Nervous System

Learning Outcome C11 & C12

Learning Outcome C11

- Analyse the transmission of nerve impulses

Student Achievement Indicators

Students who have fully met this learning outcome are able to:

- Identify and give functions for each of the following: dendrite, cell body, axon, axoplasm, and axomembrane
- Differentiate among sensory, motor, and interneurons with respect to structure and function
- Explain the transmission of a nerve impulse through a neuron, using the following terms:
  - resting and action potential
  - depolarization and repolarization
  - refractory period
  - sodium and potassium gates
  - sodium-potassium pump
  - threshold value
  - "all-or-none" response
  - Polarity

Student Achievement Indicators

- Relate the structure of a myelinated nerve fibre to the speed of impulse conduction, with reference to myelin sheath, Schwann cell, node of Ranvier, and saltatory transmission
- Identify the major components of a synapse, including
  - synaptic ending
  - presynaptic and postsynaptic membranes
  - synaptic cleft
  - synaptic vesicle
  - calcium ions and contractile proteins
  - excitatory and inhibitory neurotransmitters
  - receptor
  - acetylcholinesterase (AChE)
- Explain the process by which impulses travel across a synapse
- Describe how neurotransmitters are broken down in the synaptic cleft
- Describe the structure of a reflex arc and relate its structure to how it functions

Learning Outcome C12

- Analyse the functional interrelationships of the divisions of the nervous system

Student Achievement Indicators

Students who have fully met this learning outcome are able to:

- Compare the locations and functions of the central and peripheral nervous systems
- Identify and give functions for each of the following parts of the brain:
- medulla oblongata
- cerebrum
- thalamus
- cerebellum
- hypothalamus
- pituitary gland
- corpus callosum
- meninges

Student Achievement Indicators

- Explain how the hypothalamus and pituitary gland interact as the neuroendocrine control centre
- Differentiate between the functions of the autonomic and somatic nervous systems
- Describe the inter-related functions of the sympathetic and parasympathetic divisions of the autonomic nervous system, with reference to:
- ✓ effect on body functions including heart rate, breathing rate, pupil size, digestion
- ✓ neurotransmitters involved
- ✓ overall response ("fight or flight" or relaxed state)

- Identify the source gland for adrenalin (adrenal medulla) and
- Explain its role in the "fight or flight" response

Introduction to the Nervous System

- Can be divided into two divisions:

1. The Central Nervous System (CNS)
   - ✓ Consists of the brain and spinal cord
2. The Peripheral Nervous System (PNS)
   - ✓ Consists of nerves that carry sensory messages to the CNS, and motor commands from the CNS to the muscles and glands

Introduction to the Nervous System

- The two systems work together and are connected to one another
- The nervous system consists of two types of cells:
- Neurons – cells that transmit nerve impulses between parts of the nervous system
- Neuroglia – are cells that support and nourish the neurons
- They help maintain homeostasis, form myelin and may aid in signal transduction.

Neurons

- There are three classes of neurons:

1. Sensory neuron
   - ✓ Takes message to CNS
   - ✓ Sensory neurons may be equipped with specialized ending called sensory receptors that detect changes in the environment.

Neurons

2. Interneurons
   - ✓ Lie entirely within the CNS.
   - ✓ Interneurons receive input form sensory neurons and also from other interneurons in the CNS.
   - ✓ Interneurons sum up all the messages they receive before they communicate with the motor neuron.

Neurons

3. Motor Neuron
   - ✓ Takes messages away from the CNS to an effector (muscle fiber, organ or gland)
   - ✓ Effectors carry out our responses to the environment

Neurons

- Neurons may vary in appearance but all have three parts:

1. Cell Body
   - ✓ Contains nucleus, as well as organelles
2. Dendrites
   - ✓ Are extensions leading toward the cell body that receive signals from other neurons and send them on to the cell body
3. Axon
   - ✓ Conducts nerve impulses away from the cell body towards other neurons or effector

Neurons

Resting Potential

- The axon is essentially a membranous tube filled with axoplasm (cytoplasm of the axon).
- Experiment:
- One electrode is placed inside an axon, while the other electrode is placed outside the axon. When the axon is not conducting an impulse the voltmeter records a potential difference equal to about -65mV. This indicates that the inside of the axon is negative compared to the outside.
- This is called the resting potential because the axon is not conducting an impulse.
- The difference in charge (polarity) is due to ion distribution on either side of the axonal membrane.
- The concentration of Na^+ is greater outside the axon than inside, and the concentration of K^+ is greater inside the axon than out.

Neurons

Myelin Sheath

- Covers some axons
- In the PNS, this sheath is formed by a type of neuroglia called Schwann cells
- Schwann cells contain a lipid substance called myelin in the plasma membrane.
- The myelin sheath develops when Schwann cells wrap themselves around an axon as many as 100 times.
- Since each Schwann cell myelinates only part of the axon, the myelin sheath is interrupted.
- The gaps where there is no myelin sheath, is known as nodes of Ranvier
- Each Schwann cell only covers about 1mm of an axon, since a single axon may be several feet long, more than 100 Schwann cells may be involved.

