UNIT 9 NERVOUS SYSTEM

Structure

9.1 INTRODUCTION

In the previous units, we have studied about the different systems of our body. In this unit, we will study the sensory, motor and autonomic and control apparatus of our body, mostly constituted by nerve cells and fibre tracts – the *nervous system*. Along with the endocrine system, the nervous system regulates many internal functions and also co-ordinates the activities we know collectively as *human behaviour*, which include state of consciousness, learning, memory and emotions. These phenomena which we attribute to 'mind' are believed to be related to the integrated activities of nerve cells of the brain. In vertebrates, as you would learn in this unit, the nervous system is divided into three parts: the central, brain and spinal cord, the peripheral, cranial and spinal nerves; and the autonomic, sympathetic and parasympathetic.

Finally, we will also learn the mechanism by which we can study brain electric potentials, which serve as an important diagnostic tool.

Objectives

After studying this unit, you will be able to:

- discuss the morphology of neurons,
- understand the structural organization of the nervous system,
- enumerate the different systems operating within the nervous system,
- describe the functions of various parts of the brain, and
- explain the usefulness of electroencephalography (EEG) as a diagnostic tool.

9.2 HOW DOES OUR BODY KNOW 'WHAT TO DO'?

Feeling, knowing, doing anything depends on special structures called *nerves*. Neuronal cells in the body act as various messengers according to the need involved. We are born with all the nerve cells we will ever have. There are about 100-billion nerve cells in our brain. If any nerve cell is somehow damaged, it will not be replaced by a new cell. Each nerve cell is known as a *neuron.* We will learn about the morphology of the nerve cell in the next section.

The nervous system, as you may recall reading earlier, consists of 100-billion neurons and the glial cells. The whole brain is a collection of neuronal and glial cells. These cells are also responsible for higher functions of the brain like learning, memory, speech etc. This fascinating study of biological function of nervous system is called as *neurobiology.*

So how does our body get to know, what to do? The terminal endings of the nerves are equipped with sensitive receptors. They generate the impulse in relation to any change in the environment i.e., temperature, pressure, touch and send them to main part of the nerve cell, to be transmitted to the brain. The brain receives such messages from various axonal tips. Further brain decides what information has to be processed. If actions are necessary, brain signals the muscles to carry out the work required. We will learn about this mechanism in greater details later here in this unit.

A neuron releases its messages as chemicals. These are capable of changing polarity of cells. This is because of the ionic nature of the chemicals. Since it is achieved through movement of ions, we call them *ionic channels*. Their movement is termed as *gait*. The ions which play a major role are Ca^{++}, Na^{++}, K^{+}. They are able to create energy for nerve cells to function in a better manner. This creates some amount of electricity in the cell, which can be measured in volts. This principle was discovered by an Italian scientist *Alessandre Volta* during his experiment on frog leg muscle.

We will understand the functioning of the nerve cell better by first getting to know the morphology of the nerve cell. The next section focuses on this aspect.

9.3 NERVE CELL

The basic unit of the nervous system as studied above, is the individual nerve cell – *the neuron.* The nerve cells operate by generating electrical signals and passing them from one part of the cell to another and by releasing chemical messengers to communicate with other nerve cells. Let us get to know about the nerve cell morphology first.

9.3.1 Nerve Cell Morphology

The neurons in the mammalian nervous system occur in a variety of shapes and sizes. A typical cell has a cell body, the dendrites, axon and its terminals. Look at Figure 9.1 which illustrates the structure of a nerve cell – the *neuron.* The cell body, which has a nucleus, arborizes to form *dendrites* which are the thin processes that extend out, as shown in Figure 9.1. From the thick concentrated region of the cell body arises a long extended fiber known as *axon.* Each axon is covered by a *myelin sheath.* It is made up of a protein lipid complex. This is further surrounded by schwann cells (Glial cells).The axon is constricted at various positions, where it is denuded of myelin. This region is known as *nodes of Ranvier.*

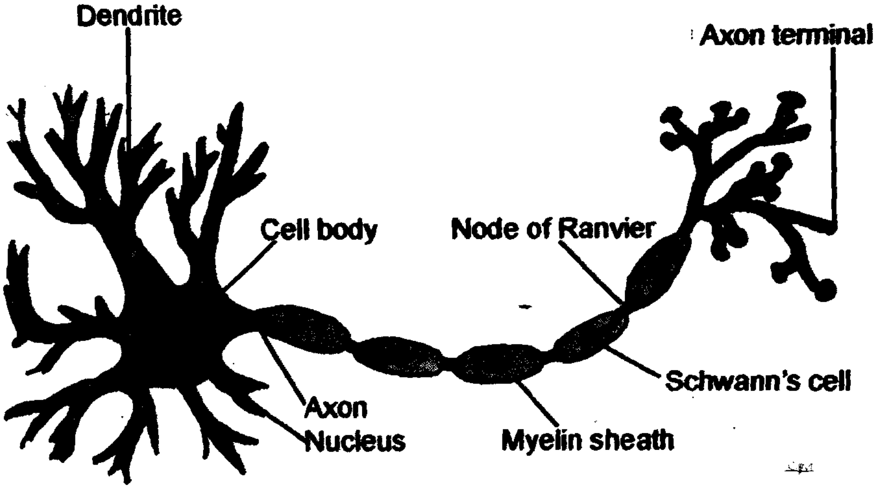


Figure 9.1: The structure of the nerve cell

Let us look at each of these parts very closely:

Cell Body: It is the portion of a neuron almost resembling with other cells. It contains a nucleus and cytoplasm, and receives impulses from dendrites.

Axon: The long part of a neuron leading away from the cell body is the axon. It transmits impulses away from the cell body.

Dendrites: These are the highly branched structures at one end of a neuron, which conducts impulses towards the cell body.

Schwann cells: These aid in the nutrition and regeneration of axon and their myelination in the peripheral nerves.

Having gone through the structure of the nerve cell, let us next learn how the neurons communicate with each other. The neurons, you must realize, are important as they help to send and receive crucial messages to and from the brain. Let us read about this process next.

9.3.2 Communication between Neurons

Communication is possible only through chains of neurons. They should interconnect with parts of the neuronal terminals which brings the message and carries the message away. This communication can be from one neuron to the other or from one neuron to muscle. The anatomically specialized junction between two neurons, where one alters the activity of the other, through a chemical messenger is known as *synapse*. Figure 9.2 depicts a typical synapse. The term synapse was coined by *Sir C. Sherington* who was a famous neurophysiologist. The process of communication between two neurons across a synapse is called a *synaptic transmission.*

The synapse is a small gap separating neurons as can be seen in Figure 9.2. The synapse consists of:

- a presynaptic ending that contains neurotransmitters, mitochondria and other cell organelles,
- a postsynaptic ending that contains receptor sites for neurotransmitters, and
- a synaptic cleft or space between the presynaptic and postsynaptic endings.

The neuron which sends a message is known as a *presynaptic neuron* and which receives a message is known as a *postsynaptic neuron.* A typical synapse junction is between the axon of presynaptic neuron and dendrites of a postsynaptic neuron.

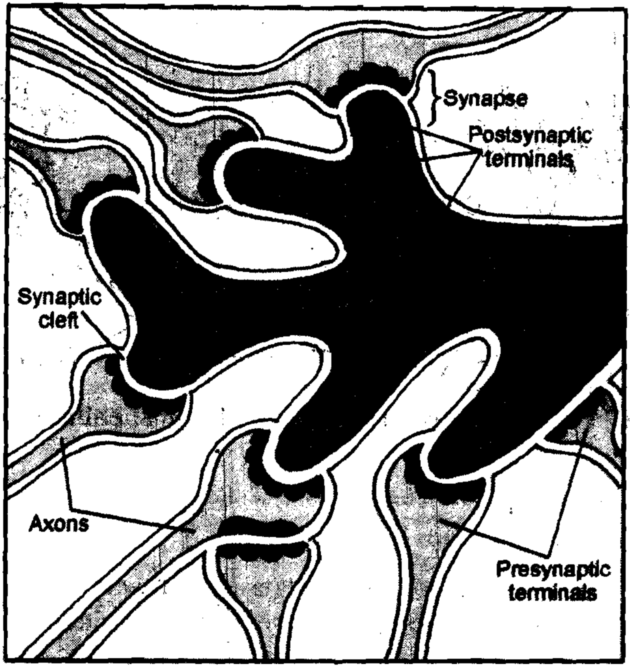


Figure 9.2: Synapse

Communication among neurons typically occurs across microscopic gaps called *synaptic* clefts. Each neuron may communicate with hundreds of thousands of other neurons. A neuron sending a signal (i.e., a presynaptic neuron) releases a chemical called a neurotransmitter, which binds to a receptor on the surface of the receiving (i.e., postsynaptic) neuron. Neurotransmitters are released from presynaptic terminals, which may branch to communicate with several postsynaptic neurons. The receiving neuron then generates a nerve impulse in form of action potential to be transmitted across its axon to the next neuron.

So it is clear to you that the neurons communicate through synapse. In the next section, we will further look into the mechanism of neural transmission of messages via the synapse.

9.3.3 The Process of Synaptic Transmission

The mechanism underlying signal transmission within neurons is based on voltage differences (i.e., potentials) that exist between the inside and the outside of the cell. This membrane potential is created by the uneven distribution of electrically charged particles, or ions, the most important of which are sodium (Na^+), potassium (K^+), chloride (Cl^-), and calcium (Ca^{2+}). Ions enter and exit the cell through specific protein channels in the cell's membrane. The channels "open" or "close" in response to neurotransmitters or to changes in the cell's membrane potential. The resulting redistribution of electric charge may alter the voltage difference across the membrane. A decrease in the voltage difference is called *depolarization*. If depolarization exceeds a certain threshold, an impulse (i.e., action potential) will travel along the neuron. Various mechanisms ensure that the action potential propagates in only one direction, toward the axon tip. The generation of an action potential is sometimes referred to as "firing."

The synaptic transmission is a fast response taking fraction of a second. As you have already studied, in this process, the message reaches in the form of action potentials propagated along the presynaptic axon as it reaches the presynaptic terminal to cross the synaptic cleft, the cell's electrical message must be converted into a chemical one. This conversion takes place when an action potential arrives at the axon tip, resulting in depolarization. The depolarization causes Ca^{2+} to enter the cell. The increase in intracellular Ca^{2+} concentration triggers the release of neurotransmitter molecules into the synaptic cleft. Once released from axon terminal, the neurotransmitter molecules diffuse along the cleft and fraction of them bind to the receptor sites of plasma membrane on postsynaptic cell. The combination of transmitter with receptor triggers generation of postsynaptic excitatory or inhibitory action potential, which is further transmitted to the next neuron.

The *excitatory potential* opens sodium and potassium channels. This creates sodium influx and potassium efflux, further leading to depolarization. In an *inhibitory type,* it opens chloride and potassium channels. The net changes cause hyper polarization. Thus, you may have noted that when a neurotransmitter is received by a receptor (postsynaptic), it either excites (depolarizes) or inhibits (hyperpolarizes) the postsynaptic neuron. When a neuron is depolarized, the membrane becomes more permeable to Na^+ and is closer to firing (action potential). When a neuron is hyperpolarized, the membrane becomes impermeable to Na^+ and will not fire. The neurotransmitter, thus crosses the synapse, binding to receptor molecules on the next neuron, prompting transmission of the message along the neuron's membrane.

In the discussion above we talked about neurotransmitters. What are neurotransmitters and what is their fate? Let's find out next.

9.3.4 Neurotransmitter and Neuromodulators

Neurotransmitters are *chemicals (small molecules or hormones), stored in small synaptic vesicles clustered at the tip of the axon (terminal buttons).*

A large number of substances have been identified which are very similar in neuronal transmission. Some of them have a long span of action. Under this influence, the postsynaptic neuronal sensitivity increases or decreases. Some of them are slow in action, hence they are called *neuromodulators.* A neurotransmitter has the following characters:

1) The synthesis should be from a neuron.
2) The stimulation of the cell should be releasing sufficient quantity of the neurotransmitters to affect the post synaptic membrane potentials.
3) The degradation and uptake mechanism should exist at the concerned synapse.
4) Mimicking agents should release a similar effect like the neuronal cell.
5) Antagonist actions should be by specific neuronal inhibitors.

The most commonly discussed example of neurotransmitter is *acetyl choline* (ACh). It is synthesized from acetyl coenzyme A and choline. Choline is available in the diet (not synthesized in the body). The sources are vegetables and egg yolk. ACh acts at the neuromuscular junction, post ganglionic endings of parasympathetic nerves. In the central nervous system (CNS), ACh is employed as a neurotransmitter, which projects into hippocampus region. If the cholinergic neurons are less, it causes Alzheimer's disease.

