Lecture 4

The Peripheral Nervous System
(181-240)

Excluded: adaptation of pacinian corpuscle (185), labeled lines (186), acuity (186-187), phototransduction (200-203), on-off-center ganglion cells (205)

Introduction

- Peripheral Nervous System
  - Afferent Division
    - Sends information from the PNS to the CNS
  - Efferent Division
    - Send information from the CNS to the PNS
- Afferent Division
  - Visceral afferents (subconscious input)
    - Pressure, O₂, temperature, etc.
  - Sensory afferents (conscious input)
    - Somatic sensation
      - Somesthetic sensation from skin
      - Proprioception from muscle joints, skin and inner ear
    - Special senses
      - Vision, hearing, taste and smell
- Efferent Division
  - Autonomic Nervous System
    - Cardiac muscle, smooth muscle, most exocrine glands, some endocrine glands, adipose tissue
  - Somatic Nervous system
    - Skeletal muscle

Receptor Physiology

- Receptors
  - Detect stimulus (detectable change) from different modalities (energy forms)
    - e.g. light, heat, sound, pressure, chemical changes
  - Adequate stimulus = the stimulus to which the receptor is most sensitive
  - Convert forms of energy into electrical signals (action potentials)
    - Process is called transduction
- Types of receptors
  - Photoreceptors
    - Responsive to visible wavelengths of light
  - Mechanoreceptors
    - Sensitive to mechanical energy
  - Thermoreceptors
    - Sensitive to heat and cold
  - Osmoreceptors
    - Detect changes in concentration of solutes in body fluids and resultant changes in osmotic activity
  - Chemoreceptors
    - Sensitive to specific chemicals
      - Include receptors for smell and taste and receptors that detect O₂ and CO₂ concentrations in blood and chemical content of digestive tract
  - Nociceptors
    - Pain receptors that are sensitive to tissue damage or distortion of tissue

Introduction

- Sensation ≠ Perception
- Perception
  - Our understanding (conscious interpretation) of the physical world
  - An interpretation of the senses
  - Different from what is out there because
    - Our receptors detect limited number of existing energy forms
    - The information does not reach our brain unaltered. Some features are accentuated and some are suppressed
    - The brain interprets the information and often distorts it (“completes the picture” or “feels in the gaps”) to extract conclusions.
    - Interpretation is affected by cultural, social and personal experiences stored in our memory
Receptor Physiology

- **Receptors may be**
  - Specialized ending of an afferent neuron ➔ receptor potential
  - Separate cell closely associated with peripheral ending of a neuron ➔ generator potential
- **Potential generation**
  - Separate receptor
    - Stimulus causes release of chemical messenger
  - Specialized afferent nerve ending
    - Stimulus alters receptor's permeability which leads to graded receptor potential
  - Usually causes nonselective opening of all small ion channels ➔ receptor (generator) potentials.
  - The magnitude of the receptor potential represents the intensity of the stimulus.
  - A receptor potential of sufficient magnitude can produce an action potential.
  - This action potential is propagated along an afferent fiber to the CNS.

- May adapt slowly or rapidly to sustained stimulation
- Types of receptors according to their speed of adaptation
  - **Tonic receptors**
    - Do not adapt at all or adapt slowly
    - Muscle stretch receptors, joint proprioceptors (to continuously receive information regarding posture and balance)
  - **Phasic receptors**
    - Rapidly adapting receptors
    - Tactile receptors in skin (the reason you don’t “feel” your clothes or watch)
  - Adaptation is not the same as habituation (synapse changes in the CNS)

Pain

- **Pain**
  - Primarily a protective mechanism meant to bring a conscious awareness that tissue damage is occurring or is about to occur
  - Storage of painful experiences in memory helps us avoid potentially harmful events in future
  - Sensation of pain is accompanied by motivated behavioral responses and emotional reactions
  - Subjective perception can be influenced by other past or present experiences (Are you afraid of your dentist?)

