Nervous System: General Structure and Functions

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The human nervous system weighs “only” about 4.5 pounds, which accounts for approximately 3% of the entire body. It is a small and complex body system that consists of an intricate network of nervous cells (or neurons) and even more glial cells. How many nervous cells does a human have? Billions is the simple answer. However, from a medical point of view, the more important questions are: how does the nervous system work, and what does its structure look like?

Functions of the Nervous System

The basic purpose of the nervous system is to regulate and adapt the human body to changes in the environment and in the body itself. It is the system responsible for communication and control in the body. Anatomically, the nervous system has 2 main subdivisions:

- The central nervous system (CNS)
- The peripheral nervous system (PNS).

The nervous system performs many different tasks and enables the human being, for instance, to smell or speak. Through receptors, the nervous system receives and processes different stimuli, such as heat or light, that can come from outside or inside the body.

Our ability to remember things or to control our body movements as well as the
regulation of our internal organs is governed by our nervous system. The **basic functions** responsible for accomplishing these activities include:

- Sensory function
- Integrative function
- Motor function

**Sensory function**

In **sensory function**, certain sensors (or neurons) that serve as receptors for stimuli from inside the body (such as hunger or thirst) or from the environment (like the touching of a hotplate) translate such stimuli into an action potential.

These neurons are called **sensory or afferent neurons** (lat. af-/ad- = towards; ferre = to carry). They are responsible for transmitting these sensory signals via the cranial and spinal nerves to the brain and spinal cord.

**Integrative function**

The processing of the received sensory information constitutes the **integrative function** of the nervous system. This information is analyzed and memorized in preparation for a corresponding reaction. Perception is an important integrative function of the brain, where sensory signals are consciously identified.

In principle, the integration process is performed by **interneurons**. They represent the largest portion of all the neurons of the human body. They have short-distance axons that connect with neurons in the brain and spinal cord.

**Motor function**

When the sensory information has been processed, the nervous system can trigger a corresponding motor response. The **motor function** can take the form of a muscle contraction or glandular secretion.
The neurons responsible for this process are called motor neurons or efferent neurons (lat. ef-/ex- = out of, from). They carry the information from the brain through the cranial and spinal nerves to the spinal cord or from the brain and spinal cord to the effectors (muscles and glands).

The stimulation of the effectors by the motor neuron causes muscle contractions and gland secretions. Pulling away the hand after having touched a hotplate is a typical example of a motor response involving muscle contraction.

Structure of the Nervous System

The nervous system can be divided into anatomic and functional parts; however, these parts are usually indistinguishable. The conductive nerve fibers run without limitations from the CNS to the PNS and vice versa. All parts of the nervous system influence each other.

Central nervous system

The CNS, which comprises the brain and the spinal cord, has to process different types of incoming sensory information. The brain is protected by the skull, while the spinal cord is protected by the spinal column.

In addition, the brain and spinal cord are covered with protective membranes, the
meninges, which are made out of connective tissue. The meninges consist of 3 layers: the dura mater, arachnoid mater, and pia mater. Between the arachnoid and pia mater is the cerebrospinal fluid, which creates a liquid cushion that protects the CNS from physical shock.

Note: The CNS comprises the brain and spinal cord.

Peripheral nervous system

All parts of the nervous system outside the CNS constitute the PNS. The PNS includes the cranial nerves and their branches as well as the spinal cord and its corresponding spinal nerves that branch out into the periphery. The PNS consists mainly of nerve fibers with nerve cell clusters in some places.

Such a cluster of nerve cells, together with the corresponding nerve fibers, forms a small bulge that is called a ganglion. The human body contains 12 cranial and 31 spinal nerve pairs.

Note: The PNS comprises all parts of the nervous system outside the CNS.

Somatic nervous system

The somatic nervous system (lat. soma = body) consists of sensory and motor neurons, and its main purpose is communication between the body and its environment.

- The sensory neurons transmit information from the head and body, and from the receptors of the special senses (sight, hearing, smell, and taste) to the CNS.
- The motor neurons exclusively conduct impulses from the CNS to the skeletal muscles. Since this motor response is initiated consciously and in a controlled manner, the somatic nervous system is called the voluntary part of the PNS.

