The Autonomic Nervous System

**Sympathetic**
- Hypothalamus, Reticular formation:
  - Pupil dilates
  - Mucus and enzymes secreted
  - Increases heart rate and contractility
  - Increases bile secretion
  - Decreases enzymes and insulin
  - Inhibits digestion
  - Increases renin secretion
  - Relaxes bladder
  - Urinary bladder:
    - Induces ejaculation
    - Stimulates contraction
  - Testes:
    - Enlargement and secretions

**Parasympathetic**
- Hypothalamus, Reticular formation:
  - Pupil constricts
  - Salivary glands:
    - Watery secretion
  - Heart:
    - Slows heart rate
  - Constricts airways
  - Lungs:
    - Bronchioles dilate
  - Digestive tract:
    - Increases motility and secretion
  - Exocrine pancreas:
    - Decreases enzyme secretion
  - Endocrine pancreas:
    - Inhibits insulin secretion
  - Adrenal medulla:
    - Secrete catecholamines
  - Kidney:
    - Increases renin secretion
  - Urinary bladder:
    - Urinary retention
  - Adipose tissue:
    - Fat breakdown
  - Male and female sex organs:
    - Ejaculation (male)
  - Uterus:
    - Depends on stage of cycle
  - Lymphoid tissue:
    - Generally inhibitory

**Effectors**

<table>
<thead>
<tr>
<th>Effector Organ</th>
<th>Sympathetic Response</th>
<th>Adrenergic Receptor</th>
<th>Parasympathetic Response *</th>
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<tbody>
<tr>
<td>Pupil of eye</td>
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<td>α</td>
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*Hormonal epinephrine only

**All parasympathetic responses are mediated by muscarinic receptors.**

**KEY**
- Red: Sympathetic
- Blue: Parasympathetic
The Autonomic Division

Controlled by the limbic system and the medulla oblongata, which is in turn controlled by the hypothalamus.
CNS
\[\uparrow\downarrow\]\ PNS

EFFERENT
- Somatic
  - Skeletal muscle
    - voluntary
- ANS
  - Cardiac & smooth muscles
    - involuntary

AFFERENT
- Somatic
  - Skeletal muscle, tendons, joints
- Visceral
  - Cardiac & smooth muscles
    - glands
Somatic vs. Autonomic

(a) Autonomic varicosities release neurotransmitter over the surface of target cells.
(b) Norepinephrine (NE) release and removal at a sympathetic neuroeffector junction

1. Action potential arrives at the varicosity.
2. Depolarization opens voltage-gated Ca\(^{2+}\) channels.
3. Ca\(^{2+}\) entry triggers exocytosis of synaptic vesicles.
4. NE binds to adrenergic receptor on target.
5. Receptor activation ceases when NE diffuses away from the synapse.
6. NE is removed from the synapse.
7. NE can be taken back into synaptic vesicles for re-release.
8. NE is metabolized by monoamine oxidase (MAO).
Somatic vs. Autonomic

What happens if innervation is absent?
Somatic vs. Autonomic

- Somatic has 1 neuron in the efferent pathway
- Autonomic division has 2
  - Preganglionic neuron has its cell body in the gray matter of brain or spinal cord
  - Postganglionic neuron has its cell body in an
**SOMATIC MOTOR PATHWAY**

- CNS
- ACh
- Nicotinic receptor
- Target: skeletal muscle

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**Autonomic pathways consist of two neurons that synapse in an autonomic ganglion.**

- Preganglionic neuron
- Postganglionic neuron
- Autonomic ganglion
- Target tissue

---

why have 2 neurons in the efferent pathway?
# Somatic vs. Autonomic

<table>
<thead>
<tr>
<th>Comparison of Somatic Motor and Autonomic Divisions</th>
<th>SOMATIC MOTOR</th>
<th>AUTONOMIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of neurons in efferent path</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Neurotransmitter/receptor at neuron-target synapse</td>
<td>ACh/nicotinic</td>
<td>ACh/muscarinic or NE/α- or β-adrenergic</td>
</tr>
<tr>
<td>Target tissue</td>
<td>Skeletal muscle</td>
<td>Smooth and cardiac muscle; some endocrine and exocrine glands; some adipose tissue</td>
</tr>
<tr>
<td>Neurotransmitter released from</td>
<td>Axon terminals</td>
<td>Varicosities and axon terminals</td>
</tr>
<tr>
<td>Effects on target tissue</td>
<td>Excitatory only: muscle contracts</td>
<td>Excitatory or inhibitory</td>
</tr>
<tr>
<td>Peripheral components found outside the CNS</td>
<td>Axons only</td>
<td>Preganglionic axons, ganglia, postganglionic neurons</td>
</tr>
<tr>
<td>Summary of function</td>
<td>Posture and movement</td>
<td>Visceral function, including movement in internal organs and secretion; control of metabolism</td>
</tr>
</tbody>
</table>