- Three categories of nociceptors
  - **Mechanical nociceptors**
    - Respond to mechanical damage such as cutting, crushing, or pinching
  - **Thermal nociceptors**
    - Respond to temperature extremes
  - **Polymodal nociceptors**
    - Respond equally to all kinds of damaging stimuli
  - Presence of prostaglandins (released after tissue injury)
    - Lowers nociceptors threshold for activation
    - Greatly enhances receptor response to noxious stimuli
  - Aspirin-like drugs inhibit their synthesis ➔ analgesic effect
  - Nociceptors do not adapt to sustained or repetitive stimulation
Pain

- Characteristics of pain

<table>
<thead>
<tr>
<th>Fast Pain</th>
<th>Slow Pain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occurs on stimulation of mechanical and thermal nociceptors</td>
<td>Occurs on stimulation of polymodal nociceptors</td>
</tr>
<tr>
<td>Carried by small, myelinated A-delta fibers</td>
<td>Carried by small, unmyelinated C fibers</td>
</tr>
<tr>
<td>Produces sharp, prickling sensation</td>
<td>Produces dull, aching, burning sensation</td>
</tr>
<tr>
<td>Easily localized</td>
<td>Poorly localized</td>
</tr>
<tr>
<td>Occurs first</td>
<td>Occurs second, persists for longer time, more unpleasant</td>
</tr>
<tr>
<td>Provoked and sustained by release of bradykinin</td>
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</tbody>
</table>

Two best known pain neurotransmitters

- Substance P
- Glutamate

Substance P

- Activates ascending pathways that transmit nociceptive signals to higher levels for further processing

Glutamate

- Major excitatory neurotransmitter
- Causes hypersensitivity in the area
  - Protection mechanism for healing and against further damage
- How does a sunburn feel?

Brain has built in analgesic system

- Suppresses transmission in pain pathways as they enter spinal cord
  - Suppress release of Substance P
- Depends on presence of opiate receptors
  - Endogenous opiates (morphine like substances) – endorphins, enkephalins, dynorphin
- Factors which modulate pain
  - Exercise ("runner’s high")
  - Stress (survival mechanism)
  - Acupuncture
**Vision**

**Eye**
- Sensory organ for vision
  - Mechanisms that help protect eyes from injury
    - Eyeball is sheltered by bony socket in which it is positioned
  - Eyelids
    - Act like shutters to protect eye from environmental hazards
  - Eyelashes
    - Trap fine, airborne debris such as dust before it can fall into eye
  - Tears
    - Continuously produced by lacrimal glands
    - Lubricate, cleanse, bactericidal

- Pupil
  - Round opening through which light enters the eye
- Iris
  - Controls amount of light entering eye
  - Contains two sets of smooth muscle networks
    - Circular (or constrictor) muscle
    - Radial (or dilator) muscle
  - Pigment in iris is responsible for eye color
  - Unique for each individual
  - Basis for latest identification technology

Parasympathetic stimulation

Sympathetic stimulation

- Convex structures of eye produce convergence of diverging light rays that reach eye
- Two structures most important in eye’s refractive ability are
  - Cornea
    - Contributes most extensively to eye’s total refractive ability
    - Refractive ability remains constant because curvature never changes
  - Lens
    - Refractive ability can be adjusted by changing curvature as needed for near or far vision (accommodation)
Vision

• Accommodation
  • Change in strength and shape of lens
  • Accomplished by action of ciliary muscle and suspensory ligaments
  • Age-related reduction in accommodation ability - presbyopia

Sympathetic stimulation

Ciliary muscle
Lens
Suspensory ligaments
Pupillary opening in front of lens
Relaxed ciliary muscle
Flattened weak lens
Taut suspensory ligaments
Contracted ciliary muscle
Rounded strong lens
Blackened suspensory ligaments

