Nervous System

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Nervous System

- Nervous system and endocrine system are the chief control centers in maintaining body homeostasis.

- Nervous system uses electrical signals (*nerve impulses*) which produce immediate (but short-lived) responses; endocrine system uses chemical signals (*hormones*) that produce slower (but long lasting) responses.
Nervous system has 3 major functions

- **Sensory input** – sensory or afferent neurons detect internal or external changes (stimuli) and send the message to the brain or spinal cord.

- **Integration** – interneurons in the brain or spinal cord interpret the message from & relay the massage back to body parts.

- **Motor output** – motor or efferent neurons receive the message from interneuron and produce a response at the effector organ (a muscle or a gland).
Neurons

All neurons have a cell body called soma. Although there is DNA in the neuron, somehow DNA replication and mitosis do not occur, resulting in the neurons lack of ability to reproduce or regenerate. Extensions of the soma form nerve such as dendrites which conduct nerve impulses toward the soma, and axon which conducts nerve impulses away from the some (to another neuron, or to an effector organ). The number of dendrites ranges from 1 to thousands (in multipolar neurons). All neurons only contain 1 axon.
Longer axons are enclosed by a lipoprotein substance called myelin sheath produced by a type of neuroglial cell called schwann cells.

This myelin sheath insulates the axon against depolarization, and forces action potential to occur in the gaps (Node of Ranvier) in between the myelin sheath. This type of nerve impulse propagation where action potential jumps from one gap to the next, is called saltatory conduction.

g) axons enclosed by myelin sheath are called myelinated axons which make up the white matter in the nervous system; while axons that have no myelin sheath are called unmyelinated axons which make up the gray matter in the nervous system.
A synapse is the junction between two neurons, or between a neuron and an effector organ (muscle or gland). Each synapse consists of:

- **Presynaptic neuron** – the neuron that sends an impulse to the synapse.
- **Axon** – the nerve fiber extends from the presynaptic neuron, that propagates the impulse to the synapse.
- **Synaptic knobs** – the round endings of the axon.
- **Synaptic vesicles** – membranous sacs that contain a neurotransmitter (e.g. acetylcholine, norepinephrine, dopamine), located in the synaptic knobs.
- **Synaptic cleft** - a gap between the two neurons in the synapse.

- **Dendrite** – the nerve fiber that continues to propagate the nerve impulse to the second neuron (postsynaptic neuron). Receptors on this dendrite receive the neurotransmitter from the axon.

- **Postsynaptic neuron** - the neuron that receives the nerve impulse from the presynaptic neuron, through the synapse.
Excitable membrane

1. The membrane is semi-permeable some things get through, while others do not get through. Important ions to be concerned with are Na\(^+\), K\(^+\), Cl\(^-\), and anions\(^-\).

2. There are differences in concentration of these various ions between the inside and outside of the cell, so there are conc. gradients for each of these ions across the cell membrane.

3. There is electrical potential differences across the membrane, such that the inside is negative with respect to the outside in the resting state. The production of activity in nerve cells are due to changes in this membrane potential.
The resting membrane potential (-70 mv)

- Cell membrane is usually polarized as a result of unequal distribution of ions on either side.
- A high concentration of Na\(^+\) is on the outside and a high concentration of K\(^+\) is inside. The outside of the membrane is more positive relative to the inside of cell (inside is negative).
Polarized membrane:

The concentrations of Na\(^+\) and K\(^+\) on each side of the membrane are different.

- The Na\(^+\) concentration is higher outside the cell.
- The K\(^+\) concentration is higher inside the cell.

Na\(^+\)-K\(^+\) pumps maintain the concentration gradients of Na\(^+\) and K\(^+\) across the membrane.
stimulation of a membrane affects its resting potential in a local region.

a. The membrane is **depolarized** if it becomes less negative.

b. The membrane is **hyperpolarized** if it becomes more negative.

Resting membrane potential is maintained by **Na – K pump** (pumps 3 Na\(^+\) outside, 2 K\(^+\) inside).

**Membrane potential – summery:**

1. \([\text{Na}^+]\) outside > \([\text{Na}^+]\) inside.

2. \([\text{K}^+]\) inside > \([\text{K}^+]\) outside.

3. \([\text{Na}^+]\) outside + \([\text{K}^+]\) outside > \([\text{Na}^+]\) inside + \([\text{K}^+]\) inside.
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The permeabilities of Na\(^+\) and K\(^+\) across the membrane are different. In the next three panels, we will build the resting membrane potential step by step.

