ANS consists of motor neurons that

- Innervate smooth and cardiac muscle, and glands
- Make adjustments to ensure optimal support for body activities
- Operate via subconscious control

• Also called *involuntary nervous system* or *general visceral motor system*
Somatic Versus Autonomic Nervous Systems

Both have motor fibers

Differ in

- **Effectors**
- Efferent pathways and ganglia
- Target organ responses to neurotransmitters

**Effectors**

**Somatic nervous system**
- Skeletal muscles

**ANS**
- Cardiac muscle
- Smooth muscle
- Glands

### Comparison of Autonomic and Somatic Motor Systems

<table>
<thead>
<tr>
<th>Body in central nervous system</th>
<th>Peripheral nervous system</th>
<th>Neurotransmitter</th>
<th>Effector organs</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SOMATIC NERVOUS SYSTEM</strong></td>
<td>Single neuron from CNS to effector organs</td>
<td>Ach</td>
<td>Skeletal muscle</td>
<td>+ Stimulatory</td>
</tr>
<tr>
<td></td>
<td>Heavily myelinated axon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AUTONOMIC NERVOUS SYSTEM</strong></td>
<td>Two-neuron chain from CNS to effector organs</td>
<td>Ach</td>
<td>Adrenal medulla</td>
<td>- Stimulatory or inhibitory, depending on neurotransmitter and receptors on effector organs</td>
</tr>
<tr>
<td>sympathetic</td>
<td></td>
<td>Ach, NE</td>
<td>Blood vessel</td>
<td></td>
</tr>
<tr>
<td>parasympathetic</td>
<td></td>
<td>Epinephrine and norepinephrine</td>
<td>Carotid sinus</td>
<td></td>
</tr>
</tbody>
</table>
Somatic nervous system

Cell body in CNS; thick, myelinated, group A fiber extends in spinal or cranial nerve to skeletal muscle

ANS pathway uses two-neuron chain

1. **Preganglionic neuron** (in CNS) has a thin, lightly myelinated **preganglionic axon**.

2. **Postganglionic (ganglionic) neuron** in **autonomic ganglion** outside CNS has nonmyelinated **postganglionic axon** that extends to effector organ
Somatic nervous system

- Cell body in CNS; thick, myelinated, group A fiber extends in spinal or cranial nerve to skeletal muscle

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Somatic nervous system

All somatic motor neurons release acetylcholine (ACh)
Effects always stimulatory

ANS

Preganglionic fibers release ACh
Postganglionic fibers release norepinephrine or ACh at effectors
Effect is either stimulatory or inhibitory,
   depending on type of receptors
Most spinal and many cranial nerves contain both somatic and autonomic fibers.

Adaptations usually involve both skeletal muscles and visceral organs.
<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>PARASYMPATHETIC</th>
<th>SYMPATHETIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin</td>
<td>Cranioskeletal part: brain stem nuclei of cranial nerves III, VII, IX, and X; spinal cord segments S2-S4.</td>
<td>Thoracolumbar part: lateral horns of gray matter of spinal cord segments T1-L2.</td>
</tr>
<tr>
<td>Location of ganglia</td>
<td>Ganglia (terminal ganglia) are within the visceral organ (intramural) or close to the organ served.</td>
<td>Ganglia are within a few centimeters of CNS: alongside vertebral column (sympathetic trunk ganglia) and anterior to vertebral column (collateral, or prevertebral, ganglia).</td>
</tr>
<tr>
<td>Relative length of pre- and postganglionic fibers</td>
<td>Long preganglionic; short postganglionic.</td>
<td>Short preganglionic; long postganglionic.</td>
</tr>
<tr>
<td>Rami communicantes</td>
<td>None.</td>
<td>Gray and white rami communicantes. White rami contain myelinated preganglionic fibers. Gray contain nonmyelinated postganglionic fibers.</td>
</tr>
<tr>
<td>Degree of branching of preganglionic fibers</td>
<td>Minimal.</td>
<td>Extensive.</td>
</tr>
<tr>
<td>Functional role</td>
<td>Maintenance functions; conserves and stores energy; &quot;rest and digest.&quot;</td>
<td>Prepares body for activity; &quot;fight or flight.&quot;</td>
</tr>
<tr>
<td>Neurotransmitters</td>
<td>All preganglionic and postganglionic fibers release ACh (cholinergic fibers).</td>
<td>All preganglionic fibers release norepinephrine (adrenergic fibers). Postganglionic fibers serving sweat glands release ACh. Neurotransmitter activity is augmented by release of adrenal medullary hormones (norepinephrine and epinephrine).</td>
</tr>
</tbody>
</table>
Mobilizes body during activity; "fight-or-flight" system