Vision

• Photoreceptors
  • Rod and cone cells
  • Photopigments on the disk membranes
    • Rod → one type
      • one pigment, high sensitivity
    • Cones → three different types
      • Red, green, blue sensing pigments, lower sensitivity
  • Undergo chemical alterations when activated by light
    • Change the receptor potential
    • Induce action potentials
    • Unlike other receptors, photoreceptors hyperpolarize!
Vision

- Color Vision
  - Perception of color
  - Depends on the ratio of stimulation of three different cones
    - Different absorption of cone pigments
  - Coded and transmitted by different pathways
  - Processed in color vision center of primary visual cortex
  - Color blindness
    - Defective cone
    - Colors become combinations of two cones
    - Most common = red-green color blindness

- Properties of Rod and Cone Vision
  - Rods
    - 100 million per retina
    - Vision in shades of gray
    - High sensitivity to light
    - Much convergence in retinal pathways
    - Night vision (from sensitivity and convergence)
    - Low acuity
    - More numerous in periphery
  - Cones
    - 3 million per retina
    - Color vision
    - Low sensitivity to light
    - Little convergence in retinal pathways
    - Day vision (lack sensitivity and convergence)
    - High acuity
    - Concentrated in fovea

- The sensitivity of the eyes varies through dark and light adaptation
  - Dark adaptation
    - Can gradually distinguish objects as you enter a dark area.
    - Due to the regeneration of rod photopigments that had been broken down by previous light exposure.
  - Light adaptation
    - Can gradually distinguish objects as you enter an area with more light.
    - Due to the rapid breakdown of cone photopigments.
  - Along with pupillary reflexes increase the range of vision
Vision

- **Visual field**
  - Area which can be seen without moving the head \(\rightarrow\) overlap between eyes
- **Visual Pathway**
  - Optic nerve
  - Optic chiasm
  - Thalamus
    - Sorts information to appropriate areas for processing
  - Optic radiation
  - Primary visual cortex (occipital lobe)
  - Higher processing areas
- **Information arrives altered at the primary visual cortex**
  - Upside down and backward because of the lens
  - The left and right halves of the brain receive information from the left and right halves of the visual field

Hearing

- **Hearing**
  - Neural perception of sound energy
  - Involves two aspects
    - Identification of the sounds ("what")
    - Localization of the sounds ("where")
  - **Sound waves**
    - Traveling vibrations of air
    - Consist of alternate regions of compression and rarefaction of air molecules

Vision

- **>30% of cortex participates in visual information processing**
  - "What" and "where" pathways
- **Depth Perception**
  - Visual field of two eyes slightly different
  - Depth perception with one eye
    - Other cues (such as size, location, experience)

Hearing

- **Characteristics of sound**
  - **Pitch (tone) of sound**
    - Depends on frequency of air waves
  - **Intensity (loudness)**
    - Depends on amplitude of air waves
  - **Timbre (quality)**
    - Determined by overtones
Hearing

- **Ear**
  - Consists of three parts
  - **External ear**
    - Consists of pinna, external auditory meatus, and tympanicum
    - Transmits airborne sound waves to fluid-filled inner ear
    - Amplifies sound energy
  - **Middle ear**
    - Transmits airborne sound waves to fluid-filled inner ear
    - Amplifies sound energy
  - **Inner ear**
    - Houses two different sensory systems
      - Cochlea (Contains receptors for conversion of sound waves into nerve impulses which makes hearing possible)
      - Vestibular apparatus (Necessary for sense of equilibrium)

**Sound Wave Transmission**

- **Inner ear**
  - Sound dissipates in cochlea
  - Waves in cochlear fluid (endolymph) set basilar membrane in motion
  - Sound converted to electrical signals by the Organ of Corti

- **Middle ear**
  - Transfers vibrations through ossicles (malleus, incus, stapes) to oval window (entrance into fluid-filled cochlea)
  - Amplify the pressure 20x
    - Large surface of the tympanic membrane transferred to the smaller oval window
    - Lever action of the ossicles
  - Small muscles change the stiffness of the tympanic membrane
    - Protection mechanism
    - Slow action (40 msec) protects only from prolonged sounds

