# CHAPTER 3

# Introduction to the Structure and Function of the Nervous System

## STRUCTURE AND FUNCTION OF THE NERVOUS SYSTEM

The nervous system is a complex regulatory system that, along with the *endocrine system* (see Chapter 23), controls and coordinates activities and functions throughout the body, internally and externally, by sending, receiving, and sorting electrical impulses. Disruption of any part of the nervous system affects body function in some way, either internally or externally.

The nervous system consists of the *central nervous system*, which includes the *brain* and *spinal cord*, and the *peripheral nervous system*, which includes *nerve fibers* extending from the brain and spinal cord that carry information between the central nervous system and the rest of the body. The peripheral nervous system is further divided into two parts: *the afferent* (sensory) *system,* which carries messages from other parts of the body *to* the central nervous system, and the *efferent* (motor) *system*, which carries messages *from* the central nervous system to other parts of the body (see **Table 3-1**).

### Function of the Nervous System

Functions of the nervous system include the following:

- Organizing and directing motor responses of the *voluntary muscle system*, enabling the body to move more effectively as a whole and to achieve purposeful movement. This coordination of voluntary muscles makes possible complex activities, such as walking, running, playing a piano, and using a computer, as well as simple activities, such as maintaining muscle tone and posture while at rest.
- Monitoring and recognizing stimuli (and information) within the environment, and then directing an appropriate response to the stimuli. This function makes possible reflex actions, such as pulling away one's hand from a hot surface, as well as perceiving music being played in the next room.
- Monitoring and coordinating internal body states so that internal organs function as a unit, internal body constancy (**homeostasis**) is maintained, and protective action is taken. For example, in response to a lack of oxygen, more rapid breathing occurs; the body shivers in response to cold; and when threat or danger is encountered, the heart beats more rapidly.

Other functions, such as display of personality traits, language, speech, learning, remembering, feeling emotion, reasoning, and generating and relaying thoughts, are also controlled by the nervous system—specifically, by the brain.

### Nerve Cells

Specialized cells called **neurons** are the functional units of the nervous system. Neurons transmit messages to and from the brain. They consist of a cell body and processes (*nerve*

**Table 3-1 The Nervous System (Central and Peripheral)**

| | |
|---|---|
| I. Central nervous system | |
| A. Brain | |
| B. Spinal cord | |
| II. Peripheral nervous system | |
| A. Afferent (sensory) | |
| B. Efferent (motor) | |
| 1. Somatic nervous system | |
| 2. Autonomic nervous system | |
| a. Sympathetic nervous system | |
| b. Parasympathetic nervous system | |

*fibers*) that extend beyond the cell body. In most cases, a single long nerve fiber called an *axon* conducts nerve impulses (and information) away from the cell body to other neurons. Smaller, shorter nerve fibers called **dendrites** conduct nerve impulses toward the cell body after receiving information from other neurons. Fibers that carry information from parts of the body to the brain are called **afferent neurons** (sensory neurons). Fibers that carry information from the brain to other parts of the body are called **efferent neurons** (motor neurons).

Surrounding neurons is a fatty sheath called **myelin,** which, much like the covering of electrical cords, provides insulation, ensuring that electrical impulses are able to flow smoothly and reliably. Information is passed from neuron to neuron by both electrical and chemical impulses. The electrical impulse, which has been picked up by the dendrites, is passed through the cell body to the axon. The electrical impulse then moves down the full length of the axon until it reaches its tip. At the tip of the axon are tiny processes, which release chemicals known as **neurotransmitters**. Neurotransmitters, through chemical means, transfer the impulse from one neuron to another across a space between the two neurons called the **synapse**. The electrical impulse, through the vehicle of neurotransmitters, then moves to the next neuron's dendrites and the process begins again (see **Figure 3-1**). After neurotransmitters are released, they are either taken up again by the neuron or destroyed.

