Structure of the Nervous System

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Nervous System Hierarchy

In the last lesson we examined the fundamental building blocks of the nervous system, the neurons. In this lesson we will greatly broaden our focus to the structure of the nervous system as a whole. This combined knowledge of the micro- and macroscopic aspects of the nervous system will aid you in forming a framework in which to consider the rest of the lessons.

Figure 1 is the hierarchy of the nervous system, which we will consider in more detail in the remainder of the lesson. As the figure depicts, the two principle divisions of the nervous system are the central and peripheral. The former consists of the brain and spinal cord, while the latter is the rest of the nervous system. The brain and spinal cord carry out the bulk of the complex processing, while the peripheral acts as a sort of buffer between the central nervous system and the outside world. The peripheral system can be further subdivided into the somatic and automatic, the former responsible for somatosensation and conscious/purposeful action, while the latter is responsible for "vegetative" processes. The autonomic division can also be divided into two systems, the sympathetic and parasympathetic, which carry out the opposing processes of arousal and relaxation. We now turn to a more detailed discussion of these components, beginning with the central nervous system.

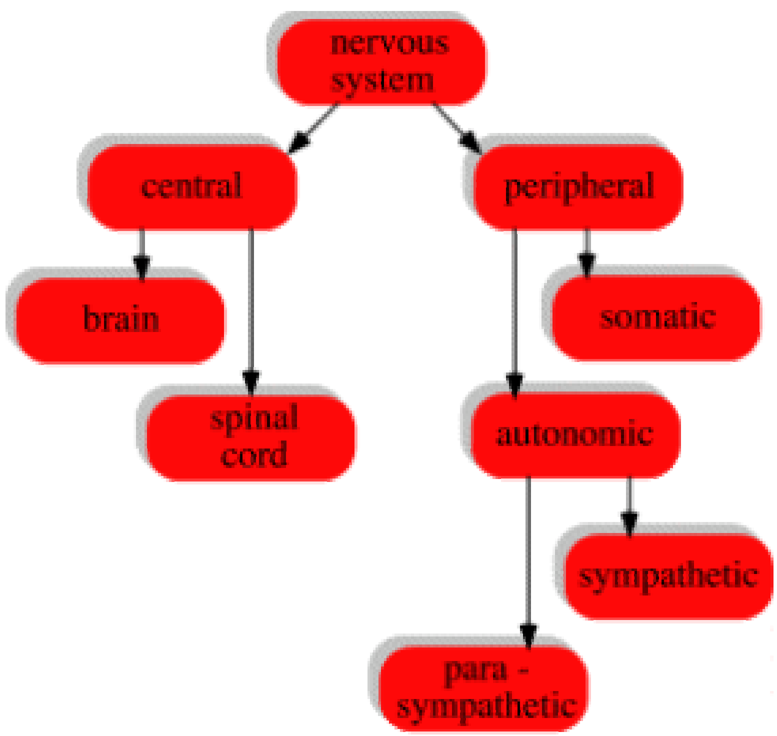

Figure 1. Nervous System Hierarchy

Characteristics of the Central Nervous System

The most fundamental way of categorizing groups of neurons that make up the central nervous system is as nuclei and tracts. (Figure 2 illustrates the difference between nuclei and tracts). The nuclei are collections of cell bodies and tracts are pathways consisting of large groups of axons. Due to their myelin the axons often appear white and the cell bodies appear gray, thus creating what is often referred to as **gray** and **white matter** in the brain. You can think of the brain as a big collection of nuclei and groups of nuclei where processing occurs, and tracts which carry the messages from one group of nuclei to another. Although we will speak of the brain in terms of various "structures" you should keep in mind that the brain is not neatly divided into sections, rather the "structures" refer to areas where clumps of nuclei occur, these areas are not neatly partitioned off from other areas, rather all the structures are interconnected in a myriad of complex patterns.