Nerve Impulse

Action Potential

- Rapid changes in polarity across an axonal membrane as nerve impulses occur.
- All or nothing phenomenon
- If a stimulus causes an axonal membrane to depolarize to a certain level called a threshold an action potential occurs.
- The strength of an action potential does not change, but a strong stimulus can cause an axon to fire more rapidly.
- An action potential requires two types of gated channel proteins.
- Allows Na^+ to pass through the membrane to inside the cell
- Allows K^+ to pass through the membrane outside the cell

Nerve Impulse

- The unequal distribution of Na^+/K^+ is due to the sodium-potassium pump
- This pump is a membrane protein that actively transports Na^+ out of the cell and K^+ into the axon.
- This pump is always working because the membrane is somewhat permeable to these ions and tends to diffuse to their lesser concentration.
- Membrane is more permeable to K^+ than to Na^+, there are always more positive ions outside the membrane than inside.
- This accounts for the polarity recorded by the voltmeter

Nerve Impulse

Conduction of Action Potential

- In non-myelinated axons, the action potential travels down an axon one small section at a time.
- Once the action potential as moved on, each axon undergoes a brief refractory period where the Na^+ gates are unable to open
- Therefore an action potential cannot move backwards
- In myelinated axons, the gated ions channels that produce an action potential are concentrated at the Nodes of Ranvier
- Ion exchange only occurs at the Nodes so action potentials can travel faster.
- This is called saltatory conduction means that action potentials jump from node to node

Nerve Impulse

Transmission across a Synapse

- Each axon branches into many fine endings each tipped with a small swelling known as an axon terminal.
- Each terminal lies very close to either a dendrite or cell body of another neurons
- This region of close proximity is where the chemical synapses occur.
- Two neurons at a chemical synapse don't ever physically touch.
- They are separated by a tiny gap called a synaptic cleft.
- At a synapse the membrane of the first neuron is called the pre-synaptic membrane.

Nerve Impulse

- While the membrane of the second neuron is called the post-synaptic membrane
- Communication between two neurons at a chemical synapsis is carried out by neurotransmitters.
- Neurotransmitters are stored in synaptic vesicles in the axon terminals
- When impulses traveling along an axon reach an axon terminal , gated channels for Ca^{2+} open and calcium enters the axon terminal
- The sudden increase in Ca^{2+} causes synaptic vesicles to merge with the presynaptic membrane and neurotransmitters are released into the synaptic cleft.
- The neurotransmitters diffuse across the cleft to the post-synaptic membrane where they bind with specific receptor proteins.
- Depending on neurotransmitters and type of receptors - excitation or inhibition occurs
- Excitation – action potential occurs
- Inhibition – action potential stops

Nerve Impulse

Synaptic Integration

- A single neuron may have may have many dendrites that carry signals to the cell body.
- A neuron may receive excitatory or inhibitory stimuli.
- An excitatory neurotransmitter produces a potential change that drives the neuron closer to an action potential; an inhibitory signal drives the neuron farther away from an action potential.
- Excitatory signals have a depolarizing effect, while inhibitory signals have a hyperpolarizing effect (increase polarity).
- Synaptic integration is the summing up of all excitatory and inhibitory impulses.
- If a neuron receives many excitatory impulses (either rapidly from one synapse or from several synapses) the neuron will transmit a nerve impulse.
- If a neuron receives both inhibitory and excitatory impulses it may or may not fire.

Neurotransmitters

- Acetylcholine (Ach)
- Norepinephrine (NE)
- Once a neurotransmitter has been released into the synaptic cleft and it has initiated a response it is removed from the cleft.
- Enzymes in post-synaptic membranes may break down neurotransmitters
- Example – the enzyme acetylcholinesterase (AChE) breaks down acetylcholine
- The pre-synaptic membrane may also reabsorb the neurotransmitter
- Drugs may mimic or inhibit neurotransmitter release.

The Brain

Cerebrum

- Largest portion of the brain
- Last center to receive sensory input
- Communicates and coordinates the activities of the other parts of the brain
- Carries out higher though processes required for learning, memory, language and speck.
- The cerebrum can be divided into two halves; the left and right cerebral hemispheres.
- The two cerebral hemispheres are connected by a bridge of white matter within the corpus callosum.
- The corpus callosum is made up of nerve fibers.

