The Autonomic Nervous System
Outline of class lecture for Physiology

After studying the endocrine system you should be able to:
1. Describe the organization of the nervous system.
2. Compare and contrast the somatic and autonomic nervous system in terms of structure and function.
3. Compare and contrast the sympathetic and parasympathetic portions of the autonomic nervous system in terms of structure and function.
4. Describe antagonistic control within the autonomic nervous system and explain the exceptions to this dual control.
5. Explain how nitric oxide relaxes the smooth muscle of penile arteries and how Viagra works.
6. Explain how atropine, atenolol, and albuterol work.
7. Discuss the Clinical Applications from the study guide and be able to describe the disorders from the Applications to Health located at the end of this chapter.

Organization of The Nervous System

Nervous System Overview
- Divided into two major divisions: CNS and PNS
- Central nervous system (CNS): Consists of the brain and spinal cord
- Peripheral nervous system (PNS): Consists of nerves (cranial and spinal) that lie outside the CNS and contains sensory and motor neurons.
- The peripheral nervous system can be divided into two subdivisions:

1. Somatic nervous system (SNS) which consists of:
   - Sensory (afferent) neurons: Transmit nerve impulses from somatic receptors of the skin and for special senses of vision, hearing, taste, and smell to the CNS).
   - Motor (efferent) neurons: Transmit impulses from the CNS to skeletal muscles.

Somatic Motor Neuron

Spinal cord
(Myelinated)
ACh
contraction of skeletal muscle (excitatory transmitters)
2. **Autonomic nervous system (ANS)** which consists of:
   - **Sensory (afferent) neurons**: Transmit nerve impulses from the visceral receptors to the CNS.
   - **Motor (efferent) neurons**: Transmit nerve impulses from the CNS to **smooth muscle**, **cardiac muscle**, and **glands**.

- **Motor portion of ANS** consists of two divisions that usually have opposing actions:
  - **Sympathetic division**: Visceral processes that expend energy; the “fight-or-flight” response.
  - **“E” division**:
    - **Examples**: Increases heart rate and blood pressure, dilates the pupils, dilates the trachea and bronchi, stimulates the conversion of liver glycogen into glucose, shunts blood away from the skin and viscera to the skeletal muscles, brain, and heart, inhibits peristalsis in the gastrointestinal (GI) tract
  - **Parasympathetic division**: Visceral processes that restore and conserve energy; “rest-and-digest” activities.
  - **“D” division**:
    - **Examples**: Decreases heart rate and blood pressure, constriction of the pupils, increased blood flow to the skin and viscera, peristalsis of the GI tract

**Organization of Somatic and Autonomic NS**

<table>
<thead>
<tr>
<th>Somatic nervous system</th>
<th>Sympathetic division</th>
<th>Parasympathetic division</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central nervous system</td>
<td>Somatic nervous system</td>
<td>Autonomic nervous system</td>
</tr>
<tr>
<td>Peripheral nervous system</td>
<td>Acetylcholine</td>
<td>Somatic nervous system</td>
</tr>
<tr>
<td>Effector organs</td>
<td>Acetylcholine</td>
<td>Somatic nervous system</td>
</tr>
<tr>
<td>Skeletal muscle</td>
<td>Acetylcholine</td>
<td>Somatic nervous system</td>
</tr>
<tr>
<td>Smooth muscle</td>
<td>Acetylcholine</td>
<td>Somatic nervous system</td>
</tr>
<tr>
<td>Glands</td>
<td>Acetylcholine</td>
<td>Somatic nervous system</td>
</tr>
<tr>
<td>Cardiac muscle</td>
<td>Acetylcholine</td>
<td>Somatic nervous system</td>
</tr>
</tbody>
</table>

Key:
- Preganglionic axons (sympathetic)
- Postganglionic axons (sympathetic)
- Myelination
- Preganglionic axons (parasympathetic)
- Postganglionic axons (parasympathetic)
Key Terms for Nervous System
- Category of neuron determined by type of neurotransmitter released:
  - Cholinergic neurons
  - Adrenergic neurons
- Neurotransmitters bind to specific receptors:
  - Cholinergic Receptors: Bind acetylcholine (ACh) and have two different forms: nicotinic and muscarinic
    - Nicotinic: All receptors on postganglionic neurons, all
    - Muscarinic: All receptors on parasympathetic effectors, receptors of some sweat glands
  - Adrenergic receptors bind norepinephrine/epinephrine and have two categories of receptors: Alpha and beta adrenergic receptors.
    - These are further subdivided into categories: $\alpha_1$ and $\beta_1$ and $\alpha_2$ and $\beta_2$
Neuron Organization of the ANS

- An autonomic nerve pathway consists of two-neurons in series.
  - The 1\textsuperscript{st} neuron is the \textit{preganglionic neuron}.
    - Its axon innervates the cell body of the 2\textsuperscript{nd} neuron within an \textbf{autonomic ganglion}.
  - The 2\textsuperscript{nd} neuron is the \textit{postganglionic neuron}.
    - Its cell body is in the \textit{autonomic ganglion}
    - Its axon innervates the \textit{effector} (target)