Longer axons are generally grouped in bundles. When they are transmitting impulses within the central nervous system, these bundles are referred to as *tracts*. Those bundles located outside the central nervous system are referred to as *nerves.*

## The Central Nervous System

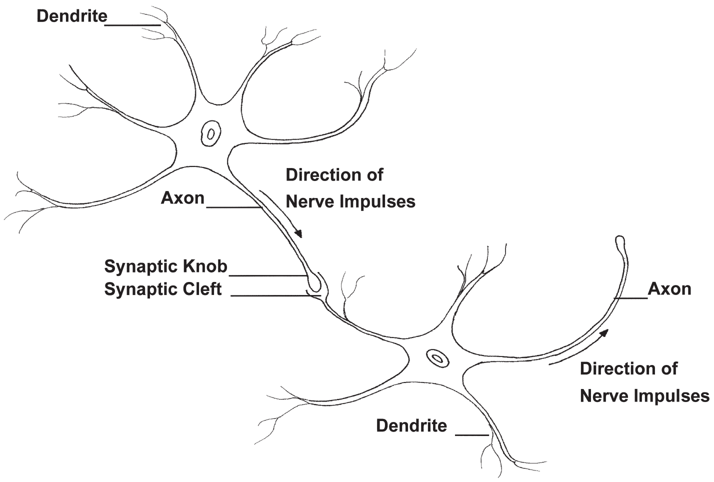
The *central nervous system* is made up of the brain and spinal cord. Bony coverings protect both the brain and the spinal cord. On the interior of these bony coverings are three membranes (**meninges**) that provide additional protection:

- The **dura mater** is the outer membrane, lying closest to the bony covering of the brain and spinal cord.
- The **arachnoid membrane** is the middle membrane, a cobweb-appearing membrane.
- The **pia mater** is the inner membrane, which lies closest to the brain and spinal cord.

Between each of the membrane layers are spaces. The space between the dura mater and the inner surface of the bony covering is the *epidural space*. T; the space between the dura mater and the arachnoid membrane is the *subdural space*; and the space between the arachnoid membrane and the pia mater is the *subarachnoid space.*

The central nervous system is also protected and cushioned by **cerebrospinal fluid** (CSF), which is formed by specialized capillaries called the *choroids plexus* in inner chambers within the brain called **ventricles**. The cerebrospinal fluid bathes the brain and spinal cord, circulating from the ventricles into the subarachnoid space (see **Figure 3-2**). From the subarachnoid space it the CSF flows to the back of the brain, down around the spinal cord, and then back to the brain, where it is reabsorbed into the blood through the arachnoid membrane. The amounts of cerebrospinal fluid produced and absorbed are equally balanced, so that under normal conditions, the amount of CSF within the central nervous system remains constant.

**Figure 3-1 Neurons**

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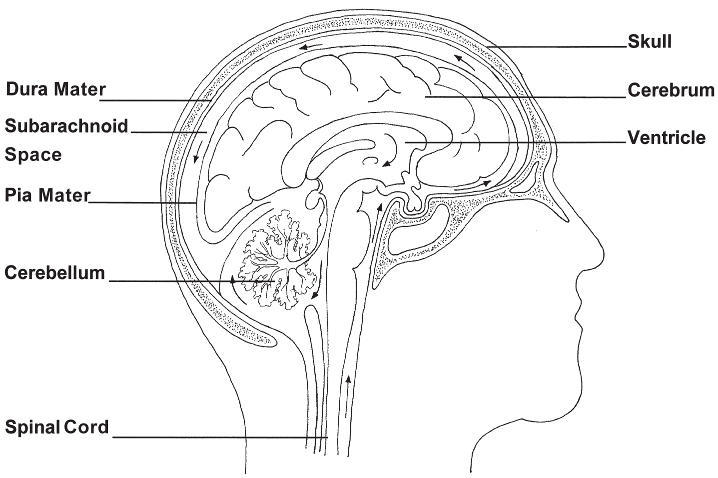
Another protective device is the *blood–brain barrier*, a structural arrangement of capillaries that selectively determines which substances can move from the blood into the brain. While substances such as oxygen and glucose are necessary to brain survival and consequently move freely across the blood–brain barrier, other potential harmful substances, such as toxins, are prevented from crossing into the brain.

The central nervous system is composed of white matter and gray matter. **White matter** makes up the inner part of the brain and the outer portion of the spinal cord and consists of myelinated covered axons that conduct nerve impulses.

**Figure 3-2 Circulation of Cerebrospinal Fluid**

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It is called white matter because of its whitish appearance due to the myelin covering. **Gray matter** makes up the thin outer layer of the brain and the inner portion of the spinal cord. Small segments of gray matter are also embedded deep within certain parts of the white matter of the brain. Gray matter consists of groups of neuron cell bodies; it gets its name from . It is called gray matter because of its grayish appearance. Gray matter of the brain receives, sorts, and processes nerve messages, while gray matter of the spinal cord serves as a center for reflex action (automatic response to stimuli).

