Nervous System: General Structure and Functions

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 organism to changes in the environment and in the body itself. It is the system responsible for communication and control of the body, and it innervates all bodily organs.
Anatomically, the nervous system has two main subdivisions:

- **Central nervous system (CNS)** and
- **Peripheral nervous system (PNS).**

The nervous system performs many different tasks and enables us, for instance, to smell or speak. Through so-called receptors, the nervous system receives and processes different stimuli, such as heat or light, that can come from either the environment or from inside the body.

Our ability to remember things from the past or to control our body movements as well as the regulation of our internal organs are all governed by our nervous system. Which are the basic functions responsible for accomplishing these activities?

- **Sensory function**
- **Integrative function**
- **Motor function**

### Sensory function

The **sensory function** refers to certain sensors (or neurons) that serve as receptors for stimuli from the body’s inside (such as hunger or thirst) or from the environment (like the touching of a hotplate), which will later be translated into an action potential.

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

### Integrative function

The processing of the received sensory information constitutes the **integrative function** of the nervous system. Hereby, 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.
On principal, 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 a glandular secretion.

The responsible neurons 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 the 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 your hand after having touched a hotplate is the typical example of a motor response involving muscle contraction.

Structure of the nervous system

The nervous system can be divided into an anatomic and a functional part; however, they are inseparably intertwined. The conductive nerve fibers run without limitations from the central to the peripheral nervous system and vice versa. All parts of the nervous system influence each other mutually.
Central nervous system

The central nervous system (CNS), which comprises the brain and the spinal cord, has to process many different types of incoming sensory information. The brain (lat. cerebrum) is protected by the skull; the spinal cord (lat. medulla spinalis) 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. They consist of three layers: the dura mater, the arachnoid mater and the pia mater. Between the arachnoid and the pia mater is the cerebrospinal fluid, creating a kind of liquid cushion that protects the CNS against physical shock.

Note: The central nervous system comprises the brain and the spinal cord.

Peripheral nervous system

All parts of the nervous system outside the CNS constitute the peripheral nervous system (PNS). This includes the cranial nerves and their branches as well as the spinal cord and its corresponding spinal nerves, branching 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 ganglion. The human body contains twelve cranial and 31 spinal
nerve pairs.

**Note:** The peripheral nervous system comprises all parts outside the central nervous system.

# Somatic nervous system

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

- The **sensory neurons** are in charge of transmitting information from the head, the body’s outer shell and extremities and from the receptors of the special senses (sight, hearing, smell and taste) to the CNS.
- The **motor neurons** exclusively conduct the 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 peripheral nervous system.

**Note:** The somatic nervous system acts voluntarily.

# Autonomic nervous system

The **autonomic nervous system** (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 and, therefore, the autonomic nervous system (ANS) works involuntarily.

**Note:** The autonomic nervous system acts involuntarily.
How can the motor part of the ANS be further subdivided? There are the sympathetic division and the 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 body’s energy.

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

<table>
<thead>
<tr>
<th>Sympathetic system</th>
<th>Parasympathetic system</th>
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<td>Excitation</td>
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<td>Activity</td>
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Properties of the sympathetic and the parasympathetic systems

Note: The sympathetic system leads to sympathy.

Enteric nervous system

A special part of the nervous system is the **enteric nervous system** (lat. enter = inside), the “brain of the gut”. The enteric nervous system (ENS) consists of approximately 100 million neurons in the **plexus entericus**; an **intramural nervous system** in the gastrointestinal tract, made up of sympathetic and parasympathetic fiber networks and parasympathetic cells and small ganglia.

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

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

The **enteric motor neurons**, on the other hand, regulate the contractions of the smooth muscles of the gastrointestinal tract, in order to move the food through the intestines. Controlling the secretions of the organs belonging to the gastrointestinal tract, like the gastric acid in the stomach, is also part of the enteric motor neurons’ responsibility.

Note: The enteric nervous system (ENS) works involuntarily.

Structure of a nerve in the nervous system

The nervous tissue is made up of **nerve cells and their processes as well as neuroglia, i.e., glial cells**.

There are about 86 billion nerve cells in the human brain. Their specific capabilities 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 muscles or glandular cells.

