Summary: Nervous System Structure and Function

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Contents

1 Overview: actors and structures of the nervous system

1.1 Structure of the Neuron

In contrast with the chemical message-reliant **endocrine** system, the **nervous system** is capable of quickly conveying particular messages to and from different actors in the body through **neurons**— chemically and electrically signaling nerve cells. Typically, a neuron consists of:

- A **cell body** containing the nucleus and organelles
- Extensions that convey signals

In some cases, a **neuron** may be referred to as a **nerve**, should it be wrapped in connective tissue.

1.2 Structure of the Nervous System

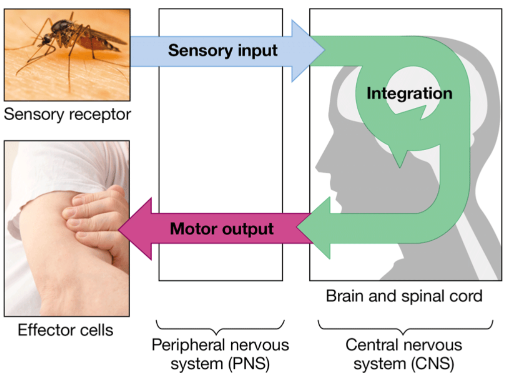

Figure 1: The three functions of the nervous system, exemplified in the human body.

The nervous system can be divided into two spatially distinct systems: the **central nervous system (CNS)** and the **peripheral nervous system (PNS)**. The former of the aforementioned anatomical divisions—the CNS —is comprised by the *brain* and the *spinal cord* (where applicable). The latter consists of neurons that work in conjunction with the CNS to transmit and convey information through the body. These systems function with the goal of providing utility with respect to three functions:

1. **Sensory input**: the flow of signals from sensory receptors, through the PNS to the CNS
2. **Integration**: the formation of appropriate responses to certain stimuli
3. **Motor output**: the application of responses generated through integration via **effector cells** (e.g., muscle, gland cells)

In the nervous system, implementation of these three functions is achieved through the utilization of three distinct classes of neruons: **sensory neurons**, **interneurons**, and **motor neurons**. Sensory neurons are responsible for making data collected from the sensory receptors available to the central nervous system. Of course, this data must *integrated*. This is achieved by the interneurons. The last of the aforementioned functions, motor output, is provided by motor neurons, which apply responses generated through integration via effector cells.

For example, consider the pathway of data from the outside world to effector cells with respect to a **reflex**, such as the "knee jerk:"

1. A tendon in the knee is tapped
2. The quadricep muscles are stretched
3. The stretch is detected by a sensor receptor
4. The stretch is conveyed to the spinal cord via a sensory neuron
5. A motor neuron in the CNS receives data regarding the "tap"
6. Several interneurons are made aware of the event
7. A motor neuron signals the quadriceps to contract

2 The structure of the neuron

2.1 Overview: neuron structure

Neurons posess all of the cell organelles found in typical somatic cells. However, they do posess two additionall organelles:

- **Dendrites**: a network of branching extensions that convey information from other neurons to the given neuron
- **The axon**: a branching extension that connects the neuron to other cells, and conveys information about its consituent schwann cells
- **Glia**: supporting cells that may insulate, nourish, or otherwise aid in maintaining homeostasis inside a neuron

Though its appearance might suggest otherwise, the axon is generally considered the most structurally complicated of the three aforementioned organelles, and its structure must be addressed independently.

2.2 The structure of the axon

Generally, the function of the axon can be likened to that of drainage pipe: it controls the flow of a given content—in this case, data—from the user (i.e., axon) to the consumer of such information (i.e., other cells). This function is achieved through the utilization of a chain of communicating cells (the **myelin sheath**), of which there are several variants:

- **Schwann cells**: carry a signal from the neuron through the axon
- **Nodes of Ranvier**: carry a signal from one schwann cell to another schwann cell, amplifying the signal non-instantaneously (150 m/sec)

A common disease that affects this flow of information, and, thus, the efficiency of information propagation via the axon is termed "multiple sclerosis", and results in the degradation of the myelin sheath, and, thus, the conductivity of a signal from the neuron to the **synaptic terminal** which connects to various **synapses**—"connectors", if you will, that carry the output signal to a nearby cell. A similar, but noticeably differentiatede behiavor termed **neuronal plasticity** describes the ability of the brain to "remodal" synpatic connections between neurons. This behavior is hypothesized to contribute to the various underlying factors describing autism.

