Introduction to the Nervous System.

Code: HMP 100/ UPC 103/ VNP 100. Course: Medical Physiology

Level 1 MBChB/BDS/BPharm

Lecture 2. Functional Organisation of the Nervous System

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1.1 Introduction

In the last lecture, we covered the basic anatomy of the nervous system. We saw that it is divided into many divisions and parts. Now in this lecture, we will cover some functional organisation of the nervous system. You know that the nervous system carries out many different functions unlike other physiological systems of our body. To do these many different functions, the nervous system has functional divisions involving different part of the nervous system. And this adds to the difficulty in studying how the nervous system works. In this lecture, we will cover the functional organization of 4 functions: language, sensory, motor, and pain. We will not cover them in details; this will be done in later lectures. Here we want to being to understand the functional organization of the nervous system.

Learning which parts of the nervous system are involved in carrying out the different functions is important. This will help us predict the type of dysfunction a person will have when there is damage to a particular part of their nervous system. And if we know or observe the symptoms in the person, we can predict where in the nervous system the damage has occurred.

1.2 Learning Outcomes
At the end of this lecture, you should be able to:
1. State the function of the Nervous System
2. Name and show the location of the areas of the cerebral hemisphere involved in language function.
3. Describe with a diagram the somatic sensory system.
4. Describe with a diagram the somatic motor system.
5. Describe with a diagram the pain (nociceptive) system.
1.3 Areas on the Cerebral Hemisphere involved Language Function

In recent years, techniques and methods have been developed that allow us to study the activity of brain when it is involved in a particular task. With these techniques, we ask a person to do a particular task and see which areas of the cerebral hemispheres are active when that task is being done. From these studies, we can conclude that these areas are involved in that function. Of course it does not tell us how these parts of cerebral hemispheres are carrying out that function.

Figure 1.1 shows the results of a study on brain activity when the person was asked to do 4 different tasks: (1) look at words, (2) listen to words, (3) speak words, and (4) think of words. The imaging is of the lateral surface of the left cerebral hemisphere. The areas on the surface showing red and yellow color are areas that became active when the person was doing each of the different tasks.

Positron Emission Tomography.

*The technique cannot tell you how the function is being, e.g., how is hearing done by this area; it only tells you which areas of the brain are involved.*

Figure 1.1 Imaging of the surface of the left cerebral hemisphere when a person was asked to (1) look at words, (2) listen to words, (3) speak words, and (4) think of words. The areas in red/yellow show the areas which became active for the different tasks. The front part of the cerebral hemisphere is towards the left.

When the person was asked to look at words (top left image), we can see that their occipital lobe became more active than other parts of the brain. In later lectures, you will learn that this part of the surface of the cerebral cortex with other parts is involved in producing images from the signals that come from the retina of our eyes. This area is called the **primary visual cortex**. It is here that the signals from the retina are beginning to be processed to produce visual images.
Now, when the subject was asked to listen to words (top right image), we can see that another area of the cerebral cortex has become active. This is the **primary auditory cortex** and is located on the superior temporal gyrus of the temporal lobe, and it is here that the processing of signals coming from the **organ of Corti** located in inner part of the ear begins and we will 'hear' sounds.

When the subject was asked to speak words, an area above the lateral fissure in the frontal lobe becomes active (lower, left image). This is the **Broca's area**, named after Dr. Paul Broca, a neurologist, who discovered that people who had difficulty in speaking words, invariably had damage to this area of the surface of the cerebral cortex. However, the same people had no difficulty in understanding what was being said; only they had difficulty in speaking.

When the subject was asked to think about words, several areas of the subject's cerebral cortex became active (lower right image). Note in particular the area in the parietal cortex. This is called the **Wernicke's area** after, of course, Dr. Wernicke, a neurologist, who found that people who had difficulty in understanding language had damage to this area. However, they could speak fluently though not related to what was being asked!

Can you explain how a person who has difficulty in understanding the spoken word can still talk and write fluently but cannot specifically provide answers to your question?