Another neurotransmitter, *nor-epinephrine* (synthesis from phenylalanine or tyrosine), acts at post ganglionic endings of the sympathetic system. Decrease in levels of dopamine can cause Parkinson's disease.

5-Hydroxytryptamine (5 HT) is involved in sleep mechanisms. *Gamma-amino butyric acid* is a neurotransmitter which has powerful inhibitory actions. Some of the neuromodulators are neuroactive peptides. They are generally polyproteins and act through secondary messengers like cyclic AMP (cAMP).

9.3.5 The Fate of the Neurotransmitter

Postsynaptic membranes bind the neurotransmitters by an active process. The chemicals keep moving in and out of the membrane. The synapse takes care not to have a continuous indefinite action. This is brought about by enzyme degradation, re-uptake mechanisms, recycling mechanisms etc. To illustrate, acetylcholine is removed by enzymatic hydrolysis from post synaptic membrane while nor-adrenaline is removed from the synaptic cleft by catechol-o-methyl transferase. It is further partly uptaken, partly recycled and inactivated by monoamine oxidase.

Neurotransmitters therefore, cross the synapse enabling impulse transmission to an adjacent neuron. Once in the synapse, they are active for only a short time – between 0.5 and 1 millisecond. Enzymes in the synapse inactivate neurotransmitters, which are either taken back into the axon (reuptake) and transported back to the neuron for re-usage or destroyed.

Next, having studied about the mechanism of transmission, let us now get to know how we perceive and respond to stimulus.

9.3.6 How do You Perceive and Respond to a Stimulus

In this world, our first perception is to see, then to hear, sense, smell or taste. The organs involved respectively are the eyes, ears, skin, nose and tongue. These organs have specific sensory cells which enable them to receive any change in the environment. These structures are generally known as *receptors*. They convey their messages to the brain. The brain translates the message into a state called *perception* (awareness). In addition to this, we have baroreceptors (senses pressure changes), chemoreceptors (senses chemical changes) and proprioreceptors (changes/ shifts in positions / posture). The basic mechanism is that all the sensory receptors are very similar. E.g. skin, it can feel pain, temperature, pricks and many more responses. Here, as soon as the receptor cell receives a stimulus, it brings a conformational change in the membrane so that Na^+ ion channels become more permeable. This leads to depolarization and results in creation of a receptor potential. Further, it leads to generation of an action potential.

Action potential is brief, all or none depolarization occurs. The signal propagated slowly changes the frequency in the postsynaptic neuron. We generally get adapted to a prolonged stimulus. The degree and rate would vary e.g. though our touch receptors are fully functional, we are not aware of our clothes touching our body. This is because we are adapting ourselves to the stimulus. This occurs due to regular, continuous information which is persisting.

Finally, in our study of the nerve cell, we will look at how the signals get conveyed to the central nervous system (CNS).

9.3.7 How the Signals are Conveyed to the CNS

Once the action potential is generated at the periphery receptors on the skin in relation to the specific stimulus such as pain, touch, temperature etc., as we have studied above, these action potentials go to the spinal cord through the dorsal root ganglion cells as can be seen from the Figure 9.3. In the spinal cord, the synapse occurs at the *dorsal horn cell* (which is first order sensory relay neurons). The information then passes along the spinothalmic tract system, as you may have noticed in Figure 9.3, to the specific sensory neurons of the thalamus (second order sensory relay neurons). From this thalamic area, the sensations project to the somato-sensory area of the cortex (third order neuron relay station). The sensations are processed and perceived in this area. Therefore, it must be clear to you that at least three neuron relay stations are required for processing and perception of any sensation coming from the periphery. At each of these relay stations, the inter-neuronal transmission occurs through synaptic transmission. This system involved in conveying the sensations from the periphery to the CNS is called the *anterolateral (spinothalamic) system*, which you have already studied in Figure 9.3.

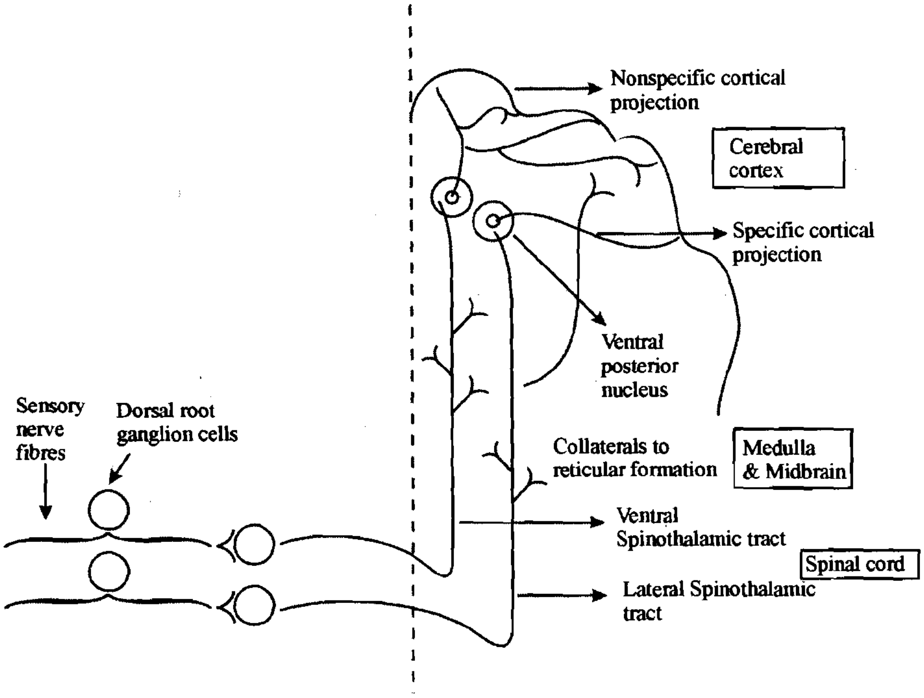


Figure 9.3: Anterolateral system

We have looked at the system involved in perceiving the signals coming from the periphery. What about the signals/sensations from the deep structures such as the joints, muscles etc.? How are these signals conveyed to the CNS? Let's find out.

Sensations from the deep structures (proprioceptive i.e. from the joints, muscles, viscera etc.) after reaching the spinal cord column are relayed through the dorsal column and the lemniscal system to the higher centres, wherein, some of them are perceived and others are subconsciously processed. Figure 9.4 illustrates the dorsal column pathway which you now know are meant for deeper sensations.

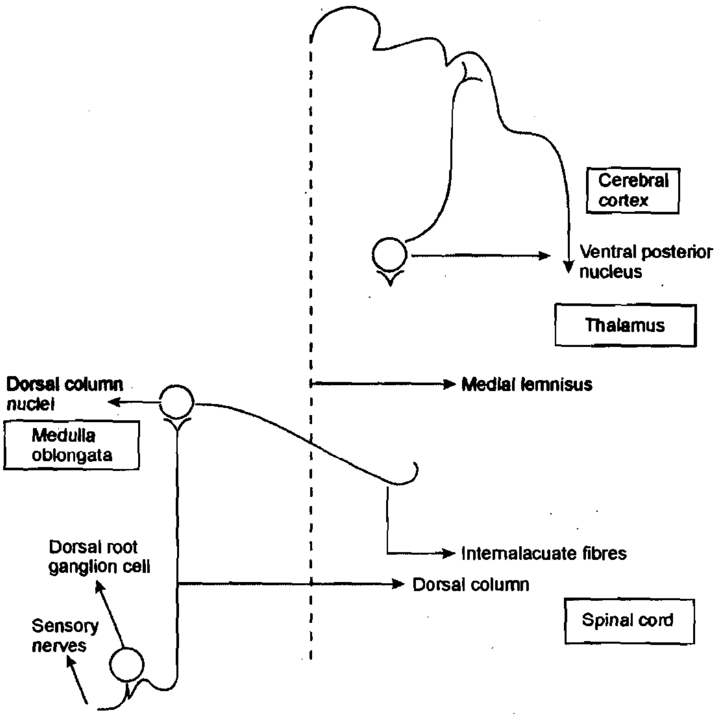


Figure 9.4: Dorsal column system

The processing and perception of this information is censored by the descending tracts at thalamus or spinal cord level (second order or first order relay station). This forms the descending fibres influencing the sensory system. The next sections focus on this aspect.

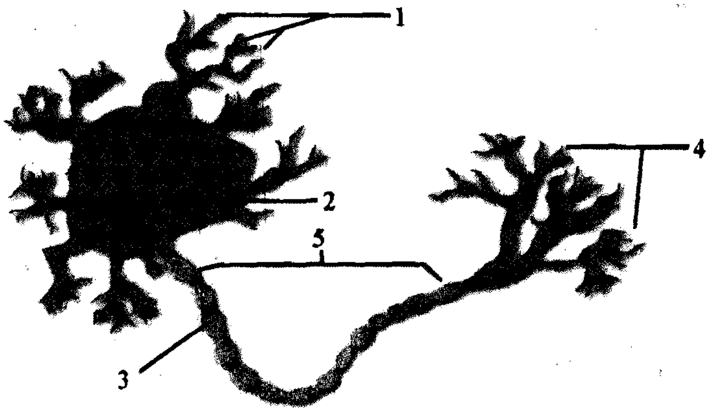
9.3.8 Descending Fibres of the Sensory System

The sensory cortex also sends descending fibers to the thalamic nuclei. They follow a similar route which is very close to that of ascending fibres at all levels. Thus, every region of nervous system has a control on the information that goes to it.

A stimulus perceived depends on the nature of the stimulus and descending influences. Descending fibre activity may be affected by accompanying sensory stimuli other than the one under consideration. The perception of a stimulus is affected by associated stimuli. E.g. intensity of a painful stimulus may be reduced by touch, specially a loving touch or needle movement/vibration as in acupuncture for treatment of pain. We shall now study how the nervous system is structurally organized. But before that, let us review what we have learnt till now.

Check Your Progress Exercise 1

1) Label the parts of neuron in the structure given herewith. Enumerate the functions of a neuron.



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2) Discuss the role of neurons in the process of communication.

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3) What are neurotransmitters? Enlist any two characters of neurotransmitter.

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4) Discuss how messages are conveyed throgh DRG.

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9.4 STRUCTURAL ORGANIZATION OF NERVOUS SYSTEM

Nervous system has an axial organization. The *central* and *peripheral nervous system* make up the nervous system. The brain and spinal cord forms the *central nervous system*. It receives information through sensory neurons, passes the messages to carry out specific actions back by motor nerves. The *peripheral nervous system* has sensory and motor nerves. The mixed nerves consist of sensory and motor fibers together. Together, the central and peripheral nervous system control every activity of our daily life, from breathing and blinking to helping us memorize facts for a test.

Let us get to know the organs of the nervous system. We shall start with the central nervous system.

9.5 THE CENTRAL NERVOUS SYSTEM

We have seen above that the brain and the spinal cord form the central nervous system. In this section we will study about the brain and understand how the spinal cord conducts sensory information from the *peripheral nervous system* (both *somatic* and *autonomic*) to the brain and conducts motor information from the brain to our various effectors – skeletal muscles, cardiac muscle, smooth muscle and glands. It also serves as a minor reflex center.

The brain receives sensory input from the spinal cord, as well as, from cranial nerves (e.g., olfactory and optic nerves and others) and devotes most of its volume (and computational power) to processing its various sensory inputs and initiating appropriate coordinated motor outputs.

We shall learn the structure and functions of these organs in this section. We start with the brain.

9.5.1 Organization of Brain

The brain is made of three main parts: the *forebrain, midbrain* and *hindbrain*. The forebrain consists of the cerebral hemispheres and central core – diencephalon i.e. thalamus and hypothalamus (part of the limbic system). The midbrain consists of the tectum and tegmentum. The hindbrain is made of the cerebellum, pons and medulla. Often the midbrain, pons and medulla are referred together as the *brainstem*. Figure 9.5 illustrates the structure of the brain.