3 A neuron operates on the basis of membrane charge differences

In order to transmit a signal from one part of the body to another, a neuron must have the energy to do so. A **resting neuron** posesses this **potential energy** in the form of charge differences across the membrane of a neuron—that is, a neuron has **membrane potential**, a kind of potential energy, which provides a neuron's capability to produce and transmit a signal. Typically, a resting neuron posesses a negative internal charge, relative to the charge of the surrounding fluid. This charge gradient is generated through an equally disproportionate gradient of various ions. This strategy of storing energy by holding separating opposite charges can be likened to a battery, and, thus, as can a battery, the stored energy in a neuron can be measured in terms of the neuron's **resting potential** (typically around -70 mV).

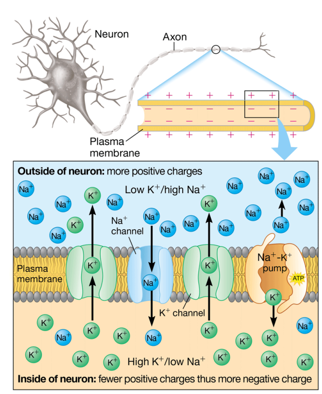

Figure 2: How the resting potential is generated.

In a neuron, the careful balance of potassium ions inside and outside of the cell (again, there is usually a greater concentration of K^+ inside the cell than outside of the cell and a lower concentration of Na^+ inside the cell than outside the cell) is maintained through the utilization of an active Na^+-K^+

pump, wherein energy is expended in the intake of K^+ and in the expulsion of Na^+. However, active transport is not the only membrane-bound force at play in resting potential: **ion channels** allow K^+ and Na^+ to diffuse through the cell membrane, passively, through their respective pores.

In response to **stimuli**, or any factor illiciting the generation of a nerve signal, a neuron might expend its resting potential through a series of electrical changes comprising an **action potential**, which is caused as a result of rapid ion movement at various **voltage-gated ion channels**:

1. The cell posesses resting potential (higher K^+ concentration inside than outside, and a lower concentration of Na^+ inside the cell than outside)
2. Should the application of the stimulus be sufficient to trigger the neuron, the voltage of the neuron rises to the activation threshold (i.e., -50 mV).
3. The action potential is triggered, resulting in a positive internal cell charge, with respect to the outside of the cell
4. The voltage inside the neuron rapidly decreases
5. The voltage inside the neuron undershoots the resting potential
6. The voltage inside the neuron reaches the resting potential