** Suppose a cell has only K\(^+\) channels...

** Now, let’s add some Na\(^+\) channels to our cell...

** Finally, let’s add a pump to compensate for leaking ions.

K\(^+\) loss through abundant leakage channels establishes a negative membrane potential.
- The membrane is highly permeable to K\(^+\), so K\(^+\) flows down its concentration gradient.
- As positive K\(^+\) leaks out, a negative voltage (electrical gradient) develops on the membrane interior. This electrical gradient pulls K\(^+\) back in.
- At ~90 mV, the concentration and electrical gradients for K\(^+\) are balanced.

Na\(^+\) entry through a few leakage channels reduces the negative membrane potential slightly.
- Adding Na\(^+\) channels creates a small Na\(^+\) permeability that brings the membrane potential to ~70 mV.

Na\(^+\)-K\(^+\) pumps maintain the concentration gradients, resulting in the resting membrane potential.
- A cell at rest is like a leaky boat: K\(^+\) leaks out and Na\(^+\) leaks in through open channels.
- The “bailing pump” for this boat is the Na\(^+\)-K\(^+\) pump, which transports Na\(^+\) out and K\(^+\) in.
Depolarization

(a) **Depolarization**: A small patch of the membrane (red area) depolarizes.

(b) **Depolarization spreads**: Opposite charges attract each other. This creates local currents (black arrows) that depolarize adjacent membrane areas, spreading the wave of depolarization.
Depolarization vs. Hyperpolarization

(a) Depolarization: The membrane potential moves toward 0 mV, the inside becoming less negative (more positive).

(b) Hyperpolarization: The membrane potential increases, the inside becoming more negative.
Communication within the CNS

- 1. Electrical messages – conduction
  
  
b. Action – travels long distances intensity is unchanged.

- 2. Chemical messages – Neurotransmitters.
  
a. Excitatory: through membrane depolarization.
  
b. Inhibitory: through membrane hyperpolarization.
Events leading to nerve impulse conduction

1. Nerve fiber membrane maintains resting potential by diffusion of $\text{Na}^+$ and $\text{K}^+$ down their concentration gradients as the cell pumps them up the gradients.

2. Neurons receive stimulation, causing local potentials, which may sum to reach threshold.

3. Sodium channels in a local region of the membrane open.
4. sodium ions diffuse inward, depolarizing the membrane. $\text{Na}^+$ rushes in following its concentration gradient.

5. potassium channels in the membrane open.

6. potassium ions diffuse outward, repolarizing the membrane.
The big picture
What does this graph show? During the course of an action potential (below), voltage changes over time at a given point within the axon.

1. Resting state. No ions move through voltage-gated channels.

2. Depolarization is caused by Na⁺ flowing into the cell.

3. Repolarization is caused by K⁺ flowing out of the cell.

4. Hyperpolarization is caused by K⁺ continuing to leave the cell.
In response to a nerve impulse, the end of a motor nerve fiber secretes a neurotransmitter, which diffuses across the junction and stimulates the muscle fiber.

Action potential: Electrical changes that occurs along the sarcolemma.

1. Membrane Depolarization – Na\(^+\) entering the cell.
2. Action potential is propagated as the move of depolarization spreads.
3. Repolarization – Na\(^+\) channels close and K\(^+\) opens, and K\(^+\) diffuse out.
4. Absolute refractory period: cell can not be stimulated during this phase (Na\(^+\) - K\(^+\) pump restores the electrical condition) [pumps 3 Na\(^+\) outside, 2 K\(^+\) inside].
Action potential – characteristic

-maybe excitatory or inhibitory.

-travels down the axon (not in dendrites).

-they are non-decremental.

-they may carry sensory or motor information.

-Generated by neurons and muscle cells.

-All – or – None response.

-impulse conduction is more rapid in myelinated fibers (saltatory conduction).
Action Potential - Summery

1. Resting membrane potential
2. Depolarizing stimulus
4. Rapid Na$^+$ entry depolarizes cell.
5. Na$^+$ channels close and slower K$^+$ channels open.
6. K$^+$ moves from cell to extracellular fluid.
7. K$^+$ channels remain open and additional K$^+$ leaves cell, hyperpolarizing it.
8. Voltage-gated K$^+$ channels close, less K$^+$ leaks out of the cell.
9. Cell returns to resting ion permeability and resting membrane potential.
1. Action potential passes along a nerve fiber and over the surface of its synaptic knob.

