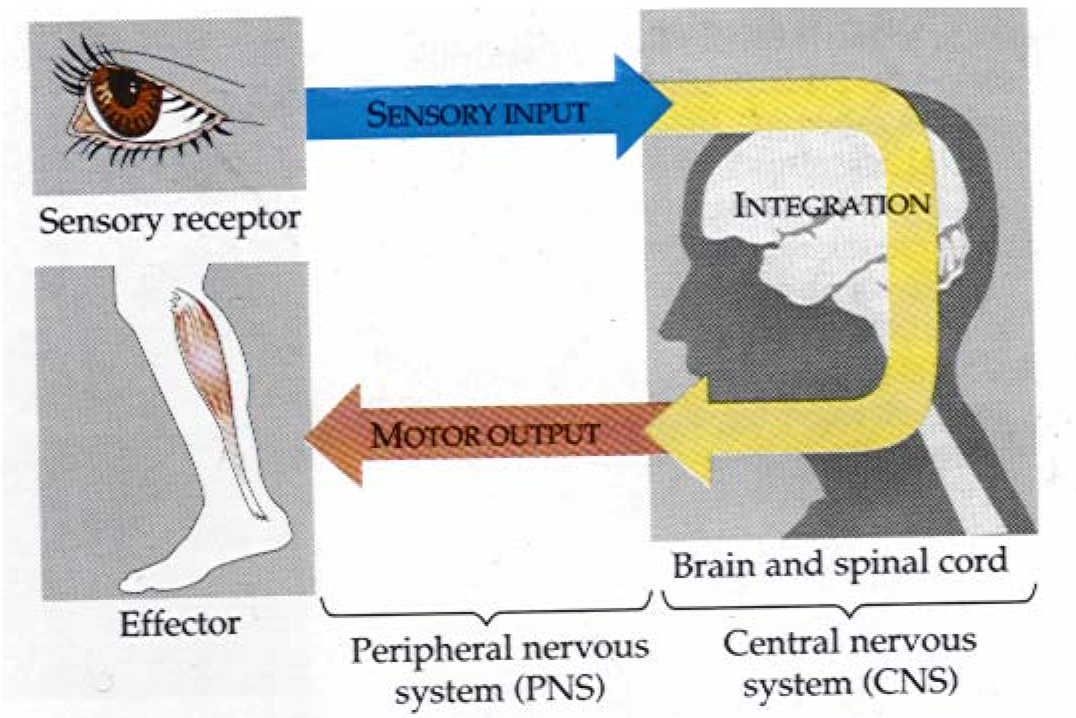
Nervous System

Nervous system performs three overlapping functions of **sensor input**, **integration**, and **motor output**. This process is generally the same even at a very primitive level of nervous system, but we will focus here mostly on human nervous system.

The sensory input is sensing the environment and changes around an organism, and is carried out by **sensory organs** like eyes, ears, nose, tongue, and skin, some of them performing simultaneously.

The integration involves processing of information, and is carried out by the **central nervous system** (CNS), which consists of brain and spinal cord.



▪ **Overview of a vertebrate nervous system.** The brain and spinal cord together form the central nervous system (CNS), which is responsible for the integration of information. A network of nerves forming the peripheral nervous system (PNS) carries information from sensory receptors (sensory input) to the CNS and motor commands from the CNS (motor output) to various target organs or glands, collectively called effectors.

Motoneuron output is conduction of signals from the integration center, the CNS, and is carried out by a group of **effector cells**, the muscle cells or gland cells, which actually carry out body's responses to external stimuli.

Both sensory input and motor output signals are carried through **nerves**, which are long ropelike structures made from nerve cells. Nerve cells are two types – **neurons** and **glia**. Neurons are the cells which actually carry through signals whereas glia cells provide supporting structures and maintenance of neuronal cells. Nerves are many times are made from end to end connection between neurons, supported by the glial cells.

The nerves that communicate sensor and motor signals between the central nervous system and rest of the body are collectively referred to as **peripheral nervous system** (PNS).

Sensory inputs are received by receptor cells located in sensory organs. For examples, light receptor cells are located in eyes, or chemical receptor cells are located on the surface of tongue. Signals from these receptors are carried through **sensory neurons** of the PNS into the CNS, and after processing in the CNS, instructions are communicated through the **motor neurons** of the PNS to effector cells, such as muscles.

Communication from the receptor cells to effector cells is carried in two forms – chemical and electrical. Since communication of information involves more than one cells, the communication is through special chemicals called **neurotrasmitters** or a specialized form of electric signal called **action potential**.