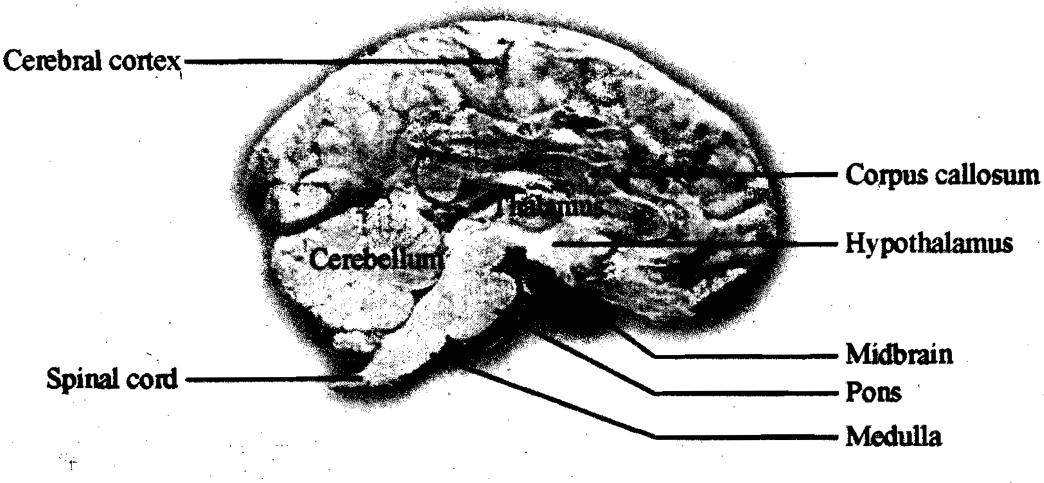

Figure 9.5: The brain

The external covering, skull/cranium protects the brain. Brain being a soft tissue has a meningal membranes covering it. These membranes have spaces in between them which are filled with cerebrospinal fluid (CSF). In fact, the entire surface of the central nervous system is bathed by the clear, colourless cerebrospinal fluid. The CSF is contained within a system of fluid-filled cavities called *ventricles*. There are 4 ventricles as illustrated in Figure 9.6. Two are lateral, which communicate with the 3rd ventricle through independent openings, which are known as *interventricular foramen* (foramen of Monro). 3rd ventricle further communicates with narrow duct passing through mid brain called the *aqueduct of Sylvius*. This further leads through 4th ventricle as shown in Figure 9.6, which is enclosed by medulla oblongata and it continues through the spinal cord as central canal.

The 4th ventricle of the brain posses bunches of vascular tissue – *choroid plexus*. This is an arterial bunch which comes from main arterioles and supplies the brain. The major source of CSF is choroid plexus. The other sources of CSF are ependymal cells of the ventricles and the brain itself via the perivascular spaces. Total volume of CSF in an adult is about 100-125 ml. The rate of CSF formed per day averages to 500 ml per day.

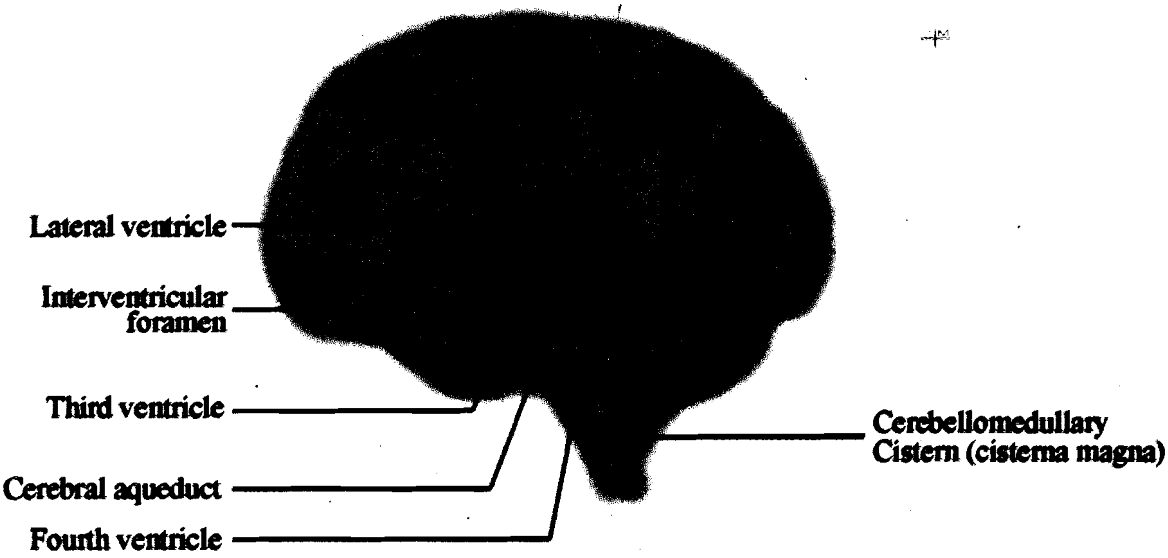

Figure 9.6: The ventricles

So we have seen that the CSF flows through the ventricles. But what does the CSF do? What is its role in the brain?

The CSF has many functions. These include the following:

1) It provides the optimum condition for a meaningful signal/stimulus. The neurons become very sensitive.
2) It helps in maintaining homeostasis. It can transmit neuronal messages to respond for chemo sensitivity which enhances the appropriate homeostatic signals.
3) It helps in removing the proteins which are leaked into the brain since no major lymphatic system prevails here. CSF further shunts these proteins to the blood stream.
4) It protects the brain as a cushion by absorbing all the shocks/jerks etc. It also helps the brain to remain floating inside the skull cavity.
5) It provides buoyancy to the brain. Because the brain is immersed in fluid, the net weight of the brain is reduced from 1400 g to about 50 g only. Therefore, pressure at the base of the brain is reduced.
6) It helps in the excretion of waste materials. The one-way flow from the CSF to the blood takes potentially harmful metabolites, drugs and other substances away from the brain.

We have seen how important CSF is. However, under certain pathological conditions the CSF builds up within the ventricles. This condition is *hydrocephalus*.

So when we look into the internal anatomy, the brain has hollow structures. These hollow spaces are known as *ventricles*. They are filled with CSF. Having got a general idea about the brain organization, next, let us look at each of the specific structures of the brain, starting with the cerebrum.

9.5.1.1 The Cerebrum

The cerebrum is the largest part of the brain, consisting of two cerebral hemispheres. It is divided by a deep cleft, the longitudinal cerebral fissure, into right and left hemispheres, each contains one of the lateral ventricles. These hemispheres are connected by a mass of white matter – corpus callosum (refer to Figure 9.5). A thin layer of gray matter, *the cerebral cortex*, lies on the outside of the cerebrum and contains 75% of the cell bodies in the nervous system. Beneath the cortex lies a mass of *white matter* made up of myelinated nerve fibers connecting the cell bodies of the cortex with the rest of the nervous system.

The superficial part of the cerebrum i.e. the cortex shows many infoldings or furrows of varying depths. These folds are known as *gyri*. They are separated by the fissures known as the *sulci*. These foldings increase the area of the cerebrum. The interior of the cerebrum, as learnt above, are connected by masses of nerve fibres, tracts which make up the white matter of the brain. The afferent or efferent fibres linking the different parts of the brain and spinal cord are:

- *Arcuate (association fibres):* connects different parts of the cerebral cortex by extending from one gyrus to another, some are adjacent, some are distant.
- *Commissural fibres:* connects the two cerebral hemispheres (corpus callosum).
- *Projection fibres:* connects cerebral cortex gray matter with lower parts of the brain with the spinal cord.

The cerebral cortex is divided into four sections, called "lobes" - *the frontal lobe, parietal lobe, occipital lobe* and *temporal lobe.* Figure 9.7 presents the visual representation of the cortex, where you can locate these four lobes.

Figure 9.7: The four lobes of the cerebral cortex

What is each of these lobes associated with? Let us consider.

- *Frontal Lobe:* reasoning, planning, parts of speech, movement, emotions and problem solving.
- *Parietal Lobe:* movement, orientation, recognition and perception of stimuli.
- *Occipital Lobe:* visual processing.
- *Temporal Lobe:* perception and recognition of auditory stimuli, memory and speech.

Looking at the functionality of each lobe, it must be evident to you that cerebrum has a major function in our body. Let us get to know these functions.

Functions of the cerebrum

The cerebrum is associated with higher brain functions such as thought and action. The three major varieties of activities involved are:

1) Mental activities involved in memory, intelligence, sense of responsibility, thinking, reasoning, moral sense and learning attributed to higher centres.
2) Sensory perception, including pain, touch, temperature, sight, hearing, taste and smell, and
3) Initiation and control of voluntary muscle contraction.

The main areas of the cerebrum are associated with sensory perception (sensory centre) and voluntary motor activity (motor activity). Both hemispheres are equally active unless mentioned specifically. Figure 9.8 shows these cerebral functional areas. Let us get to know them.

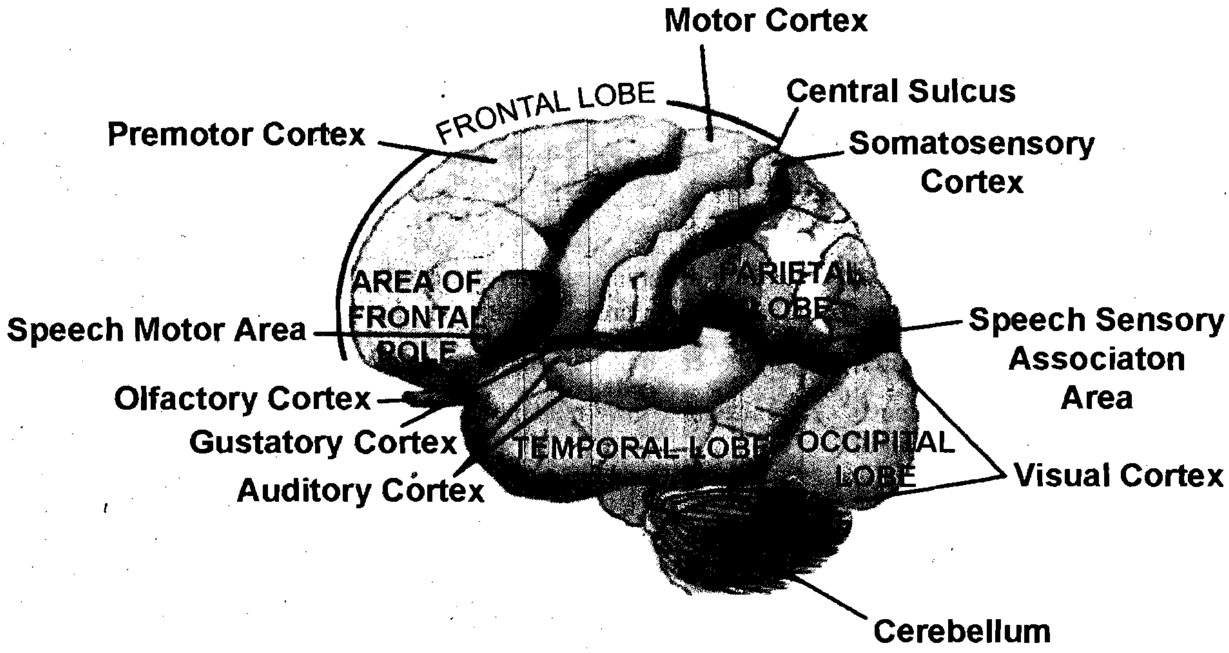

Figure 9.8: Cerebral functional areas

The *motor area* lies in the frontal lobe, immediately anterior to the central sulcus (a brain fissure extending upward on the lateral surface of both hemispheres, separates the frontal and parietal lobes). The nerve cells are pyramid shapes and imitate contraction of voluntary muscles. The nerve fibre from this cell passes downwards through internal capsule to the medulla and then crosses to the opposite side, descends in the spinal cord. In the spinal cord, the nerve synapse to stimulate a second neuron which terminates at the motor end-plate of a muscle fibre. This shows that the motor area of the right hemisphere of the cerebrum controls voluntary muscle movement on the left side of the body and vice-versa. The neuron which has its cell in the cerebrum is the *upper motor neuron*, while the one with the cell in spinal cord is the *lower motor neuron*. Damage to either of them causes paralysis.

In the motor area of the cerebrum, body is represented upside down, i.e. the cells nearest the cortex control the feet and those in the lowest part control the head, neck, face, fingers. In comparison with the trunk, the hand, tongue and lips are represented by large cortical areas.

The pre motor areas too lie in the frontal lobe immediately anterior to the motor area as highlighted in the Figure 9.8. The cells are thought to exert a controlling influence over the motor area, ensuring a series of movements, e.g. while writing or tying a shoe lace, many muscles contract but the movement must be carried out in a particular sequence. This is described as *manual dexterity*. In the lower part of this area, just above the lateral sulcus is the *broca's area* which controls movement for speech. It is dominant in the left hemisphere in the right handed people and vice versa.

The *frontal area* or pole, as shown in the Figure 9.8, extends anteriorly from the pre motor area to include the remainder of the frontal lobe. This area is large and is highly developed in humans. Communications between this region and the other region and other areas are responsible for behaviour, character and emotional state of the individual, as mentioned above.

The *post central area* is behind the central sulcus. Here, the sensations of pain, temperature, pressure and touch, knowledge of muscular movements and position of joints are perceived. The sensory areas of the right hemisphere receive impulses from left side of the body and vice versa.

The *parietal area,* as you can see in the Figure 9.8, lies behind the post central area and includes greater part of parietal lobes of the cerebrum. It is functional in providing accurate knowledge of objects. The objects can be recognized by touch alone, because of the knowledge from past experience is retained in this area.

