Exercise and Physiology: Nervous System

Key Terms

**Acetylcholine**: a neurotransmitter that links electrical signals in motor neurons with electrical signals in skeletal muscles

**All-or-None Principle**: neuron generations an action potential when stimulation reaches threshold or doesn’t fire when stimulation is below threshold. The strength of the action potential is constant whenever it occurs

**Axon Hillock**: The conical area of a neuron cell body, where the axon begins and the nerve impulse is generated. A neuron can receive excitatory signals (depolarize neuron, cell is more (+)) or inhibitory signals (polarize the cell). These signals are added up at the axon hillock. If the excitatory signal is strong enough, the axon will create an action potential, an electrical impulse that travels down the axon. The axon hillock will do both temporal summation, adding electrical impulses that happen over a short period of time, and spatial summation, adding the signals that occur across the cell body.

**Cholinergic**: relating to nerve cells or fibers that use acetylcholine as their neurotransmitter

**Contralaterality**: control one side of your body by the other side of your brain (Ex: right side of body controlled by left hemisphere of brain)

**Golgi Tendon Organ**: a sensory nerve ending embedded among the fibers of a tendon, often near the musculotendinous junction; it is compressed and activated by any increase of the tendon’s tension, caused either by active contraction or passive stretch of the corresponding muscle.

**Glial Cells**: supportive cells of the nervous system that nourish neurons and help form Myelin sheath

**Hyperpolarization**: a change in the membrane potential that makes the membrane more polarized than at resting potential (for ex, goes from -70 mV to -80 mV); the inside of the cell becomes more negative as more K+ channels open so more K+ leaves the cell, this makes it difficult for a nerve impulse to arise

**Motor Reflex**: involuntary response to stimulus, due to a special neural path that is connected to pressure points of the body. When these points are pressed, the muscles of the body will contract or extend, depending on the muscle being stimulated

**Nerve Impulse**: a signal (action potential) transmitted along a nerve fiber. It consists of a wave of electrical depolarization that reverses the potential difference across the nerve cell membranes. A flow of Na+ into cell causes a rapid change in potential across the membrane when stimulation reaches threshold

**Neurotransmitter**: chemical messengers that are passed from a presynaptic neuron to a postsynaptic cell (neuron/ muscle/ gland); stored in synaptic vesicle on terminal buttons

- Excitatory: causes neuron on other side of synapse to generate an action potential
- Inhibitory: reduces or prevents neural impulses in the postsynaptic dendrites
- The sum of all excitatory and inhibitory inputs determines whether the next neuron will fire

**Resting Membrane Potential (RMP):** difference in electrical charges between the outside and inside of the cell, caused by uneven separation of charged ions. The outside of the cell is more positive than the inside, which produces a difference of -70mV

**Sensory Nerves:** afferent nerves that carry impulses toward the CNS from the PNS (sensory receptors)

**Sodium-Potassium Pump:** a form of active transport that moves sodium and potassium ions across the cell membrane. Transports 3 Na\(^+\) for every 2 K\(^+\), an imbalance of which produces an electrochemical gradient and can lead to depolarization and hyperpolarization of a nerve cell and is therefore an important contributor to action potential produced by nerve cells

**Adrenergic:** refers to norepinephrine or epinephrine (also called noradrenaline or adrenaline)

**Depolarization:** a change in the membrane potential that makes the membrane less polarized (less negative) than at resting potential (for example, going from -70 mV to -50 mV); the inside of the cell becomes less negative. Depolarization is required for a nerve impulse to arise and travel.