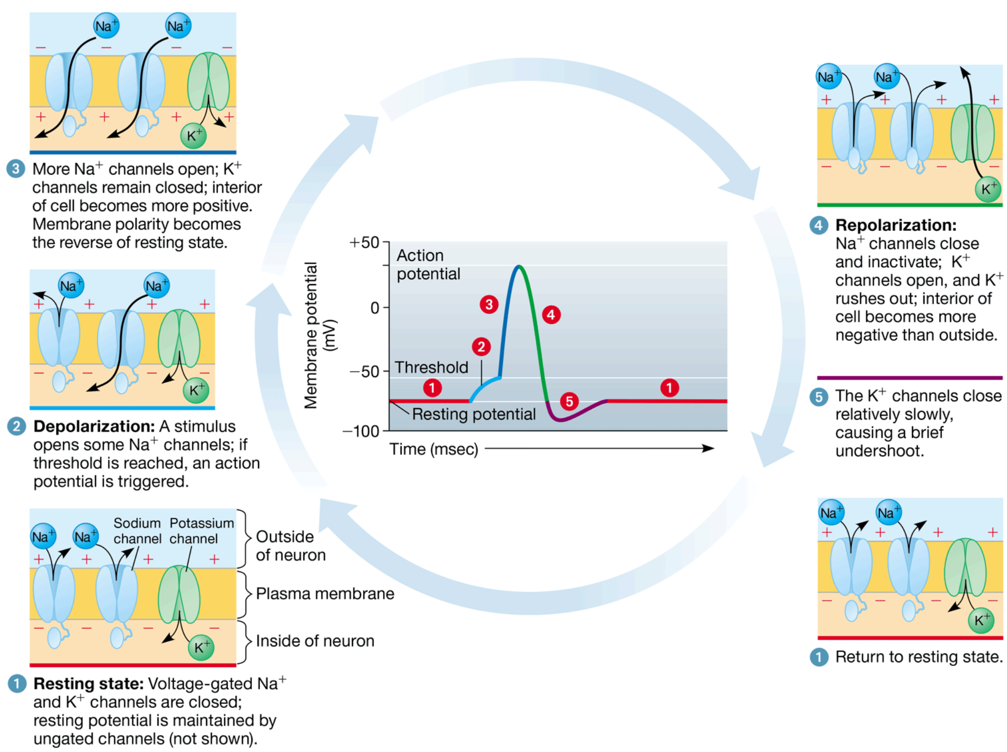

Figure 3: The electrical changes and ion movements in an action potential

3.1 The continuation of action potential through the axon

In order to be transferred from the body of the nerve cell to the synaptic terminal, a signal must be regenerated along the axon. This action can be likened to a chain of dominos, wherein various distinct actors change the state of a much larger space via a "chain reaction". In the axon, this "domino effect" takes place as such:

1. Na^+ rushes into a Schwann cell somewhere along the axon, resulting in the generation of action potential
2. K^+ is expelled from the Schwann cell via diffusion, as Na^+ remain in the cell, resulting in a decreasing action potential
3. No action potential exists in the schwann cell

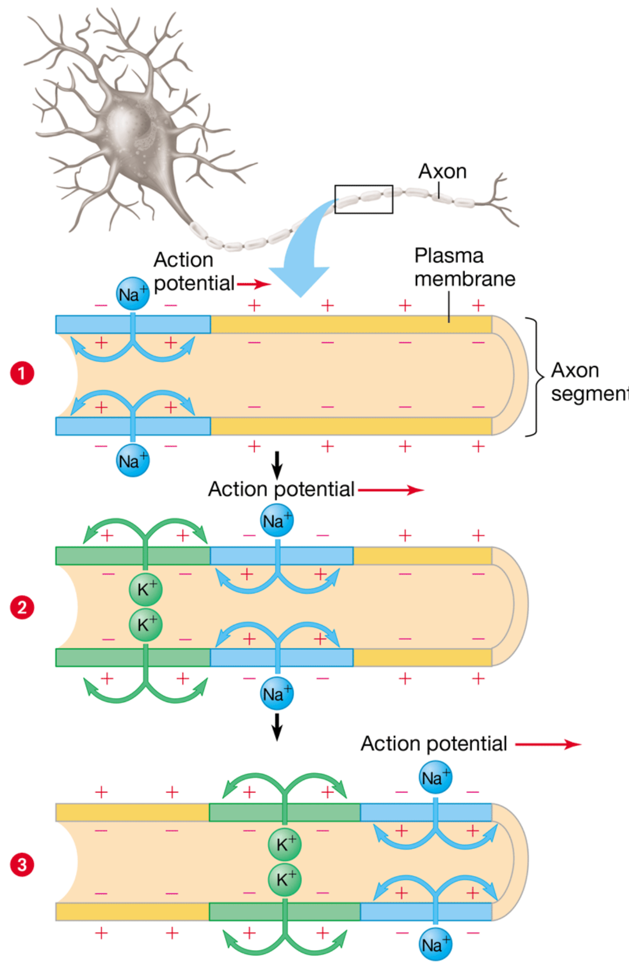

Figure 4: Propagation of the action potential along an axon

This system of cascading action potentials is not capable of back-propagation. However, it is capable of illustrating various intensities of activation through differing *frequencies* of action potentials.