The *sensory speech* area is situated in the lower part of the parietal lobe and extends into temporal lobe as indicated in the Figure 9.8. This area perceives spoken word. Dominance is in left area if the individual is a right handed person and vice versa.

The *auditory area* lies immediately below lateral sulcus within the temporal lobe as can be seen in Figure 9.8. Cells receive and interpret impulses transmitted from inner ear by vestibulocochlear nerve.

The *olfactory area* lies deep within the temporal lobe. Look at Figure 9.8 for its position. Cells receive and interpret impulses from nose which come through olfactory nerves. The taste area is above lateral sulcus, in deep layers of the sensory area.

The *visual area* lies behind the parieto-occipital sulcus and includes greater part of occipital lobes. Optic nerve passes from eyes to this area which receives and interprets impulses as visual impressions.

Deep within the cerebral hemispheres are groups of nerve cells called *nuclei* or *ganglia* which act as relay stations, where impulses are passed from one neuron to next in a chain. The basal nuclei are, therefore, also called the *basal ganglia.* The term *"basal"* refers to the location of these collections of neurons (nuclei or ganglia) deep within the brain, seemingly at its very base. This region located at the base of the brain is composed of 4 clusters of neurons or nerve cells – sensory nuclei, association nuclei, non specific nuclei and motor nuclei. This area of the brain is responsible for body movements and coordination. The area influences skeletal muscle tone. If control is inadequate or absent, movements are jerky, clumsy and unco-ordinated.

The discussion above focused on the cerebrum. Next, let us look at the other structures of the forebrain i.e. the *thalamus* and *hypothalamus (diencephalon)*, which you learnt earlier, are a part of the limbic system.

9.5.1.2 The Limbic System

The limbic system, as you would realize, is also referred to as the *emotional brain.* It is found buried within the cerebrum. This system contains the thalamus, hypothalamus and other related part like the amygdala and hippocampus. Let us get to know about the thalamus and the hypothalamus.

Thalamus

Thalamus is *a large mass of gray matter deeply situated in the forebrain.* Figure 9.9 illustrates the position of the thalamus.The structure has sensory and motor functions. Almost all sensory information enters this structure where neurons send that information to the overlying cortex. Axons from every sensory system (except olfaction) synapse here, as the last relay site before the information reaches the cerebral cortex.

Thalamus consists of two masses of nerve cells and fibres situated below corpus callosum, one on each side of the 3rd ventricle. Sensory inputs from skin, viscera and special sense organs are transmitted to the thalamus before re-distribution to the cerebrum. Thalamus is a collection of neurons which are organized into a number of nuclear masses. All sensory information reaches thalamus where it can be integrated. It also has non-sensory functions.

Hypothalamus

The hypothalamus is composed of a number of groups of nerve cells. It is situated below and in front of thalamus, immediately above the pituitary gland. Refer to Figure 9.9 for identifying its location in the brain. Hypothalamus is linked to the posterior lobe of pituitary gland by nerve fibres and to anterior lobe by a complex system of blood vessels. Through these connections, hypothalamus controls output of hormones from both lobes of the gland. The structure is involved in functions including homeostasis, emotion, thirst, hunger, body temperature, circadian rhythms, defensive reactions – fear, anger, rage etc. and control of the autonomic nervous system. In addition, it controls the pituitary.

With this, we end our discussion of the limbic centre. We shall move on to the mid brain next.

9.5.1.3 Midbrain

The midbrain is the area of the brain situated around the cerebral aqueduct between the cerebrum above and the pons varolli below. Midbrain consists of a group of nerve cells and nerve fibers which connects the cerebrum with lower parts of the brain and with spinal cord. These nerve cells act as relay stations for the ascending and descending nerve fibers.

The midbrain consists of the *tectum* and *tegmentum*. It is involved in functions such as vision, hearing, eye movement and body movement. The anterior part of the mid-brain has the cerebral peduncle, which is a huge bundle of axons travelling from the cerebral cortex through the brain stem and these fibers (along with other structures) are important for voluntary motor function. Often the midbrain, pons and medulla are referred together as the *brain stem*. Figure 9.9 illustrates the brain stem.

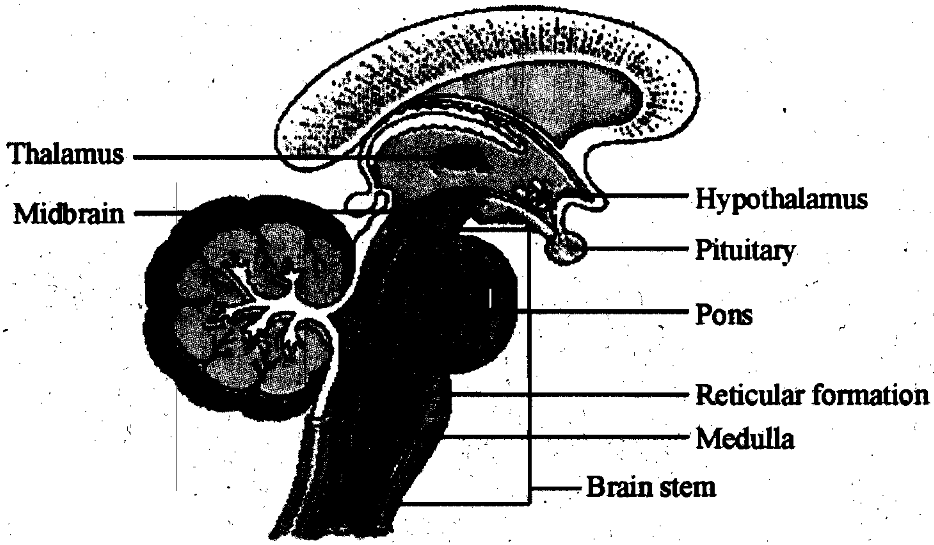

Figure 9.9: The brain stem

The brain stem is the lowest part of the brain. It serves as the path for messages travelling between the upper brain and spinal cord but is also the seat of basic and vital functions such as breathing, blood pressure and heart rate, as well as reflexes like eye movement and vomiting. A canal runs longitudinally through the brain stem structures i.e. medulla, pons and midbrain, carrying cerebrospinal fluid. Also distributed along its length is a network of cells, referred to as the *reticular formation*, which governs the state of alertness. We shall study about it later in section 9.5.1.7.

Check Your Progress Exercise 2

1) Briefly discuss the structural organization of nervous system.

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2) What are the components of the brain?

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3) State the functions of the following:

a) Cerebrum

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b) Thalamus

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c) Hypothalamus

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d) Midbrain

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4) Match the following:

A	B
a) Frontal area	i) Manual dexterity
b) Pre-motor area	ii) Knowledge of Muscular movements and position of joints
c) Post central area	iii) Emotional state
d) Temporal lobe	iv) Visual areas
e) Occipital lobe	v) Auditory

Next, we move on to the hindbrain. The hindbrain is made of the cerebellum, pons and medulla. Let us learn about each of these structures.

9.5.1.4 Pons Varolli

Look at Figure 9.9. Situated in front of the cerebellum below the midbrain and above the medulla oblongata, is the pons. It is involved in motor control and sensory analysis. For example, information from the ear first enters the brain in the pons. It has parts that are important for the level of consciousness and for sleep. Some structures within the pons are linked to the cerebellum, thus are involved in movement and posture.

Pons consists mainly of nerve fibers which form a bridge between the two hemispheres of the cerebellum and fibers passing between higher levels of brain and spinal cord. There are groups of cells which act as relay stations and some of which are associated with the cranial nerves. The anatomical structure of pons varolli is different from that of cerebrum in the aspect that here the nerve cells lie deeply and nerve fibers are on the surface.

Next, we shall read about the medulla oblongata.

9.5.1.5 Medulla Oblongata

The medulla extends from the pons above and is continuous with the spinal cord below as can be seen in Figure 9.9. It is about 2.5 cm long shaped like a pyramid with a base upwards. It lies within the cranium just above foramen magnum. The anterior and posterior surfaces are marked by central fissures. The outer aspect is composed of white matter, which passes between the brain and spinal cord and gray matter lies centrally. Some cells constitute relay stations for sensory nerves passing from spinal cord to the cerebrum. The vital centers consisting of groups of cells associated with autonomic reflex activity lie in the deeper area. These are the cardiac, respiratory, vasomotor and reflex centers for vomiting, coughing, sneezing and swallowing.

The medulla has several special features:

- *Pyramids:* Pyramids are the bulges of ventral surfaces, where most of the lateral corticospinal tracts originating from motor area of cerebrum decussate and cross over to opposite side. This means left hemisphere of cerebrum controls right half of the body and vice versa.
- *Sensory decussation:* Some of the sensory nerves ascending to the cerebrum from spinal cord, cross from one side to the other in the medulla.
- *Cardiac centers:* These control rate and force of cardiac contraction. Sympathetic and parasympathetic fibers originating in the medulla pass to the heart. Sympathetic stimulation increases the rate and parasympathetic decreases.
- *Respiratory center:* The center for regulating rate and depth of respiration is present in the medulla. Here, nerve impulses initiate respiratory mechanism. The center is stimulated by excess CO_2, to a lesser extent by deficiency of O_2 in blood.
- *Vasomotor center:* The vasomotor center is found in medulla. It controls diameter of the blood vessels especially the ones which have smooth muscle fibers in their walls. The impulse reaches the blood vessel through autonomic nervous system. Stimulation may either cause constriction or dilatation, depending on the site. It also controls vasomotor responses linked with body temperature, emotions, excitement, fall in blood pressure etc.

- *Reflex center:* This center present in the medulla is responsible for controlling reflexes such as swallowing, vomiting, coughing and sneezing. When irritating substances are present in the stomach or respiratory tract, nerve impulses pass to medulla (which controls vomiting, coughing, sneezing and swallowing.)
- *Cranial nerves:* Four cranial nerves (9-12) leave the medulla.

So we have seen that the medulla oblongata is responsible for maintaining vital body functions, such as breathing, blood pressure and heart rate.

Next, we shall review the third part of the hindbrain i.e. the cerebellum.

9.5.1.6 The Cerebellum

Cerebellum is situated behind pons and immediately below posterior region of the cerebrum occupying the posterior cranial fossae (as shown in Figure 9.9). It is ovoid in shape as can be seen in Figure 9.10 and is similar to the cerebrum in that it has two hemispheres and has a highly folded surface or cortex. Gray matter forms surface of the cerebellum and white matter lies deeply. This structure is associated with the regulation and coordination of movement, posture and balance. A number of fibers project to and from the cerebellum. They are mainly the cerebellar *afferents* and *efferents*. There are a number of nuclei in the center which connect through different pathways to the motor neurons.

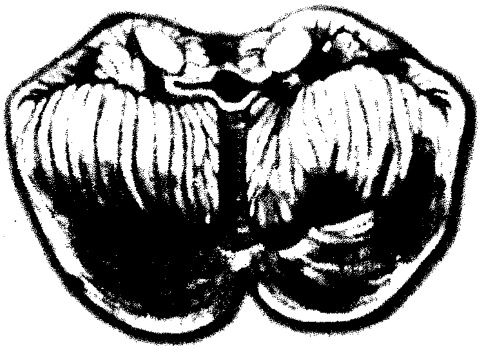

Figure 9.10: The cerebellum

We shall look at the intra cerebellar organization next. This discussion will give you a good idea about the functioning of the cerebellum. You will find this section a bit technical. Do not get bog down by the information provided. Try to understand the organization and its function.

The cortex of the cerebellum consists of 3 layers – *molecular layer, purkinje cell layer* and *granular layer*. The granular layer receives most of the inputs to the cerebellum and transmits them to molecular layer. The major cellular elements in the molecular layer are the *stellate* (star shaped), *golgi* and the *basket cells* and in the middle layer are present purkinje cells as illustrated in Figure 9.11. Inputs to cerebellum reach through mossy fibers from spinal cord and brainstem. The fiber makes a close synaptic contact with numerous granular cells and forms a glomerulus. The axons of these cells run perpendicular to the cerebellar cortical surface and on reaching the molecular layer, bifurcate into parallel fibers. They run parallel to each other and to the cortical surface. These fibers make axo-dendrite synapses with numerous purkinje cells and also with the 3 types of inter neurons i.e. golgi, stellate and basket cells. Their axons further synapse with purkinje cells. Thus, purkinje cells receive direct and indirect inputs from parallel fibres.