## STRUCTURE AND FUNCTION OF THE BRAIN

The brain is directly connected to the spinal cord and serves as the primary center for the integration, coordination, initiation, and interpretation of most nerve messages. It regulates and monitors many unconscious body functions, such as heart and respiratory rate, and coordinates most voluntary movements. In addition, it is the site of higher cognitive processes such as learning, generating and relaying thoughts, reasoning, judgment, memory, consciousness, and emotion. The brain also has a sensory function, which is responsible for vision, hearing, touch, taste, and smell. Language function, including the ability to communicate and to comprehend, is also controlled by the brain as well. Finally, the brain controls basic behavior patterns and the display of general personality traits, which are characteristic of how each individual responds to stimuli.

The brain is protected by the bony covering of the skull (**cranium** or *cranial bones*). The largest part of the brain, the **cerebrum**, is covered with a thin outer layer of gray matter called the **cortex**, which contains billions of nerve cells. The cortex has three specialized areas, which serve three major areas of function:

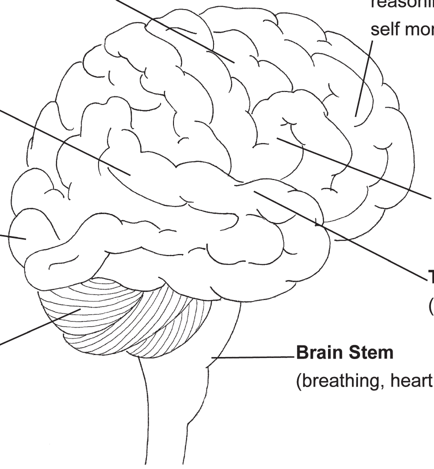
- The *motor cortex* coordinates voluntary movements of the body.
- The *sensory cortex* is responsible for the recognition or perception of sensory stimuli, such as touch, pain, smell, taste, vision, and hearing.
- The *associational cortex* is involved in cognitive functions such as memory, reasoning, abstract thinking, and consciousness.

The cerebrum is divided into two halves, called the *right hemisphere* and the *left hemisphere*. These two hemispheres communicate with each other. Dividing the hemispheres and connecting specific areas of the two hemispheres are bundles of nerve fibers called the *corpus callosum*. Each hemisphere has centers for receiving information and for initiating responses. The left hemisphere mostly receives information from and sends information to the right side of the body, whereas the right hemisphere mostly receives information from and sends information to the left side of the body.

Deep within the cerebral hemispheres are groups of gray matter called **basal ganglia**, which are part of the *extrapyramidal system*. ("Extrapyramidal" denotes nerve fiber tracts that lie outside the pyramidal tract, a relatively compact group of nerve fibers that originate from cells in the outer layer of the brain.) Extrapyramidal function is concerned with postural adjustment and gross voluntary and automatic muscular movements. The basal ganglia help to maintain tone in muscles in the trunk and extremities, enabling individuals to maintain balance and posture and to engage in movements such as walking. The basal ganglia also play a role in enabling individuals to react swiftly, appropriately, and automatically to stimuli that demand an immediate response, such as after tripping, enabling the individual to adjust his or her movement to avoid a fall.

Each hemisphere of the cerebrum is divided into lobes that contain areas related to specific functions (see **Figure 3-3**). The **frontal lobe** is located in the front of each hemisphere and contains motor areas that initiate voluntary movement and skilled movements, such as those, involved in handwriting. Other areas in the frontal lobe control higher intellectual functions such as foresight, analytical thinking, and judgment. The **parietal lobe** is located in the middle of each hemisphere and is primarily the sensory area, integrating and interpreting sensation such as touch, pressure, pain, and temperature. Some memory functions are also located in the parietal

**Figure 3-3 Areas of Brain Function**






lobe, especially those responsible for storage of sensory memory. The **temporal lobe** is located under the frontal and parietal lobes and is primarily responsible for the interpretation of and distinction between auditory stimuli. The **occipital lobe** is located at the back or posterior portion of each hemisphere; i. It is the primary area for reception and interpretation of visual stimuli.

