The Cyprus International Institute for the Environment and Public Health
In collaboration with the Harvard School of Public Health

Lecture 4

The Peripheral Nervous System
(181-240)

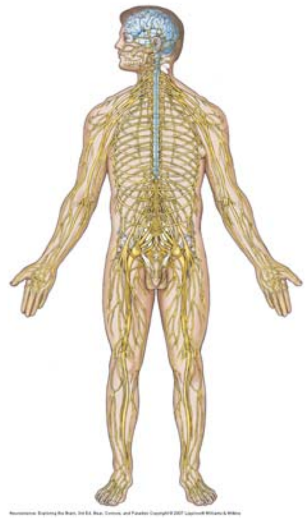
Excluded: adaptation of pacinian corpuscle (185), labeled lines (186), acuity (186-187), phototransduction (200-203), on- off- center ganglion cells (205)

Constantinos Pitris, MD, PhD

Assistant Professor, University of Cyprus
cpitris@ucy.ac.cy
http://www.eng.ucy.ac.cy/cpitris/courses/CIIPhys/

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, O_2, 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



Introduction

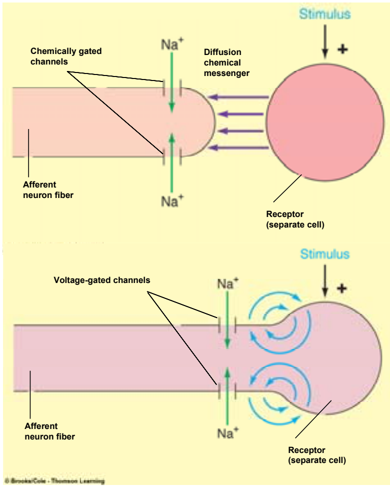
- **Sensation ≠ Perception**
- **Perception**
  - Our understanding (conscious interpretation) of the physical world
  - An interpretation of the senses
  - Different from what is out there because
    - Our receptors detect limited number of existing energy forms
    - The information does not reach 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**
  - 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 O_2 and CO_2 concentrations in blood and chemical content of digestive tract
  - Nociceptors
    - Pain receptors that are sensitive to tissue damage or distortion of tissue

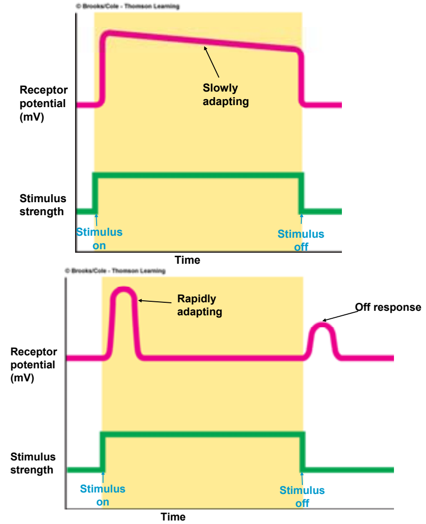
Receptor Physiology

- **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.



Receptor Physiology

- **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?)

Pain

- **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**

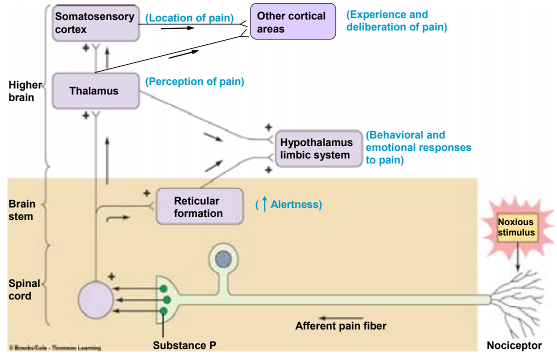
Pain

- **Characteristics of pain**

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

Pain

- **Two best known pain neurotransmitters**
  - Substance P
  - Glutamate
- **Substance P**
  - Activates ascending pathways that transmit nociceptive signals to higher levels for further processing