The **nerve cell, also called neuron, is the smallest functional unit of the nervous system**. It consists of three 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 for the nerve cell.
The cytoplasm surrounding the nucleus holds many different cell organelles, typical ones being the lysosome, mitochondria or the Golgi apparatus. Free ribosomes, which serve as the site of protein synthesis, and distinctive clusters of 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 two 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 extending out 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

An axon (Latin for axis) has a long, thin and cylindrical cable-like form. It is connected to the cell body with a small elevation, the axon hillock. The axon’s function is to conduct nerve impulses to another neuron, a muscle fiber or a glandular cell.

Axons are enclosed in a multilayered shell composed of lipids and proteins which is called myelin. The myelin sheath increases the velocity of the 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 axon hillock and initial segment is the site where nerve impulses are initiated. It is also called trigger zone: from here, the nerve impulses start their way along the axon towards their final destination.

An axon contains mitochondria, the site of cellular respiration and production of ATP, 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 is 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, so-called synaptic boutons form. This is the area we call a synapse, where the communication between two neurons, or a neuron and an effector cell, takes place. Many neurons contain two 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 the afferent reception of 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 peripheral and the central nervous system. These cells are of crucial importance 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 action potentials, nor do they transmit them.

In a mature nervous system, glial cells reproduce and divide. Especially 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 for half of the total volume of the nervous system since glial cells are much smaller than nerve cells. The glial cells in the central and peripheral nervous system differ from each other structurally and also in some functional respects.

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).

Wave of depolarization 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:
- 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 in charge of building the myelin sheath 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, thus increasing the 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 in fetal development.

Every Schwann cell forms multiple layers around a segment of an axon that is about one millimeter 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 two adjacent Schwann cells, there is a gap, or node, in the myelin sheath. Those gaps in the myelin sheath are
called 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 (MS)
- Alzheimer’s disease
- Parkinson’s disease
- Meningitis
- Encephalitis
- Myelitis
- Polio
- Epilepsy
- Amyotrophic lateral sclerosis (ALS)

Image: "Photomicrograph of a demyelinating MS-Lesion" by Marvin 101. License: CC BY-SA 3.0

Depression
Strong genetic component, especially within immediate family members. Deficiencies also seen in structures of the frontal lobe, cerebellum, hippocampus, and others.

Monoamine hypothesis for the disease:

Alzheimer’s Disease (AD)

The most prevalent form of dementia characterized by memory loss. Anterograde amnesia is an inability to form new memories. AD is a cortical disease affecting the outermost layer of the brain, the cortex. Linked to formation of beta-amyloid plaques and neurofibrillary tangles. Formation could lead to “synaptic clutter” which would impact normal function. Abnormalities in the activity of ACh in the hippocampus (memory).

Parkinson’s Disease (PD)

Movement disorder caused by death of cells that generate dopamine in:
Symptoms include: resting tremor, slow movement, 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 psychologically extremely strenuous situation. Many 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,
- a severe accident,
- injuries,
- sudden illness, or
- permanent stress.

The nervous system does not literally break down; it rather responds to extraordinary strain in always 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.
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 hop 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 a sedative like diazepam or proceeding to behavioral therapy.

**Frequent exam questions about the nervous system**

1. **Which basic function is necessary for the initial reception of stimuli?**
   - A. The basic motor function
   - B. The basic sensory function
   - C. The basic integrative function
   - D. The basic enteric function
   - E. The basic ergotropic function

2. **Which statement is wrong?**
   - A. The ANS acts involuntarily.
   - B. The SNS acts voluntarily.
   - C. The motoric division of the SNS comprises a sympathetic and a parasympathetic part.
   - D. The CNS consists of the brain and the spinal cord.
   - E. The PNS comprises all the parts outside of the CNS.

3. **Which statement about the nerve is correct?**
   - A. Schwann cells are responsible for building the myelin sheath in the CNS.
   - B. The purpose of an axon is to conduct nerve impulses to another neuron.
   - C. Oligodendrocytes are responsible for building the myelin sheath in the PNS.
   - D. A nerve cell is made up of a cell body, a dendrite and the myelin sheath.
   - E. Dendrites are the trophic center of the nerve cell.

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**Correct answers:** 1B, 2C, 3B

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