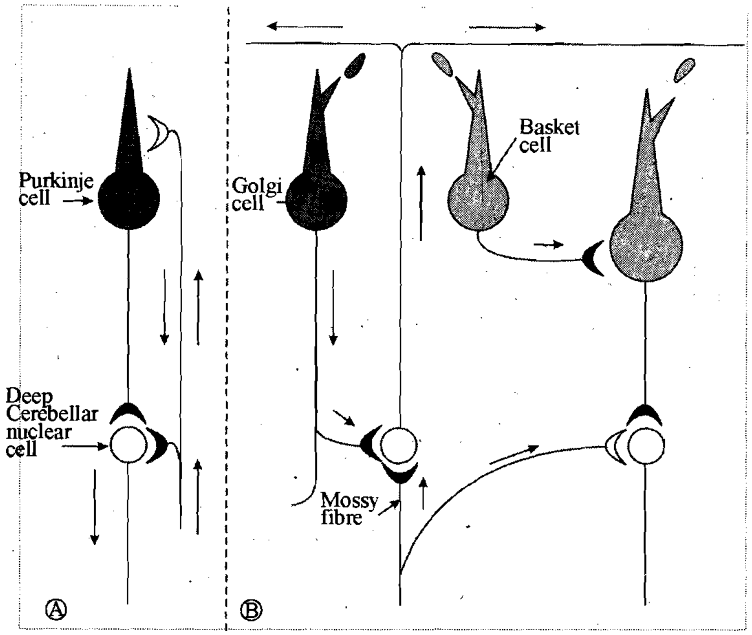

Figure 9.11: A schematic representation showing intra cerebellar organization

There is a single climbing fibre associated with single purkinje cell. This one to one contact of the fibre involves multiple synapses over the dendritic tree of each purkinje cell they activate. The purkinje cells in this way reflect a very powerful input.

A third input to cerebellar cortex is aminergic. It includes noradrenergic afferents. They regulate the excitability of the cortical neurons.

The parallel fibres through the 3 interneurons send inhibitory signals to purkinje cells. Golgi cells send messages as feedback to inhibit granular cells thus shutting off the input via mossy fibre system. Basket and stellate cells also inhibit purkinje cells.

Thus, one can conclude that the function of this precise arrangement correlates to:

1) Mossy fibre activitation of granular cells can excite purkinje cells via parallel fibres.
2) Parallel fibres can excite basket and stellate cells which surrounds purkinje cells.
3) After a short delay, Golgi cell feedback inhibition shuts off the activating input from granular cells.

Thus, the regulatory action can govern the rate, range, direction and force of movements.

What functions does the cerebellum perform?

The main functions of cerebellum include control of muscle tone and posture, equilibrium and coordination of movements. Let us see how these functions are performed.

Corticospinal tract informs the cerebellum about the output of motor cortex. The feedback is also received through spinocerebellar tract, which comes from muscles, tendons and joints. It can discriminate stages between actual movements and position.

Functional medial and lateral corticonuclear divisions of cerebellum (i.e. medial cortico fastigial or flocculonodular and lateral corticodental) influence medial and lateral motor systems. Thus medial portion of cerebellum controls tone, posture and equilibrium and lateral controls and coordinated fine and skilled movements at distal joints.

Having learnt about the functions, consider the situation when the cerebellum does not functions properly. What are the disorders related to the non-functioning of the cerebellum? Let's find out.

Some disorders of the cerebellum

Damage to cerebellum causes motor disorder. Synergy refers to *smoothness and co-ordination of various movements.* Disturbances can create asynergia or ataxia, a common form is dysmetria, in which the patient looses ability to bring his/her own muscles back to desired position. It produces an unsteady joint. It can also produce speech disorders. Cerebellar ataxia, tremors (trembling/shaking) and hypotonia (low muscle tone) are examples.

Finally, let us study about the reticular formation.

9.5.1.7 Reticular Formation

Reticular formation, as shown in Figure 9.9, is an apparently diffusely organized area that forms the central core of the brain stem. It is *the collection of neurons and meshwork of fibres in the core of the brain stem.* It has many synaptic links with other parts of the brain, hence constantly receiving information, being transmitted in specific ascending and descending tracts.

What are the functions of the reticular formation?

The reticular formation is involved in four general types of functions:

Motor control: Co-ordination of skeleton-muscular activity is associated with voluntary motor movements and the maintenance of balance.

Visceral control: It controls activities of autonomic nervous system e.g. cardio vascular, respiratory and gastrointestinal activity.

Sensory control: Selective awareness through reticular activating system which selectively blocks or passes sensory information to the cerebral cortex. E.g. slight noise produced by an ill child's movement makes the mother awake but responses of regular trains passing may be suppressed.

Control of consciousness: The activity of the cerebral cortex (arousal) depends upon ascending reticular activating system (ARAS). It also regulates cortical excitability hence electrical activity (EEG of the brain)

With the functions of the reticular formation, we come to an end of our study of the brain.

Check Your Progress Exercise 3

1) Mention the special features of medulla oblongata.

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2) List the major functions of cerebellum.

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3) What is meant by reticular formation? Enlist its functions.

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You may recall reading earlier in the beginning of the Unit, that the brain is a part of the central nervous system. Do you recall which other organ forms the central nervous system? Yes, it is the *spinal cord.* Next, we shall read about the spinal cord.

9.5.2 The Spinal Cord

Spine is one of the most important parts of the body. Without it perhaps we would not keep ourselves upright or even stand up. In fact, it gives our body a structure and support. The spine is so designed so as to protect our spinal cord. The spinal cord is *a column of neural tissue that connects our brain with the rest of our body, allowing us to control our movements.* Figure 9.12 illustrates the spinal cord. Without a spinal cord, we would not be able to move any part of our body and our organs would not function.

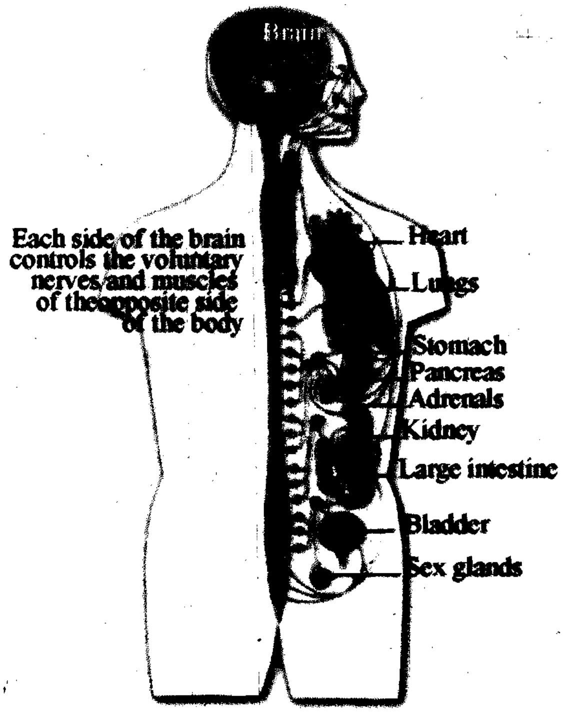

Figure 9.12: The spinal cord and the nerves supplying impulses to various organs

The spinal cord is an elongated cylindrical part of the CNS. It is a column of millions of nerve fibers that run through our vertebral canal. The spinal cord is suspended in the vertebral canal surrounded by the meninges and cerebrospinal fluid. It extends from the brain to the area between the end of our first lumbar vertebra and top of the second lumbar vertebra. At the second lumbar vertebra, the spinal cord divides into several different groups of fibers that form the nerves that will go to the lower half of the body.

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A protective membrane called the *dura mater* covers the spinal cord. The dura mater forms a watertight sack around the spinal cord and the spinal nerves. Inside this sack, the spinal cord is surrounded by spinal fluid. The spinal cord is about 45 cm in length in Caucasian males. Nerves conveying impulses from brain to various organs and tissues descend through the spinal cord. At appropriate levels, they leave the cord and pass to the structure they supply. This is why damage to the spinal cord can cause paralysis in certain areas and not others – it depends on which spinal nerves are affected. Figure 9.12 illustrates how the nerves supply impulses to various organs. The nerves of the *cervical spine* go to the upper chest and arms. The nerves in our *thoracic spine* go to our chest and abdomen. The nerves of the *lumbar spine* then reach to our legs, bowel and bladder. These nerves coordinate and control all the body's organs and parts, and let us control our muscles.

Similarly, sensory nerves from organs and tissues enter and pass upwards in the spinal cord to the brain. Spinal reflexes are independent of the brain. They are facilitated by extensive nervous connection between sensory and motor neurons at the same or different levels on the cord.

Spinal cord is incompletely divided into 2 equal parts by a shallow median fissure anteriorly and by a narrow posterior median septum at the posterior part. A cross section shows that it is composed of gray matter in the center and is surrounded by white matter supported by neuroglia as highlighted in Figure 9.13. Let us see what the gray and white matter is composed of.

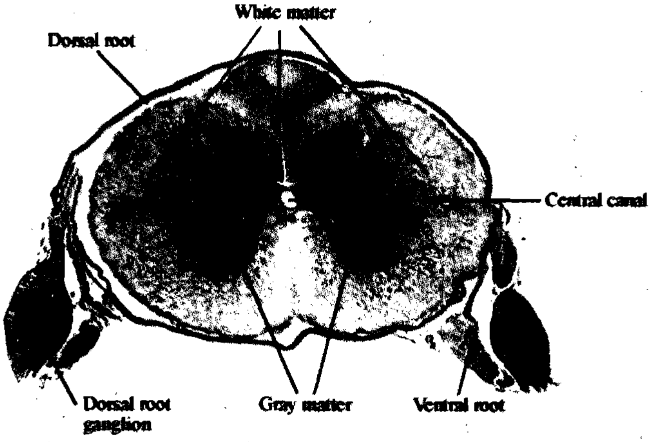

Figure 9.13: Cross-section of spinal cord

Gray matter

The gray matter has two posterior, two anterior and two lateral columns. The area which lies transversely is known as *transverse commissure*. The nerve cells may be sensory cells receiving impulses from periphery of the body, it can transmit impulses to skeletal muscles through motor neurons.

A posterior column of gray matter contributes to the formation of white matter of the cord and transmits sensory impulses to the brain. Anterior columns promote onward movements of nerve impulses.

White matter

The white matter of the spinal cord is arranged in three columns or tracts – *anterior, posterior* and *lateral*. These tracts are formed by the sensory nerve fibres ascending towards brain and motor fibres descending from brain and fibres of connector.

Moving a muscle usually involves communication between the muscle and the brain through nerves. The impetus to move a muscle may originate with the senses. For example, the special nerve endings in the skin (sensory receptors) may sense pain when a person steps on a sharp rock or sense discomfort when a person picks up a very hot cup of coffee. This information is sent to the brain and the brain sends a message to the muscle about how to respond. This type of exchange involves two complex nerve pathways: *the sensory nerve pathway to the brain* and *the motor nerve pathway to the muscle.* Figure 9.14 illustrates these pathways. Let's get to know about these ascending and descending nerve tracts next.

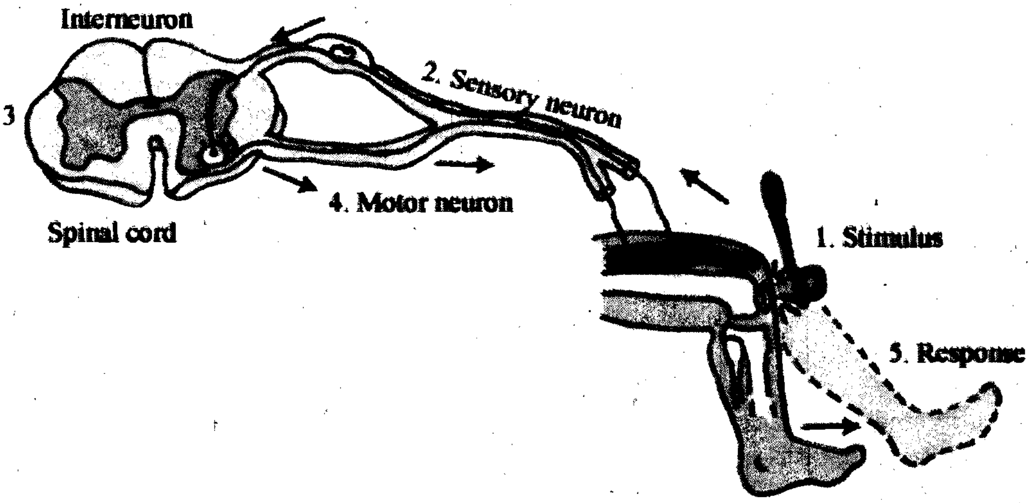

Figure 9.14: Sensory and motor nerve pathways

A) *Sensory Nerve tracts (Afferent/Ascending)*

There are 2 main sources of sensation transmitted to the brain via spinal cord. These include:

1) *The nerve ending in the skin* – Cutaneous receptor is stimulated by three neurons to the sensory area in the opposite hemisphere of the cerebrum. Here it is perceived. Crossing to the other side or decussation occurs either at the level of entry into the cord or in the medulla.