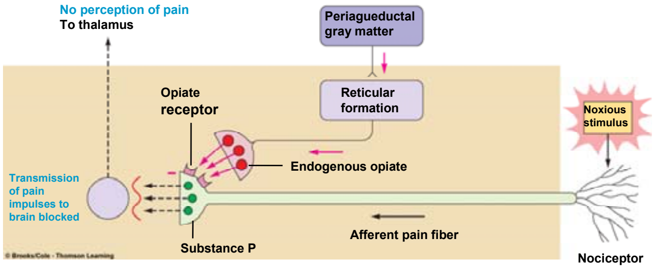


Pain

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

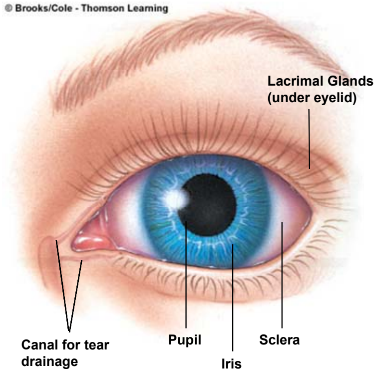
Pain

- **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



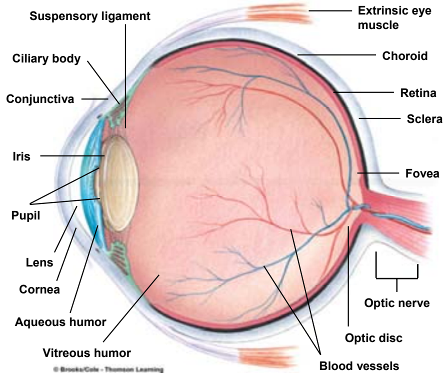
Vision

- **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



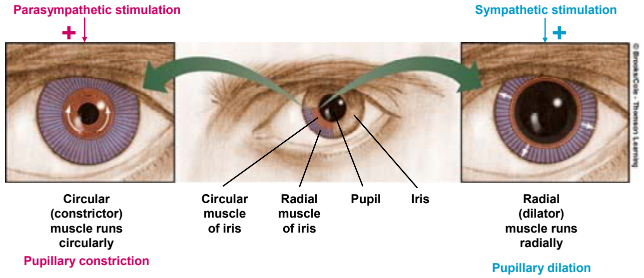
Vision

- **Eye**
  - Spherical, fluid-filled structure enclosed by three tissue layers
  - Sclera/cornea
    - Sclera – tough outer layer of connective tissue; forms visible white part of the eye
    - Cornea – anterior, transparent outer layer through which light rays pass into interior of eye
  - Choroid/ciliary body/iris
    - Choroid - middle layer underneath sclera which contains blood vessels that nourish retina
    - Choroid layer is specialized anteriorly to form ciliary body and iris
  - Retina
    - Innermost coat under choroid
    - Consists of outer pigmented layer and inner nervous-tissue layer
      - Rods and cones



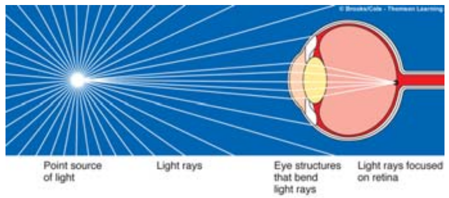
Vision

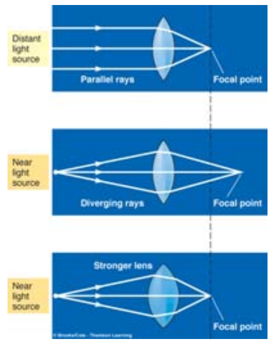
- **Eye**
  - Pupil
    - Round opening through which light enters the eye
  - Iris
    - Controls amount of light entering eye
    - Contains two sets of smooth muscle networks
      - Circular (or constrictor) muscle
      - Radial (or dilator) muscle
    - Pigment in iris is responsible for eye color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



Vision

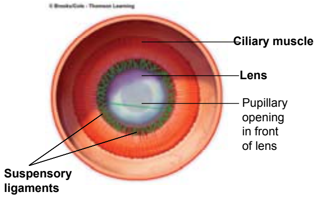
- **Convex structures of eye produce convergence of diverging light rays that reach eye**
- **Two structures most important in eye's refractive ability are**
  - Cornea
    - Contributes most extensively to eye's total refractive ability
    - Refractive ability remains constant because curvature never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