So from studies like this, we now know that different areas of the brain are involved in different functions of the nervous system, and also that many brain functions involve several different parts of the brain. So information is being sent between different areas of the brain producing networks for processing the signals and producing a behavioral output. Learning the neuronal circuits adds to the effort we have to make to understand how your brain works.

In figure 1.2, the areas of the cerebral hemispheres involved in language function are shown. These two areas for language function in over 80% of adult persons are found only in the left cerebral hemisphere, not the right. Hence, the left hemisphere is often referred to as the dominant hemisphere, meaning that it is the dominant hemisphere for language function, not that the left hemisphere “dominate” the right hemisphere. In 25% or so of left-handed persons, the language hemisphere is the right one.
Figure 1.2 The areas of the cerebral cortex that are involved in language function. The area in red located in the parietal cortex is also known as the Wernicke's area. The area in blue located in the frontal lobe is also called Broca's area.

The example of the language function of the nervous system is our first introduction to the neuronal organisation or neuronal circuitry that are involved in carrying out the different functions of the nervous system.

Clinical note: **Dysarthria** is a speech disorder caused by disturbance of muscular control. The person has no difficulty in understanding and but has difficulty in articulating his or her words. **Dysphasia** is impairment of language function which can either be in speaking meaningfully (expressive) or understanding in what is being said (receptive).

1.4 Neuronal Pathway for Somatic Sensory, Somatic Motor and Pain Sensation.

1.4.1 Sensory System

How do we “know” that we have touched an object, or when someone or something touches us? How do we know which part of our body touched the object or where on our body surface we were touched? There is a neuronal system called the **somatic sensory system** that functions to give us the ‘ability’ of knowing that a stimulus has been applied to our skin, and what type of stimulus it is, e.g., light touch, pressure, tickle, etc, and where on the body.

In figure 1.3, the pathway the nerve signal travels from the receptor in the finger to the brain is shown. When we touch an object with our fingertip, receptors in the fingertip are activated. They produce a nerve signal. In later lectures, we will learn how the nerve signal is produced. But for now, let us take it that a signal has been produced. This signal travels along the nerve that enters the spinal cord on its dorsal side. (Remember that all sensory input to the spinal cord enter through the spinal dorsal roots). From here the signal travels up the spinal cord in nerves that form the **dorsal columns** of the spinal cord white matter. On reaching the top of
the spinal cord, the nerves carrying the signal make connections with other nerve cells located in the **dorsal column nuclei**.

![Diagram of the neuronal pathway of the sensory system](image)

**Figure 1.3** The neuronal pathway of the sensory system. In this figure, spinal cord sections are shown in the horizontal plane, and the cerebral cortex in a coronal section. Notice the nerve fibers from the dorsal column nuclei cross the spinal midline and go up into the brain on the opposite side.

Now something unusual happens but which, as you will learn, is quite common in the nervous system. The nerve cells of the dorsal column nuclei extend nerves that cross the midline of the CNS and continue up to the **thalamus** creating a nerve pathway called the **medial lemniscus**. The signal has crossed from one side of the body to the other. From the thalamus, the signals travel along the thalamic nerves to the nerve cells in the cortex of the cerebral hemisphere, which is called the **primary sensory cortex**.

The word nucleus (plural: nuclei) is used to describe different structures. It is used to describe a structure in the cell that contains the DNA. In neuroanatomy, the word is used to describe a collection of nerve cells.
As you can see in figure 1.4, the primary sensory cortex is located on the gyrus just posterior to the central sulcus. It is this area that informs you that you have touched an object with your fingertip.

You can also “see” with your sensory system. Say that we have coins and keys in our pocket and we want to take out some coins. We can put our hand in our pocket and feel the objects and without having to look at them with our eyes, we will take out the coins and leave the keys. By feeling the objects, we create an image of them by touch.
Figure 1.4 This figure shows the area of the cerebral cortex that receives the sensory input from the surface of your body. It is posterior to the central sulcus.

So now we have learnt the parts of our nervous system and the nerve pathways that carry out the function of sensation. To recap, the pathway involves 3 nerve cells: First, the nerve connection from the skin to the spinal cord by nerve cells located in the dorsal root ganglia, second connection by the nerve cells of the dorsal column nuclei to the thalamus, and third, by the nerve cells of the thalamus to nerves cells in the primary sensory cortex.