- \textbf{Parasympathetic division}
  - Cell bodies of \textit{preganglionic} neurons are in the \textbf{brain stem} and \textbf{sacral segments}.
    - Its cell
      - Have long preganglionic fibers that synapse with ganglion that lie in or near the effector (target) organ.
      - Have very short postganglionic fibers that innervate the organ.
  - \textbf{Preganglionic neurons} release acetylcholine (ACh) to activate
  - \textbf{Postganglionic neurons} release acetylcholine (ACH) to activate \textit{muscarinic receptors} on the target cell
• **Sympathetic division**
  - Cell bodies of preganglionic neurons are in the **thoracic** and the **lumbar** segments of the spinal cord
  - Called the

  - Most have short preganglionic fibers that synapse with ganglion that lie in the sympathetic chain or collateral ganglia
  - Have long postganglionic fibers innervate organ.
  - **Preganglionic neurons** release acetylcholine (ACH) to activate

  - **Postganglionic neurons** release norepinephrine to activate **adrenergic receptors** on target cell.

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**Rules for Autonomic Nervous System Neurotransmitters /Receptors**

1. Both sympathetic and parasympathetic preganglionic neurons release acetylcholine (ACH) onto nicotinic receptors on the postganglionic cell.
2. Most postganglionic sympathetic neurons secrete norepinephrine (NE) onto adrenergic receptors (α, β) on the target cell.
3. Most postganglionic parasympathetic neurons secrete
### Summary of Sympathetic vs. Parasympathetic

<table>
<thead>
<tr>
<th></th>
<th>Sympathetic</th>
<th>Parasympathetic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Point of CNS Origin</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NT at Ganglion</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Receptor at Ganglion</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NT at Target Synapse</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Type of NT Receptors at Target Synapse</strong></td>
<td></td>
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</tbody>
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### Exceptions in the Sympathetic Nervous System:

- **Sweat glands:**
  - Postganglionic sympathetic neurons that innervate sweat glands secrete ACh rather than norepinephrine.
    - Involved with
    - Note: Only innervated by

- **Adrenal glands**
  - *Preganglionic neurons* synapse directly on the cells of the adrenal medulla, release acetylcholine, and activate nicotinic receptors on the adrenal gland cells.
    - Adrenal gland cells, called
  - Adrenal glands release mostly epinephrine (adrenaline) and some norepinephrine (noradrenaline) into the systemic circulation.

### Antagonistic Control

- Most internal organs are innervated by both branches of the ANS which exhibit *antagonistic* control.
  - Example: **Heart rate.**
    - Increased sympathetic stimulation increases HR.
    - Increased
Exceptions

- **Exception to the dual innervation rule:**
  - Sweat glands and most blood vessels (smooth muscle) are only innervated by sympathetic nerves.
  - **Note:** Most arterioles and veins are innervated; arteries and capillaries are not.
    - Activated by
    - Deactivated by

- **Exception to the antagonism rule:**
  - Sympathetic and parasympathetic work cooperatively to achieve male sexual function.
    - **Parasympathetic**
    - **Sympathetic**
      - There's similar ANS cooperation in the female sexual response.
Sympathetic vs. Parasympathetic Effects:
- In the following tables (see attachment at end of notes), note the effects of the sympathetic and parasympathetic nervous systems on various body organs.
- Try to deduce why the divisions cause these particular actions.

Other Autonomic Neurotransmitters
- A few autonomic neurons do not secrete ACh or norepinephrine.
  - Proposed neurotransmitters include ATP, vasoactive intestinal peptide (VIP), and nitric oxide (NO).

NO and Vasodilatation of Penal Arteries
- Stimulation of parasympathetic neurons relax smooth muscle of
  - A small population of parasympathetic neurons can make and release NO directly.
  - Most parasympathetic neurons innervating the penis release acetylcholine (ACh) which stimulates endothelial cells in the area to make and release NO.
    - No causes
- Vasodilatation of arteries supplying the penis causes them to distend and compress the penal veins which inhibits the outflow of venous blood, resulting in an erection.
- Ejaculation is a sympathetic reflex causing the peristaltic waves of contraction of smooth muscle to propel semen out of the urethra.
- Penis returns to flaccid state when

How Does Viagra Work?
- Viagra inhibits the enzyme (A type of phosphodiesterase) that stops the action of nitric oxide.
  - Allows the arteries supplying the penis to
How do drugs influence the ANS?
- Mimic or block the effects of the two primary neurotransmitters, Acetylcholine and Norepinephrine/Epinephrine
  - Drugs that mimic neurotransmitters are referred to as “receptor agonists” or “agonists”
  - These drugs
  - Drugs that block neurotransmitters are referred to as “receptor antagonists” or “antagonists”
  - These drugs block the

Muscarinic Antagonist
- **Atropine** blocks ACh from stimulating muscarinic receptors.
- Results in decreased
- Used clinically to
  - Dilate pupils during eye examinations
  - Treat peptic ulcers
- History
  - Used in by women during the Middle Ages to dilate their pupils and enhance their beauty.
  - Derived from the deadly nightshade plant (Atropa belladonna).