4 The structure of a synapse

Once a signal reaches the synaptic terminal, the signal can be conveyed via an electrical or chemical synapse, corresponding to a neuron, effector cell, muscle cell, or endocrine cell. The former of these two synapse types—the elecrical synapse—operate on the basis of gap junctions, which allow for the direct transmission of an electrical current from the neuron to a receiving cell. By contrast, chemical synapses operate on the basis of conversion of an electrical current to a chemical signal comprised of **neurotrasmitters**, which induce an action potential across a synaptic cleft in the receiving cell.

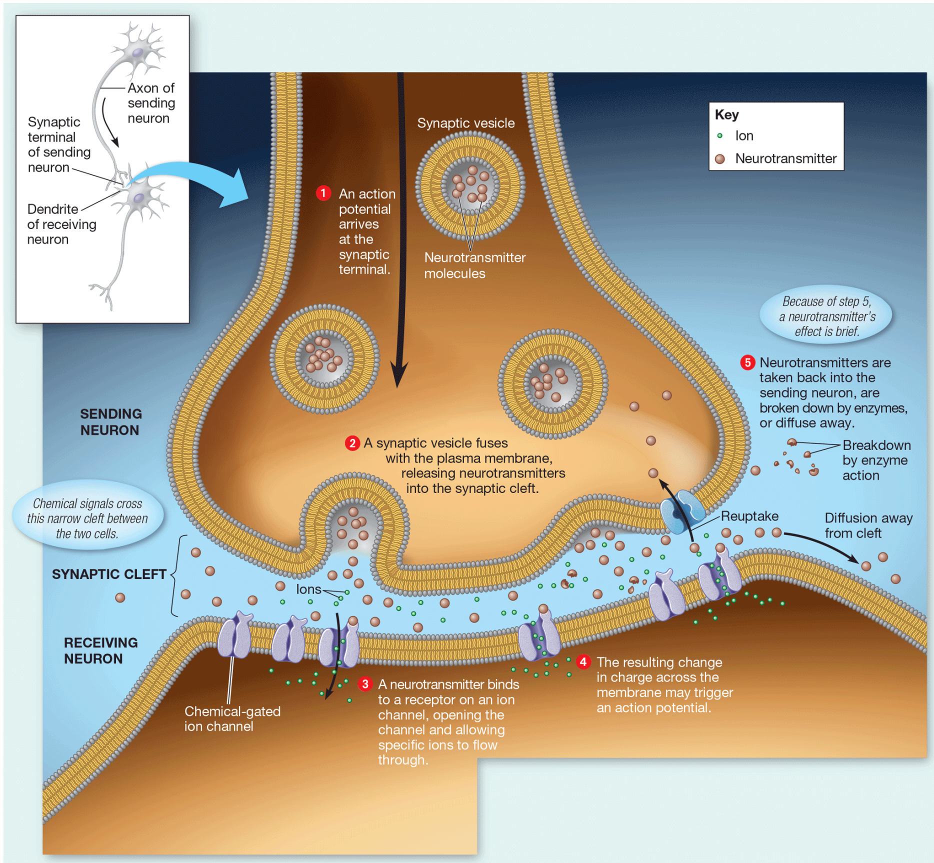

Figure 5: The synaptic cleft

4.1 The structure of a chemical synapse

A neurotransmitter that is released at a synaptic cleft acts on a receiving cell in one of two ways: by *triggering* an action potential (excitatory) or by decreasing the likelihood of action potential developing in the receiving cell (inhibitory).

Respectively, these outcomes are achieved through the opening of Na^+ channels and the opening of K^+ release channels (i.e., in order to decrease the probability of developing potential action in a receiving cell, Cl^- must enter the cell, while K^+ should exit). Furthermore, excitatory and inhibitory reactions can be caused by any one of the 100 neurotransmitters commonplace in the human nervous system: **acetylcholine**, for example, is used to stimulate skeletal muscles, and is released by motor neurons. The function of various neurotransmitter molecules is outlined below:

- Acetylcholine: slows the rate of contraction of cardiac muscles, while stimulating skeletal muscles
- Botulinum toxin: inhibits the release of acetylcholine
- Glutamate: aids in the formation of long-term memory
- Gamma aminobutyric acid: serves as a neurotransmitter in amny inhibitory CNS synapses
- Serotonin, dopamine: affect sleep, mood, attention, and learning

5 Systems of the nervous system

5.1 The central nervous system

In all vertebrates, the **brain** and **spinal cord** comprise the central nervous system (CNS). The former of these composing structure, the **brain** aids in maintaining homeostasis by integrating sensory data. The **spinal cord**, on the other hand, allows for the transmission of data from the PNS to the brain.