- **Tympanic membrane**
  - Vibrates when struck by sound waves
  - Translates vibrations through ossicles (malleus, incus, stapes) to oval window (entrance into fluid-filled cochlea)

- **Vestibular membrane**
  - Hairs (stereocilia)
  - Mechanically gated channels open and close
  - Communicate via chemical signals with the nerves which form the auditory nerve

- **Hair cells**
  - Inner hair cells are tilted as basilar membrane oscillates
  - Mechanically gated channels open and close
  - Graded potentials
  - Outer hair cells adjust length with respond to electrical stimulus (electromotility)
  - Accentuate motion of basilar membrane and fine tune response

- **Scala media**
  - Scala vestibuli
  - Scala tympani

- **Organ of Corti**
  - Hair cells with ~ 100 stereocilia each
  - Inner hair cells are tilted as basilar membrane oscillates
  - Mechanically gated channels open and close
  - Graded potentials
  - Communicate via chemical signals with the nerves which form the auditory nerve
  - Outer hair cells adjust length with respond to electrical stimulus (electromotility)
  - Accentuate motion of basilar membrane and fine tune response

- **Scala media**
  - Scala vestibuli
  - Scala tympani
Hearing

- Auditory pathway
  - Hair cells
  - Auditory nerve
  - Brain stem
    - Signals cross over to opposite site (unlike visual signals)
  - Thalamus
    - Sorts and relays signals to cortical regions
  - Cortex
- Cortical Processing
  - Primary auditory cortex in the temporal lobe
    - Tonotopically mapped (i.e. mapped according to tone)
  - Higher cortical processing
    - Separates coherent and meaningful patterns

- Pitch discrimination
  - Basilar membrane does not have uniform mechanical properties
    - Narrow and stiff to wide and flexible
  - Different regions vibrate maximally at different frequencies
  - Frequency (or frequencies) are discriminated by the location of hair cells firing

- Loudness discrimination
  - Exquisitely sensitive organ (motion less than a molecule of Hydrogen) easily damaged
  - Wide range (every 10 dB means 10-fold increase in intensity)
  - Higher intensity causes larger basilar membrane movement
  - Stronger graded potential of hair cells
  - Faster rate of action potentials from auditory nerve cells
  - Anything > 100 dB can cause permanent damage

- Localization
  - Up-Down localization (elevation)
    - External ear (Pinna) shape changes sound timbre and intensity slightly according to elevation
  - Left-right localization (azimuth)
    - Sound arriving to proximal ear arrives
      - Slightly earlier (~ 0.5 msec)
      - Slightly stronger
    - Brain uses the electrical activity changes to these two cues to localize the direction
Hearing

- Deafness
  - Conductive
    - Sound waves not adequately conducted through external and middle portions of ear
    - Blockage, rupture of ear drum, middle ear infection, iddle ear adhesions
    - Hearing aids might help
  - Sensorineural
    - Sound waves conducted but not translated into electrical signals
    - Neural presbycusis, certain antibiotics, poisoning
    - Cochlear implants might help
      - Electrical devices stimulating the auditory nerve directly

Equilibrium

- Semicircular canals
  - Three circular tunnels arranged on perpendicular planes
  - Detect rotational acceleration or deceleration in any direction
  - Hair cells
    - On a ridge in the ampulla
    - Have on kinocilium and several stereocilia (mirovilli)
    - Embedded in gelatinous material, the cupula
  - Endolymph
  - Perilymph
  - Operculum
  - Ampulla
  - Oval window
  - Round window
  - Cochlea
  - Hair of hair cell: kinocilium (red) and stereocilium (blue)