**Graded Potential:** localized changes in membrane potential that help the cell body decide whether to pass the signal (Action Potential) to the axon; can excite or inhibit a neuron

- Localized changes in membrane potential generated by incoming signals from dendrites, such as a specific stimulus or the binding of a neurotransmitter with a receptor on the postsynaptic membrane
- Inhibitory signal is K\(^+\) efflux \(\rightarrow\) hyperpolarization
- Excitatory signal is Na\(^+\) influx \(\rightarrow\) depolarization
- Strong graded potential produces an action potential

**Motor Nerves:** efferent nerves that carry impulses to skeletal muscle

**Muscle Spindle:** skeletal muscle sensory organs composed of a bundle of intrafusal muscle fibers innervated by gamma nerve fibers; involved in motor control. Muscle spindles stimulate reflexively a muscle contraction to prevent overstretching and muscle fiber damage

**Neuromuscular Junction:** the area of contact between the ends of a large myelinated nerve fiber and a fiber of skeletal muscle

**Norepinephrine:** neurohormone stored in adrenal medulla and released in response to sympathetic stimulation; produces vasoconstriction, an increase in heart rate, and elevation of blood pressure

**Sensory-Motor Integration:** process of communication and interaction between sensory and motor systems

1. Stimulus sensed by sensory receptor
2. Sensory action potential (AP) sent on sensory neurons to CNS (first to spine, then brain)
3. CNS interprets sensory info (if reflex, then it stays at the spinal cord and initiates an immediate motor response) and sends out a response
4. Motor AP sent out on alpha motor neurons
5. Motor AP arrives at skeletal muscle, response occurs

**Threshold Potential**: the level of polarization that the membrane must reach in order to initiate an action potential; -50mV

**Afferent Nerves**: the sensory division of the peripheral nervous system, carrying impulses toward the central nervous system

**Efferent Nerves**: the motor division of the peripheral nervous system, carrying impulses from the CNS toward the periphery for the purpose of contracting a muscle or stimulating secretion of a gland

**Central Nervous System (CNS)**: brain and spinal cord

**Excitatory Postsynaptic Potential (EPSP)**: a reduction in the resting potential of a postsynaptic cell caused by the arrival of neurotransmitter from the presynaptic cell. The reduction takes the membrane potential close to the threshold and nearer to forming an action potential

**Inhibitory Postsynaptic Potential (IPSP)**: The change in potential produced in the membrane of the next neuron when an impulse that has an inhibitory influence arrives at the synapse; it is a local change in the direction of hyperpolarization

**Myelin Sheath**: a layer of lipid cells that insulate the axon of nerve cells and speed up the transmission of an action potential. The entire axon is NOT myelinated and there are little gaps between each section of myelination called Nodes of Ranvier.

**Neuron**: a specialized cell in the nervous system responsible for generating and transmitting nerve impulses

- Cell Body: contains nucleus and cytoplasm and directs synthesis of neurotransmitters
- Dendrites: receive information from sending neuron
- Axon: “carries” the action potential to the terminal buttons
- Terminal Buttons/Axon Terminals: endings of axon by which axons make synaptic contacts with other nerve cells or with effector cells (muscle or gland cells), contain neurotransmitters

**Peripheral Nervous System (PNS)**: portion of the nervous system outside of CNS, it includes all of the sensory and motor neurons and subdivisions called the autonomic and somatic nervous systems

**Salutatory Conduction**: rapid conduction of impulses when the axon is myelinated since depolarizations jump from node (of Ranvier) to node

**Synapse**: the space btwn the sending neuron and the receiving dendrites of a muscle or neuron where an action potential is passed using neurotransmitters, which can start a second action potential in the receiving muscle/neuron
**Voltage Gated Channels**: channels that open and close in response to changes in membrane potential (Na+, K+ channels)

**Chemically Gated Channels**: channels that change allosterically in response to the binding of specific chemical messengers with a membrane receptor

**Study Questions**

1. What are the major divisions of the nervous system? What are their major functions?
2. Name the different parts of a neuron.