Several parts of the cerebrum are involved in the language function, which consists of the process of receiving, interpreting, and integrating visual and auditory stimuli as well as the ability to express thoughts in a coordinated way so that others can comprehend them. Language function is located in the left hemisphere of the cerebrum in most individuals, whether they are right- or left-handed. An area located over the temporal and parietal lobes, called **Wernicke's area**, is the major area responsible for *receptive function* (speech understanding), or the ability to integrate visual and auditory information so as to understand communication received. An area located in front of the temporal lobe and in the frontal cortex, called **Broca's area**, is responsible for speaking ability and is closely associated with motor areas that control the muscles needed for articulation. This area contributes to *expressive function* (speech formation), or the ability to integrate and coordinate words so that the meaning can be comprehended.

A structure known as the *thalamus* lies within the center of the brain. The thalamus acts as a relay station that sorts, interprets, and directs sensory information. Below the thalamus is the *hypothalamus*, which coordinates neural and endocrine activities. It This structure helps regulate the body's internal environment and behaviors that are important to survival, such as eating, drinking, and reproduction. Below the hypothalamus is the *pituitary gland*, an endocrine gland that will be discussed in more detail in a later chapter.

The *limbic system* is comprises a group of structures consisting of both gray and white matter that surround the thalamus. The limbic system plays a role in expression of instincts, drives, and emotions and as in the formation of memories. A band of gray matter called the *hippocampus* is involved in learning and long-term memory, helping to determine where important and relevant aspects of facts will be stored.

Beneath the occipital lobe of the cerebrum is a structure called the *cerebellum*. The cerebellum is primarily responsible for the coordination and integration of voluntary movement and for the maintenance of equilibrium, posture, and balance of the body. It also regulates and coordinates fine movements of the extremities, which are initiated by the frontal lobe.

The **brain stem**, which is located beneath the cerebellum at the base of the brain just above the spinal cord, acts as a relay station, transmitting nerve impulses between the spinal cord and the brain. It is the primary center of involuntary functions. Control of vital organ functions, such as regulation of heartbeat or respiration, occurs in the brain stem. Areas in the brain stem also regulate the diameter of blood vessels, contributing to the control of blood pressure. Reflex actions, such as coughing and swallowing, are controlled in the brain stem as well. Finally, the brain stem contains scattered groups of cells, called the **reticular formation**, which are involved in the initiation and maintenance of wakefulness and alertness.

The brain requires both oxygen and nourishment in the form of *glucose* in order to function and to survive. Oxygen and glucose are transported to the brain by blood carried by four major arteries: two *carotid arteries* and two *vertebral arteries*. The vertebral arteries join to form the *basilar artery*. The carotid and basilar arteries then connect at the base of the brain to form the *circle of Willis,* from which *cerebral arteries* branch out to carry blood to the rest of the brain.

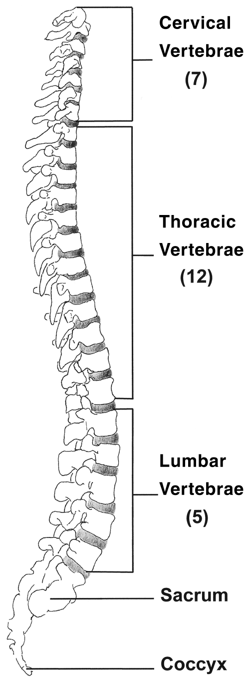
## STRUCTURE AND FUNCTION OF THE SPINAL CORD AND PERIPHERAL NERVOUS SYSTEM

### The Spinal Cord

The spinal cord is part of the central nervous system and extends from the brain stem to the lower part of the back. Bony coverings called *vertebrae* surround the spinal cord and protect it. Taken as a whole, this bony covering, as a whole, forms the vertebral column. The *vertebral column* consists of 7 *cervical vertebrae*, located in the neck area; 12 *thoracic vertebrae*, located in the upper and middle back; and 5 *lumbar vertebrae*, located in the lower back. The *sacrum*, located below the lumbar vertebrae, consists of fused (joined) bone. At the tip of the sacrum is the *coccyx*, or tailbone (see **Figure 3-4**).

The spinal cord conducts impulses to and from the brain. The outer white matter of the spinal cord, which consists of bundles or tracts of myelinated fibers of sensory (*afferent*) and motor (*efferent*) neurons, conveys electrical impulses up and down the spinal cord between the **peripheral nervous system** (those nerves lying outside the central nervous system) and the brain. In most instances, sensory information traveling up the right side of the spinal cord crosses over to the left side of the brain, so the left hemisphere of the brain would, for example, interpret pain in the right hand. Conversely, motor impulses originating in the left brain cross to the right side of the spinal cord and initiate a response to the right side of the body. Because of this crossover effect, damage on one side of the brain typically causes manifestations itself on the opposite side of the body.