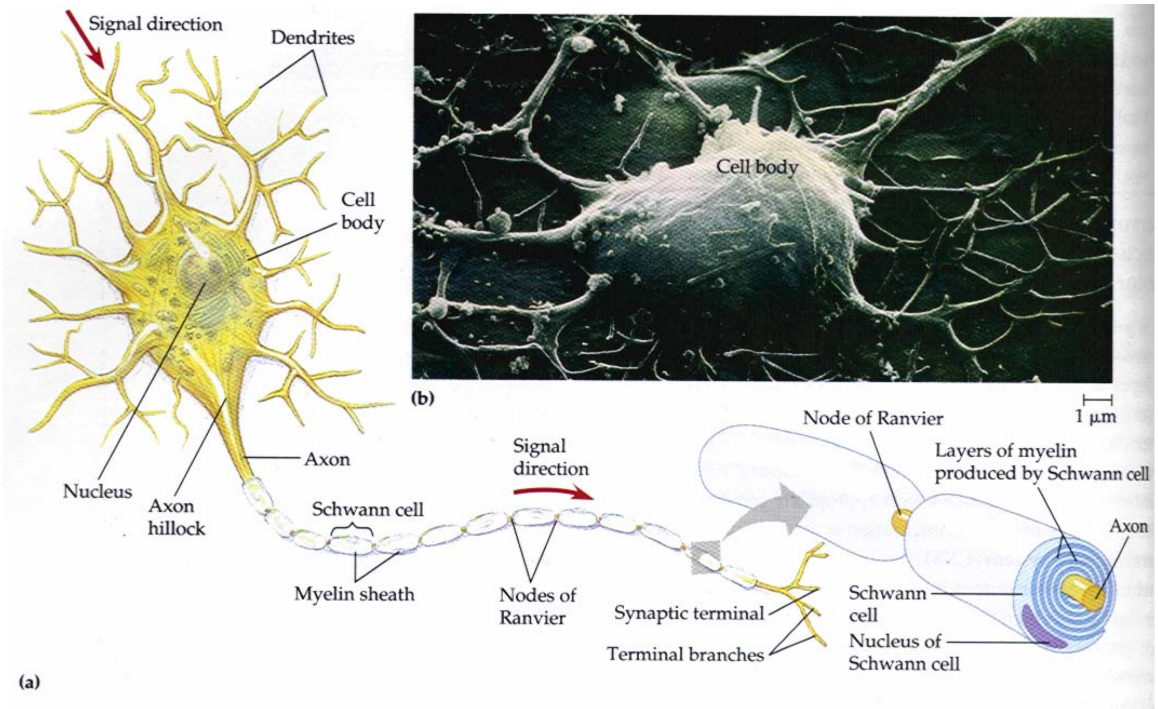
Nerve Cells

Neurons are the functional unit of the nervous system. A neuron consists of three major parts – a cell body that contains nucleus, dendrites which receive signals, and a long axon that carries the signal to the next cell. Length of neurons varies depending on their location. Neurons located in CNS could be a few millimeter long but some of the neurons in PNS could be more than a meter long.

In a normal human body, there are about two billion neurons, approximately 1 billion in the brain, and another billion in rest of the body.

Glial cells are supporting cells provide structural and functional support to the neurons and help them carry out their functions. For example, **Schwann cells** provide a covering of the axons in the PNS. End of a neuron is known as **synaptic terminal**, which generally connects with either another neuron to continue the process of communication or to a muscle to trigger muscle action.

Glial cells outnumber neurons by 10 to 50-folds.



▪ **Structure of a vertebrate neuron. (a)** The cell body has two types of processes, or extensions: Dendrites generally receive inputs and conduct signals toward the cell body, whereas axons conduct signals away from the cell body. At the end of the axon, terminal branches each have a synaptic terminal that makes connections with other neurons or target cells. In the peripheral nervous system, supporting cells called Schwann cells wrap many axons with an insulating myelin sheath. Gaps between successive Schwann cells are called nodes of Ranvier. **(b)** A scanning electron micrograph of a neuron.

Organization of Nervous System

Structurally, the nervous system is organized in two parts – the **central nervous system** and the **peripheral nervous system.**

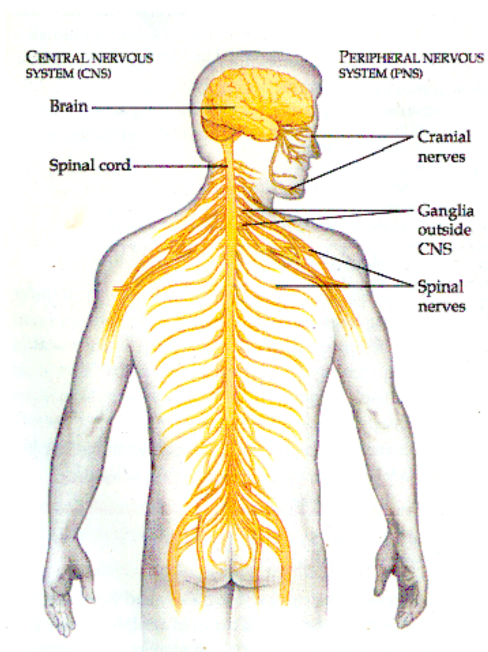


FIGURE 48.14 ▪ The nervous system of a vertebrate. The vertebrate nervous system is highly centralized. The components of the central nervous system (brain and spinal cord) develop from the dorsal, hollow nerve cord, a hallmark of chordates. Cranial nerves (originating in the brain), spinal nerves (originating in the spinal cord), and ganglia outside the central nervous system make up the peripheral nervous system.

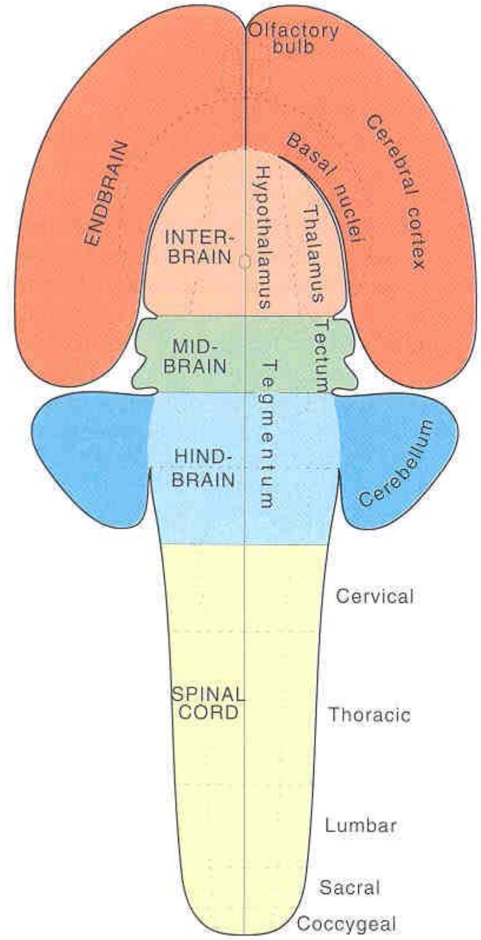
CNS

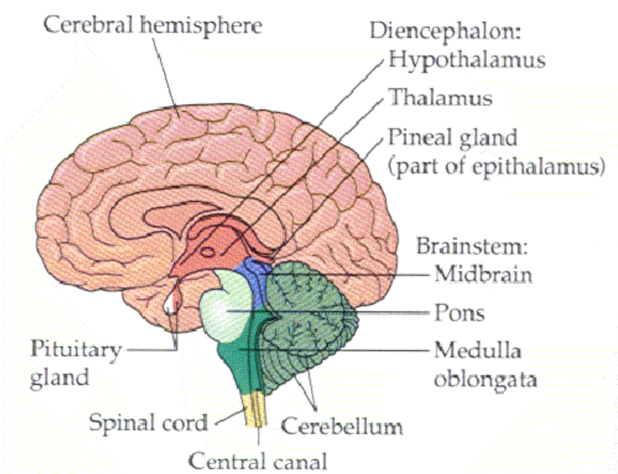
The CNS is made of brain and the spinal cord. The brain is divided into three parts – Forebrain, Midbrain, and Hindbrain.

The Forebrain develops into two parts – the telencephalon which consists of the cerebrum or the cerebral hemispheres, and includes cerebral cortex, white matter, and basal nuclei; and diencephalon which consists thalamus, hypothalamus, and epithalamus.

