

Title: Nervous System

Teacher: Agnieszka Adamczak-Ratajczak MD

Cool. Anatomicum, 6 Świącicki Street, Dept. Of Physiology

I. Organization of the nervous system

II. Functions of the nervous system

The nervous system carries out a complex array of tasks, such as sensing various smells, producing speech, remembering, providing signals that control body movements, and regulating the operation of internal organs.

1. Sensory function.
2. Integrative function.
3. Motor function

III. Transport across cell membranes

1. **Simple diffusion** – is the only form of transport across cell membrane that is not carrier-mediated.
2. **Facilitated diffusion** – is also called carrier-mediated diffusion because a substance transported in this manner diffuses through the membrane with a specific carrier protein helping it to do so.
3. **Primary active transport** – examples Na^+ , K^+ -ATPase or Na^+ - K^+ pump
 - a) both Na^+ and K^+ are transported against their electrochemical gradients
 - b) energy is provided from the terminal phosphate bond of ATP
 - c) the usual stoichiometry is $3\text{Na}^+/2\text{K}^+$
 - d) specific inhibitors of Na^+ , K^+ -ATPase are the cardiac glycoside drugs ouabain and digitalis.
4. **Secondary active transport.**

IV. Electrical signals in neurons

1. Structure of a typical **neuron** (dendrites – cell body – axon – axon terminals) and types of neurons (multipolar, unipolar, bipolar).
2. **Ion channels**
 - a) ion channels are selective
 - b) ion channels may be open or closed
 - c) types of ion channels (a leakage channels, a voltage-gated channel, a ligand-gated channel, a mechanically gated channel)
3. **Resting membrane potential**
 - a) resting membrane potential is expressed as the measured potential difference across the cell membrane in millivolts (mV)
 - b) in neurons, the resting membrane potential ranges from -40 to -90mV. A typical value is -70mV
 - c) the minus sign indicates that the inside is negative relative to the outside
 - d) a cell that exhibits a membrane potential is said to be polarized
4. **Action potentials** (depolarizing phase, threshold, repolarizing phase)
 - a) is a very rapid change in membrane potential that occurs when a nerve cell membrane is stimulated.
 - b) specifically, the membrane potential goes from the resting potential (typically -70mV) to some positive value (typically about +30mV) in a very short period of time (just a few milliseconds).
 - c) action potential have stereotypical size and shape, are propagating and are all-or-none.
5. **Refractory period**
 - a) the period of time after an action potential begins during which an excitable cell cannot generate another action potential.
 - b) absolute refractory period
 - c) relative refractory period
6. **Propagation of nerve impulses**
 - a) nerve impulses propagate more rapidly along myelinated axon than along unmyelinated axons
 - b) larger-diameter axon propagate impulses faster than small ones

V. Signal transmission at synapses

1. The role of synapses – synapses determine the directions that the nervous signals will spread in to the nervous system.
2. Physiologic anatomy of synapses (presynaptic terminals, synaptic cleft, postsynaptic neuron).
3. The major type of synapses
 - a) **the chemical synapse** (transmitters, “one-way” conduction)
 - b) **the electrical synapse** (action potentials conduct directly between adjacent cells through gap junctions)
4. Excitatory and inhibitory synaptic potential
 - a) EPSP – a depolarizing postsynaptic potential is called an **excitatory postsynaptic potential**
 - b) IPSP – a hyperpolarizing postsynaptic potential is termed an **inhibitory postsynaptic potential**
5. Summation at synapses
 - a) **temporal summation** - occurs when two excitatory inputs arrive at a postsynaptic neurons in rapid succession.
 - b) **spatial summation** – occurs when two excitatory inputs arriver at a postsynaptic neuron simultaneously.
6. Neurotransmitters
 - a) **excitatory** – neurotransmitters that make membrane potential less negative (for example norepinephrine, dopamine, epinephrine, serotonin, histamine)
 - b) **inhibitory** – neurotransmitters that make membrane more negative (for example Gamma aminobutyric (GABA) and glycine).
7. Second messenger system (G-proteins).