**Figure 3-4 The Spine**

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The inner gray matter of the spinal cord, which is composed of cell bodies and *unmyelinated* neurons, acts as a coordinating center for reflex and other activities, such as voluntary movements and control of internal functions. A reflex center in the gray matter of the spinal cord is where sensory and motor neurons connect; this part of the spinal cord serves as a center for spinal reflexes. A **reflex** can be defined as an automatic response to a given stimulus. Spinal reflexes control not only muscle reflexes, but also the reflexes of internal organs.

The gray matter within the spinal cord resembles the letter "H." The projections of the H are named according to the direction to which they project. The *posterior horns* extend toward the back, and the *anterior horns* project toward the front. Cerebrospinal fluid, which nourishes and protects the spinal cord, fills both the *central canal*, located within the center of the gray matter, and the subarachnoid space surrounding the outer portion of the spinal cord.

Motor (*efferent*) impulses originate in the motor cortex of the brain, extend down the spinal cord through *descending tracts*, and exit through motor spinal nerve roots that extend through openings between the vertebrae that surround the spinal cord. Sensory (*afferent*) impulses from the body enter the spinal cord through spinal nerve roots that also extend through openings between vertebrae and then travel up *ascending tracts* in the spinal cord to the brain.

Spinal nerve roots are named for the vertebral level from which they exit. For example, the nerve roots that leave the spinal cord at the *cervical* level are labeled C1 through C8, and the nerve roots that leave at the **thoracic** level are labeled T1 through T12 (see **Figure 3-5**). The *sensory* (afferent) nerve fibers from outside the central nervous system carry body sensations into the *sensory nerve roots* (posterior roots) at the back of the spinal cord, where they are then carried up the spinal cord to the brain. *Motor* (efferent) impulses travel from the brain down the spinal cord and exit from *motor nerve roots* (anterior roots) at the front of the spinal cord. Motor nerve fibers then carry impulses to the voluntary muscles of the body.

Many types of neurons work together to transmit impulses through the spinal cord. Sensory impulses entering the spinal cord at the lumbar region are relayed vertically to the brain through a number of connecting sensory neurons. Motor impulses from the brain to the peripheral nerves, however, are conducted through two separate categories of motor neurons. *Upper motor neurons* originate in the brain and are contained entirely within the central nervous system. *Lower motor neurons*, although originating in the central nervous system, have fibers extending to the peripheral nerves in voluntary muscles. Alteration of function of either upper or lower motor neurons can generally affect the voluntary muscles. The location of the alteration of function determines the nature of the manifestations.

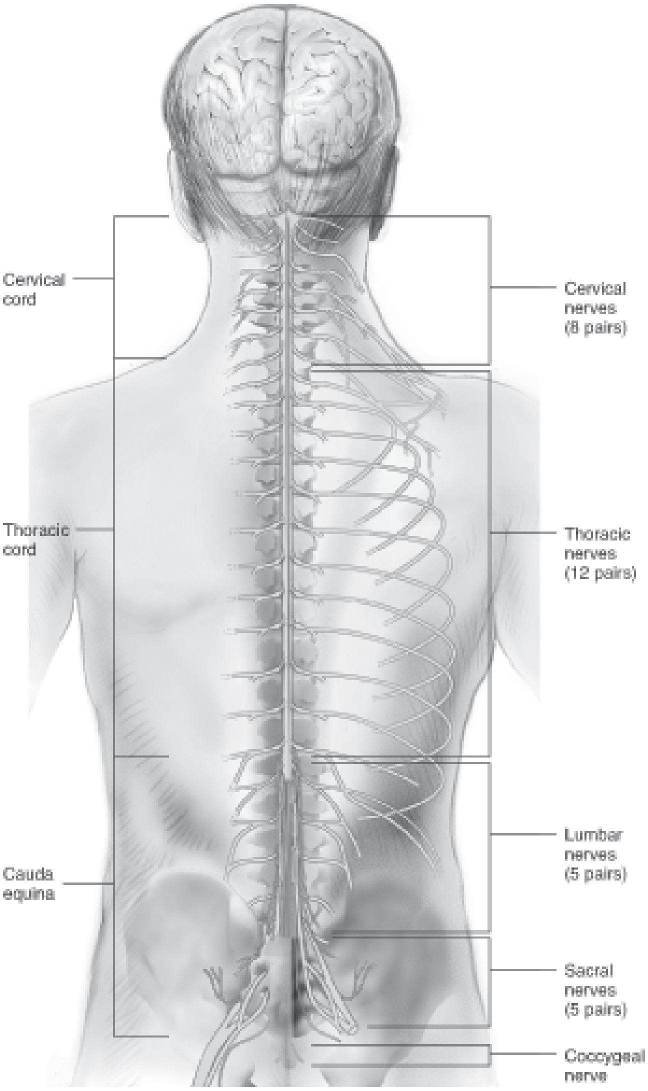
## Structure and Function of the Peripheral Nervous System