The Midbrain develops through mesencephalon into a part of brainstem.

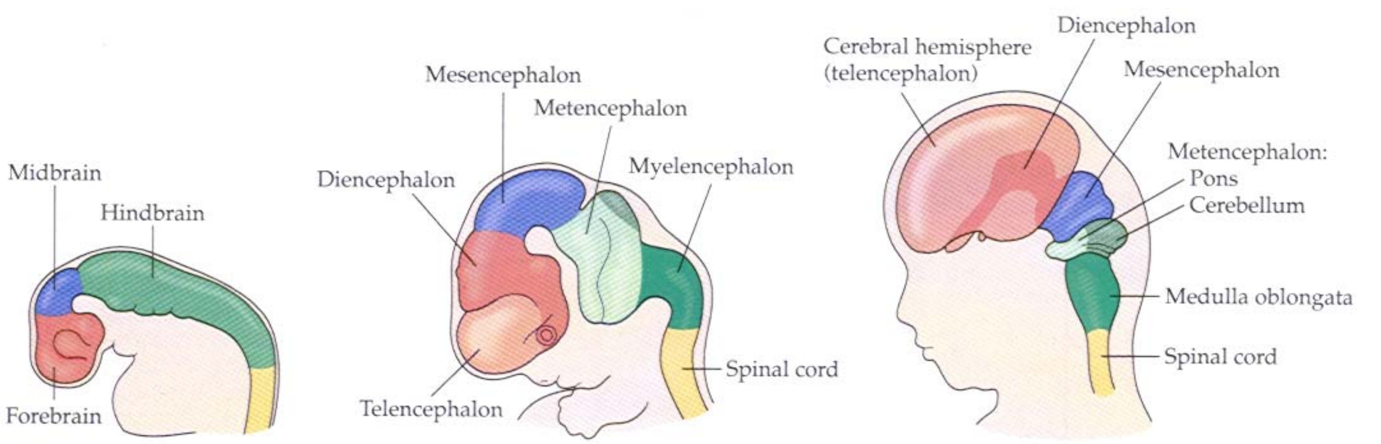
The Hindbrain develops through two parts, the metencephalon and myelencephalon. The metencephalon eventually develops into pons (part of the brain stem) and cerebellum. The myencephalon develops into medulla oblongata. which is also part of the brain stem.





(d) Adult

Spinal cord begins from the brain stems and extends till the lowest end of backbone. The spinal cord containing bundle of nerves is protected by a series of vertebrae, **artificially** divided into five regions – cervical (7), thoracic (12), lumber (5), sacral (5), and coccygeal (1). The latter two are fused together. The spinal cord itself spans only about two-thirds of the vertebral column, but the rest of the space is filled with nerve fibers of spinal roots.



(a) Embryo one month old (b) Embryo five weeks old (c) Fetus three months old

Both the brain and spinal cord contain fluid filled spaces or cavities. The fluid in these spaces is called **cerebrospinal fluid** (CSF), and contains nutrients, hormones, white

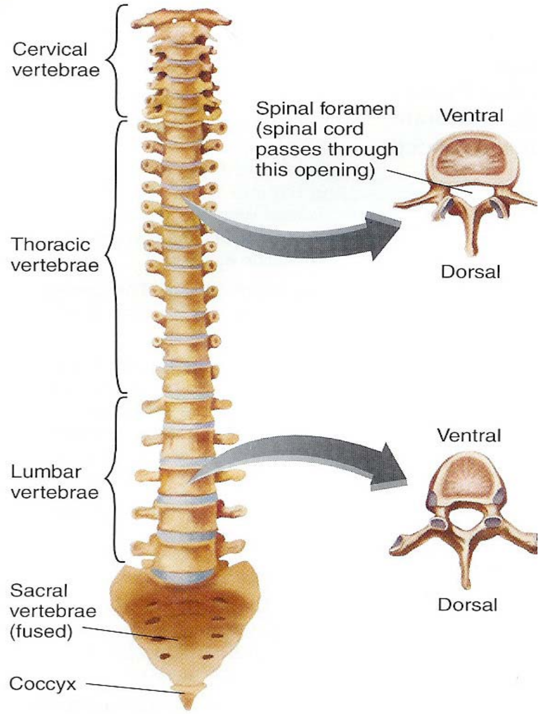


FIGURE 3.17

A ventral view of the human spinal column, with details showing the anatomy of the vertebrae.

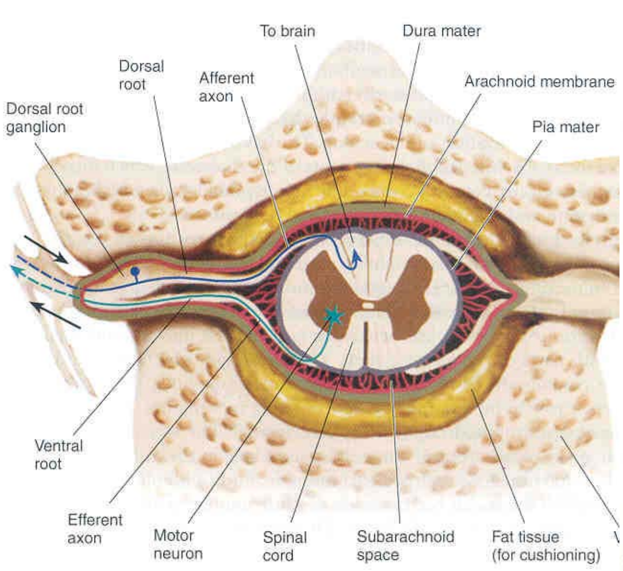
blood cells to maintain the CNS. Additionally, the fluid acts as shock absorber cushioning the brain. The CSF provides a direct link across the blood brain barrier for exchanging nutrients and other essential biomolecules.

A typical human brain weighs about 1.4 kilogram, and contains 1 billion neurons. The CSF has a half-life of about 3.5 hours, and thus remains fresh for supporting the brain and spinal cord.

The spinal cord provides junction points for motor and sensory nerves, through **afferent** (ventral) and **efferent (dorsal)** roots, respectively. The cell body giving rise to afferent axon reside outside the spinal cord, in a cluster, called dorsal root ganglion (ganglion is where nerves form some sort of a knot). The afferent nerves bring the somatosensory information intended for the brain and efferent nerves take the information from brain to rest of the body.

A cross section of spinal cord shows a butterfly shape structure in which inside is the gray matter and outside the white matter. The gray matter is primarily made of cell bodies whereas white matter is made of axons.