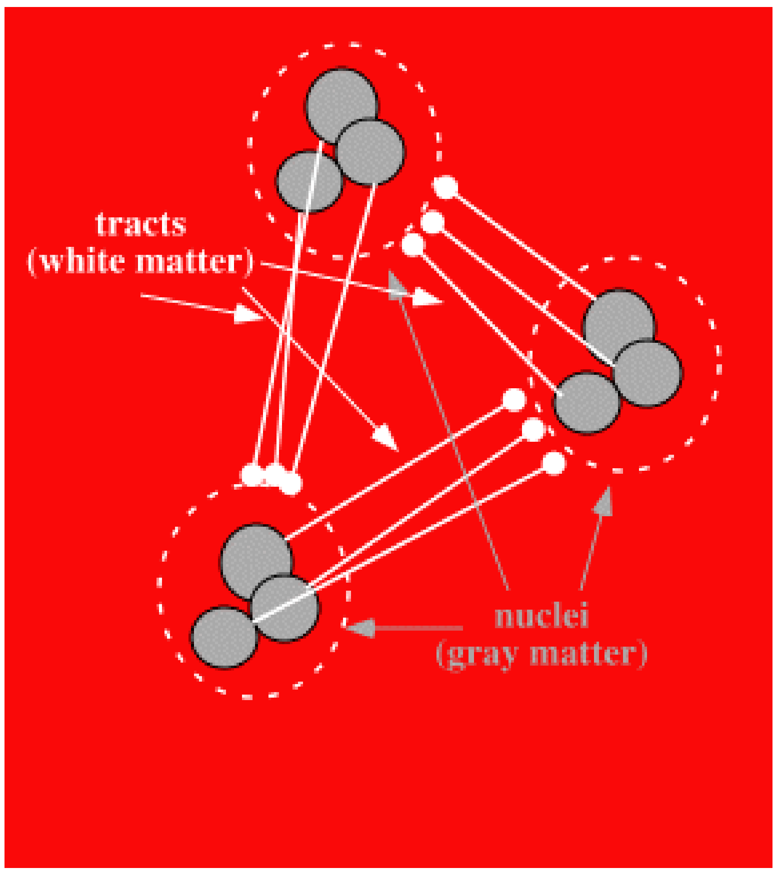

Figure 2. Nuclei and Tracts in the CNS

The importance of the central nervous system is reflected in the way in which it is protected. The central nervous system is protected in many ways. First of all the brain sits inside the **skull** and the spinal cord is surrounded by a series of **vertebrae**. Inside these bony structures lie a series of layers of tissue referred to as **meninges**. These meninges surround the brain and spinal cord, and act as a protective lining adding additional layers of protection. Within the layers of the meninges is a channel referred to as the

subarachnoid space and, within this space the **cerebral spinal fluid (CSF)** runs. This fluid is constantly recycled through the meninges and spaces within the brain called **ventricles**. The brain in effect "floats" in the cerebral spinal fluid, so that the CSF greatly reduces the net weight of the brain on the base of the skull, and acts to protect the brain from blows to the head.

The brain is also protected by the relative impermeability of blood vessels that supply it. The supply of blood to the brain is a relatively closed system in which most substances cannot pass from the blood to the brain. While there are pores (openings) in the capillaries that supply other parts of the body, such pores don't occur in the capillaries of the brain. This phenomenon is referred to as the **blood brain barrier**, and acts to further protect the brain by not allowing harmful substances to enter.

General Organization of the Brain

When all the brain structures and their functions are considered as a whole, a common theme involving the relationship between them emerges. As we move from the base of the brain at the top of the spinal cord, to the most outer layer of the brain, in general, the functions of the structures become more and more complex, with the structures nearest to the spinal cord responsible for basic survival functions and those toward the outside of the brain most responsible for complex "human-like" processes. In fact, the brains of many mammals, such as rats are organized very much like human brains at lower levels, but differ a great deal when we consider the cortex on the outer surface. With this in mind, we will discuss briefly the functions of some of the major brain structures beginning with those at the base of the brain and working our way out.