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Divisions of the Autonomic Nervous System

Parasympathetic Division
- pupil constricted
- stimulated
- heart rate slow
- stomach stimulated
- contracted

Sympathetic Division
- inhibited
- salivation inhibited
- accelerated
- airways expanded
- inhibited
- adrenal gland stimulated
- bladder relaxed
Sympathetic (Thoracolumbar) Division

- Preganglionic neurons originate in the thoracic and lumbar regions; paravertebral ganglia

- 'Flight or Fight' system
Parasympathetic (Craniosacral) Division

- Preganglionic neurons originate in the brain (midbrain, medulla oblongata and pons) and sacral region of the spinal cord and send axons to ganglia located at or near effector organs.

- "Rest and Digest" system
Homeostasis is a dynamic balance between the autonomic branches. 

for the most part…

Rest-and-digest: Parasympathetic activity dominates.  
Fight-or-flight: Sympathetic activity dominates.
Functions of the Autonomic NS

What Determines the Meaning of a Message?

Oh yes, here we go again…
Neurotransmitters of the ANS

Cholinergic: Acetycholine

Epinephrine

Norepinephrine
Cholinergic Neurons of the ANS

- ACh is the neurotransmitter of all preganglionic fibers of both divisions (as well as for somatic motor neurons).
- ACh is also the NT for parasympathetic postganglionic neurons
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<td>Preganglionic</td>
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</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Postganglionic</td>
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</tr>
</tbody>
</table>
Cholinergic Stimulation Responses

- Cholinergic effects of somatic motor neurons and of preganglionic neurons are always
  excitatory.

- Cholinergic effect of postganglionic parasympathetic neurons may be stimulatory or inhibitory.

*How is that possible?*
Cholinergic Receptors

- **Nicotinic subtype**
  - $N_m$ found in neuromuscular junctions
  - $N_n$ found elsewhere

- **Muscarinic subtypes**
  - $M_1$: CNS, gastric parietal cells, ANS ganglia
  - $M_2$: myocardium
  - $M_3$: smooth muscle
  - $M_4, M_5$: CNS
(a) The **neuromuscular junction** consists of axon terminals, motor end plates on the muscle membrane, and Schwann cell sheaths.

(b) The **motor end plate** is a region of muscle membrane that contains high concentrations of ACh receptors.
(c) The neuromuscular junction

Synaptic vesicle (ACh)
Presynaptic membrane
Synaptic cleft
Postsynaptic membrane is modified into a motor end plate.

(d) An action potential arrives at the axon terminal, causing voltage-gated Ca\(^{2+}\) channels to open. Calcium entry causes synaptic vesicles to fuse with the presynaptic membrane and release ACh into the synaptic cleft.

(e) The nicotinic cholinergic receptor binds two ACh molecules, opening a nonspecific monovalent cation channel. The open channel allows Na\(^+\) and K\(^+\) to pass. Net Na\(^+\) influx depolarizes the muscle fiber.

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(e) The nicotinic cholinergic receptor binds two ACh molecules, opening a nonspecific monovalent cation channel. The open channel allows Na\(^+\) and K\(^+\) to pass. Net Na\(^+\) influx depolarizes the muscle fiber.
ACh Muscarinic Receptors

**M₃**
- ACh binds to the receptor
- Activates the G protein (α, β, γ)
- Opens potassium channels (K⁺)
- **Hyperpolarization**
- **Inhibition**
- Produces slower heart rate

**M₂**
- ACh binds to the receptor
- Activates the G protein (α, β, γ)
- Promotes sodium or calcium influx (Na⁺ or Ca²⁺)
- **Depolarization**
- **Excitation**
- Causes smooth muscles of the digestive tract to contract
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<tr>
<td>Postganglionic</td>
<td>Postganglionic</td>
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<tr>
<td></td>
<td>ACh binds to _____ Receptors</td>
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Adrenergic Stimulation Responses

- Most postganglionic sympathetic nerve fibers release norepinephrine
- Effects vary

*How is that possible?*
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<td><strong>Postganglionic</strong></td>
<td><strong>Postganglionic</strong></td>
</tr>
<tr>
<td>NE and E bind to ______________ Receptors</td>
<td>ACh binds to Muscarinic Receptors</td>
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# Adrenergic Receptors

<table>
<thead>
<tr>
<th>Receptor</th>
<th>Found in</th>
<th>Sensitivity</th>
<th>Effect on Second Messenger</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_1$</td>
<td>Most sympathetic target tissues</td>
<td>NE &gt; E*</td>
<td>Activates phospholipase C</td>
</tr>
<tr>
<td>$\alpha_2$</td>
<td>Gastrointestinal tract and pancreas</td>
<td>NE &gt; E</td>
<td>Decreases cAMP</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>Heart muscle, kidney</td>
<td>NE = E</td>
<td>Increases cAMP</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>Certain blood vessels and smooth muscle of some organs</td>
<td>E &gt; NE</td>
<td>Increases cAMP</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>Adipose tissue</td>
<td>NE &gt; E</td>
<td>Increases cAMP</td>
</tr>
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</table>

*NE = norepinephrine, E = epinephrine.

