i.e.* the **interpretation** of the impulses as sensation by the cerebral cortex**. Somatic sensations** arise from stimulation of sensory receptors in the skin, skeletal muscles and joints while **visceral sensations** result from the stimulation of sensory neurons in the walls of the internal organs.



The Somatosensory Cortex in the Human Brain. Left: A 3D rendering of the somatosensory cortex in red with a cortical homonculus (credit: Database Center for Life Science CC BY-SA 2.1); right: cortical sensory homonculus (credit: OpenStax College CC BY 3.0).

The nature of a sensation is determined by the part of the brain receiving the impulse rather than by the type of receptor being stimulated. For example, the auditory center interprets all signals it receives as sounds regardless of their origin. However, different types of sensory neurons respond to different stimulation:

- **mechanoreceptors** are excited by pressure, position change or acceleration
- **pain receptors** respond to tissue damage
- **thermoreceptors** detect temperature changes
- **chemoreceptors** detect substances dissolved in fluid
- **photoreceptors** respond to light

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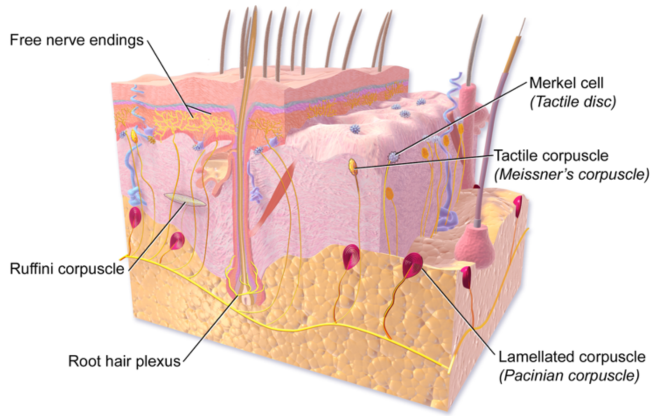


Tactile Receptors in the Human Skin. Free nerve endings are stimulated by pain, heat and cold; Ruffini's corpuscules are excited by sustained pressure; root hair plexi respond to hair movements**;** Pacinian corpuscules are sensitive to vibrations and pressure; Meissner's corpuscules and Merkel cells respond to light pressure (credit: Bruce Blaus CC BY 3.0).

Activity 4. Senses of the Skin

The human skin contains receptors for touch, pain, pressure, hot and cold. You will work in pairs to detect certain characteristics of sensations involving some of your skin receptors.

4.1 - *Ability to discriminate between 2 pressures points*: Ask the subject to keep her/his eyes closed and hold the 2 points of a hairpin or scissors on a given area of the skin. Vary the distance between the two points and each time note whether or not the subject feels one or two points. Repeat in different skin areas. Explain your results.

4.2 - *Detecting temperature (heat and cold)*: Fill 3 beakers with ice water, tap water and warm water (about 50°C)

(1) Place your subject's index finger in the water in each beaker, in sequence, and note the sensations. Does s/he recognize the temperature difference?

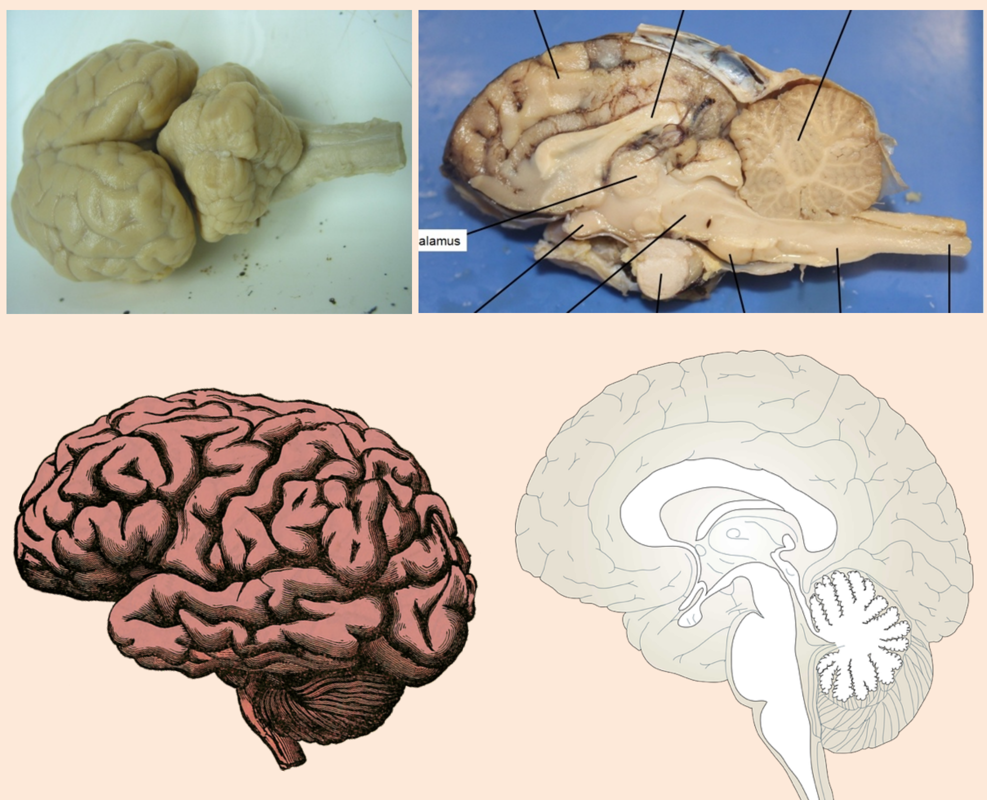
(2) Immerse the left hand in the warm water and the right hand in the cold water. After 30 seconds, place both hand in the beaker with tap water. Record the sensation for each hand.

(3) Explain all your observations.

Review Questions

1. Describe the nervous divisions and functions
2. Explain how neurons communicate
3. Provide a definition for CNS and PNS.
4. Describe the brain of vertebrates and the particularities of the brains of mammals such as humans.
5. What is a neurodegenerative disease?
6. Where can you find meninges? What function(s) do they have?
7. Describe white matter and gray matter, their location in the brain and spinal cord and provide a function for each.
8. List, in order, the types of neurons involved in a spinal reflex.
9. Described the steps involved in a sensation.
10. Mini Practicum: Identify the structures listed below on the illustrations and label them.

Cerebellum
Cerebrum
Corpus callosum
Frontal lobe
Hypothalamus
Lateral ventricle
Longitudinal fissure
Medulla oblongata
Midbrain
Occipital lobe
Olfactory bulb
Optic chiasma
Optic nerve
Parietal lobe
Pineal gland
Pituitary gland
Pons
Spinal cord
Temporal lobe
Thalamus



Brain Anatomy. Top: Sheep brain (credits: Aaron Bornstein CC BY 2.0 and Michael J. Gregory, Ph.D., Clinton Community College, CC BY-SA-NC 3.0); bottom: Human brain (credits: Public Domain)