PNS



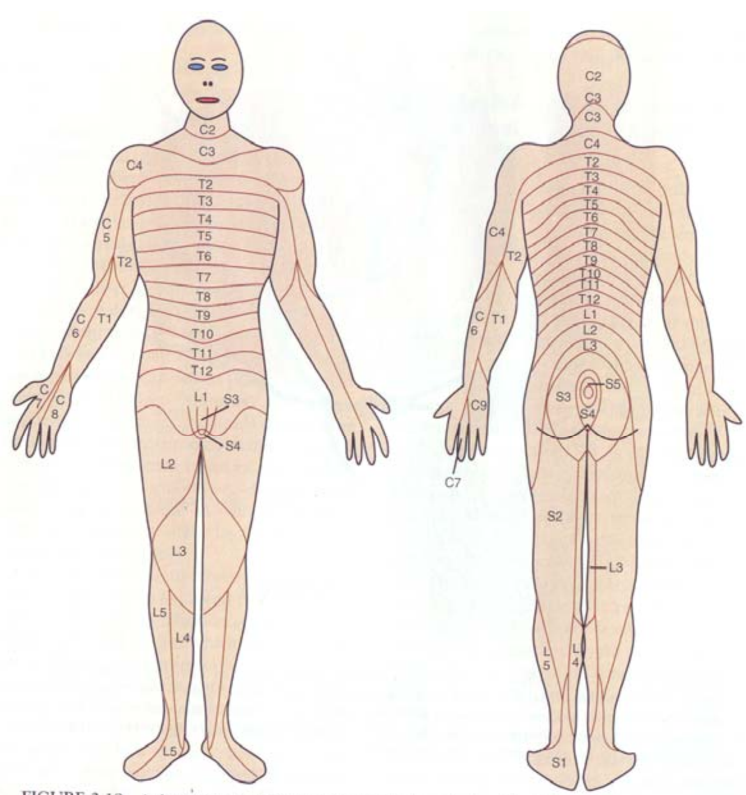


FIGURE 2.19 A dermatome map of the human body. The spinal cord level that selectively innervates each dermatome is indicated. Note the twisting of the dermatomes of the lower limb, which arises from rotation of that limb as it develops to accommodate bipedal motion.

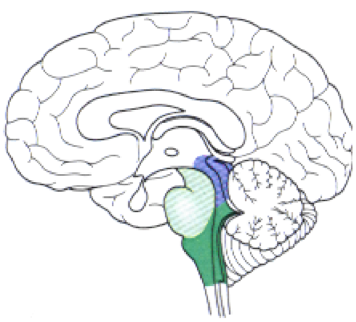
The brain and spinal cord communicate with rest of the body through Cranial and Spinal nerves. These nerves are part of the peripheral nervous system, which conveys the sensory information to the brain either directly or through the spinal cord, and conveys instructional information to body's muscles and glands.

There are 12 cranial nerves and 31 spinal nerves which form the part of PNS.

Summary for functions of main parts of the central nervous system

Brainstem

This part of brain conducts data between brain and the spinal which in turn communicates with the rest of the body through motor and sensory nerves. The brainstem also controls activities essential for survival.



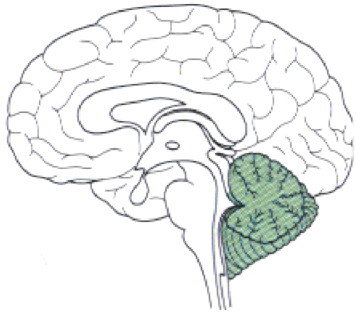
The brainstem is a stalk along with caplike swellings located at the anterior end of the spinal cord. The brainstem has three parts – medulla oblongata, pons, and the midbrain.

The **medulla oblongata** contains centers that controls several visceral (autonomic, homeostatic) functions, including breathing, heart and blood vessel activities, swallowing, vomiting, and digestion.

Most of the axons carrying instructions about movement from forebrain and midbrain to the spinal cord cross from one side of the CNS to the other as they pass through medulla. This leads to the control of movement in the left side of the body by the right side of the brain, and vice versa.

The **pons** also participate in the functions described for medulla. All the bundles of axons carrying sensory information to and motor instructions from higher brain regions pass through medulla and pons.

The **midbrain** part of the brainstem contains centers for the receipt and integration of several types of sensory information, including those from auditory and visual systems. It also serves as a projection center, sending coded sensory information along neurons to specific regions of the forebrain.

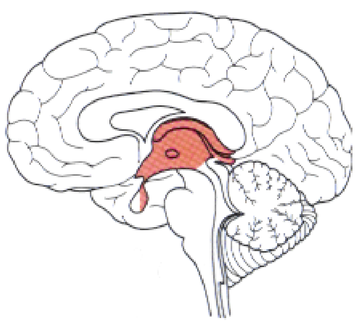


Cerebellum

This part of brain's primary function is coordination of movement, thus it controls movement and balance by receiving sensory information about the position of the joints and the length of muscles, along with information from the auditory and visual systems. It also receives instructional motor inputs from the cerebrum for automatic coordination of movements and balance.

Thalamus and Hypothalamus

The **thalamus** acts as a major integrating center for sensory information going to the cerebrum and the main output center for motor information leaving the cerebrum. Incoming information from all the senses is sorted out in the thalamus and sent on to the appropriate higher brain centers for further interpretation and integration. The thalamus also receives information from cerebrum and from parts of brain that regulate emotion and arousal.



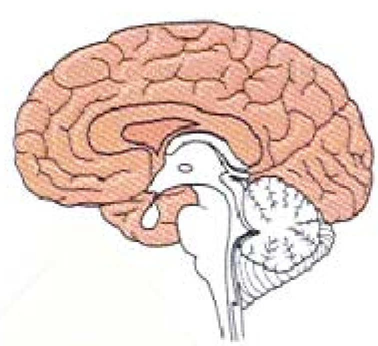
The **hypothalamus** is one of the most important brain regions for the homeostatic regulation of the body. It secretes two sets of hormones - the posterior pituitary hormones (oxytocin and antidiuretic hormones) and releasing hormones (e.g., growth hormones, prolactin, endorphins, etc.) that act on the anterior pituitary.

The hypothalamus contains body's thermostat, centers for regulating hunger, thirst, and many of the body's survival mechanisms. Hypothalamus neurons also play a role in sexual response and mating behaviors, fight and flight response, and pleasure.

The hypothalamus also controls the circadian rhythm in humans and animals.