Note: The somatic nervous system acts voluntarily.

Autonomic nervous system

The autonomic nervous system (ANS; lat. autos = self; nomos = law) contains sensory and efferent neurons that primarily control the functions of the internal organs.

- The sensory neurons pass on the information from the autonomic sensory receptors, located, for example, in the stomach or the lungs, to the CNS.
- The efferent neurons conduct the impulses received from the CNS to the smooth muscles (e.g., the heart) and to the glands. Under normal circumstances, the efferent responses are not consciously controlled; therefore, the ANS works involuntarily.

Note: The ANS acts involuntarily.
The motor part of the ANS can be further subdivided into the **sympathetic division** and **parasympathetic division**; the effectors contain, with few exceptions, sympathetic or parasympathetic nerves that each have contrary effects.

**Sympathetic neurons**, for instance, speed up the heart rate. They support physical processes or exertions and stimulate the fight-or-flight response, i.e., ergotropic reactions that increase the energy of the body.

**Parasympathetic neurons**, in contrast, slow down the heart rate and stimulate rest-and-digest activities, i.e., trophotropic reactions that support body regeneration and build up energy reserves. The parasympathetic system also controls the homeostatic balance.
Properties of the sympathetic and parasympathetic systems

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Enteric nervous system

Special part of the nervous system is the enteric nervous system (ENS; lat. enter = inside)—the ‘brain of the gut’. The ENS consists of approximately 100 million neurons in the enteric plexus, which is an intramural nervous system in the gastrointestinal tract made up of sympathetic and parasympathetic fiber networks and parasympathetic cells and small ganglia.

The enteric plexus stretches along the entire gastrointestinal tract. To a certain extent, the neurons of the enteric plexus act independently from the ANS and CNS, although they communicate with the CNS through sympathetic and parasympathetic neurons.

The sensory neurons of the ENS are responsible for chemical changes in the gastrointestinal tract.

The motor neurons of the ENS regulate the contractions of the smooth muscles of the gastrointestinal tract, in order to move the food through the intestines. Controlling the secretions of organs of the gastrointestinal tract, such as gastric acid in the stomach, is also a function of enteric motor neurons.

Note: The ENS works involuntarily.

Structure of a nerve in the nervous system

At a cellular level, the nervous tissue is made up of nerve cells (neurons) and their processes, as well as neuroglia, i.e., glial cells, which are the cells that form the support structure of the nervous system.

There are about 86 billion nerve cells in the human brain. Their specific functions include receiving stimuli from changes in the environment, transmitting these impulses over very long distances, processing the transmitted information, and passing impulses on to other nerve cells or effector organs, like the muscles or glandular cells.

The nerve cell, also called the neuron, is the smallest functional unit of the nervous system. It consists of 3 parts:

- Cell body (also called soma or perikaryon)
- Dendrites
- Axon

Cell body

The cell body contains the nucleus, which has a large vesicular form and is located in the center of the cell body. The perikaryon is the trophic center of the nerve cell.
The cytoplasm surrounding the nucleus houses many different cell organelles, typical ones being the lysosome, mitochondria, and the Golgi apparatus. Free ribosomes, which serve as the site of protein synthesis, and distinctive clusters of the rough endoplasmic reticulum (**Nissl bodies**) can also be found in the cell body.

The Nissl bodies use the newly synthesized proteins to replace cellular components that serve as material for neuron growth and to repair damaged axons in the PNS.

Most neurons possess **2 types of processes (appendages):**

- Several dendrites
- One axon

### Dendrites

Dendrites are ‘small trees’ whose **purpose is receiving information from other nerve cells.** In many neurons, they form a tree-like structure of processes with numerous branches that extend from the cell body.

Their cytoplasm contains **Nissl bodies, mitochondria, and other organelles.** Highly responsive peripheral nerves have especially long dendrites that run from the spinal cord all the way to peripheral organs like the skin.