2) *The tendons, muscles, joints* – Sensory nerve endings here are known as *proprioceptors* which are stimulated by stretch. They are associated with balance, posture, perception of body position etc. with the inputs from eyes and ears. They specifically reach the areas by:
   - a 3 neuron system whereby the impulses reach sensory area of opposite hemisphere of cerebrum, and
   - a 2 neuron system, impulses reach cerebellar hemisphere of the same side.

B) *Motor Nerve tracts (Efferent/Descending)*

Neurons, which transmit nerve impulses away from the brain, as you learnt earlier, are motor neurons. Their stimulation results in:

a) *Contraction of voluntary muscles (striated, skeletal):* Stimulations here are under our will, consciously controlled in the cerebrum. Some impulses are initiated in the midbrain, brainstem and cerebellum. This occurs below the level of consciousness. It is associated with co-ordination of muscular activity. e.g. fine movements required in posture and balance. The motor pathways from brain to muscle are made up of 2 neurons – upper motor neuron and lower motor neuron.

b) *Contraction of the smooth (involuntary) muscles* and secretion by glands is controlled by nerves of the autonomic part of the system. Here, four neurons are involved:

1) *Upper motor neurons:* These have their cells in brain at a level below the cerebrum i.e. in midbrain, brain stem and spinal cord. They influence muscular movements with relation to posture balance, co-ordination and muscle tone.

2) *Spinal reflexes:* They have 3 elements – sensory neurons, connector neurons and lower motor neurons and simple reflex arc. A reflex action is an immediate motor response to a sensory stimulus. Impulses from skin are transmitted to spinal cord by sensory nerves. These stimulate many connector and lower motor neurons in the cord which results in contraction of many skeletal muscles. Reflex action takes place quickly, the motor response may have occurred simultaneously with the perception itself. Reflexes of this type are invariably protective and occasionally can be inhibited e.g. a precious plate, which is very hot, when lifted every effort will be made to over come the pain to prevent dropping of the plate.

3) *Stretch reflexes:* Here only two neurons are involved. Cell of lower motor neuron is stimulated by sensory neuron. There are no connector neurons involved e.g. knee jerk reflex can be demonstrated here at any point, where a stretched tendon crosses a joint. Tap the tendon just below the knee when it is bent, sensory endings in the thigh muscle and tendons are stretched. This initiates an impulse to pass into spinal cord into the lower motor neuron in the anterior column of gray matter on the same side. As a result, thigh muscle suddenly contracts and the foot kicks forwards.

4) *Autonomic reflex:* We shall read about this subsequently in the section on autonomic nervous system.

Based on our discussion above, now can you highlight the functions of the spinal cord? Here, the functions have been presented for your perusal.

The spinal cord carries out two main functions:

- It connects a large part of the peripheral nervous system to the brain. Information (nerve impulses) reaching the spinal cord through sensory neurons is transmitted up into the brain. Signals arising in the motor areas of the brain travel back down the cord and leave in the motor neurons.
- The spinal cord also acts as a minor coordinating center responsible for some simple reflexes like stretch reflex and the withdrawal reflex.

With the study of the structure of the spinal cord and the sensory and motor nerve impulses, we end our discussion about the spinal cord.

We looked at the brain and the spinal cord which forms the central nervous system in this section. Next, let us foous on the peripheral nervous system.

Check Your Progress Exercise 4

1) Explain the structure of spinal cord, giving its functions.

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2) Give the details of sensory nerve pathway.

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3) What is the role of motor neurons in voluntary and involuntary muscle movements?

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4) What is a reflex action or reflex arc?

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9.6 PERIPHERAL NERVOUS SYSTEM (PNS)

The peripheral nervous system or PNS, is *a part of the nervous system* and consists of the *nerves* and *neurons* that reside or extend outside the central nervous system-to serve the limbs and organs.

The peripheral nervous system consists of:

- *sensory neurons* running from stimulus receptors that inform the central nervous system of the stimuli, and
- *motor nerves* running from the spinal motor neurons to the muscles and glands – called effectors – that take action. Figure 9.15 illustrates the systems within the PNS.

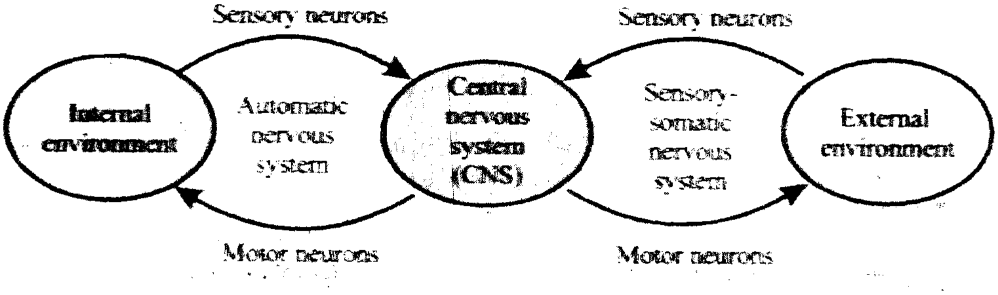


Figure 9.15: The sensory and the motor neurons

The peripheral nervous system, as can be seen in Figure 9.15, is subdivided into:

- Somatosensory nervous system, and
- Autonomic nervous system

Let us now get to know these two systems within the PNS.

9.6.1 Somatosensory System

The somatosensory system consists of:

- 12 pairs of cranial nerves, and
- 31 pairs of spinal nerves.

All our conscious awareness of the external environment and all our motor activity to cope with it operate through the somatosensory division of the PNS. Each nerve has nerve bundles, each bundle has a covering of following protective connective tissue:

1) Endoneurium: delicate tissue surrounding individual fibres
2) Perineurium: smooth tissue surrounding bundles of fibres.
3) Epineurium: surrounds and encloses members of bundles of nerve fibres.

Let us get to know more about these nerves. We shall start with the spinal nerves.

A) *Spinal Nerves*

As mentioned earlier, there are 31 pairs of spinal nerves that leave the vertebral canal by passing through the intervertebral foramina formed by adjacent vertebrae. All of the spinal nerves are "mixed", that is, they contain both sensory and motor neurons. A representation of these spinal nerves supplying to the specific organs, you may recall has already been presented, in Figure 9.12. Look up Figure 9.12 now.

You will realize that these spinal nerves are named and grouped according to vertebrae to which they are associated.

8 – Cervical, 12 – Thoracic, 5 – Lumbar, 5 – Sacral, 1 – Coccygeal

Although there are only 7 cervical vertebrae, there are eight nerves because the first pair leaves the vertebral canal between the occipital bone and the atlas and eighth pair leaves below last cervical vertebrae.

Lumbar, sacral, coccygeal nerves leave spinal cord near its termination at the level of first lumbar vertebrae. They extend down inside the vertebral canal in the subarachnoid space, which forms a sheaf of nerves, which resembles a horse's tail – the cauda equina. They leave the vertebral canal at the appropriate lumbar, sacral or coccygeal level.

There are 12 pairs of thoracic nerve. Eleven of them are situated between the ribs, and are therefore termed *intercostal;* the twelfth lies below the last rib. They pass in-between the ribs supplying the intercostal muscles and overlying skin. The 12th pairs are the sub costal nerves. The 7th to 12th thoracic nerves also supply muscles of the skin of posterior and anterior abdominal walls.

The spinal nerve arises from both sides of spinal cord and emerges through intervertebral foramina. Each nerve is formed by the union of a motor and sensory nerve root and thus forms a mixed nerve, as mentioned above. Each spinal nerve has contributions from sympathetic part of autonomic nervous system in the form of a preganglionic fibre.

Nerve roots: Each nerve is attached to the medulla spinalis by two roots, an *anterior* or ventral, and a *posterior* or dorsal (as you may have noticed in Figure 9.13). The *anterior nerve root* consists of motor nerve fibres which are the axons of nerve cells. The axons of nerve cells are in the anterior column of the gray matter in the spinal cord. In the thoracic and lumbar region, sympathetic nerve fibres which are axons of cells, is in the lateral columns of gray matter.

Posterior nerve root consists of sensory nerve fibres, having cell bodies in root ganglions and enter the spinal cord.

Immediately after emerging from the intervertebral foramen, each spinal nerve divides into ramus communicants, *posterior* and *anterior ramus*. The ramus communicants are part of pre ganglionic sympathetic neurons of the autonomic nervous system.

The posterior rami pass backwards and divide into medial and lateral branches to skin, muscles etc. The anterior rami supply anterior and lateral aspects of the trunk, upper and lower limbs.

In the cervical, lumbar and sacral regions, the anterior rami unite near the origins to form large masses of nerves or plexus. They divide and branch to proceed to skin, muscles, joints etc. There are 5 such large plexus. They are the cervical plexus, brachial plexus, lumbar plexus, sacral plexus and coccygeal plexus.

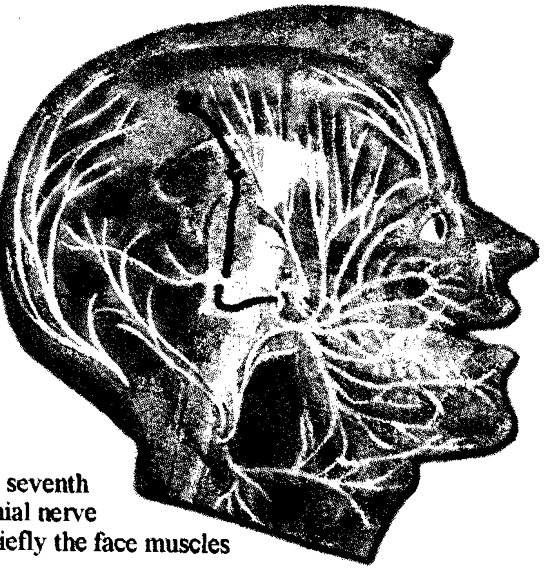
B) *Cranial Nerves*

There are 12 pairs of cranial nerves originating from the brain. Some are sensory, some are motor and some mixed. Table 9.1 presents their type and functions. Look at Figure 9.16, which illustrates these nerves and their functions.

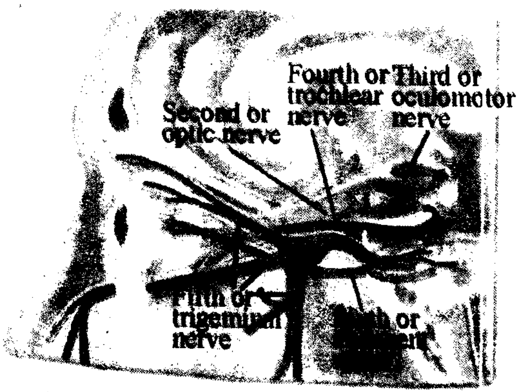
Table 9.1: Cranial nerves – type and functions

Nerve	**Type**	**Functions**
I Olfactory	Sensory	Olfaction (smell)
II Optic	Sensory	Vision (contains 38% of all the axons connecting to the brain)
III Oculomotor	Motor	Eyelid and eyeball muscles
IV Trochlear	Motor	Eyeball muscle
V Trigeminal	Mixed	Sensory: facial and mouth sensation Motor: chewing
VI Abducens	Motor	Eyeball movement
VII Facial	Mixed	Sensory:taste Motor: facial muscles and salivary glands
VIII Auditory	Sensory	Hearing and balance
IX Glossopharyngeal	Mixed	Sensory:taste Motor: swallowing
X Vagus	Mixed	Main nerve of the parasymethatic nervous system
XI Accessory	Motor	Swallowing; moving head and shoulder
XII Hypoglossal	Motor	Tongue muscle

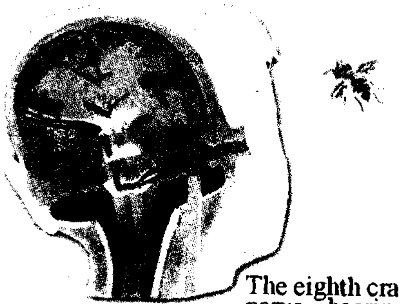
With the discussion on cranial nerves, we end our study of the somatosensory system of the periphery nervous system. Next, we shall study about the autonomic nervous system, which you may recall reading earlier, is the other system of the PNS.