The Cerebrum

The cerebrum, divided into left and right cerebral hemispheres, is the most complex integrating center in the CNS. Each hemisphere consists of gray matter or cerebral cortex, internal white matter, and a cluster of nuclei deep within the white matter, the basal nuclei or basal ganglia.



The cerebral cortex is the largest and the most complex part of the human brain. Sophisticated behavior in mammals is associated with the relative size of the cerebral cortex and the presence of convolutions that increase its surface area. The cerebral cortex accounts for 80% of the total brain mass, and covers about 0.5 m^2 surface area. The thickness of the cerebral cortex layer is less than 5 mm.

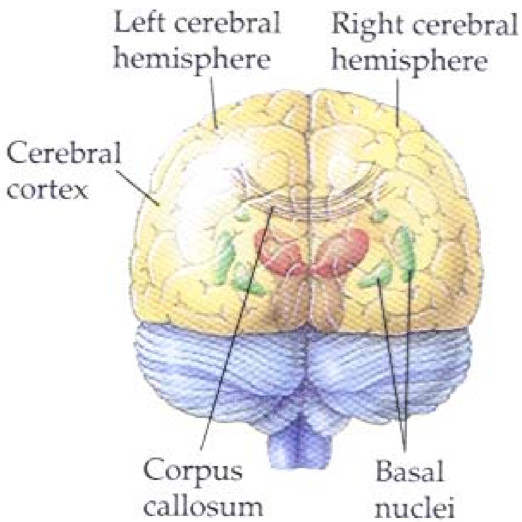


Fig. X1. Rear view of the human brain showing bilateral nature of the cerebral hemisphere. The corpus collosum (large fiber tracts connecting the hemisphere) and basal nuclei (ganglia) shown are not actually visible and are covered by the cerebral cortex

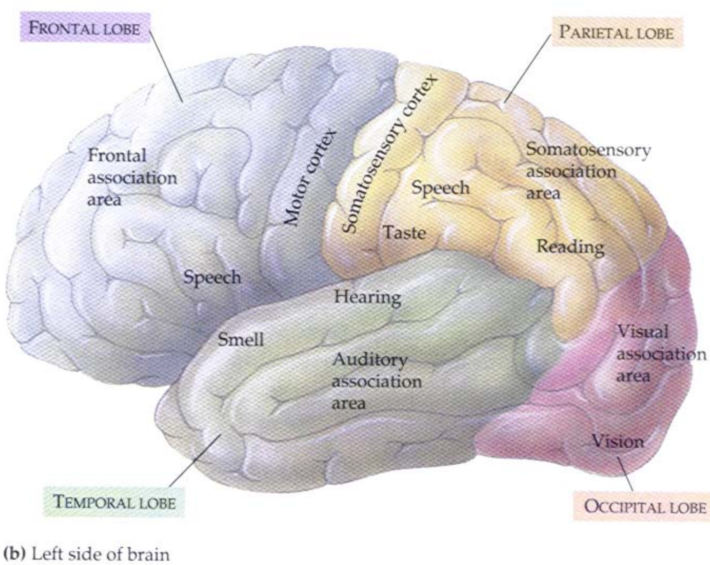


Fig. X2. Left side of the brain. The left cerebral hemisphere shows four lobes. Specialized functions are localized in each lobe. The association areas of the left hemisphere are not the same as the right hemisphere.

Cerebral cortex is divided into right and left sides, which are connected through a thick band of fibers, the cerebral white matter known as corpus callosum (**Fig. X1**). Each side has four discrete lobes – frontal lobe, temporal lobe, parietal lobe, and occipital lobe (**Fig. X2**). A number of functional areas within each lobe have been identified (**Fig. X2**). Two such areas, the primary motor cortex (PMC) and the primary somatosensory cortex (PSC), form the boundary between the frontal and parietal lobes

The PMC region functions mainly in sending commands to skeletal muscles with appropriate response to sensory stimuli.

The PSC region receives and partially integrates signals from touch, pain, pressure, and temperature perceptions throughout the body. The proportions of PMC and PSC regions devoted to a particular part of body is correlated with the importance of motor or sensory information for that part of the body, as shown in **Fig. X3**. Impulses transmitted from receptors to areas of somatosensory cortex enable people to associate pain, touch, pressure, heat, or cold with specific parts of the body receiving those stimuli. Notably, the special senses – vision, hearing, smell, and taste – are integrated by other cortical regions, although the functional regions obviously cooperate with respective association areas shown in **Fig. X2**.

Summary of the function of the main part of the peripheral nervous system

Peripheral nervous system is complex and expansive in its structure and function. It is easier to classify it in its functional hierarchy. A hierarchical diagram of peripheral nervous system and its relationship to the central nervous system is shown in **Figure. X4**.