### Axon

Axon (Lat. axis) has a long, thin, and cylindrical cable-like form. It is connected to the cell body by a small elevation, the axon hillock. The axonal function is **to conduct nerve impulses to another neuron, muscle fiber, or a glandular cell.**

Axons are enclosed in a multilayered shell (**myelin**) composed of lipids and proteins. The myelin sheath increases the velocity of nerve impulses and serves as insulation for the axon.

The **initial segment** is the part of the axon that is adjacent to the axon hillock. In most neurons, the junction between the axon hillock and the initial segment is the site where nerve impulses are initiated. It is also called a trigger zone; from here, the nerve impulses start their way along the axon towards their final destination.

An axon contains **mitochondria,** which is the site of cellular respiration and production of ATP. The axon also contains **microtubules,** which are responsible for transporting material between the cell body and the axon, and **neurofilaments,** which provide structural support to the cell.

The **axoplasm** in the cytoplasm of an axon and is covered by a plasma membrane, the axolemma (lat. lemma = shell). The axon ends in numerous thin processes: the axon terminals and the telodendria.

At the end of some axon terminals, **synaptic boutons** form. This is the area we call a synapse, where the communication between 2 neurons, or a neuron and an effector cell, takes place. Many neurons contain 2 or even more types of neurotransmitters, each having different effects on the postsynaptic cell. The molecules of the neurotransmitter inhibit or excite other neurons, muscle fibers, or glandular cells.

**Note:** Dendrites handle afferent nerve impulses, and axons serve as efferent transmitters of impulses to muscle, nerve, and glandular cells.
Neuroglia of the nervous system

The neuroglia, or glial cells (gr. glia = glue), are the second most important components of the PNS and CNS. These cells are crucial to the functioning of the nervous system. They are involved in all transport processes, contribute to the alimentation of the nerve cells, and serve as protection and insulation. Unlike the neurons, the glial cells do not initiate or transmit action potentials.

In a mature nervous system, glial cells reproduce and divide. Particularly in the case of injuries or diseases, they reproduce in order to fill up the space that was formerly occupied by neurons.

For every nerve cell, there exist about 10 glial cells. Still, the glial cells only make up half of the total volume of the nervous system since glial cells are much smaller than nerve cells. The glial cells in the CNS and PNS differ from each other structurally and functionally.

The action potential
The resting membrane potential is an electric potential across the plasma membrane (-70 mV). The inside of the cell is more negative than the outside. The gradient is maintained by the Na⁺ / K⁺ ATPase pumps (3 Na⁺ out for 2 K⁺ in).

A depolarization wave of the plasma membrane travels down the axon. Mediated by voltage-gated Na⁺ channels. The electric potential across the plasma membrane is quickly restored to a resting state by voltage-gated K⁺ channels. The ATP travels by a process termed saltatory conduction.

**Saltatory conduction**
Functions of the glial cells in the central nervous system

**Astrocytes (macroglia):**
- Exchange of substances
- Storage of glycogen and providing adjacent neurons with glucose
- Building the blood-brain-barrier
- Phagocytosis of dead synapses
- Forming glial scar tissue in the CNS, e.g., following a stroke or multiple sclerosis

**Oligodendrocytes:**
- Building the myelin sheath in the CNS

**Microglia (Hortega cells):**
- Phagocytosis of foreign bodies and of endogenous dead tissue

**Ependymal cells:**
- The lining of the ventricles of the brain and of the central canal of the spinal cord
- Part of the cerebrospinal fluid

Functions of the glial cells of the peripheral nervous system

The **Schwann cells** are responsible for myelination in the PNS. The **satellite cells** serve as helpers for the neurons and substitute cerebral astrocytes in the peripheral ganglia.

**The Myelin Sheath of a Neuron in the Nervous System**

As mentioned above, the myelin sheath protects the axon of a neuron against electrical shocks and speeds up the transmission of nerve impulses. From birth to maturity, the amount of myelin grows constantly, increasing transmission speed significantly.