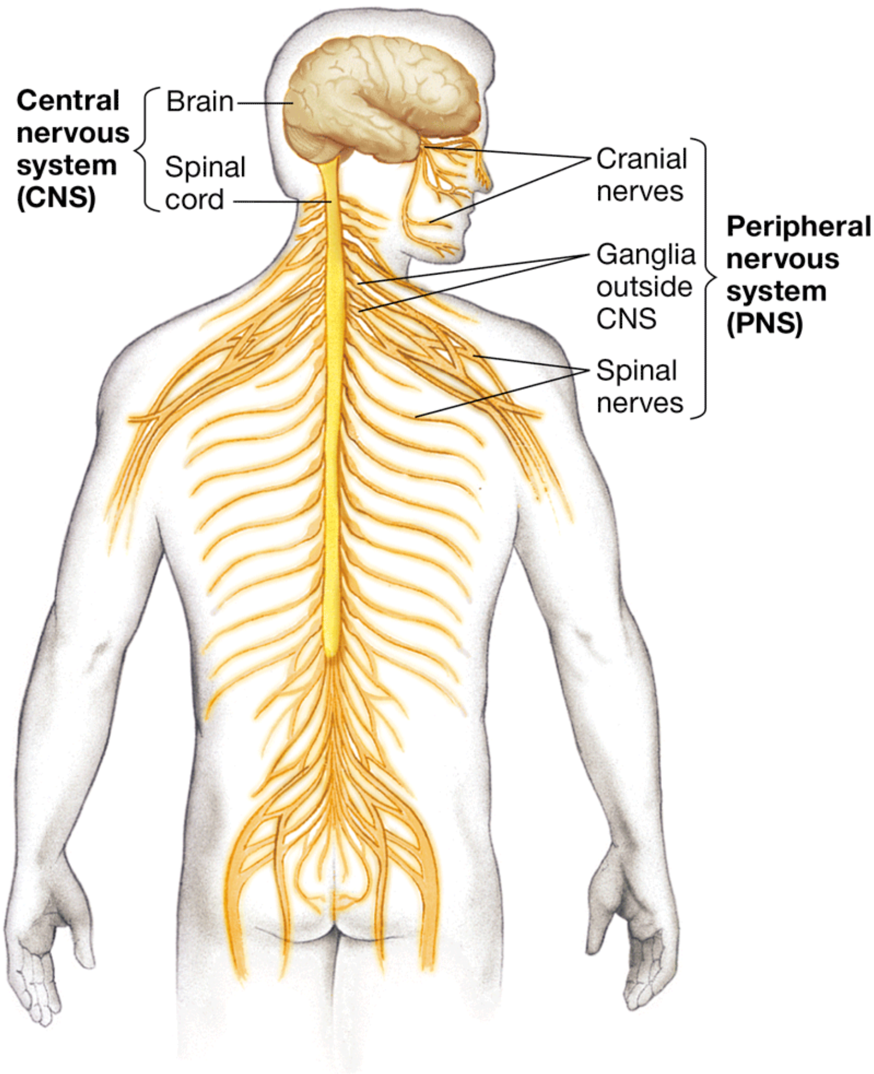

Figure 6: A vertebrate nervous system

Furthermore, the functionality of the central nervous system is maintained through various blood vessels (termed the *blood-brain barrier*), which allow for the propagation of nutrients and oxygen into the brain. Through the utilization of this system, **cerebrospinal fluid**—nourishing fluid that circulates through the central canal—is able to be produced via the filtration of blood passed to this region. In addition to the cerebrospinal fluid, two types of fluid circulate through these organs:

- **White matter** composed of axons and myelin sheaths
- **Gray matter** composed of neuron cell bodies

5.2 The periphery nervous system

In vertebrates, the PNS is divided into sensory neuron groups, which convey data to the central nervous system, and motor neuron groups. In contrast with sensory neurons which take information from the periphery of the body to the central nervous system (i.e., in an outward-in fashion), motor neurons transmit information in an outward-in manner—that is, once a signal has been "transformed" or "integrated", the signal can be sent to an effector cell.