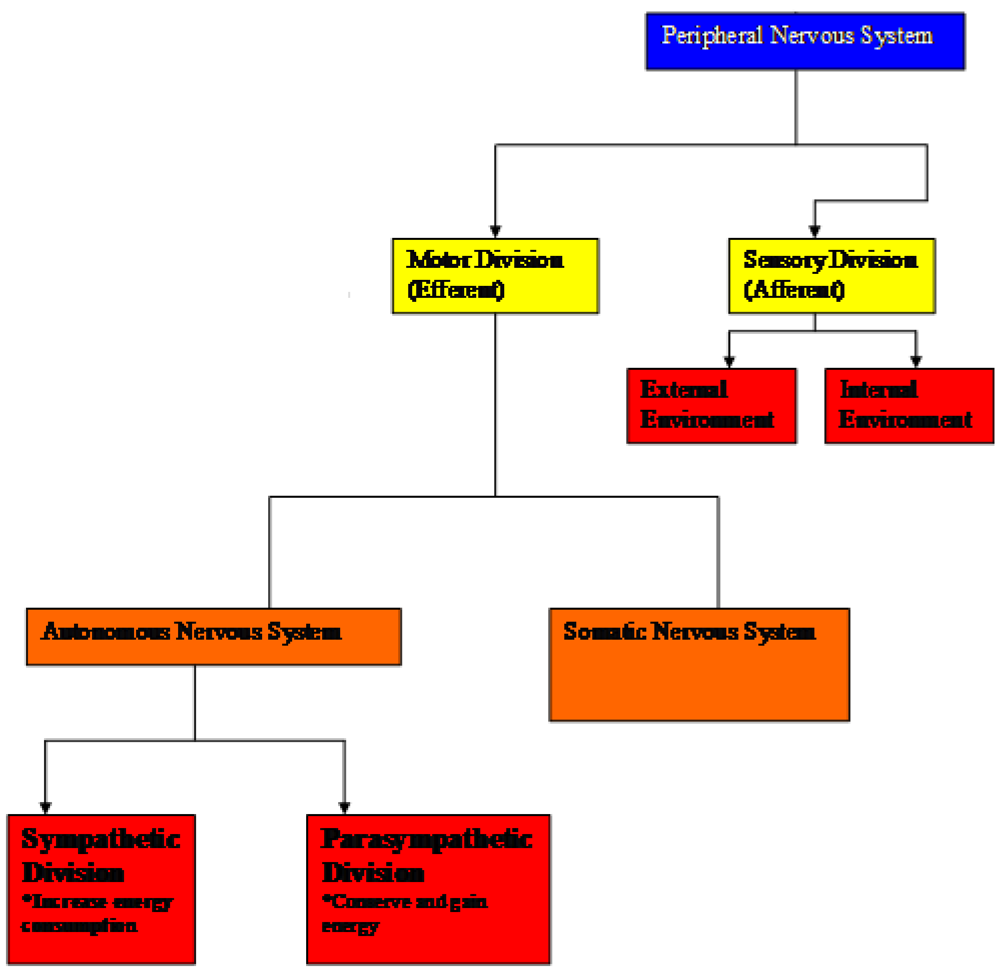


Fig. X4: Different elements of peripheral nervous system.

The sensory and motor systems of the peripheral nervous system are part of the cranial and spinal nerves. The 12 pairs of cranial nerves serve sensory and motor functions in the head and neck region, as shown in **Figure X5**. One of these cranial nerves, known as **vagus nerve**, regulates the functions of organs in the thoracic and abdominal cavities, and plays a major role in physiological function of cardiovascular system, hepatic system, and urinary system. Sensory information from head and neck region, including somatosensory inputs, and inputs related to taste, hearing, vision, and smell are received through cranial nerves.

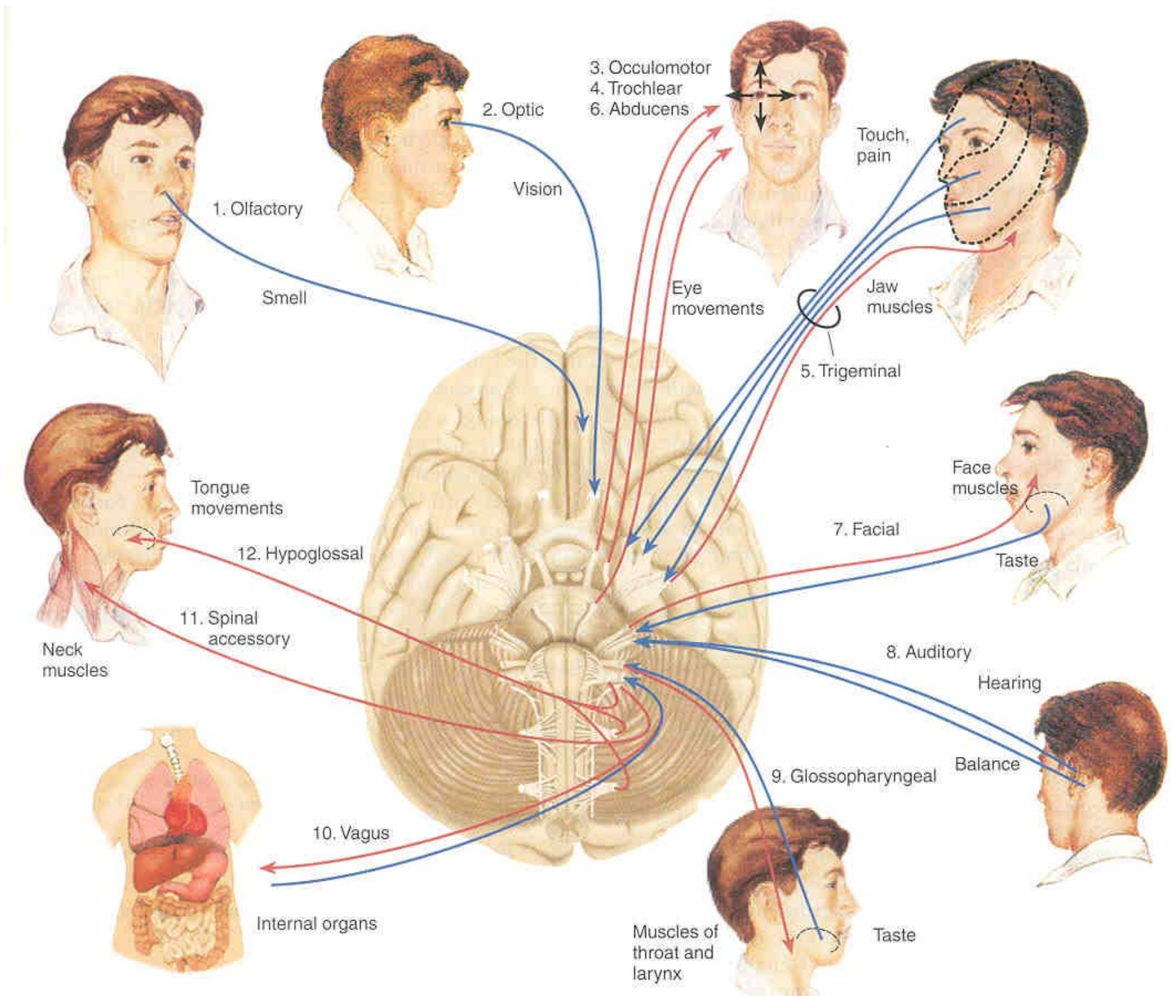


Fig. X5: Cranial nerves and their target of action

Spinal nerves sprouting from the spinal cord innervate the rest of the body for sending and receiving information related to external and internal environment.

Functionally speaking the peripheral nervous system is divided into sensory and motor divisions. The s**ensory division** consisting of afferent or sensory neurons that convey information to the CNS from sensory receptors that monitor external and internal environment.

The **motor division** is composed of efferent neurons that convey signals from the CNS to the effector cells, and is divided into two regions – the **somatic** nervous system and **autonomous** nervous system. The **somatic nervous system** carries signals to skeletal muscles mainly in response to ***external*** stimuli, thus being often referred to as voluntary nervous system. However, a substantial proportion of skeletal muscle movement is actually determined by reflexes mediated by the spinal cord or lower brain, without involving integration of information at the cerebral cortex level.