The seventh cranial nerve - chiefly the face muscles

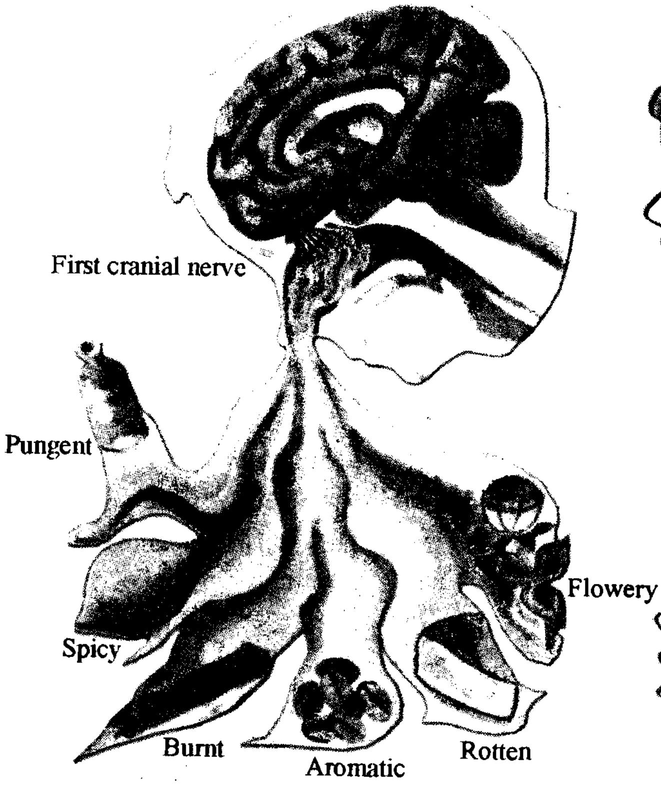


Branches showing 2nd, 3rd, 4th, 5th, 6th cranial nerves



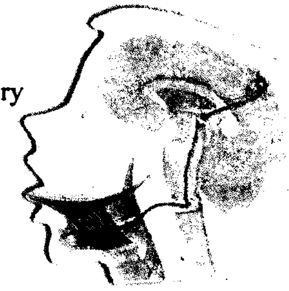
The eighth cranial nerve - hearing and balance

The ninth cranial nerve - taste

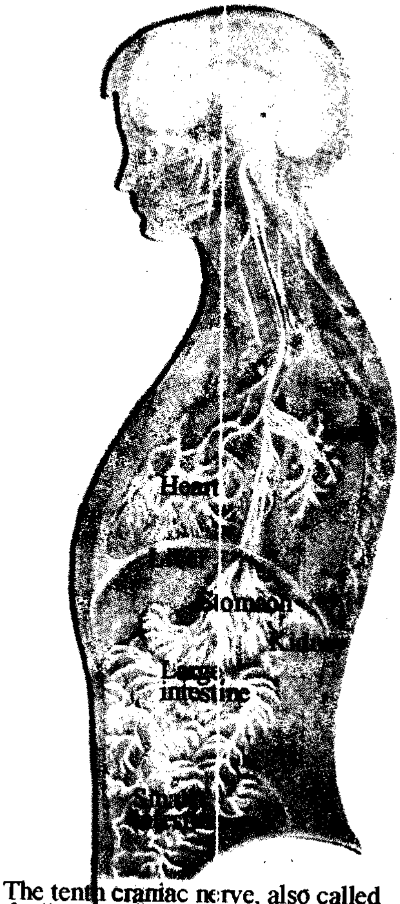


The first cranial nerve known as olfactory nerve, helps us to identify different kinds of odours

The eleventh cranial nerve - neck and shoulder muscles



The twelfth carnial nerve - tongue muscles



The tenth craniac nerve, also called the "vagus nerve", automatically controls the body's heart beat, breathing and digestion

Figure 9.16: The cranial nerves

9.6.2 Autonomic Nervous System (ANS)

The autonomic or involuntary part of nervous system controls the functions of the body carried out automatically i.e. initiated in the brain below the level of cerebrum. Although stimulation may not occur voluntarily, the individual may be conscious of its effect, e.g. an increase in the heart rate. Some of the physiological activities controlled by the ANS are:

1) Rate and force of heart beat
2) Secretion of the glands of alimentary canal
3) Contractions of involuntary muscle
4) Size of pupil of the eyes

So it must be clear to you by now that the actions of the autonomic nervous system are largely involuntary (in contrast to those of the somatosensory system). The autonomic nervous system consists of sensory neurons and motor neurons that run between the central nervous system (especially the hypothalamus and medulla oblongata) and various internal organs such as the heart, lung, viscera and glands. It is responsible for monitoring conditions in the internal environment and bringing about appropriate changes in them. The contraction of both smooth muscle and cardiac muscle is controlled by motor neurons of the autonomic system.

We must also emphasize here that the autonomic nervous system also differs from the somatosensory system in using two groups of motor neurons – the *preganglionic* and *postganglionic* – to stimulate the effectors instead of one.

Autonomic nervous system is divided into 2 parts – *sympathetic* and *parasympathetic.* Sympathetic is a thoracolumbar outflow, parasympathetic craniosacral outflow. What do we mean by thoracolumbar and craniosacral outlfow? Let us get to know about these two systems.

Sympathetic Nervous System

The sympathetic component of the autonomic nervous system is concerned with increasing the level of arousal and energy expenditure – primitive 'fight or flight' behaviour at times of stress.

Alike the parasympathetic nervous system, the central integrating center for sympathetic activity is within the hypothalamus. This may be influenced by higher cortical centre. Efferent fibres descend from the hypothalamus within the intermediolateral columns of the spinal cord. As sympathetic fibres emerge from the central nervous system at spinal segments T1 (thoracic) to L5 (lumbar), the sympathetic system is also known as the *thoraco-lumbar outflow*.

Here 3 neurons are involved in covering impulses from the hypothalamus and medulla oblongata to effectors organs and tissues.

Neuron – 1: has its cell in the brain and its fibre extends to the spinal cord.

Neuron – 2: has its cell in lateral column of gray matter in the spinal cord.

Neuron – 3: has its cell in a *ganglion* (small mass of nerve tissue containing the cell bodies of the neuron) and terminates in the organ or tissue supplied.

The preganglionic motor neurons of the sympathetic system arise in the spinal cord (lateral group column). They pass into sympathetic ganglia which are organized into two chains that run parallel to and on either side of the spinal cord.

The neurotransmitter of the preganglionic sympathetic neurons is *acetylcholine (ACh)*. It stimulates action potentials in the postganglionic neurons. The neurotransmitter released by the postganglionic neurons is *noradrenaline* (also called *norepinephrine*). The action of noradrenaline on a particular gland or muscle is excitatory in some cases, inhibitory in others.

Parasympathetic Nervous System

The main nerves of the parasympathetic system are the tenth cranial nerves, the *vagus nerves*. They originate in the medulla oblongata. Other preganglionic parasympathetic neurons also extend from the brain, as well as, from the lower tip of the spinal cord.

Two neurons are involved in the transmission of impulses from their source to the effectors organ. Neuron -1 has its cell either in the brain or spinal cord. Neuron-2 has its cell either in a ganglion or in the wall of the organ supplied. Having read about the sympathetic and parasympathetic system, now can you explain what are the functions of the ANS? The functions are detailed next.

What are the functions of ANS?

Autonomic nervous system is involved in a complex of reflex activities, which also depend on sensory input and motor output to brain or spinal cord. The reflex actions are contractions of involuntary muscles or glandular secretion. The reflexes are co-ordinated in the brain below the level of consciousness below the cerebral level.

The effects of autonomic stimulation on the body systems are summarized next in Table 9.2.

Table 9.2: Effects of autonomic stimulation on the body systems

Sympathetic	Parasympathetic
On Cardiovascular System:	
Increase rate and force of heart beat, causes dilatation of coronary arteries, increases blood supply to heart muscle.	Effects opposite to those of sympathetic stimulation on heart, spleen and blood vessels.
Causes dilations of blood vessels in skeletal muscles and thus increases the supply of O_2, nutritional materials thereby increasing capacity of muscles to do work.	
Causes sustained contraction of spleen, increases the volume of the circulating blood, can increase blood pressure of the skeletal muscles, can cause constriction of blood vessels and reduces flow of digestive juices.	
On Respiratory System:	
Causes dilatation of bronchi allowing greater amount of air to enter the lungs. O_2 intake and CO_2 output is increased.	Produces constriction of bronchi.
Digestive System:	
Liver converts increased amount of glycogen to glucose.	In stomach and intestine, rate of digestion and absorption of food is increased.
Adrenal glands are stimulated to release adrenaline and nor adrenaline.	There is an increase in the secretion of pancreatic juices and insulin release.
In stomach, intensive contraction and secretion of digestive juices are inhibited, micturation, defaecation	A urethral and anal sphincter relaxation of the sphincter are accompanied by contraction of muscles, micturation and defaecation occurs.
On Eye:	
Contracts muscle fibres of the iris, dilates the pupil, eyes open widely, alertness and excitement etc are maintained.	Circular muscle fibres contract, constricts the pupil, eyelids tends to close and sleepy appearance is met with.
On Skin:	
Increases sweat, increased heat loss occurs, can cause contraction of muscles in the skin, causes appearance of 'goose flesh'.	No parasympathetic supplies to the skin, hence a specific opposite reaction.
Causes constriction of blood vessels, prevents heat loss. Hence sympathetic has dual functions of facilitating heat loss and increases heat production.	
On Genitalia:	
Causes generalized vasoconstriction.	Generalized vasoconstriction.

Having gone through the effect of autonomic stimulation on the body, you would now know that, sympathetic stimulation has similar effects as produced by adrenaline and noradrenaline. It prepares the body to deal with excitement and stressful situation. It mobilizes the body for 'fight' or 'flight' responses. Parasympathetic stimulation, on the other hand, has a tendency to slow down body process except digestion and absorption of food and functions of genitourinary system. Its general effect is that of a peace maker allowing restoration process to occur quietly and peacefully. Normally the two systems function simultaneously maintaining a compatible environment.

In the discussion above, we looked at the functions of the ANS. The autonomic system also receives *afferents* that carry information about the internal organs. Let us get a brief insight into this aspect.

Afferent Impulses from Viscera

The sensory fibres from viscera, which travel along with autonomic nervous system, are called *autonomic afferents*. The impulses they transmit are associated with:

1) Visceral reflexes, usually at the unconscious level.
2) Sensation–hunger, thirst, nausea, sexual sensation, rectal bladder distension etc.
3) Visceral pain.

In *visceral pain*, the nerves are stretched, large number of fibres are stimulated, ischemia and accumulation of metabolites occurs. In *referred pain*, sensory fibres from viscus enter the same segment of the spinal cord as somatic nerves, they stimulate somatic nerves, transmits impulses to cerebral cortex, pain is perceived as originating in the area supplied by somatic nerve. For example, afferents from the heart enter the spinal cord at the same level as those from the shoulder region. This is why pain in the heart (a heart attack) is often referred to the shoulder. For other examples, look at the Table 9.3.

Table 9.3: Tissue of origin and site of referred pain

Tissue of origin of pain	Site of referred pain
Heart	Shoulder
Biliary tract	Right shoulder
Kidney, urethra	Loin and grain
Uterus	Low back
Male genitalia	Low abdomen
Prolapsed disc	Leg

Check Your Progress Exercise 5

1) What is Peripheral Nervous system? What does it consists of ?

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2) Name any two pairs of cranial nerves. Also state the role of each of these.

Nerve	Type	Functions

3) List the physiological activities of the autonomic nervous system.

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4) What are the two components of ANS? Discuss the roles of each of these.

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5) Giving one or two examples, present the effects of autonomic stimulation on the cardiovarcular system.

Sympathetic effect	Parasympathetic effect

The discussion above focussed on the nervous system, its organs and its functioning. Do you know how the functioning of the nervous system, particularly, the brain is monitored? Yes it is throgh a process called EEG. What is EEG? Let us find out.

9.7 ELECTROENCEPHALOGRAM (EEG)

EEG is short for electroencephalogram. An electroencephalography (EEG) is *a painless procedure used to measure the brain's electrical activity.*

Oscillations in electrical potential occur almost continuously between any 2 electrodes placed on the surface of head or on cerebral cortex itself, the records are termed as *Electroencephalogram (EEG)* and *Electrocorticogram (ECG)* respectively. They persist in altered forms during excitement, drowsiness, sleep, coma, anesthesia, epileptic attacks etc. They serve as a direct and measurable indices of brain activity. The study of brain waves has become an important diagnostic tool in clinical medicine.

The spontaneous electrical activity of the brain was discovered by *Caton* in 1875. However, it was *Hans Berger* between 1929-1938 who showed that this could be recorded from the scalp surface of human beings and developed methods for making such recordings.The development of these techniques opened a faithful field of investigation for neurosurgery.

For those of you who are interested to know how EEG is recorded and analyzed, here is a simple description in Box 1.

Box 1: All you wanted to know about EEG

Recording EEG

To record an EEG, electrodes are placed in the frontal, parietal, temporal and occipital regions. These are called *active electrodes*. An indifferent electrode may be placed on the tip of 7th cervical vertebrae, or may be attached to both ears and earthed. An EEG records potential difference between two active electrodes (bi-polar recording) or between an active and indifferent electrode (monopolar recording). EEG leads are named accordingly.