Furthermore, once data has been integrated, it must be sent from the CNS to the PNS, and to one of the types of motor neurons: a **motor system** neuron handling generally voluntary actions, or an **autonomic nervous system** neuron dealing with involuntary actions. These two systems are asynchronous, and cooperate in order to maintain homeostasis. On an even more physiologically detailed basis, one may differentiate between the **parasympathetic**, **sympathetic** and **enteric** divisions within the autonomic nervous system. The function of each of these divisions is defined as such:

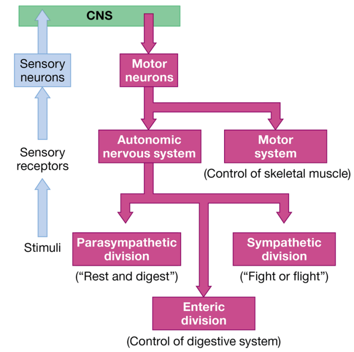

Figure 7: Divisions of the PNS in vertebrates

- **Parasympathetic division**: stimulate the digestive organs, preparing the body to conserve or gain energy
- **Sympathetic division**: inhibits the function of the digestive organs temporarily, preparing the body for energy-consuming activities
- **Enteric division**: aid in the secretion of hormones that control peristalsis—the constriction and relaxation of the intestine

5.3 The development of the brain in vertebrates

In vertebrates, the neural tube gives rise to three divisions that are molded into the various structures present in the developed brain: the **forebrain**, the **midbrain** and the **hindbrain**.

The first of these divisions, the forebrain gives rise to both the **cerebrum** and the **dinecephalon**. The midbrain, on the other hand, is aptly described as simply the "midbrain". Finally, the hindbrain develops in the form of the **pons**, **cerebellum** and the **medulla oblongata**.

6 The brain

6.1 The structures of the brain

As can the nervous system, the brain can be divided into several function compartments: the **forebrain**, the **midbrain** and the **hindbrain**.

As can each of the remaining segments of the brain, the hindbrain can be further divided into various constituent components:

1. The **medulla oblongata** and the **pons**: transfer data from the CNS—the spinal cord, specficially—to the forebrain, and maintain autonomic bodily functions
2. The **cerebellum**: coordinates movement and balance with respect to information obtained from the sensory organs dealing with the position of joints and the length of muscles in the body (e.g., hand-eye coordination)
3. The **brainstem**: deals with the integration and transfer to the forebrain of sensory data

In contrast with the hindbrain, the forebrain is generally concerned with the maintanence of much higher-level body functions, and is composed of the following structures:

- The **cerebrum**: deals with the mobility of each side of the body—though mobility is generally delegated to one of the two **cerebral hemispheres** within the cerebrum (i.e., the right cerebral hemisphere is responsible for the mobility of the left side of the body, while the right side is responsible for the right side of the body). The cerebrum is the largest structure in the brain.
- The **thalamus**: relays sensory information to the cerebral cortex after sorting data into categories.
- The **hypothalamus**: responsible for the body's "biological clock", and exerts control over the pituitary gland, thus giving it responsibility with respect to the fight-or-flight response, thirst, hunger, and mating behaviours.
- The **pituitary gland**