2. Synaptic knob membrane becomes more permeable to Ca\(^{+}\) ions, and they diffuse inward.

3. In the presence of Ca\(^{+}\) ions, synaptic vesicles fuse to synaptic knob membrane.
4. synaptic vesicles release their neurotransmitter by exocytosis into the synaptic cleft.
5. synaptic vesicles become part of the membrane.
6. the added membrane provides material for endocytotic vesicles.
Summary

- Action potential in presynaptic cell.
- Depolarization of the cell membrane of the presynaptic axon terminal.
- Release of the chemical transmitter by the presynaptic terminal.
- Binding of the transmitter to specific receptors on the plasma membrane of the postsynaptic cells.
- Transient changes in the conductance of the postsynaptic plasma membrane to specific ions.
- Transient change in the membrane potential of the postsynaptic cell (excitatory or inhibitory).
Neurotransmitters

- Acetylcholine – stimulates the post synaptic membrane.

- Epinephrine & nor epinephrine – main signal in sympathetic NS.

- Dopamine – used in mid. brain.

- Serotonin – mostly inhibitory. Plays a role in sleep, appetite, and regulation of mood.

- GABA (gamma-aminobutiric acid) – Inhibitory.

  Endorphins – Inhibitory.

- Substance "p" – Excitatory.

- Somatostatin – Inhibitory.
Disorders

- Alzheimer's Disease – Low (Deficient) acetylcholine.
- Depression - Deficient norepinephrine, serotonin.
- Huntington disease – Deficient GABA.
- Parkinson's disease – Deficient dopamine.
- Schizophrenia – deficient GABA and excessive dopamine.
Integration: Organization of neurons

- Neurons are organized into neuronal pools within the CNS.
- Each pool receives / processes, and conducts away impulses.
- **Facilitation:** each neuron in a pool may receive excitatory or inhibitory stimuli. A neuron is facilitated when it receives (excitatory or inhibitory) subthreshold stimuli and becomes more excitable.
Divergence:

a. impulses leaving a pool may diverge by passing onto several output fibers.

b. Divergence amplifies impulses.

Convergence:

a. incoming impulses may converge on a single neuron.

b. convergence enables a neuron to summate impulses from different sources.
The largest organ in the nervous system; composed of about 100 billion neurons (interestingly, although the neurons contain DNA, there is no DNA replication or mitosis in the brain, as a result the number of neurons decreases as a person ages).

Divided into 3 main regions: cerebrum, cerebellum, and the brain stem.

Contains spaces called ventricles where choroids plexuses of pia mater produce cerebrospinal fluid (CSF), and these ventricles allow CSF to circulate around the brain and into the spinal cord (through the central canal).
cerebral cortex (outer region) is made of gray matter (unmyelinated neurons) which contains up to 75% of all neurons in the nervous system, while cerebral medulla (inner region) is made of white matter (myelinated neurons).

Consists of left and right hemispheres, created by the longitudinal fissure at the center of cerebrum, and are connected by the corpus callosum.

Its surface is marked by ridges called convolutions (or gyri) which are separated by grooves called sulcus (or fissure, if the grooves are deeper).
Lobes of the Brain

- **Frontal lobe** controls skeletal muscle movement and intellectual processes.
- **Parietal lobe** controls sensations and speech.
- **Temporal lobe** controls hearing and memory.
- **Occipital lobe** controls vision.
(b) Parasagittal view, right cerebral hemisphere

- Primary motor cortex
- Motor association cortex
- Primary sensory cortex
- Sensory association cortex
- Multimodal association cortex

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Motor areas - located in frontal lobe, to control voluntary muscles.

Motor speech area ("Broca’s area") - Located in frontal lobe, to control muscles of mouth, tongue, and larynx for speech.

Frontal eye field - located in frontal lobes just above the Broca’s area, to control muscles of the eye and eyelid.

Auditory area - located in temporal lobe, to control hearing.

Visual area - located in occipital lobe, to control visual recognition of objects and combine visual images.

Sensory areas - located in parietal lobe, to be involved in cutaneous sensations of temperature, touch, pressure and pain.

Association areas - located in all of cerebral cortex, to interconnect sensory and motor functions of all lobes of the cerebrum.
Functional Regions of the cerebral cortex

FRONTAL LOBE
- Primary motor cortex
- Motor association area (premotor cortex)
- Prefrontal association area
- Taste → Gustatory cortex
- Smell → Olfactory cortex

PARIETAL LOBE
- Primary somatic sensory cortex
- Sensory association area

OCCIPITAL LOBE
- Visual association area
- Visual cortex

TEMPORAL LOBE
- Auditory association area
- Hearing
Cerebellum

- Coordinates and controls muscular movement and muscle tone.
- Maintains body posture, by working with the equilibrium receptors in the inner ear.
- New data suggest that it also functions as the speech area that is involved with finding the right words to use.
Brain Stem

- Made up of brain tissue at the base of cerebrum, connecting the cerebrum to the spinal cord.