- Detection of position and motion
  - Posture and coordination
  - Vestibular apparatus
    - Fluid filled tunnels in the inner ear
    - Semicircular canals
      - Three circular tunnels arranged on perpendicular planes
      - Otolith organs (Utricle and saccule)
    - Two bulges arranged in perpendicular directions
  - Vestibular nerve fibers
  - Auditory nerve fibers
  - Hair cells
  - Support cells
  - Kinocilium
  - Stereocilia
  - Cupula
  - Vestibular nerve fibers

- Semicircular canals
  - Signal transduction
    - Head is rotated
    - Two of the canals are rotated around their axis in opposite directions
    - Endolymph moves opposite to the direction of motion (inertia)
    - Cupula leans in that direction
    - Cilia bent and $K^+$ channels open or close
    - The hair cells are depolarized or hyperpolarized
    - Neurotransmitter realize from the hair cells is modified
    - Firing of the vestibular nerve is modified
Equilibrium

- Vestibular pathway
  - Vestibular nuclei in brain stem
  - Motor neurons for controlling eye movement, perceiving motion and orientation
    - E.g. vestibuloocular reflex
  - Cerebellum for use in maintaining balance and posture,

- The vestibular system detects acceleration
  - Speed is calculated by integrating circuitry in the brain stem

- Otolith Organs
  - Detect changes in rate of linear movement in any direction
  - Arranged in perpendicular directions
  - Provide information important for determining head position in relation to gravity
  - Hair cells
    - As described before
    - In addition, calcium carbonate crystals (otoliths) are embedded in within the gelatinous layer
      - Increased inertia
      - Sensitivity to gravity

Equilibrium

- Otolith Organs
  - Signal transduction
    - Utricle → Forward or backward motion or tilt (motion due to gravitational force)
    - Saccule → vertical motion
    - Endolymph and gelatinous mass with otoliths move in the opposite direction
    - Cilia bent and K⁺ channels open or close
    - The hair cells are depolarized or hyperpolarized
    - Neurotransmitter realize from the hair cells is modified
    - Firing of the vestibular nerve is modified

Taste and Smell

- Taste (gustation) and smell (olfaction)
  - Receptors are chemoreceptors
  - In association with food intake, influence flow of digestive juices and affect appetite
  - Stimulation of receptors induces pleasurable or objectionable sensations and signals presence of something to seek or to avoid
  - In lower animals also play a role in finding direction, seeking prey, avoiding predators and sexual attraction to a mate
  - Less developed and important in humans
    - Really? How much do you spend on perfumes and colognes
### Taste (Gustation)

- **Chemoreceptors housed in taste buds**
- **Present in oral cavity and throat**
- **Taste receptors have life span of about 10 days**
- **Taste bud consists of**
  - **Taste pore**
    - Opening through which fluids in mouth come into contact with surface of receptor cells
  - **Taste receptor cells**
    - Modified epithelial cells with surface folds called microvilli
    - Plasma membrane of microvilli contain receptor sites that bind selectively with chemical molecules

### Signal transduction
- **Tastant (taste-provoking chemical)**
- **Binding of tastant with receptor cell**
- **Alters cell’s ionic channels to produce depolarizing receptor potential**
- **Receptor potential releases neurotransmitter**
- **Initiates action potentials within terminal endings of afferent nerve fibers with which receptor cell synapses**
- **Signals conveyed via synaptic stops in brain stem and thalamus to cortical gustatory area**

### Five primary tastes
- **Salty**
  - Stimulated by chemical salts, especially NaCl
- **Sour**
  - Caused by acids which contain a free hydrogen ion, H⁺
- **Sweet**
  - Evoked by configuration of glucose
- **Bitter**
  - Brought about by more chemically diverse group of tastants
  - Examples – alkaloids, toxic plant derivatives, poisonous substances
- **Umami**
  - Meaty or savory taste (MSG receptor!)