Physiological basis of EEG

An EEG samples the summated activity of a very large number of cortical neurons close to the active electrodes. Summation of excitatory and inhibitory, postsynpatic potentials is recorded. The amplitude of EEG waves depends on how synchronous are the activities of the neurons. Synchronous activity gets summated to give large waves. Asynchronous activities lead to simultaneous deflection in opposite directions, which cancel each other out. A positive deflection may correspond to excitation very close to the surface or to inhibition at a slightly deeper level.

EEG Waveforms: There are normally four waves of EEG. These include:

The alpha waves: They are recorded when a person is relaxed with their eyes closed. He is mentally relaxed and not distracted by sensory stimuli. Hence, it is best to record these waves in a quiet room with the subjects eyes closed.

These waves have an average amplitude of about 50 micro volts in adults, at a frequency of 8-13/second. The high amplitude is suggestive of synchronized activity. It is recorded in the best wave forms from parietal and occipital regions.

The beta waves: These waves are recorded when a person is awake and alert or he is mentally busy or tense. Alpha is promptly replaced by beta rhythm by asking the person to open the eyes or by exposing the person to a sensory stimulus such as clap, bang or touch.

An EEG rhythm indistinguishable from beta rhythm is also recorded when a person is in dream sleep. Beta waves have an average amplitude of 20 micro volts and a frequency of 13-30 per second. The brain is presumably highly active when beta waves are recorded, the amplitude is low due to desynchronized activity. It is recorded from frontal and parietal regions.

Theta waves: These can be recorded when a person is in light sleep, emotional stress and in normally awake children. Average amplitude is 10 micro volt and frequency 4-7/second.

Delta waves: These are recorded when a person is in deep sleep. They have an average amplitude of 100 micro volts and a frequency of 0.5-4/second. These waves represent a highly synchronous inherent activity of cortical neurons, when deprived of thalamic inputs.

Variation with age: Upto 2 years, they are in the delta range. The frequency of waves becomes lower during sleep. From 2 – 6 years of age, awake EEG activity is in theta range. Alpha rhythm appears at about 6 years of age. It is a characteristic of the awake inattentive state for the rest of the person's life.

Analysis of EEG: The analysis of an EEG is known as *power spectral analysis*.

The basic steps are: (1) the computer performs a Fourier analysis on 4 second segment of the EEG, (2) the bar spectrum thus obtained is smooth, and (3) the graphs from 4 second segments are packed sequentially one upon another.

Due to these operations, predominant frequency in EEG appears as a series of tall peaks. The frequency corresponding to the tallest peaks gives EEG rhythm during the recording.

Check Your Progress Exercise 5

1) What is an EEG? How is it useful?

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2) What are the different types of waves in an EEG? Differentiate between α and β waves.

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9.8 LET US SUM UP

In this unit, we learnt about the neurons – the nerve cells. The nerve cell morphology gives us the structural details of a neuron. A neuron, as you would know, has a cell body, dendrites, nucleus and axon etc. Their main function is the transmission of signals.

The nervous system, we learnt, is made up of the central and peripheral nervous system. The brain and the spinal cord form the central nervous system. We studied about the brain, the different organs/parts i.e. cerebellum, medulla, pons etc. and their functions. The spinal cord, we learnt, is a column of nerves that connect our brain with the rest of our body.

The peripheral nervous system, we learnt, is a part of the nervous system which consists of the nerves and neurons that reside outside the central nervous system. We studied the somatosensory and autonomic nervous system within the peripheral nervous system. The peripheral nervous system supplies nerves to all parts of the body. Spinal nerves are 31 pairs, spread throughout the body and reach all parts. There are 12 cranial nerves in our system. While the autonomic nervous system functions through sympathetic and parasympathetic fibers. They are antagonistic to each other and they can co-ordinate and control human systems.

Finally, we got to know about EEG, which helps us to measure the firing and activity patterns of the brain during various physiological conditions.

9.9 GLOSSARY

Autonomic afferents	:	the sensory fibers from viscera which travel along with the autonomic nervous system.
Electroencephalogram	:	a record of electrical activity of the brain measured by electrodes placed on the surface of head or on cerebral cortex.
Ganglia	:	group of nerve cells which act as relay stations.
Gyri	:	folds of cerebral cortex.
Manual dexterity	:	cells of the pre-motor area having a controlling influence over motor area, ensuring a series to movements.

Neurobiology	a study of biological functions of nerves.
Neuron	nerve cell.
Postsynaptic neuron	neuron which receives message.
Post Tetanic facilitation	a higher frequency in the response of a fiber caused due to repeated stimulation of fiber.
Presynaptic neuron	neuron which sends a message.
Receptors	organs having specific sensory cells which enable them to receive a change in environment.
Reflex action	an immediate stereotyped involuntary motor response to a sensory stimulus.
Sulci	fissures separating the folds of cerebral cortex.
Synapse	the junction between two neurons or a neuron and muscle.
Synaptic fatigue	the reduction in the postsynaptic gradual response on repeated stimulation.
Synaptic transmission	process of communication between two neurons across a synapse.
Synergy	smoothness and coordination of various movement.
Threshold	the minimum magnitude by which a depolarized fiber triggers for an action potential.
Vermis	a narrow central 'C' shaped strip separating the 2 hemispheres of cerebellum.

9.10 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

1) (2) Cell Body, (5) Axon, (1 and 4) Dendrite, (3) Schwann cells.

   Neuron is a cell which conducts electric neural impulses from one part of the body to another. Neurons are made up of dendrites and axons. It communicates with other neurons and effector organs at junctures called synapses.

2) Communication occurs through chains of neurons, which interconnect with parts of the neuronal terminals which brings the message and carries the message away. This communication can be from one neuron to the other or from one neuron to muscle. The junction between two neurons is called a synapse.

3) Neurotransmitters are the substances involved in neuronal transmission. They have the following characteristics:

   - The synthesis should be from a neuron.
   - The degradation and uptake mechanism should exist at concerned synapse.

4) The messages through DRG are conveyed to the spinal cord. The information then passes along the spinothalamic tract system to the special neurons in the thalamus and from the thalamic area to the where messages are perceived. The specific pathways for peripheral messages and for deep structures include dorsal column system and anterolateral systems.

Check Your Progress Exercise 2

1) The central and peripheral nervous system make up the nervous system. The brain and spinal cord forms the central nervous system. The brain receives information through sensory neurons, passes the processes messages to carry out specific actions back by motor nerves. The peripheral nervous system has sensory and motor nerves.

2) The brain is made of three main parts: the forebrain, midbrain and hindbrain. The forebrain consists of the cerebrum, thalamus and hypothalamus (part of the limbic system). The midbrain consists of the tectum and tegmentum. The hindbrain is made of the cerebellum, pons and medulla. Often the midbrain, pons, and medulla are referred together as the brainstem.

3) a) The cerebrum performs the following functions:
   - Mental activities
   - Sensory perception
   - Initiation and control of voluntary muscle contraction.

   b) Sensory inputs from skin, viscera and special sense organs are transmitted to the thalamus before re-distribution to the cerebrum. All sensory information reaches thalamus where it can be integrated. It also has non sensory functions.

   c) Hypothalmus controls output of hormones from both lobes of the gland. It is involved in functions including homeostasis, emotion, thirst, hunger, body temperature, circadian rhythms, defensive reactions – fear, anger, rage etc., and control of the autonomic nervous system. Also, it controls the pituitary.

   d) Midbrain is involved in vision, hearing, eye movement and body movement. The anterior part of the mid brain is important for voluntary motor function. The brain stem serves as the path for messages travelling between the upper brain and spinal cord. It is also the seat of basic and vital functions such as breathing, blood pressure, and heart rate, as well as reflexes like eye movement and vomiting. Also distributed along its length is a network of cells, referred to as the reticular formation, which governs the state of alertness.

4) a) - iii)
   b) - i)
   c) - ii)
   d) - v)
   e) - iv)

Check Your Progress Exercise 3

1) The special features of medulla oblongata includes the 1) pyramids: bulges of ventral surface – major site for crossing of both sensory and motor nerves 2) centers for regulation of blood pressure and breathing 3) swallowing and vomiting centers 4) reticular formation (continues to midbrain) – involved in consciousness, attention, sleep and 5) four cranial nerves (9-12) that leave the medulla.

2) The cerebellum is involved in the co-ordination of voluntary motor movement, posture balance and equilibrium and muscle tone.

3) Reticular formation is an apparently diffusely organized area that forms the central core of the brain stem. It is the collection of neurons in the core of the brain stem. The reticular formation is involved in four general types of functions– motor control, visceral control, sensory control and control of consciousness.

Check Your Progress Exercise 4

1) Spinal cord is incompletely divided into 2 equal parts by a shallow median fissure anteriorly and by a narrow posterior median septum at the posterior part. A cross section shows that it is composed of gray matter in the center and is surrounded by white matter supported by neuroglia. Its functions are:

   - It connects a large part of the peripheral nervous system to the brain. Information (nerve impulses) reaching the spinal cord through sensory neurons is transmitted up into the brain. Signals arising in the motor areas of the brain travel back down the cord and leave in the motor neurons.
   - Acts as a minor coordinating center responsible for some simple reflexes like the stretch and withdrawal reflex.

2) In the sensory nerve pathway, there are 2 main sources of sensation transmitted to the brain via spinal cord. These include:

   - The nerve ending in the skin – cutaneous receptors is stimulated by three neurons to the sensory area in the opposite hemisphere of the cerebrum. Here it is perceived.
   - The tendons, muscles, joints. Sensory nerve endings here are known as proprioceptors, which are stimulated by stretch.

3) Motor neurons transmit nerve impulses away from the brain. Their stimulation results in:

   a) Contraction of voluntary muscles (striated, skeletal): Stimulations are under our will, consciously controlled in the cerebrum some impulses are initiated in the midbrain, brainstem and cerebellum. The motor pathways from brain to muscle are made up of 2 neurons – upper motor neuron and lower motor neuron.

   b) Contraction of the smooth (involuntary) muscles and secretion by glands controlled by nerves of the autonomic part of the system, four neurons are involved, that is, upper motor neuron, spinal reflexes stretch reflexes and autonomic reflex are involved.

4) A reflex action or reflex arc is an immediate motor response to a sensory stimulus. Impulses from skin are transmitted to spinal cord by sensory nerves. These stimulate many connector and lower motor neurons in the cord which results in contraction of many skeletal muscles.

Check Your Progress Exercise 5

1) The peripheral nervous system or PNS is a part of the nervous system. The peripheral nervous system consists of:

   - sensory neurons running from stimulus receptors that inform the central nervous system of the stimuli, and
   - motor neurons running from the central nervous system to the muscles and glands – called effectors – that take action.

2)

Nerve	**Type**	**Functions**
I Olfactory	sensory	Olfaction (smell)
II Optic	Sensory	Vision (contains 38% of all the axons connecting to the brain)
III Oculomotor	Motor	Eyelid and eyeball muscles
IV Trochlear	Motor	Eyeball muscle

3) The physiological activities of the ANS are:
   - Rate and force of heart beat
   - Secretion of the glands of alimentary canal
   - Contractions of involuntary muscle
   - Size of pupil of the eyes.

4) The two components of ANS are sympathetic nervous system and parasympathetic nervous system. Sympathetic stimulation prepares the body to deal with excitement and stressful situation. It mobilizes the body for 'fight' or 'flight' responses. Parasympathetic stimulation has a tendency to slow down body process except digestion and absorption of food and functions of genitoo urinary system.

5) The effects of autonomic stimulation on the body systems are: (any two of the following):

Sympathetic	**Parasympathetic**
On Cardiovascular System:	
Increase rate and force of heart beat, causes dilatation of coronary arteries, increases blood supply to heart muscle.	Effects opposite to those of sympathetic stimulation on heart spleen and blood vessels.
Causes dilations of blood vessels in skeletal muscles and thus increases the supply of O_2, nutritional materials thereby increasing capacity of muscles to do work.	
Causes sustained contraction of spleen, increases the volume of the circulating blood, can increase blood pressure of the skeletal muscles, can cause constriction of blood vessels and reduces flow of digestive juices.	

Check Your Progress Exercise 6

1) EEG is electroencephalogram. It is a painless procedure used to measure the brain's electrical activity.

2) There are normally four waves of EEG: The alpha waves, beta waves, theta waves and Delta waves.

   The alpha waves are recorded when a person is relaxed with eyes closed. He is mentally relaxed and not distracted by sensory stimuli. These waves have an average amplitude of about 50 micro volts in adults, at a frequency 8-13 / second. It is recorded in the best wave forms from parietal and occipital regions while the Beta waves are recorded when a person is awake and alert, he is mentally busy or tense. Beta waves have average amplitude of 20 micro volts and a frequency of 13-30 per second. It is recorded from frontal and parietal regions.