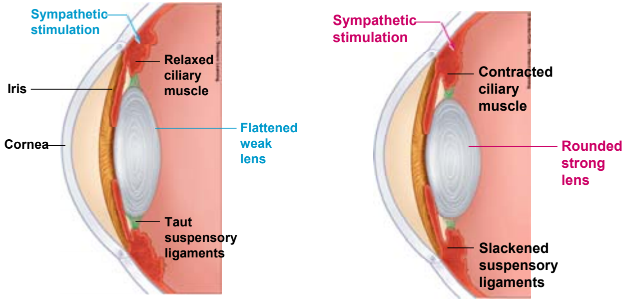




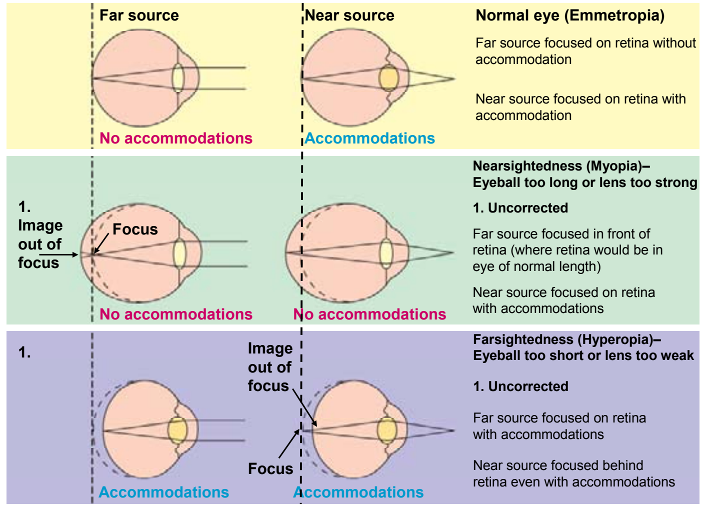
Vision

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



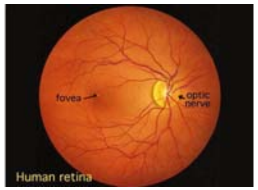


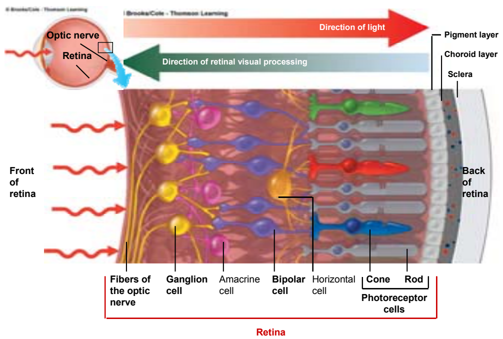
Vision



Vision

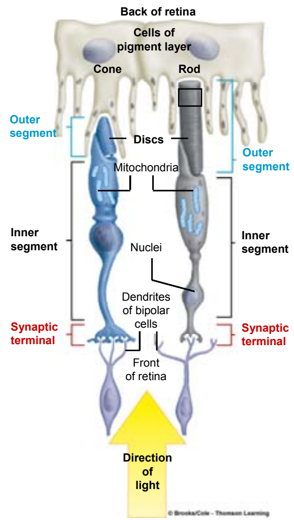
- **Retina**
  - Several layers of cells
  - Receptor containing portion is actually an extension of the CNS
- **Fovea**
  - Pinhead-sized depression in exact center of retina
  - Point of most distinct vision
  - Has only cones





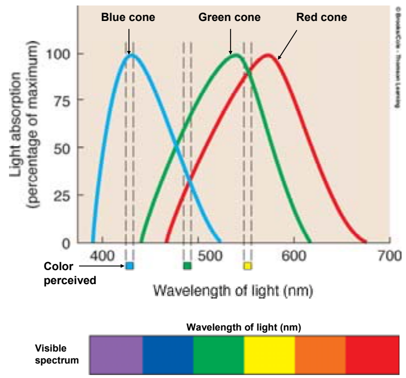
Vision

- **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 transmitter 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



Color perceived	Percent of maximum stimulation		
	Red cones	Green cones	Blue cones
■ (blue)	0	0	100
■ (green)	31	67	36
■ (yellow)	83	83	0