Exercise, excitement, emergency, embarrassment
  Increased heart rate; dry mouth; cold, sweaty skin; dilated pupils

During vigorous physical activity
  Shunts blood to skeletal muscles and heart
  Dilates bronchioles
  Causes liver to release glucose
Picture of chain – leading through series pictures to schematic rep of autonomic nervous system
Note ganglia – implies cell bodies in peripheral nervous system
Chain of ganglia
Picture with no bone

Cell bodies receive and send out processes – axons from and to other cells
Sympathetic system
Schematic
Generally opposite of sympathetic division

Rest and Digest

Slows heart rate (resting rate from parasympathetic tone)

Constricts airways and pupils
Paravertebral ganglia vary in size, position, and number.

There are 23 paravertebral ganglia in the sympathetic trunk (chain):

3 cervical
11 thoracic
4 lumbar
4 sacral
1 coccygeal
Preganglionic neurons are in spinal cord segments $T_1 - L_2$

Form lateral horns of spinal cord

Preganglionic fibers pass through **white rami communicantes** and enter **sympathetic trunk (chain or paravertebral) ganglia**
Upon entering sympathetic trunk ganglion short preganglionic fiber may

1. **Synapse with ganglionic neuron in same trunk ganglion**

2. Ascend or descend sympathetic trunk to synapse in another trunk ganglion

3. Pass through trunk ganglion and emerge without synapsing (only in abdomen and pelvis)
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3. **Pass through trunk ganglion and emerge without synapsing (only in abdomen and pelvis)**
Postganglionic axons enter ventral rami via gray rami communicantes.

These fibers innervate:
- Sweat glands
- Arrector pili muscles
- Vascular smooth muscle
Fibers emerge from T₁ – T₄ and synapse in the superior cervical ganglion

These fibers

- Innervate skin and blood vessels of the head
- Stimulate dilator muscles of the iris
- Inhibit nasal and salivary glands
- Innervate smooth muscle of upper eyelid
- Branch to the heart
Fibers emerge from T₁ – T₄ and synapse in the superior cervical ganglion.

These fibers:
- Innervate skin and blood vessels of the head
- Stimulate dilator muscles of the iris
- Inhibit nasal and salivary glands
- Innervate smooth muscle of upper eyelid
- Branch to the heart
The cervical part of the trunk does not receive pre-ganglionic fibres through white rami communicantes from the cervical segments of spinal cord, but it gives postganglionic fibres via grey rami communicantes to each of the 8 cervical nerves.

All pre-ganglionic fibres for the cervical trunk are derived from the lateral horn cells of T-T segments of spinal cord and ascend through the trunk before the final relay synapses in the three cervical sympathetic ganglia.
Preganglionic fibers emerge from T₁ – T₆ and synapse in cervical trunk ganglia.

Postganglionic fibers emerge from middle and inferior cervical ganglia and enter nerves C₄ – C₈.

These fibers innervate:
- Heart via the cardiac plexus
- Thyroid gland and the skin
- Lungs and esophagus
Most fibers from T5 – L2 synapse in collateral ganglia
They form thoracic, lumbar, and sacral splanchnic nerves
Their ganglia include the celiac and the superior and inferior mesenteric
Preganglionic fibers from T₅ – L₂ travel through thoracic splanchnic nerves
Synapses occur in celiac and superior mesenteric ganglia
Postganglionic fibers serve the stomach, intestines, liver, spleen, and kidneys
Preganglionic fibers from T₁₀ – L₂ travel via lumbar and sacral splanchnic nerves
Synapses occur in the inferior mesenteric and hypogastric ganglia
Postganglionic fibers serve the distal half of the large intestine, the urinary bladder, and the reproductive organs
Primarily inhibit activity of muscles and glands in abdominopelvic visceral organs
Some preganglionic fibers pass directly to adrenal medulla without synapsing. Upon stimulation, medullary cells secrete norepinephrine and epinephrine into blood.

Sympathetic ganglia and adrenal medulla arise from same tissue. Adrenal medulla is "misplaced" sympathetic ganglion.
Promotes maintenance activities and conserves body energy
  Directs digestion, diuresis, defecation
As in person relaxing and reading after a meal
  Blood pressure, heart rate, and respiratory rates are low
  Gastrointestinal tract activity high
  Pupils constricted; lenses accommodated for close vision
**Long preganglionic fibers** from brain stem and sacrum

- Extend from CNS almost to target organs
- Synapse with postganglionic neurons in **terminal ganglia** close to/within target organs