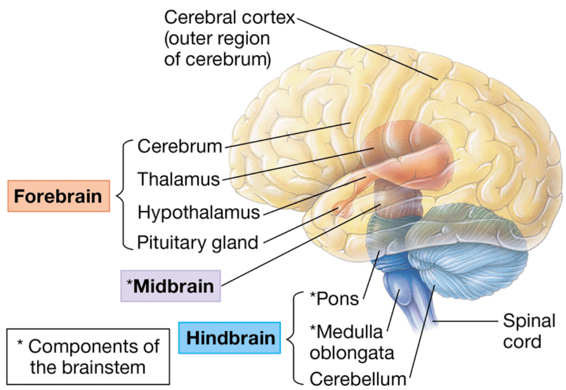

Figure 8: The basic structure of the brain

6.2 The cerebral cortex

Structurall, the cerebral cortex bears similarity to the cerebrum in its division into a right and left side, connected by the **corpus callosum**, each of which are further divided into quadrants named according to a nearby placemarker (i.e., a bone). Functionally, however, the cerebral cortex could not be more dissimilar to the cerebrum. In other words, the cerebral cortex is responsible for the proper expression of the most advanced behaviors exhibited by humans: personality, metacongnitive ability, etc..., each of which is dealt with by the respective lobe (i.e., according to recent research, it appears that the left hemisphere is more suited towards logical operations, while the right hemisphere deals with patterns, relations, and nonverbal thinking).

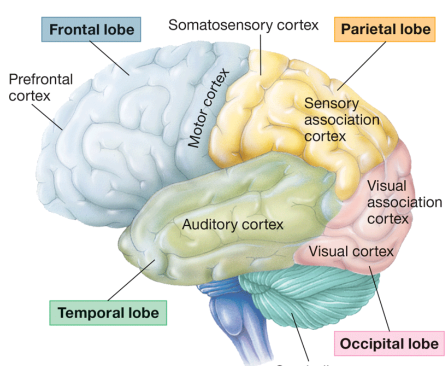

Figure 9: The various lobes in the cereberal cortex

6.3 The limbic system

The limbic system is composed of various parts of the thalamus and hypothalamus, and is responsible for human emotion, motivation, and memory. In addition to the aforementioned segments of the thalamus and hypothalamus, the amygdala and hippocampus aid in the formation of emotional memories and the formatio and recollection of general memories, respectively. In the case of short-term memory formation, for example, a “link” forms in the hippocampus to information stored in the cerebral cortex. Long-term memories, on the other hand, are comprised by connections in the cerebral cortex, rather than the hyppocampus.

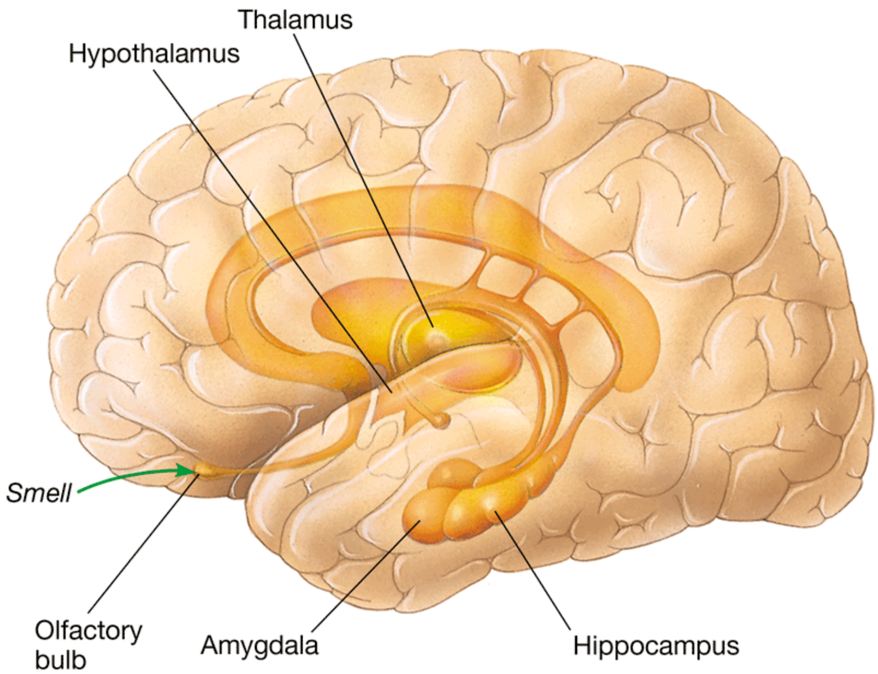

Figure 10: The limbic system