Structures at the Base of the Brain

At the very base of the brain is a structure referred to as the **medulla**. The medulla is responsible for basic survival, and, thus controls heart rate and respiration. In this sense the medulla is the least important structure for complex processing, and the most important for survival. As we move up the brain stem we encounter the cerebellum, which is a large structure in the back of the brain, that looks like a miniature version of the brain. The **cerebellum** is important for smooth/coordinated movements, and for the integration of different sensory information for the purpose of controlling movement. When we carry out a simple exercise such as picking up a glass, or typing (such as I'm doing right now!), we rarely consider how complex the interaction of the brain, the sensory system, the motor system, and the muscles is in carrying out these tasks. Just consider how difficult it would be to design a robot to carry out these intricate tasks. It is the cerebellum which is most responsible for controlling these types of smooth movements. One way to understand the function of the cerebellum is to recognize that cats have a much larger cerebellum than humans, relative to the size of their brain, and as a result, can easily carry out tasks such as jumping many times their body height, landing nimbly, and scampering across an area strewn with stuff, and not touching a thing. It is their cerebellum that is largely responsible for this ability. Another structure that is located primarily at the base of the brain is the **reticular activating system (RAS)**. I say that the RAS is located "primarily" at the base of the brain because it sends out tracts that affect many other structures of the brain, and, as a result, the activity of the RAS has a diffuse effect on the brain as a whole. It is primarily important in attention and wakefulness. At this moment the amount of attention that you are paying to this lesson, is to some extent, a function of RAS activity. When the RAS of an animal is lesioned the animal goes to sleep (but does not die), and when the RAS of a sleeping animal is stimulated, the animal wakes up.

Structures in the Middle of the Brain

As we move a little farther up into the brain we contact a number of small structures which play large roles. Among these is the **thalamus**. Most of the sensory information that comes from the various senses is funneled through the thalamus. There the information passes through one of many specialized nuclei and is directed toward the appropriate site. For example, visual information passes from the eye, down the optic nerve to the thalamus and then to the visual cortex (Figure 3). For this reason we can think of the thalamus as a sort of filter and switching station.

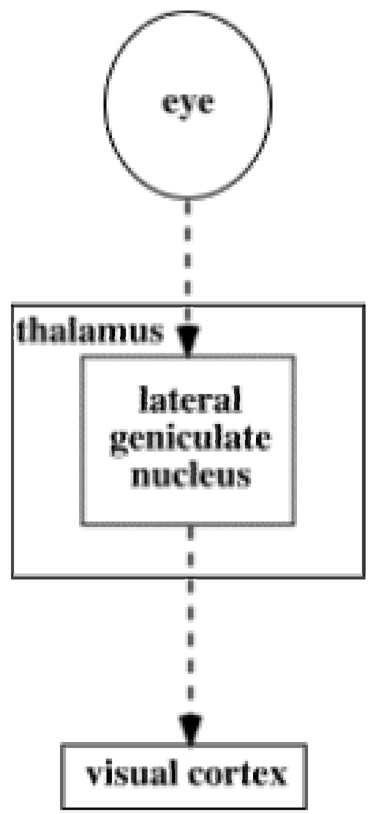

Figure 3. Pathway from Eye to Visual Cortex

Also in the middle of the brain is a set of interconnected structures which play an important role in emotion, and memory. These structures are referred to as the **limbic system**. Three of the most important structures in the limbic system are the amygdala, the hypothalamus, and the hippocampus. It is said that the limbic system, and the hypothalamus in particular, is responsible for the four F's: feeding, fleeing, fighting, and mating. (I would like to say I made this up but, in reality, it's one of the oldest jokes in neuroscience.)