By knowing this neural pathway, we also learnt something amazing. The signals from one side of our body are sent to the opposite cerebral hemisphere. So sensation signals coming from the right side of the body are sent to the left cerebral hemisphere and vice versa.

1.4.2 Somatic Motor System

The next nervous system function that we will look at is our ability to carry out movement whether it is voluntary or not. The range and variety of movement that we are able to do is very large. For example, consider the complexity of movement required for playing a guitar or dribbling a football with our foot. Movement is everything to us, without it we can do nothing.

There are many parts of the nervous system and pathways involved in movement function. In this section, we will only discuss one pathway out of the five that are involved in motor function. In later lectures, we will look in more details at the parts and pathways of our nervous system that provide us with the ability of movement.

Unlike the somatic sensory system, we will start from the cortex of the cerebral hemisphere and work our way down to the muscles. Looking back at figure 1.4, we can see that there is an area just in front of the central sulcus of the cerebral hemisphere, which is called motor cortex. Nerve cells in this area send out nerve fibers that travel through the cerebral hemispheres and enter the brain stem. These nerves form a structure inside the cerebral hemispheres called the internal capsule.
Figure 1.5. Shows one of the five motor pathway. It starts from an area of the cortex of the cerebral hemisphere just in front of the central sulcus and goes all the way to the muscles (corticospinal tract).

When the nerves enter the brainstem, the nerve pathway formed is called the **basis pedunli**. It is on the ventral part of the brainstem. When the nerves reaches the medulla, they form a structure called the **pyramids** and start to cross the midline of the CNS. This crossing is called the **pyramidal decussation**. In the spinal cord, these nerves travel down the white matter of the spinal cord making the **lateral corticospinal tract**. All along the spinal cord, the nerves leave the lateral corticospinal tract and enter the spinal cord gray matter. In the spinal cord

| Nomenclature: There is a method for naming nerve fiber tracts. The first part of the word gives the location of the nerve cells and the second part the termination point of the nerve fibers. So the corticospinal tract has nerve cells in the cerebral cortex (cortico-) and the nerve fibers that end in the spinal cord (-spinal). If the nerve cell bodies were in the spinal cord and the nerve fibres ended in the cortex then the nerve fiber tract would be called the spinocortical. |
Gray matter, the nerves make a connection with nerve cells, called the **alpha motor neurons**, which send nerves fibers out from the ventral root of the the spinal cord. These motor nerve fibers travel throughout the body and make connection with striated muscle cells.

The innervation of the smooth and cardiac muscles and their state of contraction or relaxation is controlled by the autonomic nervous system.

So when we want to make a movement, we produce signals in the nerve cells of the primary motor cortex and these are sent along nerve pathways to the muscles to make them contract. And to remind ourselves, this is not the only pathway involved in our ability to carry out movement. There are 4 other pathways and we will discuss these in the lectures on lectures on the motor system.

**1.4.3 Pain Pathways**

Finally, an overview of a special sensory system that serves to protect our body from stimulus that can cause us tissue injury. This is called the pain or nociceptive pathway. Note that pain is subjective feeling produced by our brain. Nociception, from the Latin, *nixer*, ‘to harm or hurt’, is the processing of harmful stimuli. Nociception may not result in pain. For example, when we need to have a surgical procedure we are given an anesthetic chemical that blocks pain nerve signals reaching our brain. So though our pain receptors are producing signals, these do not reach our brain so we do not feel the sensation of pain. So thought there is nociceptive activity, there is no pain.

We have receptors on our skin that respond only to strong stimulus or when the skin has been damaged. These receptors are different from the receptors for the somatic sensory system; they do not react to light touch but if, for example, a strong pressure or high or very low temperature is applied, this is sensed as a potential nociceptive stimulus and the appropriate protective action taken to prevent injury. We are familiar with the reaction we produce when we a touch hot object; we quickly remove our hand. This is called the withdrawal reflex and serves to move our hand rapidly away from the nociceptive stimulus to prevent the skin on our hand being burnt.