Adrenergics
- **Adrenergic neurons** release norepinephrine (noreadrenaline); and adrenal glands release both norepinephrine and epinephrine (adrenaline).
  - Most sympathetic postganglionic neurons are
  - Epinephrine and norepinephrine affect 2 categories of membrane receptors – designated as alpha (α) 1 and 2 receptors and beta (β) 1 and 2 receptors.

Action:
- **Excitatory** – Increased contraction of heart muscle and constriction of most blood vessels.
- **Inhibitory** –

![Diagram of nervous system divisions and neurotransmitter actions](image)

Beta Blockers
- Activation of β1 receptors increases heart rate and contraction strength.
- **Atenolol** is a β1 antagonist that
  - Used to treat hypertension

Beta Agonists
- Activation of **β2 receptors** causes relaxation of bronchial smooth muscle cells.
- **Epinephrine** is a β1 and
  - Can be used to treat asthma, but also increases heart rate and force of contraction
- **Albuterol** is a β2 agonist that causes bronchodilation.
  - Used to treat asthma symptoms.
**Sympathetic vs. Parasympathetic Effects:**

- In the following tables (see attachment), note the effects of the sympathetic and parasympathetic nervous systems on various body organs.
- Try to deduce why the divisions cause these particular actions.

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<tr>
<th>Target Organ</th>
<th>Parasympathetic Effects</th>
<th>Sympathetic Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salivary Glands</td>
<td>No innervation.</td>
<td></td>
</tr>
<tr>
<td>Sweat Glands</td>
<td>Stimulates smooth muscle to contract and expel bile.</td>
<td>Inhibits gallbladder smooth muscle.</td>
</tr>
<tr>
<td>Gallbladder</td>
<td></td>
<td></td>
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<tr>
<td>Arrector Pili</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac Muscle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coronary Blood Vessels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lungs</td>
<td>Contracts bronchiole (small air passage) smooth muscle.</td>
<td>Dilates bronchioles.</td>
</tr>
<tr>
<td>Digestive Organs</td>
<td>Increases peristalsis and enzyme/mucus secretion.</td>
<td>Decreases glandular and muscular activity.</td>
</tr>
<tr>
<td>Blood Vessels</td>
<td>Little effect.</td>
<td>Constricts most blood vessels and increases BP. Exception – dilates some blood vessels serving skeletal muscle fibers (cholinergic). Greater dilation effect from epinephrine stimulating beta receptors</td>
</tr>
<tr>
<td><strong>Target Organ</strong></td>
<td><strong>Parasympathetic Effects</strong></td>
<td><strong>Sympathetic Effects</strong></td>
</tr>
<tr>
<td>------------------</td>
<td>-----------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>Kidney</td>
<td>No innervation.</td>
<td>Releases the enzyme renin which acts to increase BP.</td>
</tr>
<tr>
<td>Vagina; Clitoris</td>
<td>Vasodilation. Erection.</td>
<td>Vaginal reverse peristalsis.</td>
</tr>
<tr>
<td>Mental Activity</td>
<td></td>
<td></td>
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<tr>
<td>Cellular Metabolism</td>
<td></td>
<td></td>
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<tr>
<td>Adipose Tissue</td>
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</tr>
</tbody>
</table>

**Alpha 1 Agonist**

- **Phenylephrine**, an \( \alpha_1 \) receptor agonist, is a common ingredient in cold and sinus medications.
  - Reduces mucus production in the nose by constricting blood vessels in the nasal mucosa, thus relieving nasal mucosa.

**Nicotine from Cigarettes**

- Nicotine is a stimulant drug that acts as an agonist at nicotinic acetylcholine receptors on autonomic ganglia, the adrenal medulla, neuromuscular junctions and in the brain.

  - In the brain nicotine exerts a reward effect in the **limbic system** and is a highly addictive substance. In the brain, nicotine binds to nicotinic acetylcholine receptors on dopaminergic neurons in the **limbic system**. This binding stimulates the release of dopamine which is responsible the pleasurable and addictive properties of nicotine.

![Dopamine Pathways](image)

**Functions**
- Reward (motivation)
- Pleasure, euphoria
- Motor function (fine tuning)
- Compulsion
- Perseveration

**Serotonin Pathways**

- Striatum
- Substantia nigra
- Hippocampus
- Raphe nuclei

**Functions**
- Mood
- Memory processing
- Sleep
- Cognition
- Nicotine stimulates the postganglionic neurons of both the **sympathetic** and **parasympathetic division** and can have a wide variety of effects.
  - Nicotine binds to **nicotinic receptors** on the chromaffin cells of the adrenal medulla. It stimulates the chromaffin cells to release epinephrine and norepinephrine into the bloodstream, which causes **vasoconstriction**, **increased heart rate**, **increased blood pressure**, and **increased blood glucose levels**.
  - Nicotine exerts a **reward effect** in the **limbic system** and is a highly addictive substance. In the brain, nicotine binds to **nicotinic receptors** on dopaminergic neurons in the **limbic system**. This binding stimulates the **release of dopamine** which is responsible the **pleasurable and addictive properties of nicotine**.