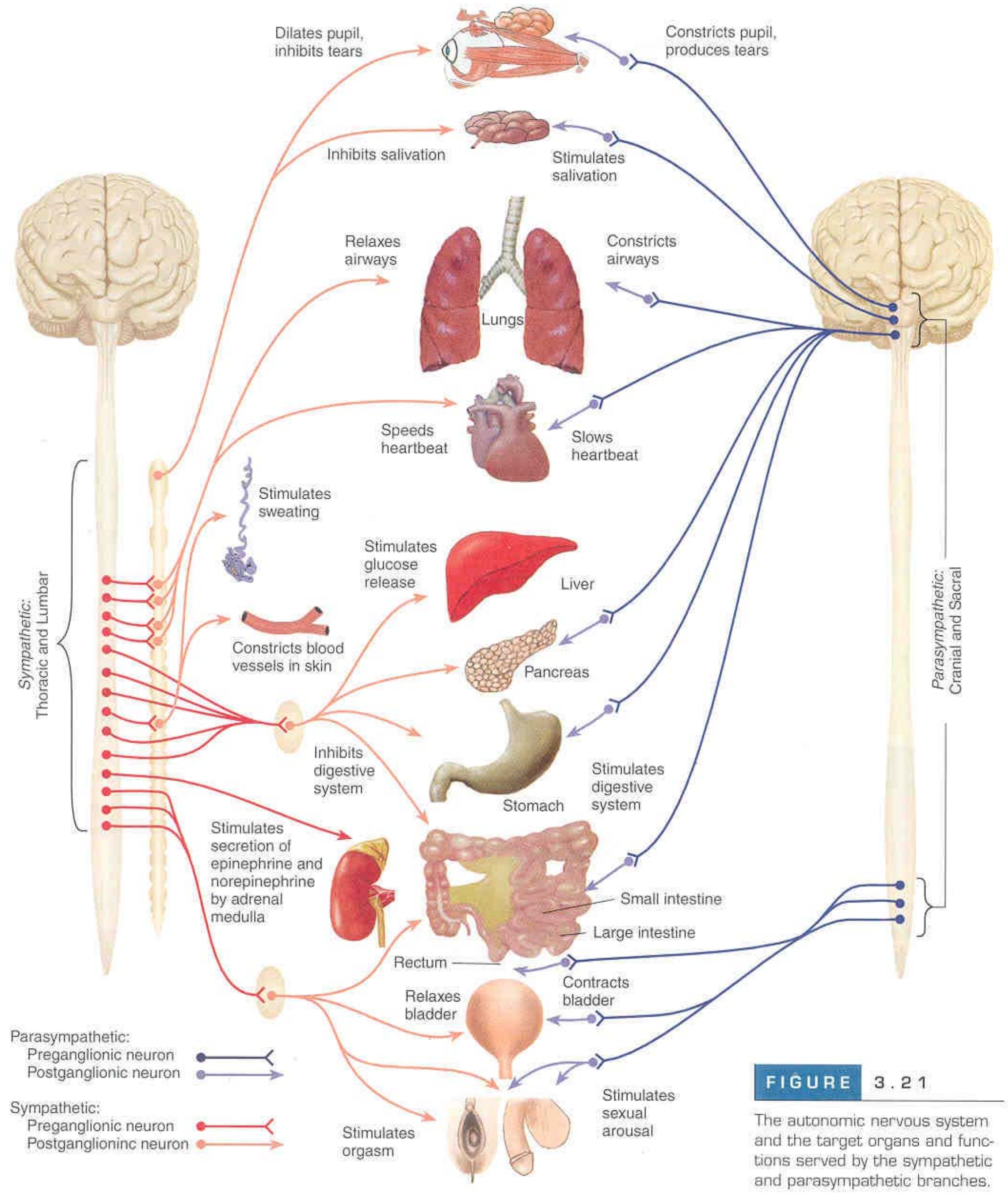


FIGURE 3.21 The autonomic nervous system and the target organs and functions served by the sympathetic and parasympathetic branches.

Fig. X6.

The autonomous nervous system conveys signals that regulate the ***internal*** environment by controlling smooth and cardiac muscles and the organs of the gastrointestinal, cardiovascular, excretory, and endocrine systems. These controls are generally considered involuntary.

The two subdivisions of autonomous nervous system – the sympathetic division and the parasympathetic division (**Fig. X6**) – are distinguishable anatomically, physiologically, and chemically.

Overview of Nervous System

The human nervous system is made up of CNS and PNS. The brain and spinal cord belong to the CNS, and rest of the nerves in human body belong to PNS. Brain and spinal cord are mainly responsible for information processing, imagination, memory and communication. The PNS consists of a complex set of motor and sensory nerves. The sensory division of PNS feeds internal and external environment information to the CNS for processing and feedback. The motor division of the PNS –divided into somatic and autonomous systems. The somatic division is involved in voluntary actions and the autonomous system – through its sympathetic and parasympathetic division – is involved largely in involuntary actions regulating actions such as breathing, cardiovascular system, digestive system, etc. A chart outlining the overview of the nervous system is shown in **Figure X7**.

Functional organization of the nervous system is very complex, yet a model has been proposed to explain the link between human behavior and signal transduction amongst external, internal, and brain environment. One model of basic information processing in the nervous system is outlined in **Figure X8**. In its simplest form the model assumes that behavior is determined by the motor output of the CNS and that the motor output is a function of three inputs – sensory, cognitive, and intrinsic. The relative importance of these three inputs varies from species to species and from individual to individual, and may even vary from time to time.

The complex set of sensory systems provides information to the CNS from various receptors available throughout the body. Sensory information generally branch in such a way that part of it goes to the cerebral cortex for sensation and perception whereas another part directly goes to the motor system for reflexive action. The information reaching cerebral cortex at the consciousness level plays a major role in developing cognition.

Cognition system of input is voluntary behavior that could be anticipatory yet difficult to predict, and is generally dependent on long-term processing of information by the cerebral cortex.