In figure 1.6, we can see that the nerve fibers from the receptors enter through the dorsal side of the spinal cord. (Remember all signals coming into the spinal cord come through the spinal dorsal side.) These nerve fibers make connections with nerve cells in the dorsal horn of spinal cord gray matter. From here the nerve fibers from these nerve cells of the dorsal horn spinal
gray matter move up the spinal cord for a few segments before crossing the CNS midline to the other side.

The nerve fibers now climb up the spinal cord all the way to the cerebral hemispheres ending on the nerve cells of the thalamus. The pathway is called the spinothalamic pathway. The nerve cells of the thalamus send nerve fibers to the primary sensory cortex (providing location of the stimuli), the cingulate gyrus (providing emotional content) and insular cortex (producing behavior associated with pain).

Both in the spinal cord and cerebral cortex the painful information is sent to the motor part of the CNS so we can produce quick motor response and avoid being injured.

1.5 Summary
So in this lecture we have looked at the parts of the nervous system that are involved in some of the different functions of the nervous system. It is important that we know these pathways so if we see a person shows difficulty in sensing, movement or pain response, we can work where the damage has taken place in the nervous system.

In other lectures on the nervous system, we will learn about the neuronal circuits (pathways) that are involved in the function of vision, audition, olfaction, gustation, memory and learning, and emotion and motivation as well as our sleep/wake cycle.
1.6 Activities

1.7 Further Reading

1.8 Sample Examination Questions

**Multiple Choice Questions (MCQs). Select the best one correct answer.**

1) The area of the cerebral hemisphere that is involved in understanding speech is located on the
   a) Frontal lobe
   b) Parietal lobe
   c) Temporal lobe
   d) Occipital lobe
   e) Insular lobe

2) The area of the cerebral hemisphere that is involved in producing speech is located on the
   a) Frontal lobe
   b) Parietal lobe
   c) Temporal lobe
   d) Occipital lobe
   e) Insular lobe

3) Which area of the cerebral cortex is likely to be most active when you are looking at words?
   a) Primary motor cortex
   b) Primary sensory cortex
   c) Primary auditory area
   d) Primary visual cortex
   e) Organ of Corti

4) If a person is right-handed, what is the probability that is his or her left hemisphere controls the language function?
   a) >80%
   b) 60-80%
   c) 40-60%
   d) 20-40%
   e) <20%

5) The primary sensory cortex is located
   a) Anterior to the central sulcus
   b) Posterior to the central sulcus
   c) Dorsal to the central sulcus
   d) Ventral to the central sulcus
   e) None of the above

6) At which level of the nervous system do the nerve signal in the somatic sensory system coming from the right side of the body cross over to the left side of the nervous system?
   a) Spinal cord level
   b) Dorsal columns level
   c) Dorsal column nuclei level
d) Thalamic level
e) There is no crossing over

7) The nerve signals coming from the primary motor cortex will cross the nervous system midline at which level?
a) Cerebral cortex level
b) Diencephalon level
c) Pons level
d) Medulla level
e) Spinal level

Short Answer Questions (SAQs). The answer to the question requires 5 key points.

1) For the following statements, fill in the blanks:
   a) The nerve cells on which the nerve endings of the lateral corticospinal tract make synaptic connections are called ____________________.
   b) The crossing of the lateral corticospinal tract as the nerve fibers descend from the primary motor cortex is called ____________________.
   c) The nerve pathways that carry nociceptive information is call the ________________.
   d) Damage to the ________________ area of surface cerebral hemisphere would make it difficult to understand what is being said.
   e) Damage to the ________________ area of surface cerebral hemisphere would make it difficult to produce meaningful speech.

2) Give some examples of the usefulness of knowing the functional organization of the nervous system.

3) The brain imaging method of positron emission tomography is useful in learning what about the brain.

4) Draw a labelled diagram of the somatic sensory system.

5) Draw a labelled diagram of the somatic motor system.

6) Draw a labelled diagram of the nociceptive pathway.

7) What is the difference between the terms nociception and pain?