- Functions largely for autonomous activities.

- Subdivided into diencephalons, midbrain, pons, and medulla oblongata.
Diencephalon, Midbrain, and Pons

- **Diencephalon**: consists of **thalamus** (a major relay center to direct nerve impulses from various sources to the proper destinations) and **hypothalamus** (an important area for regulating homeostatic activities, such as hunger, thirst, sex drive, and even addictions).

- **Midbrain**: serves as a major cerebral reflex center, and also helps direct **CSF** from the third Ventricle to Fourth Ventricle.

- **Pons**: contains at least 2 "respiratory centers" (groups of specialized neurons) which regulate the duration and depth of breathing.
Medulla Oblongata

- at the base of base of brain stem and continuous to become spinal cord.
- contains specialized neurons that form "cardiac centers" (to control heart rate) "vasomotor centers" (to control blood flow and blood pressure), and "respiratory centers" (to control respiratory rhythms).
A long nerve cord that begins at the foramen magnum and ends at the first or second lumbar vertebrae. Divided into 31 segments (named after the vertebral regions), each segment gives rise to a pair of spinal nerves (part of the PNS).

In general, the location of the spinal nerve corresponds with the location of the effector organ (e.g. cervical nerves connect to muscles and glands on the head, face, and neck).
(b) The spinal cord and its meningeal coverings

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Peripheral nervous system

- Consists of 12 pairs of cranial nerves and 31 pairs of spinal nerves.
- Serves as a critical link between the body and the central nervous system.
Cranial nerves

- Nerve I (olfactory) - for the sense of smell.
- Nerve II (optic) - for the sense of vision.
- Nerve III (occulomotor) - for controlling muscles and accessory structures of the eyes.
- Nerve IV (trochlear) - for controlling muscles of the eyes.
- Nerve V (trigeminal) - for controlling muscles of the eyes, upper and lower jaws, and tear glands.
- Nerve VI (abducens) - for controlling extrinsic eye muscles.
- Nerve VII (facial) - for the sense of taste and controlling facial muscles, tear glands, and salivary glands.
Cranial nerves

- Nerve VIII (vestibulocochlear) - for the senses of hearing and equilibrium.
- Nerve IX (glossopharyngeal) - for controlling muscles in the pharynx and to control salivary glands.
- Nerve X (vagus) - for controlling muscles used in speech, swallowing, and the digestive tract, and controls cardiac and smooth muscles.
- Nerve XI (accessory) - considered part of the vagus nerve.
- Nerve XII (hypoglossal) - for controlling muscles that move the tongue.
# Cranial Nerves

<table>
<thead>
<tr>
<th>Cranial nerves I – VI</th>
<th>Sensory function</th>
<th>Motor function</th>
<th>PS* fibers</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Olfactory</td>
<td>Yes (smell)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>II Optic</td>
<td>Yes (vision)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>III Oculomotor</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>IV Trochlear</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>V Trigeminal</td>
<td>Yes (general sensation)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>VI Abducens</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cranial nerves VII – XII</th>
<th>Sensory function</th>
<th>Motor function</th>
<th>PS* fibers</th>
</tr>
</thead>
<tbody>
<tr>
<td>VII Facial</td>
<td>Yes (taste)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>VIII Vestibulocochlear</td>
<td>Yes (hearing and balance)</td>
<td>Some</td>
<td>No</td>
</tr>
<tr>
<td>IX Glossopharyngeal</td>
<td>Yes (taste)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>X Vagus</td>
<td>Yes (taste)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>XI Accessory</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>XII Hypoglossal</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
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*PS = parasympathetic
Electroencephalogram

- Electrical changes generated by neurons in the cerebral cortex can be recorded as "brain waves" which indicate relationships between cerebral actions and body functions.

- **alpha waves** (8-13 cycles per second) are produced when a person is a wake but resting, with eyes closed.

- **beta waves** (13 cps) are produced when a person is actively engaged in mental activity.

- **Theta waves** (4-7 cps) are normally produced by children; in adults, these may be related to early stages of sleep of emotional stress.

- **Delta waves** (4 cps) are produced during sleep.
(a) Scalp electrodes are used to record brain wave activity.

(b) Brain waves shown in EEGs fall into four general classes.

1-second interval

- **Alpha waves** — awake but relaxed
- **Beta waves** — awake, alert
- **Theta waves** — common in children
- **Delta waves** — deep sleep