**Short postganglionic fibers** synapse with effectors
Cell bodies in brain stem
Preganglionic fibers in oculomotor, facial, glossopharyngeal, and vagus nerves
Oculomotor nerves – smooth muscle of eye
Facial nerves – stimulate large glands in head
Glossopharyngeal nerves – parotid salivary glands
Vagus nerves – neck and nerve plexuses for ~ all thoracic and abdominal viscera
Serves pelvic organs and distal half of large intestine

From neurons in lateral gray matter of $S_2$-$S_4$

Axons travel in ventral root of spinal nerves

Synapse with Ganglia in pelvic floor
Intramural ganglia in walls of distal half of large intestine, urinary bladder, ureters, and reproductive organs
Sympathetic division
Parasympathetic division

**Dual innervation**

~ All visceral organs served by both divisions, but cause opposite effects

Dynamic antagonism between two divisions maintains homeostasis
PNS elements that activate effectors by releasing neurotransmitters
Cholinergic fibers release neurotransmitter ACh
  All ANS preganglionic axons
  All parasympathetic postganglionic axons at effector synapse

Adrenergic fibers release neurotransmitter NE
  Most sympathetic postganglionic axons
  Exception: sympathetic postganglionic fibers secrete ACh at sweat glands
Cholinergic receptors for ACh
Adrenergic receptors for NE
Two types of receptors bind ACh

1. Nicotinic
2. Muscarinic

Named after drugs that bind to them and mimic ACh effects
Found on

- Sarcolemma of skeletal muscle cells
  (Chapter 9) at NMJ
- All postganglionic neurons (sympathetic and parasympathetic)
- Hormone-producing cells of adrenal medulla
Effect of ACh at nicotinic receptors is always stimulatory
Opens ion channels, depolarizing postsynaptic cell
Found on

All effector cells stimulated by postganglionic cholinergic fibers
Effect of ACh at muscarinic receptors

- Can be either inhibitory or excitatory
- Depends on receptor type of target organ
### Table 14.2 Cholinergic and Adrenergic Receptors

<table>
<thead>
<tr>
<th>Neurotransmitter (ACH)</th>
<th>Cholinergic</th>
<th><strong>Major Locations</strong></th>
<th>Effect of Binding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nicotinic</td>
<td>All postganglionic neurons; adrenal medullary cells (also neuromuscular junctions of skeletal muscle)</td>
<td>Excitation</td>
<td></td>
</tr>
<tr>
<td>Muscarinic</td>
<td>All parasympathetic target organs</td>
<td>Excitation in most cases; inhibition of cardiac muscle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Limited sympathetic targets (e.g., eccrine sweat glands)</td>
<td>Activation</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Norepinephrine (NE) (and epinephrine released by adrenal medulla)</th>
<th>Adrenergic</th>
<th><strong>Major Locations</strong></th>
<th>Effect of Binding</th>
</tr>
</thead>
<tbody>
<tr>
<td>β₁</td>
<td>Heart predominantly, but also kidneys and adipose tissue</td>
<td>Increases heart rate and force of contraction; stimulates kidneys to release renin</td>
<td></td>
</tr>
<tr>
<td>β₂</td>
<td>Lungs and most other sympathetic target organs; abundant on blood vessels serving the heart, liver, and skeletal muscle</td>
<td>Effects mostly inhibitory; dilates blood vessels and bronchioles; relaxes smooth muscle walls of digestive and urinary visceral organs; relaxes uterus</td>
<td></td>
</tr>
<tr>
<td>α₁</td>
<td>Adipose tissue</td>
<td>Stimulates lipolysis by fat cells</td>
<td></td>
</tr>
<tr>
<td>α₂</td>
<td>Most importantly blood vessels serving the skin, mucosae, abdominal viscera, kidneys, and salivary glands; also, virtually all sympathetic target organs except heart</td>
<td>Constricts blood vessels and visceral organ sphincters; dilates pupils of the eyes</td>
<td></td>
</tr>
<tr>
<td>membrane of adrenergic axon terminals; pancreas; blood platelets</td>
<td>Inhibits NE release from adrenergic terminals; inhibits insulin secretion by pancreas; promotes blood clotting</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note that all of these receptor subtypes are also found in the CNS.