### Taste Perception
- **Influenced by information derived from other receptors, especially odor**
- **Temperature and texture of food influence taste**
- **Psychological experiences associated with past experiences with food influence taste**
- **How cortex accomplishes perceptual processing of taste sensation is currently unknown**
Smell (Olfaction)

- Olfactory receptors in nose are specialized endings of renewable afferent neurons
- Olfactory mucosa
  - 3 cm² of mucosa in ceiling of nasal cavity
- Contains three cell types
  - Olfactory receptor cell
    - Afferent neuron whose receptor portion is in olfactory mucosa in nose and afferent axon traverses into brain
    - Axons of olfactory receptor cells collectively form olfactory nerve
  - Supporting cells
  - Basal cells
    - Precursors of new olfactory receptor cells (replaced about every two months)

Odorants
- Molecules that can be smelled
- Act through second-messenger systems to open Na⁺ channels and trigger action potentials
- To be smelled, substance must be
  - Sufficiently volatile that some of its molecules can enter nose in inspired air
  - Sufficiently water soluble that it can dissolve in mucus coating the olfactory mucosa
- 5 million olfactory receptors
  - 1000 different types
- Afferent signals are sorted according to scent component by glomeruli within olfactory bulb
- Two routes to the brain
  - Subcortical (limbic system)
  - Through the thalamus to the cortex
- The olfactory system adapts quickly and odorants are rapidly cleared (by odor-eating enzymes)

Vomeronasal Organ (VNO)
- Common in mammals but until recently was thought to nonexistent in humans
- Governs emotional responses and sociosexual behaviors
- Located about half an inch inside human nose next to vomer bone
- Detects pheromones
  - Nonvolatile chemical signals passed subconsciously from one individual to another
- Role in human behavior has not been validated
  - “Good chemistry” and “love at first sight”

PNS – Efferent Division

- Communication link by which CNS controls activities of muscles and glands
- Two divisions of PNS
  - Autonomic nervous system (ANS)
    - Involuntary branch of PNS
    - Innervates cardiac muscle, smooth muscle, most exocrine glands, some endocrine glands, and adipose tissue
  - Somatic nervous system
    - Subject to voluntary control
    - Innervates skeletal muscle
Autonomic Nervous System

- Autonomic nerve pathway
  - Extends from CNS to an innervated organ
  - Two-neuron chain
    - Preganglionic fiber (synapses with cell body of second neuron)
    - Postganglionic fiber (innervates effector organ)
  - Postganglionic fibers end in varicosities
- Two subdivisions
  - Sympathetic nervous system
  - Parasympathetic nervous system

Central nervous system

Preganglionic fiber

Preganglionic neurotransmitter

Varicosity

Preganglionic fiber

Autonomic ganglion

Effect organ

Preganglionic fiber

Preganglionic neurotransmitter

Most visceral organs innervated by both sympathetic and parasympathetic fibers

In general produce opposite effects in a particular organ

Dual innervation of organs by both branches of ANS allows precise control over organ’s activity

Sympathetic system dominates in emergency or stressful (“fight-or-flight”) situations
  - Promotes responses that prepare body for strenuous physical activity

Parasympathetic system dominates in quiet, relaxed (“rest-and-digest”) situations
  - Promotes body-maintenance activities such as digestion