A nerve is a bundle of fibers outside the central nervous system that transmits information between the central nervous system and various parts of the body. The peripheral nervous system consists of all nerves that extend from the brain and spinal cord. To function effectively, the peripheral nerves must be connected to the central nervous system. Some peripheral nerves connect directly to the brain (*cranial nerves*); others connect directly to the spinal cord (*spinal nerves*). Cranial and spinal nerves are essential links between the rest of the body and the central nervous system.

The 12 pairs of peripheral nerves that connect and transmit messages directly to the brain are called **cranial nerves**. Some cranial nerves contain only sensory fibers, whereas others contain both sensory and motor fibers. Cranial nerves mediate many aspects of sensation and muscular activity in and around the head and neck. Cranial nerves and their related functions are described in **Table 3-2**).

The 31 pairs of peripheral nerves that connect and transmit messages directly to the spinal cord are called **spinal nerves**. Each nerve divides and then subdivides into a number of branches. Nerves at each level travel to specific parts of the body, conveying information between those

**Figure 3-5 Spinal Nerves**




areas and the central nervous system. Spinal nerves and their related functions are described in Figure 3-5.

Nerves control both voluntary and involuntary functions in the body. Nerves that control voluntary functions (such as movement of the muscles in the extremities) are called **somatic nerves**. Nerves that are concerned with the control of involuntary functions are part of a subcategory of the peripheral nervous system called the **autonomic nervous system**.

The autonomic nervous system integrates the work of vital organs, such as the heart and lungs. Its primary function is to coordinate the activity of internal organs so that they can make adaptive responses to changing external situations, thereby maintaining internal equilibrium. Nerve fibers monitor the activities of internal organs as well as changes in the external environment. When changes are necessary to maintain internal **homeostasis** (equilibrium) or to protect the body, the autonomic nervous system stimulates

**Table 3-2 Cranial Nerves and Related Functions**

| Cranial Nerve | | Area of Function |
|---|---|---|
| I. | Olfactory | Smell |
| II. | Optic | Vision |
| III. | Oculomotor | Movement of eye muscles |
| IV. | Trochlear | Eyelids |
| V. | Trigeminal | Sensation in head, face, and teeth, motor activity of chewing |
| VI. | Abducens | Pupil dilation, focusing of lens |
| VII. | Facial | Taste, sensation of external ear, control of salivary glands, tears, muscles in facial expression |
| VIII. | Vestibulocochlear | Sensation of sound, balance, orientation of head |
| IX. | Glossopharyngeal | Swallowing, sensation of pain, taste, touch from tongue and throat |
| X. | Vagus | Heartbeat, digestion, speech, swallowing, respiratory function, gland functions |
| XI. | Accessory | Movement of head and shoulders, muscles of pharynx and larynx in throat, production of voice sounds |
| XII. | Hypoglossal | Tongue movement, speech, swallowing |

an immediate, involuntary response. For example, in response to a speck of dust in the eye, tears are produced; i. In response to a fearful situation, the heart beats faster.

The autonomic nervous system is divided into two subsystems:

- The sympathetic nervous system
- The parasympathetic nervous system

These two systems work both together and in opposition to control internal organs and regulate their function. Hormones and emotions can affect both systems.

The sympathetic nervous system becomes active during periods of stress and in emergencies. It prepares the body for action, deepening respirations, making the heart beat faster, dilating the pupils, stimulating production of stress hormones, and increasing blood supply to the large muscles of the body.

In contrast, the parasympathetic nervous system dominates when the body is a rest. It activates those mechanisms that focus on body conservation, such as decreasing the heart rate and constricting the pupils of the eye. The parasympathetic nervous system is also an important component of sexual arousal in both males and females.

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