3. Explain the resting membrane potential. What causes it? How is it maintained?
   1) Resting membrane potential
   2) Depolarizing stimulus
   3) Membrane depolarizes to threshold, voltage-gated Na+ channels open and Na+ enters the cell, while voltage-gated K+ channels begin to open slowly
   4) Rapid Na+ entry depolarizes the cell
   5) Na+ channels close, and slowly K+ channels open
   6) K+ moves out of cell
   7) K+ channels remain open and additional K+ leaves the cell → hyperpolarization
   8) Voltage-gated K+ channels close, less K+ leaves cell
   9) Cell returns to resting ion permeability and resting membrane potential

4. Describe an action potential. What is required before an action potential is activated?

   The action potential (AP) begins at the axon hillock, and is an electrical impulse that travels down the axon toward the terminal buttons. The AP operates on an “all or none” principle, meaning the axon hillock either creates an action potential or does nothing. The action potential ends at the terminal buttons, and stimulates the buttons to send a chemical signal using neurotransmitters to the postsynaptic cell. An AP is caused by changes in membrane permeability and ion movement and the membrane potential must change by 100mV to produce an AP.
The AP moves in only one direction because when one region of an axon is depolarized, the region of the axon in front of it is resting and ready to depolarize (AP can spread in this direction) the region of the axon behind has just finished depolarizing so it is still refractory (AP cannot spread in this direction).
5. Explain how an action potential is transmitted from a presynaptic neuron to a postsynaptic neuron. Describe a synapse and a neuromuscular junction.
Synapse
- junction between two neurons
- may be either excitatory (EPSP) or inhibitory (IPSP)
- synapses can also use adrenaline and noradrenaline and other neurotransmitters

Similarities
- Both are excitable cells separated by synaptic cleft that prevents direct transmission of electrical activity between them
- Axon terminals of both store chemical messengers
- In both, binding of NT with the receptors sites on postsynaptic membrane opens specific channels and permits ion movement that alters the membrane potential of the cell
- The resultant change in membrane potential is a graded potential

Neuromuscular Junction
- Site where motor neuron meets the muscle fiber (separated by gap called the neuromuscular cleft)
- always excitatory
- The inhibition of skeletal muscle cannot be accomplished at the NMJ: it can takes place only in the CNS through IPSPs at the cell body of the motor neuron
- NMJ always use ACh

6. What brain centers have major roles in controlling movement, and what are these roles?
- Cerebrum
  - Frontal Lobe: general intellect, motor control (motor cortex strip initiates movement and integrates activities of the skeletal muscles)
    - Broca’s Area: left frontal lobe that controls production of speech
    - Primary motor cortex: conscious control of skeletal muscle movement
  - Temporal Lobe: auditory input and interpretation
    - Wernicke’s Area: left temporal lobe that understands and interprets language
  - Parietal Lobe: general sensory input and interpretation
    - Somatosensory cortex: for touch sensations
  - Occipital Lobe: visual input and interpretation
  - Central (deep) Lobe
    - Insular: emotion and self-perception
- Basal Ganglia (cerebral white matter)
  - Clusters of cell bodies deep in cerebral cortex
  - Helps initiate sustained or repetitive movements
  - Walking running, posture, muscle tone
  - Links thalamus with motor cortex and other motor areas
- **Thalamus**
  - Major sensory relay center
  - Determines what we are consciously aware of

- **Hypothalamus**
  - Maintains homeostasis, regulates internal environment
    - Neuroendocrine control
    - Appetite, food intake, thirst/fluid balance, sleep
    - Blood pressure, heart rate, breathing, body temperature
  - Integrates with endocrine system by secretion of hormones that regulate hormones from pituitary
  - Controls autonomic functions via control of sympathetic and parasympathetic centers in medulla

- **Cerebellum**
  - Controls rapid, complex movements
  - Coordinates timing and sequence of movements
  - Compares actual to intended movements and initiates correction
  - Accounts for body position, muscle status
  - Receives input from primary motor cortex, helps execute and refine movement

- **Brain Stem**
  - Relays information between brain and spinal cord
  - Pons: includes portion of reticular activating system critical for arousal and wakefulness; sends info to and from medulla, cerebellum, cerebral cortex
  - Medulla: regulates heart rhythm, blood flow, breathing rate, digestion; contains sympathetic and parasympathetic centers; responsible for many reflexes
  - Midbrain: relay center for visual, auditory, and motor system information; regulates autonomic functions
  - Reticular Formation: coordinates skeletal muscle function and tone; controls cardiovascular and respiratory function
  - Analgesia System: opioid substances modulate pain here; Beta endorphins released with exercise