Binding of a signal molecule – into an intracellular response that modifies the behavior of target cell

- a) Phase I – binding of first messenger (transmitter) to the receptor (T+R)
- b) Phase II – transduction of a signal into the intracellular compartment. T+R complex interacts with a specific G-protein; T+R+G complex binds GTP, which activates α subunit of G protein
- c) Phase III – activated α subunit of G protein activates (or inhibits) a specific enzyme (eg. adenylate cyclase or phospholipase C), which causes synthesis of **second messenger**

When a first messenger binds to a G-protein coupled receptor, the receptor changes its conformation and activates several G-protein α subunits. Each α subunit breaks away from the $\gamma\beta$ complex, and activates a single effector protein, which, in turn, generates many intracellular second-messenger molecules. **One second messenger** activates many enzymes, and each activated enzyme can regulate many target proteins (amplification).

Second-messengers may activate certain enzymes that catalyze the phosphorylation of certain proteins, which in turn produce the physiological response of the cell to the extracellular signal (first messenger)

VI. Receptors

1. Information about the external world and internal environment exist in different energy forms – pressure, temperature, light, sound waves, etc. – but only receptors can deal with these energy forms.

2. Receptor activation: the receptor potential. The basic mechanism of receptor activation, believed to be the same for all types of receptors, is that the stimulus acts on a specialized receptor membrane to increase its permeability and thereby produce a graded potential, called a **receptor potential** (sometimes called a **generator potential**).

3. Comparison of Graded Potentials and Action Potentials

Characteristic	Graded Potentials	Action Potentials
Origin	Arise mainly in dendrites and cell body (some arise in axons).	Arise at trigger zones and propagate along the axon.
Types of channels	Ligand-gated or mechanically gated ion channels.	Voltage-gated channels for Na ⁺ and K ⁺ .
Conduction	Not propagated; localized and thus permit communication over a few micrometers.	Propagate and thus permit communication over long distance.
Amplitude	Depending on strength of stimulus, varies from less than 1 mV to more than 50 mV.	All-or-none; typically about 100 mV.
Duration	Typical longer, ranging from several msec to several min.	Shorter, ranging from 0.5 to 2 msec.
Polarity	May be hyperpolarizing (inhibitory to generation of an action potential) or depolarizing (excitatory to generation of an action potential).	Always consist of depolarizing phase followed by repolarizing phase and return to resting membrane potential.
Refractory period	Not present, thus spatial and temporal summation can occur.	Present, thus summation cannot occur.

VI. Reflexes

1. Reflex is a fast, involuntary, unplanned sequence of actions that occurs in response to a particular stimulus.
2. Some reflexes are inborn, such as pulling your hand away from a hot surface before you even feel that is hot.
3. Other reflexes are learned or acquired. For instance, you learn many reflexes while acquiring driving expertise.
4. The pathway followed nerve impulses that produce a reflex is a reflex arc.

A reflex arc includes the following five function components:

- a) sensory receptor
- b) sensory neuron
- c) integrating center
- d) motor neuron
- e) effector

VII. Demyelinating and degenerating diseases

1. Multiple Sclerosis
2. Alzheimer's Disease.
3. Parkinson's Disease.

VIII. Autonomic nervous system

1. Motor neuron pathways in the somatic nervous system and autonomic nervous system (ANS).
2. Summary of Somatic and Autonomic Nervous System

	Somatic Nervous System	Autonomic Nervous System
Sensory input	Special senses and somatic senses.	Mainly from interoceptors; some from special senses and somatic senses.
Control of motor output	Voluntary control from cerebral cortex, with contributions from basal ganglia, cerebellum, brain stem, and spinal cord.	Involuntary control from limbic system, hypothalamus, brain stem, and spinal cord; limited control from cerebral cortex.
Motor neuron pathway	One-neuron pathway: somatic motor neurons extending from CNS synapse directly with effector.	Two-neuron pathway: preganglionic neurons extending from CNS synapse with postganglionic neurons in an autonomic ganglion, and postganglionic neurons extending from ganglion synapse with a visceral effector. Also, preganglionic neurons extending from CNS synapse with cells of adrenal medulla.
Neurotransmitters and hormones	All somatic motor neurons release ACh.	Preganglionic axons release acetylcholine (ACh); postganglionic axons release ACh (parasympathetic division and sympathetic fibers to sweat glands) or norepinephrine (NE; remainder of sympathetic division); adrenal medulla releases epinephrine and norepinephrine.
Effectors	Skeletal muscle.	Smooth muscle, cardiac muscle, and glands.
Responses	Contraction of skeletal muscle.	Contraction or relaxation of smooth muscle; increased or decreased rate and force of contraction of cardiac muscle; increased or decreased secretions of glands.