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Sympathetic pathways use acetylcholine and norepinephrine.

Parasympathetic pathways use acetylcholine.

Diagram:
- CNS
- ACh
- Nicotinic receptor
- Autonomic ganglion
- Norepinephrine
- Adrenergic receptor
- Muscarinic receptor
- Target tissue
Autonomic Pathways

Somatic motor pathway
- CNS
- ACh
- Nicotinic receptor
- Muscarinic receptor
- Skeletal muscle

Parasympathetic pathway
- CNS
- ACh
- Ganglion
- Nicotinic receptor
- Muscarinic receptor

Sympathetic pathways
- CNS
- ACh
- Ganglia
- Nicotinic receptor
- NE
- α receptor
- β1 receptor
- β2 receptor
- Autonomic effectors:
  - Smooth and cardiac muscles
  - Some endocrine and exocrine glands
  - Some adipose tissue

Adrenal sympathetic pathway
- CNS
- Adrenal cortex
- Adrenal medulla
- E
- Blood vessel
One Last Thing…. The Adrenal Sympathetic Pathway

• "Postganglionic neuron" replaced by epinephrine-releasing cells

• Epinephrine is a neurohormone, released into the blood
THE ADRENAL MEDULLA SECRETES EPINEPHRINE INTO THE BLOOD.

Adrenal cortex is a true endocrine gland.
Adrenal medulla is a modified sympathetic ganglion.

The chromaffin cell is a modified postganglionic sympathetic neuron.

Epinephrine is a neurohormone that enters the blood.
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<th>Parasympathetic</th>
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<tr>
<td>Point of CNS origin</td>
<td>1st thoracic to 2nd lumbar segments</td>
<td>Midbrain, medulla, and 2nd–4th sacral segments</td>
</tr>
<tr>
<td>Location of peripheral ganglia</td>
<td>Primarily in paravertebral sympathetic chain; 3 outlying ganglia located alongside descending aorta</td>
<td>On or near target organs</td>
</tr>
<tr>
<td>Structure of region from which neurotransmitter is released</td>
<td>Varicosities</td>
<td>Varicosities</td>
</tr>
<tr>
<td>Neurotransmitter at target synapse</td>
<td>Norepinephrine (adrenergic neurons)</td>
<td>ACh (cholinergic neurons)</td>
</tr>
<tr>
<td>Inactivation of neurotransmitter at synapse</td>
<td>Uptake into varicosity, diffusion</td>
<td>Enzymatic breakdown, diffusion</td>
</tr>
<tr>
<td>Neurotransmitter receptors on target cells</td>
<td>Adrenergic</td>
<td>Muscarinic</td>
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<tr>
<td>Ganglionic synapse</td>
<td>ACh on nicotinic receptor</td>
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<tr>
<td>Neuron-target synapse</td>
<td>NE on α- or β-adrenergic receptor</td>
<td>ACh on muscarinic receptor</td>
</tr>
<tr>
<td>Receptor Type</td>
<td>Neurotransmitter</td>
<td>Agonist</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------</td>
<td>---------</td>
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<tr>
<td><strong>Cholinergic</strong></td>
<td>Acetylcholine</td>
<td>Muscarine</td>
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<td></td>
</tr>
<tr>
<td>Nicotinic</td>
<td></td>
<td>Nicotine</td>
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<tr>
<td><strong>Adrenergic</strong></td>
<td>Norepinephrine (NE), epinephrine</td>
<td>Phenylephrine</td>
</tr>
<tr>
<td>Alpha (α)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta (β)</td>
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<td>Isoproterenol</td>
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*AChE = acetylcholinesterase
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**All parasympathetic responses are mediated by muscarinic receptors.
How the Divisions Work Together
Antagonistic

Homeostasis is a dynamic balance between the autonomic branches.

Rest-and-digest: Parasympathetic activity dominates.  
Fight-or-flight: Sympathetic activity dominates.
• Sympathetic and parasympathetic on salivary gland function
• Urination
• Erection / ejaculation