The **amygdala** is important in fear and, particularly, in aggression. The amygdala is important in a type of aggression that aggression researchers refer to as **affective aggression**. This type of aggression is illustrated by the Halloween cat with hunched back and fur standing on end (I like to think of this as the "kitty mohawk"). This type of aggression is characterized by the fact that it is unpleasant to the aggressor. We can think of it as aggression due to anger, the fight or flight response. This is not enjoyable to most of us. Affective aggression is often contrasted with **predatory aggression**, which is reinforcing (enjoyable) to the aggressor. For the cat this would involve something like catching a mouse. For the human this would be exemplified by something like hunting or fishing.

The **hypothalamus** is responsible for "motivated" behavior, and, as I mentioned above, the famous joke about the four F's is often used to describe the functions of the hypothalamus. Although the hypothalamus is very small it contains specific nuclei which are very important in feeding, fight/flight, and reproductive behavior. For example, one nucleus, the **septal nucleus**, is very important for the control of affective aggression. An animal with a lesioned septal nucleus is extremely aggressive. When I was in graduate school I saw two other graduate students fleeing the rat lab where a rat with a septal lesion was loose! Another example is the **ventral medial nucleus** which is very important in the control of feeding behavior. Many general psychology text books contain a picture of an obese rat which is the result of a lesion of the ventral medial hypothalamic nucleus.

As we'll discuss in more detail in the lesson on memory, the **hippocampus** is an important structure in the storage of certain types of memories. As is the case with many brain structures, the hippocampus has other roles as well. As part of the limbic system the hippocampus plays a role in emotion, and, interestingly, is also an important part of the olfactory (smell) system. This duel role may partly account for the powerful effect of smell as a memory cue.

The Cerebral Cortex

Surely one of the most interesting brain structures is the very thin outer coating of the brain which is referred to as the **cerebral cortex**. The outer covering is very wrinkled, which acts to greatly increase the cortex surface area, so that it's thin width is somewhat misleading with regard to its size. The cortex is the most uniquely "human" part of our brain. This structure is responsible for the highest level types of human function (e.g., speech processing). Each half/hemisphere of the cortex can be considered as four lobes, the frontal, parietal, occipital, and temporal. Within each of these lobes is a relatively small area of cortex that's responsible for a specific motor or sensory function (Figure 4).

lobe	primary cortex (within)
frontal	motor
parietal	somatosensory
occipital	visual
temporal	auditory

Figure 4. Primary Cortexes and Lobes

Most of the cortex is referred to as the **association cortex**. The association cortex is responsible for the most complex processing carried out by this structure. In some sense we can think of these areas of the brain as the place where "consciousness" resides. It is here where information from the various sensory modalities is integrated to form the holistic perceptions that make up our everyday experience. Researchers in the fields of cognitive psychology and sensation and perception often refer to "labeling" processes when a person is able to categorize or identify some object. It appears that this area of the brain is responsible for these types of processes, as exemplified by humans who have damage to these areas. For example, damage to visual association areas can often result in the inability to identify objects, though they can be seen.

Characteristics of the Peripheral Nervous System

The peripheral nervous system is the part of our nervous system that, for the most part, connects the rest of our nervous system with the "real world". So, while this part of the nervous system does not get the elaborate protection of the central nervous system, and while it is not responsible for the complex processing carried out by the central nervous system, it nevertheless plays a crucial role. The same distinction between groups of cell bodies and axon pathways can be made with peripheral neurons as is the case with the central nervous system. However, in the peripheral nervous system the groups of cell bodies are referred to as **ganglia** and the axons are referred to as **nerves**. We can differentiate between two basic types of peripheral nerves by taking into account the places where they leave or enter the peripheral nervous system. Those that leave from the base of the brain are referred to as **cranial nerves**, and those that leave from the spinal cord are referred to as **spinal nerves**. Another interesting characteristics of peripheral nerves is that they most frequently are made up of both sensory neurons, which collect information from the somatosensory system, and motor neurons, which send information to the muscles, glands, and internal organs. These dual purpose nerves are called **mixed nerves**.