Sympathetic cholinergic vasodilator fibers are found in other animals, but do not appear to be present in humans.*
Two major classes

- **Alpha** (α) (subtypes $\alpha_1$, $\alpha_2$)
- **Beta** (β) (subtypes $\beta_1$, $\beta_2$, $\beta_3$)
Effects of NE depend on which subclass of receptor predominates on target organ.
Atropine

Anticholinergic; blocks muscarinic ACh receptors

Used to prevent salivation during surgery, and to dilate pupils for examination
Neostigmine

Inhibits **acetylcholinesterase** that breaks down ACh

Used to treat myasthenia gravis
<table>
<thead>
<tr>
<th>DRUG CLASS</th>
<th>RECEPTOR BOUND</th>
<th>EFFECTS</th>
<th>EXAMPLE</th>
<th>CLINICAL APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nictinic agents</td>
<td>Nicotinic ACh receptors on all postganglionic neurons and in CNS</td>
<td>Typically stimulates sympathetic effects; blood pressure rises</td>
<td>Nicotine</td>
<td>Smoking cessation products</td>
</tr>
<tr>
<td>Parasympathomimetic agents</td>
<td>Mucaricin ACh receptors</td>
<td>Enhance parasympathetic activity by mimicking effects of ACh</td>
<td>Pilocarpine</td>
<td>Glaucoma (opens aqueous humor drainage pores)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bethanechol</td>
<td>Difficulty urinating (increases bladder contraction)</td>
</tr>
<tr>
<td>Acetylcholinesterase inhibitors</td>
<td>None; bind to the enzyme (AChE) that degrades ACh</td>
<td>Indirect effect at all ACh receptors; prolong the effect of ACh</td>
<td>Neostigmine</td>
<td>Myasthenia gravis (increases availability of ACh)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sarin</td>
<td>Used as chemical warfare agent (similar to widely used insecticides)</td>
</tr>
<tr>
<td>Sympathomimetic agents</td>
<td>Adrenergic receptors</td>
<td>Enhance sympathetic activity by binding to adrenergic receptors or increasing NE release</td>
<td>Albuterol (Ventolin)</td>
<td>Asthma (dilates bronchioles by binding to β2 receptors)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Phenylephrine</td>
<td>Colds (nasal decongestant, binds to α1 receptors)</td>
</tr>
<tr>
<td>Sympatholytic agents</td>
<td>Adrenergic receptors</td>
<td>Decrease sympathetic activity by blocking adrenergic receptors or inhibiting NE release</td>
<td>Propranolol</td>
<td>Hypertension (member of a class of drugs called beta-blockers that block β receptors, decreasing blood pressure)</td>
</tr>
</tbody>
</table>
Most visceral organs have dual innervation
Dynamic antagonism allows for precise control of visceral activity

- Sympathetic division increases heart and respiratory rates, and inhibits digestion and elimination
- Parasympathetic division decreases heart and respiratory rates, and allows for digestion and discarding of wastes
Sympathetic division controls blood pressure, even at rest
Vascular system ~ entirely innervated by sympathetic fibers
Sympathetic tone (vasomotor tone)
  Keeps blood vessels in continual state of partial constriction
Sympathetic fibers fire more rapidly to constrict blood vessels and cause blood pressure to rise.

Sympathetic fibers fire less rapidly to prompt vessels to dilate to decrease blood pressure.

Alpha-blocker drugs interfere with vasomotor fibers.

Used to treat hypertension.
Parasympathetic division normally dominates heart, smooth muscle of digestive and urinary tract organs, activate most glands except for adrenal and sweat glands

- Slows the heart
- Dictates normal activity levels of digestive and urinary tracts

The sympathetic division can
override these effects during times of stress

Drugs that block parasympathetic responses increase heart rate and cause fecal and urinary retention
Adrenal medulla, sweat glands, arrector pili muscles, kidneys, and most blood vessels receive only sympathetic fibers

**Sympathetic division controls**

- Thermoregulatory responses to heat
- Release of renin from kidneys

**Metabolic effects**

- Increases metabolic rates of cells
- Raises blood glucose levels
- Mobilizes fats for use as fuels
Parasympathetic division: short-lived, highly localized control over effectors
   ACh quickly destroyed by acetylcholinesterase
Sympathetic division: longer-lasting, bodywide effects
   NE inactivated more slowly than ACh
   NE and epinephrine hormones from adrenal medulla prolong effects
Hypothalamus—main integrative center of ANS activity
Subconscious cerebral input via limbic system structures on hypothalamic centers
Other controls come from cerebral cortex, reticular formation, and spinal cord
Hypothalamus—main integrative center of ANS activity
Subconscious cerebral input via limbic system structures on hypothalamic centers
Other controls come from cerebral cortex, reticular formation, and spinal cord
Control may be direct or indirect (through reticular system)
Centers of hypothalamus control
  Heart activity and blood pressure
  Body temperature, water balance, and endocrine activity
  Emotional stages (rage, pleasure) and biological drives (hunger, thirst, sex)
  Reactions to fear and "fight-or-flight" system
Cortical Controls

Connections of hypothalamus to limbic lobe allow cortical influence on ANS
Voluntary cortical control of visceral activities is possible

Biofeedback

- Awareness of physiological conditions with goal of consciously influencing them
- Biofeedback training allows some to control migraines and manage stress