Autonomic Nervous System

<table>
<thead>
<tr>
<th>ORGAN</th>
<th>EFFECT OF SYMPATHETIC STIMULATION</th>
<th>EFFECT OF PARASYMPATHETIC STIMULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart</td>
<td>Increased rate, increased force of contraction (of whole heart)</td>
<td>Decreased rate, decreased force of contraction (of atria only)</td>
</tr>
<tr>
<td>Blood Vessels</td>
<td>Constriction</td>
<td>Dilation of vessels supplying the penis and clitoris only</td>
</tr>
<tr>
<td>Lungs</td>
<td>Dilation of bronchioles (airways)</td>
<td>Constriction of bronchioles</td>
</tr>
<tr>
<td></td>
<td>Inhibition (?) of mucus secretion</td>
<td>Stimulation of mucus secretion</td>
</tr>
<tr>
<td>Digestive Tract</td>
<td>Decreased motility (movement)</td>
<td>Increased motility</td>
</tr>
<tr>
<td></td>
<td>Contraction of sphincters (to prevent forward movement of contents)</td>
<td>Relaxation of sphincters (to permit forward movement of contents)</td>
</tr>
<tr>
<td></td>
<td>Inhibition (?) of digestive secretions</td>
<td>Stimulation of digestive secretions</td>
</tr>
<tr>
<td>Urinary Bladder</td>
<td>Relaxation</td>
<td>Contraction (emptying)</td>
</tr>
<tr>
<td>Eye</td>
<td>Dilation of pupil</td>
<td>Constriction of pupil</td>
</tr>
<tr>
<td></td>
<td>Adjustment of eye for far vision</td>
<td>Adjustment of eye for near vision</td>
</tr>
<tr>
<td>Liver (glycogen store)</td>
<td>Glycogenolysis (glucose released)</td>
<td>None</td>
</tr>
<tr>
<td>Adipose Cells (fat stores)</td>
<td>Lipolysis (fatty acids released)</td>
<td>None</td>
</tr>
</tbody>
</table>
Autonomic Nervous System

- Exceptions to general rule of dual reciprocal innervation by the two branches of autonomic nervous system
  - Beyond the scope of this course
- What is the one activity that requires sympathetic / parasympathetic coordination?

Autonomic Nervous System

- Adrenal medulla is a modified part of sympathetic nervous system
  - Modified sympathetic ganglion that does not give rise to postganglionic fibers
  - Stimulation of preganglionic fiber prompts secretion of hormones into blood
    - About 20% of hormone release is norepinephrine
    - About 80% of hormone released is epinephrine (adrenaline)
  - Reinforces the activity of the sympathetic response
    - More long-acting and sustained

Autonomic Nervous System

- Tissues innervated by autonomic nervous system have one or more of several different receptor types for postganglionic chemical messengers
- Cholinergic receptors – bind to ACh
  - Nicotinic receptors (bind nicotine)
    - Found on postganglionic cell bodies of all autonomic ganglia
    - Opens cation channels \( \rightarrow \) Na⁺ flow is higher \( \rightarrow \) AP
  - Muscarinic receptors (bind mushroom poison)
    - Found on effector cell membranes (e.g. smooth muscle, cardiac muscle, glands)
    - Several (five) types

Autonomic Nervous System

- Andrennergic receptors – bind to norepinephrine and epinephrine
  - Alpha (\( \alpha \)) receptors (\( \alpha_1, \alpha_2 \))
    - \( \alpha_1 \) – excitatory
      - In most sympathetic target tissues
      - E.g. Constriction of skin and GI arterioles, dilation of pupils, etc.
    - \( \alpha_2 \) – inhibitory
      - Decreased motility in digestive tract
  - Beta (\( \beta \)) receptors (\( \beta_1, \beta_2 \))
    - \( \beta_1 \) – excitatory
      - Primarily in the heart (increased heart rate and force of contraction)
    - \( \beta_2 \) – inhibitory
      - Dilation of skeletal muscle arterioles and bronchioles
    - \( \beta_3 \) – in adipose tissue
      - Lipolysis
### Autonomic Nervous System

#### Regions of CNS Involved in Control of Autonomic Activities
- Prefrontal association complex
  - Influences through its involvement with emotional expression characteristic of individual's personality (e.g. blushing)
- Hypothalamus
  - Plays important role in integrating autonomic, somatic, and endocrine responses that automatically accompany various emotional and behavioral states (e.g. anger or fear)
- Medulla (within brain stem)
  - Region directly responsible for autonomic output (cardiovascular, respiratory, digestive tract)
- Spinal Cord
  - Some autonomic reflexes, such as urination, defecation, and erection, are integrated at spinal cord level but control by higher levels of consciousness

#### Agonists
- Bind to same receptor as neurotransmitter
- Elicit an effect that mimics that of neurotransmitter
- E.g.
  - Salbutamol
    - Activates $\beta_2$ receptors
    - Treatment of asthma
  - Phenytoinephrine
    - Stimulates both $\alpha_1$ & $\alpha_2$ receptors
    - Vasoconstrictor
    - Used as nasal decongestant
  - Pilocarpine
    - Stimulates muscarinic receptors
    - Useful for both narrow and wide angle glaucoma
    - Side effects include sweating.