Intrinsic activities are also generated by the CNS, and is very important aspect of CNS function, away from reflexive and cognitive responses. Certain regions of the CNS generate intrinsic activity patterns that are rhythmic, such as sleep-wake cycle which is

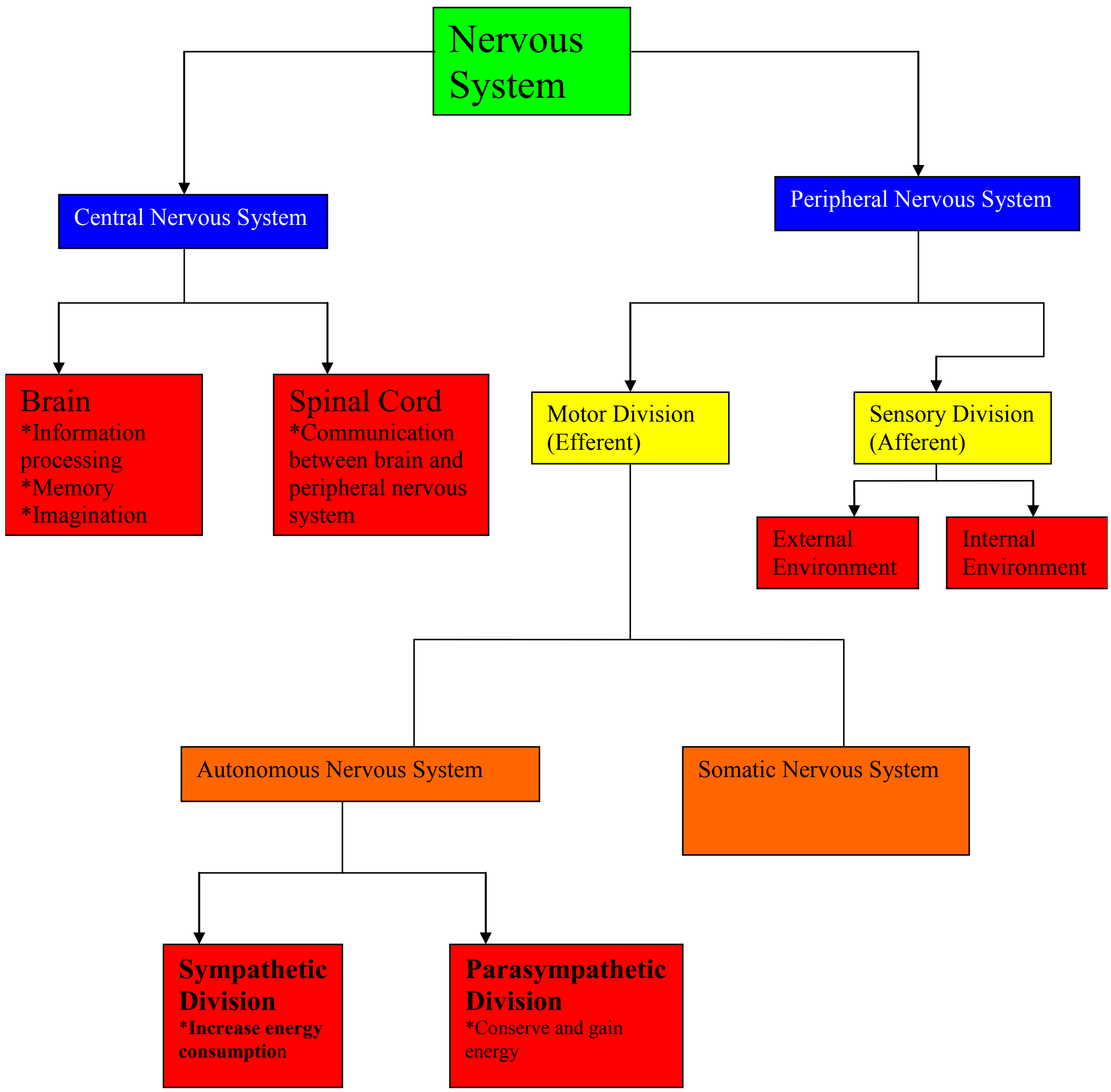
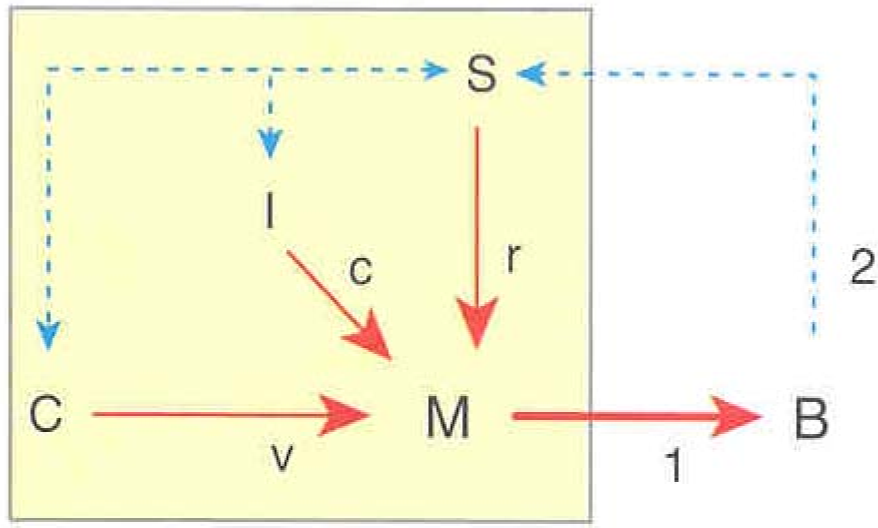


Fig. X7: An overview of different part of human nervous system.

controlled by the circadian rhythm. During the sleep the body is entirely maintained by the intrinsic and reflexive systems that control behaviors like respiration. During wakeful period is largely controlled by cognitive (voluntary) mechanisms although reflexive and intrinsic systems also play important roles.

Yoga exercises and meditation could affect the cognitive and intrinsic systems and sharpen their functions. Combined with yama and niyama, postures, pranayama,



This model of information flow through the nervous system (inside the box) postulates that behavior (B) is determined by the motor system (M), which is influenced by three neural inputs: sensory (S), intrinsic (I), and cognitive (C). Sensory inputs lead to reflex responses (r), cognitive inputs produce voluntary responses (v), and intrinsic inputs act as control signals (c) to regulate the behavioral state. Motor system outputs (1) produce behaviors whose consequences are monitored by sensory feedback (2). Sensory feedback may be used by the cognitive system for perception and by the intrinsic system to generate affect. The cognitive, sensory, and intrinsic systems are all interconnected, hence the arrowheads at the end of each dashed line within the box (nervous system). Refer to Swanson.[16] Reprinted by permission of Oxford University Press.

Fig. X8.

pratyahar, and dharana, there is ample opportunity to train much of our nervous system to make them help observe not only external but also internal signals within our bodies. This could be helpful both in physical health of body and mental perception of the world.