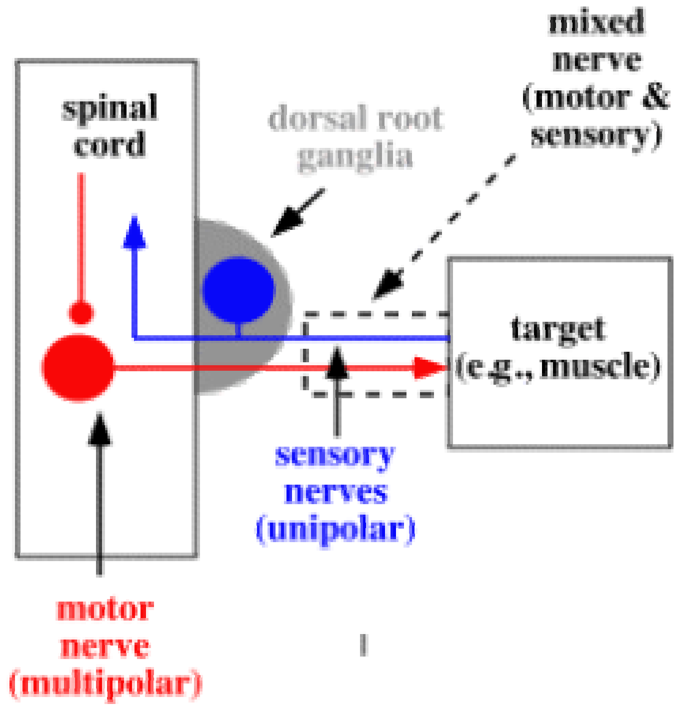

Figure 5. Spinal Nerves

Branches of the Peripheral Nervous System

As Figure 1 illustrates, the peripheral nervous system can be broken down into the **somatic** and **autonomic nervous systems**. The somatic system is responsible for gathering sensory information from receptors in the periphery and for sending out "purposeful" motor signals, such as those associated with the conscious/purposeful movements (e.g., raising your hand). The nerves of the somatic nervous system travel principally to skeletal muscles and their axons usually travel all the way from the spinal cord to their targets and synapse directly on them. In contrast, the nerves of the autonomic nervous system are principally motor nerves responsible for "nonvoluntary" processes, such as heart rate and respiration. These nerves carry messages primarily to internal organs and glands. In addition, rather than consisting of one long axon from the spinal cord to the target, they synapse into some ganglia, and the message is then carried from the ganglia, via another set of nerves, to the target. The nerves of the autonomic nervous system that carry messages from the spinal cord to the ganglia are called **preganglionic** and those that carry the signal from the ganglia to the targets are called **postganglionic**.

Branches of the Autonomic Nervous System

Figure 6 is a table that contrasts the two branches of the autonomic nervous sytstem. As you can see from the table, although these are two parts of the same branch of the peripheral nervous system, their effects are very much the opposite. While the **sympathetic** is responsible for the "fight or flight" response, which relies on energy reserves, the **parasympathetic** is responsible for relaxation and restoration, which restores energy reserves. Another difference between the two, not listed in the table is that the sympathetic tends to work much more as a unit. This is why in stressful (fight or flight) types of situations many different changes tend to occur at once (e.g., heart rate increases, respiration increases, eyes dilate, blood flow is routed to skeletal muscles). This holistic response occurs principally because of the presence of a chain of ganglia called, aptly, the **sympathetic chain**. Almost all sympathetic preganglionic nerves pass through, or synapse on this ganglionic chain.

characteristics	**division**	
	sympathetic	**parasympathetic**
energy	energy depletion	energy storage
heart rate	increase	decrease
respiration	increase	decrease
digestion	inhibits	stimulates
eye	dilates pupil, inhibits tears	constricts pupil, stimulates tears
general effect	preparation for "fight or flight"	rest and relaxation

Figure 6. Sympathetic vs Parasympathetic Nervous System