The Brain

Hypothalamus

- Located in the area known as the diencephalon
- Integrating center that helps maintain homeostasis by regulating hunger, sleep, thirst, body temperature and water balance.
- Manufactures hormones that control the pituitary gland
- The link between the nervous and endocrine systems

The Brain

Thalmus

- Located in the area of the brain known as the diencephalon
- Two masses of grey matter
- Most sensory input from the visual, auditory, taste and somatosensory systems arrive at the thalamus via the cranial nerves and tracts from the spinal cords.
- Integrates information and sends it to the appropriate portion of the cerebrum
- Participates in higher mental functions such as memory and emotions

The Brain

Cerebellum

- Looks like cauliflower
- Two portions joined together
- Primarily composed of white matter, with a thin fold of grey matter
- Receives sensory input from joints, muscles and other sensory pathways about present position of the body parts
- Also receives motor input from the cerebral cortex (grey matter that covers the cerebral hemisphere) about where there parts should be located.
- After integration the cerebellum sends motor impulses by way of the brain stem to the skeletal muscle.
- This helps maintain posture/balance
- Also ensures that all muscles work together to produce smooth, coordinated, voluntary movements
- Assists in learning new motor skills

The Brain

Medulla Oblongata

- Located in brain stem
- Contains a number of reflex centers for regulating heartbeat, breathing, and blood pressure
- Also contains reflex centers for vomiting, coughing, sneezing, hiccupping and swallowing.
- Lies superior to the spinal cord and contains tracts ascend or descend between the spinal cord and higher brain centers.

The Peripheral Nervous System

- Lies outside the central nervous system and is composed of nerves and ganglia
- Nerves are bundles of axons, the axons that occur in nerves are called nerve fibers.
- Sensory fibers carry information to the CNS, while motor fibers carry information away from the CNS
- Humans have 12 cranial nerves attached to the brain
- Some cranial nerves only have sensory fibers, some only have motor fibers, while others are mixed.
- Cranial nerves are largely associated with head, neck and the facial regions

The Peripheral Nervous System

- Humans have 3 pairs of spinal nerves that emerge between openings in the vertebral column in the spinal cord.
- The PNS is divided into:

1. Somatic System
   - ✓ Serves the skin, skeletal muscle and tendons
   - ✓ Some actions are due to reflexes which are automatic responses to stimuli

The Peripheral Nervous System

The Reflex Arc

- Is a nerve pathway that carries out a reflex
- Built-in circuits that allow protection and security
- *Example* – withdrawal reflex

If your hand touches a hot stove, sensory receptors in the skin generate nerve impulses that move along sensory fibers through the dorsal root ganglia towards the spinal cord. Dorsal root ganglia are the cell bodies of sensory neurons. Sensory neurons pass on the information to interneurons in the spinal cord. Some interneurons synapse with motor neurons whose short dendrites and cell bodies are in the spinal cord. Nerve impulses travel along these motor fibers to the effector which can now respond to the stimulus. In this case it causes the muscles to contract which allows you to withdraw your hand. You do not feel pain until your brain receive information and interprets it.

The Peripheral Nervous System

1. Autonomic System
- ✓ Regulates activity of cardiac and smooth muscle and glands
- ✓ Two divisions:
  a. Sympathetic
  b. Parasympathetic

- Common characteristics of both divisions:
- Function automatically and usually in an involuntary manner
- Innervate all internal organs
- For each signal they utilize two monitor neurons that synapse at a ganglion.
- The first neuron has a cell body within the CNS and its axon is called the pre-ganglionic fiber
- The second neuron has a cell body within the ganglion and its axon is terms post-ganglionic fiber

The Peripheral Nervous System

Sympathetic Division

- Located in middle of spinal cord
- The fibers terminate in ganglia that lie near the cord
- Preganglionic fibers are short while the post-ganglionic fibers that make contact with the organ are long.
- Especially important during emergency situations when you might be required to fight back or run.
- Accelerates heartbeat, dilates bronchi and activates muscles

The Peripheral Nervous System

- Inhibits digestive tract because digestion is not a necessity if you are under attack
- Activates the adrenal medulla to secret epinephrine (adrenaline) and norepinephrine into the blood
- Specialized pre-ganglionic sympathetic fibers go directly to the adrenal medulla without stopping at the ganglion.
- The epinephrine and norepinephrine bind to receptors on various cell types
- The post-ganglionic fibers also release the neurotransmitters norepinephrine
- The small amount of norepinephrine released by the axons spills into the blood
- During times of high sympathetic nerve activity the amount of norepinephrine entering the blood from eh neurons increase significantly
- Epinephrine and norepinephrine increases blood pressure by causing the heart to beat strong and faster and constrict blood vessels.

The Peripheral Nervous System

Parasympathetic Division

- Pre-ganglionic fibers are long and post-ganglionic fibers are short because ganglia lie near or within an organ
- Promotes all internal responses we associate with rest and digest
- Opposite to sympathetic system
- Causes pupils to contract, heartbeat to decrease and digestion to occur
- Secretes neurotransmitter acetylcholine