**Two types of neuroglia form the myelin sheath:**
- Schwann cells in the PNS
- Oligodendrocytes in the CNS

**Schwann cells** only exist in the PNS. In contrast to the CNS where all nerve cells possess a myelin sheath, some nerves in the PNS do not have a myelin sheath. The formation of myelin sheaths around the axons begins as early as during fetal development.

Every Schwann cell forms multiple layers around a segment of an axon that is about 1-mm long and delimited on each side by a node. The interior side, consisting of up to 100 membrane layers, is the myelin sheath (Schwann sheath).

The outer cytoplasmic layer of the Schwann cell that contains the nucleus and covers the myelin sheath is the neurolemma. At the junction between 2 adjacent Schwann cells, there is a gap or node in the myelin sheath. These gaps in the myelin sheath are called the nodes of Ranvier.
The **oligodendrocytes** are responsible for building the myelin sheaths in the CNS. They have longer processes than the Schwann cells and therefore, they not only cover one but up to 50 adjacent axons. Consequently, the oligodendrocytes have fewer nodes of Ranvier. Since the cell body and the nucleus of the oligodendrocyte do not cover the axon, there is no neurolemma.

### Demyelination

Demyelination is the **loss or damage of the myelin sheath around the axon** and can be the consequence of diseases like multiple sclerosis or Tay-Sachs disease. Furthermore, a vitamin B12 deficiency can cause demyelination, particularly in the spinal cord, leading to sensory dysfunctions and even motor paralysis.
Diseases of the nervous system

The nervous system can be affected by numerous diseases: inflammation, infections, tumors, disturbed blood circulation, injuries, or autoimmune diseases. They often lead to further neurological illnesses.

Some of the most well-known neurological diseases include:

- Multiple sclerosis
- Alzheimer’s disease
- Parkinson’s disease
- Meningitis
- Encephalitis
- Myelitis
- Polio
- Epilepsy
- Amyotrophic lateral sclerosis

Image: Photomicrograph of a demyelinating multiple sclerosis lesion. By: Marvin 101. License: CC BY-SA 3.0

Depression
Depression has a strong genetic component and is especially common within immediate family members. Deficiencies are also seen in structures of the frontal lobe, cerebellum, hippocampus, etc.

Monoamine hypothesis for the disease:

![Diagram of neurotransmitter system]

**Alzheimer’s Disease (AD)**

The most prevalent form of dementia is characterized by memory loss. Anterograde amnesia is the inability to form new memories. AD is a cortical disease affecting the outermost layer of the brain—the cortex. The condition is linked to the formation of beta-amyloid plaques and neurofibrillary tangles. This formation could lead to ‘synaptic clutter’ which would impact normal function. Abnormalities in the activity of acetylcholine in the hippocampus (memory) could also be contributory.

**Parkinson’s Disease (PD)**

PD is a movement disorder caused by the death of cells that generate dopamine in:
Symptoms include resting tremor, slow movement, and rigidity of movements of the face. Treatment usually centers around restoring levels of DA (i.e. L-Dopa, DA agonists).

Nervous breakdown

A nervous breakdown is, contrary to the diseases mentioned above, the colloquial name for a situation that is extremely strenuous psychologically. Different reactions or disturbances of the nervous system fall under the concept of a nervous breakdown.

They are the responses of the nervous system to unexpected or traumatic experiences, such as

- The death of a relative
- Severe accident
- Injuries
- Sudden illness

The nervous system does not literally break down. It rather responds to extraordinary strain in usually the same manner. The increased production of stress hormones enhances the impulse transmission in the nervous system and leads to either a flight-or-fight response.
As a consequence, the body rapidly activates its energy reserves, which produces the following typical symptoms:

- Shivering
- Crying fits
- Heart palpitations
- Sweating
- Panic attacks
- Concentration problems
- Outbursts of anger

The treatment of a nervous breakdown depends on the level of severity. If it does not constitute a pathological phenomenon, the symptoms will shortly disappear on their own. Valerian and hops can be helpful, though, due to their relaxing effect.

However, when the nervous breakdown becomes chronic, a first step would be to exclude other mental disorders through differential diagnosis, before prescribing sedative-like diazepam or proceeding to behavioral therapy.

References


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