- **Amygdala**: influences aggression and fear; coordinates fight-or-flight response

- **Cerebral Cortex**: receives and process sensory info and directs movement
7. **How do sympathetic and parasympathetic systems differ? What is their significance in performing physical activity?**

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<thead>
<tr>
<th>Target Organ or Organ System</th>
<th>Sympathetic Effects</th>
<th>Parasympathetic Effects</th>
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<tbody>
<tr>
<td>Heart Muscle</td>
<td>Increases rate and force of contraction</td>
<td>Decreases rate of contraction</td>
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<tr>
<td>Heart: Coronary blood vessels</td>
<td>Causes vasodilation (heart needs more blood to do more work)</td>
<td>Causes vasoconstriction</td>
</tr>
<tr>
<td>Lungs</td>
<td>Causes bronchodilation Mildly constricts blood vessels</td>
<td>Causes bronchoconstriction</td>
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| Blood Vessels               | - Increases blood pressure (clamp down on vessel so nutrients in blood surge to heart at greater force)  
                             | - Causes vasoconstriction in abdominal viscera and skin to divert blood when necessary  
                             | - Causes vasodilation in the skeletal muscles and heart during exercise | Little or no effect |
| Liver                       | Stimulates glucose release | No effect |
| Cellular Metabolism         | Increase metabolic rate (to make ATP) | No effect |
| Adipose Tissue (fat)        | Stimulates Lipolysis (break apart fat, especially Free Fatty acids to make ATP) | No effect |
| Sweat Glands                | Increase sweating | No effect |
| Adrenal Glands              | Stimulates secretion of epinephrine and norepinephrine | No effect |
| Digestive System (Sphincter: a ring of muscle surrounding and serving to guard or close an opening or tube, such as the openings of the stomach) | - Decrease activity of glands and muscles  
                             | - Constricts sphincters | - Increase peristalsis and glandular secretion  
                             | - Relaxes sphincters |
| Kidney                      | - Causes vasoconstriction  
                             | - Decrease urine formation | No effect |

8. **Explain how reflex movement occurs in response to touching a hot object.**

A reflex is a simple form of behavior that requires only a few neurons to initiate a motor reaction. The sensory information does not travel to the brain, but to the spinal cord via afferent neurons. Once in the
spinal cord, interneurons or afferent neurons communicate with motor neurons, which initiate an action, such as causing a muscle to contract or a gland to secrete.

9. **Describe the role of the muscle spindle in controlling muscle contraction.**

Muscle spindles are skeletal muscle sensory organs that are designed to sense stretch in the intrafusal muscle and send that information to the CNS. A muscle spindle contains intrafusal fibers, which are at both ends connected to either tendinous ligaments or extrafusal fibers. So, intrafusal fibers are stretched or shortened when extrafusal fibers change length. Muscle spindles stimulate reflexively a muscle contraction to prevent overstretching and muscle fiber damage, this is known as the stretch or myotatic reflex. While stretching the muscle spindle, an impulse is immediately sent to the spinal cord which sends an answer back via gamma motor neurons to contract the intrafusal muscle.

10. **Describe the role of the Golgi tendon organ in controlling muscle contraction.**

- The Golgi Tendon Organ (GTO) is an organ located in the tendon that senses muscle tension. It is activated by any increase of tension in the tendon, caused either by active contraction or passive stretch of the corresponding muscle.
- Agonist (tension) = Antagonist (stretch)   Antagonist (tension) = Agonist (stretch)
  - Ex) Quadricep concentrically contracts when the leg extends outward parallel to the floor, so the hamstring stretches. Quadricep = Agonist, Hamstring = Antagonist
  - If the agonist contracts the GTO sends a signal to the CNS, and the CNS sends a signal back to cause the antagonist to contract, which protects the agonist from injury
  - **Agonist is NOT always the one tensing, it is merely the one opposite to the Antagonist. In the previous example, the Quadricep could be the antagonist, but that means the hamstring would be considered the agonist.

Sources

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