#### Antagonists
- Bind with receptor
- Block neurotransmitter's response
- E.g.
  - Succinylcholine
    - Binds to the nicotinic receptor
    - Causes prolonged depolarization marked first by muscle fasciculations followed by flaccid paralysis
  - Atenolol
    - Selective $\beta_1$ blocker
    - Blockage produces bradycardia and decrease in blood pressure

### Table: Actions of Sympathetic and Parasympathetic Nervous System

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<tr>
<th>Action</th>
<th>Sympathetic Receptor</th>
<th>Parasympathetic Receptor</th>
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<tbody>
<tr>
<td>General Homeostasis</td>
<td>stress response</td>
<td>-constrains homeostasis</td>
</tr>
<tr>
<td></td>
<td>-expends energy</td>
<td>-constrains energy</td>
</tr>
<tr>
<td>Heart</td>
<td>$\uparrow$ rate</td>
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<tr>
<td></td>
<td>$\uparrow$ contractility</td>
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<tr>
<td>Smooth muscle</td>
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<td>M2</td>
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<tr>
<td>Blood vessels</td>
<td>$\downarrow$ dilation</td>
<td>$\downarrow$ constriction</td>
</tr>
<tr>
<td>-skeletal muscle</td>
<td></td>
<td>a</td>
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<td>-skin</td>
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<tr>
<td>-spleen</td>
<td>$\downarrow$ constriction</td>
<td>$\downarrow$ dilation</td>
</tr>
<tr>
<td>-bronchi</td>
<td>$\downarrow$ dilation</td>
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<tr>
<td>-G.I. tract</td>
<td>$\downarrow$ motility</td>
<td>$\downarrow$ motility</td>
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<tr>
<td>-sphincter</td>
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</tr>
<tr>
<td>-genitourinary tract</td>
<td>$\uparrow$ relaxation</td>
<td>$\downarrow$ constriction</td>
</tr>
<tr>
<td>-bladder wall</td>
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</tr>
<tr>
<td>-spinal cord</td>
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<td>M3</td>
</tr>
<tr>
<td>Glands</td>
<td>$\uparrow$ viscous secretion (small amounts)</td>
<td>a1</td>
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<tr>
<td>Salivary</td>
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<td>M3</td>
</tr>
<tr>
<td>-Stress</td>
<td>$\uparrow$ secretion</td>
<td>a</td>
</tr>
<tr>
<td>-Sweat</td>
<td>$\uparrow$ secretion</td>
<td>M3</td>
</tr>
<tr>
<td>Metabolism</td>
<td>$\uparrow$ glycogenolysis</td>
<td>$\downarrow$ secretion</td>
</tr>
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<td>Liver</td>
<td>a1, i2</td>
<td>a1, i2</td>
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<td>Adipose</td>
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<td>$\downarrow$ lipolysis</td>
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<td>Kidney</td>
<td>$\uparrow$ renin release</td>
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<td>Eye</td>
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<td>a1</td>
</tr>
<tr>
<td>Iris</td>
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</tr>
<tr>
<td>Cilary muscle</td>
<td>$\downarrow$ constriction</td>
<td>$\downarrow$ constriction</td>
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</tbody>
</table>
Neuromuscular Physiology
(240-249, 253-267, 270-286, 288-297)

Excluded: muscle length, tension, contraction and velocity, phosphorylation of myosin