3. Receptor types in the ANS

a) Cholinergic receptors

- **nicotinic receptor** – are located in the autonomic ganglia of the sympathetic and parasympathetic nervous systems, at the neuromuscular junction, and in the adrenal medulla. The receptors at these locations are similar but not identical. Are activated by ACh or nicotine. Produce excitation.
- **muscarinic receptor** – are located in the heart, smooth muscle (except vascular smooth muscle), and glands. Are activated by ACh and muscarine. Are inhibitory in the heart (e.g., decreased heart rate, decreased conduction velocity in AV node). Are excitatory in smooth muscle and glands (e.g., increased GI motility, increased secretion).

b) Adrenergic receptors (α, β)

- **α_1 receptor** – are located on vascular smooth muscle of the skin and splanchnic regions, the gastrointestinal (GI) and bladder sphincters, and the radial muscle of the iris. Produce excitation (e.g., contraction or constriction).
- **α_2 receptor** – are located in presynaptic nerve terminals, platelets, fat cells, and the walls of the GI tract. Often produce inhibition (e.g., relaxation or dilation).
- **β_1 receptor** – are located in the sinoatrial (SA) node, atrioventricular (AV) node, and ventricular muscle of the heart. Produce excitation (e.g., increase heart rate, increase conduction velocity, increase contractility).
- **β_2 receptor** – are located on vascular smooth muscle of skeletal muscle, bronchial smooth muscle, and in the walls of the GI tract and bladder. Produce relaxation (e.g., dilation of vascular smooth muscle, dilation of bronchioles, relaxation of the bladder wall).

4. Comparison of Sympathetic and Parasympathetic Division of the ANS.

	Sympathetic	Parasympathetic
Distribution	Wide regions of the body: skin, sweat glands, arrector pili muscles of hair follicles, adipose tissue, smooth muscle of blood vessels.	Limited mainly to head and to viscera of thorax, abdomen, and pelvis; some blood vessels.
Location of preganglionic neuron cell bodies and site of outflow	Cell bodies of preganglionic neurons are located in lateral gray horns of spinal cord segments T1-L2. Axons of preganglionic neurons constitute thoracolumbar outflow.	Cell bodies of preganglionic neurons are located in the nuclei of cranial nerves III, VII, IX, and X and the lateral gray horns of spinal cord segments S2-S4. Axons of preganglionic neurons constitute craniosacral outflow.
Associated ganglia	Two types: sympathetic trunk ganglia and prevertebral ganglia.	One type: terminal ganglia.
Ganglia locations	Close to CNS and distant from visceral effectors.	Typical near or within wall of visceral effectors.
Axon length and divergence	Preganglionic neurons with short axons synapse with many postganglionic neurons with long axons that pass to many visceral effectors.	Preganglionic neurons with long axons usually synapse with four to five postganglionic neurons with short axons that pass to a single visceral effector.
Rami communicantes	Both present; white rami communicantes contain myelinated preganglionic axons, are gray rami communicantes contain unmyelinated postganglionic axons.	Neither present.
Neurotransmitters	Preganglionic neurons release acetylcholine (ACh), which is excitatory and stimulates postganglionic neurons; most postganglionic neurons release norepinephrine (NE); postganglionic neurons that innervate most sweat glands and some blood vessels in skeletal muscle release ACh.	Preganglionic neurons release acetylcholine (ACh), which is excitatory and stimulates postganglionic neurons; postganglionic neurons release ACh.
Physiological effects	Fight-or-flight responses.	"Rest-and-digest" activities.