Vision

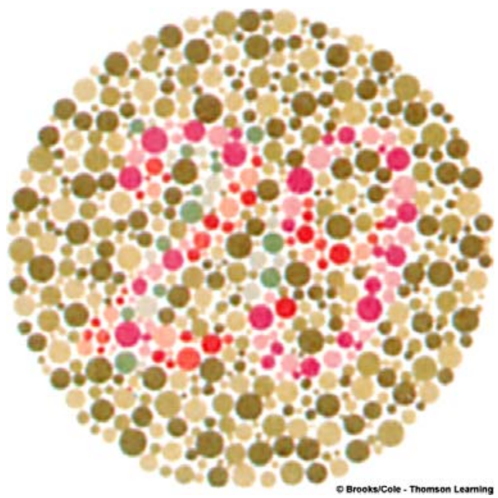
- **Properties of Rod and Cone Vision**

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

Vision

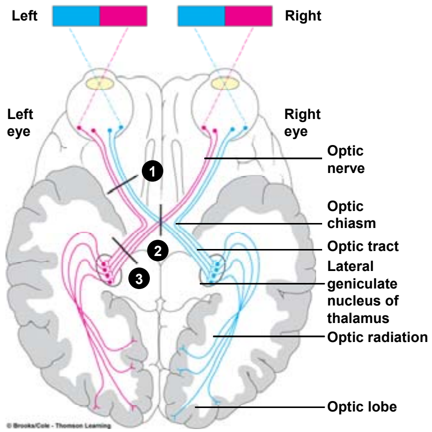
- **The sensitivity of the eyes varies through dark and light adaptation**
- **Dark adaptation**
  - Can gradually distinguish objects as you enter a dark area.
  - Due to the regeneration of rod photopigments that had been broken down by previous light exposure.
- **Light adaptation**
  - Can gradually 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



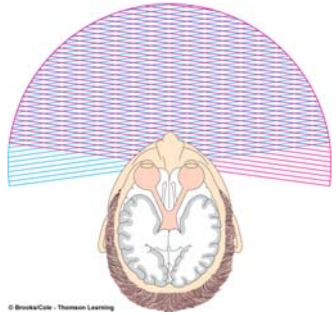
Vision

- **Visual field**
  - Area which can be seen without moving the head) → 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**



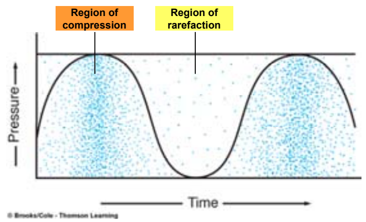
Vision

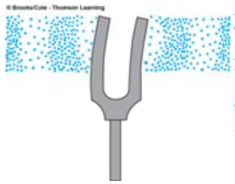
- **>30% of cortex participates in visual information processing**
  - "What" and "where" pathways
- **Depth Perception**
  - Visual field of two eyes slightly different
  - Depth perception with one eye
    - Other cues (such as size, location, experience)

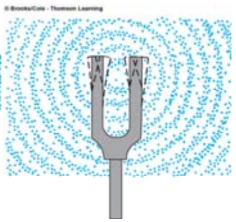


Hearing

- **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

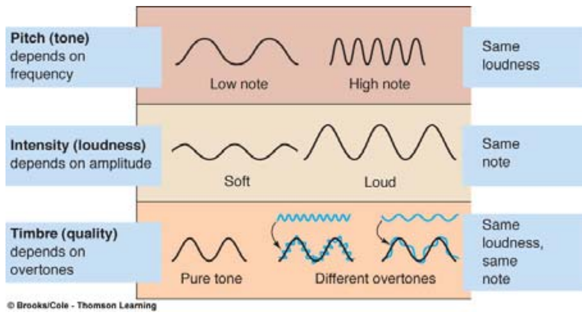






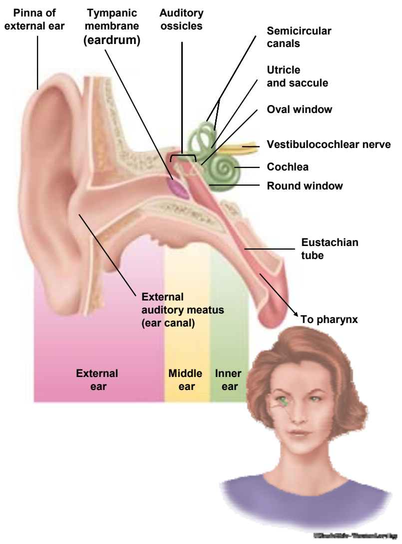
Hearing

- **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



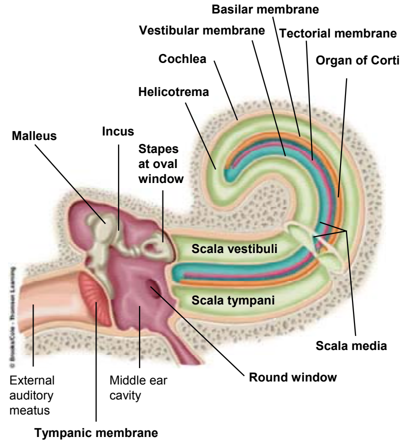
Hearing

- **Ear**
  - Consists of three parts
  - External ear
    - Consists of pinna, external auditory meatus, and tympanum
    - 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)



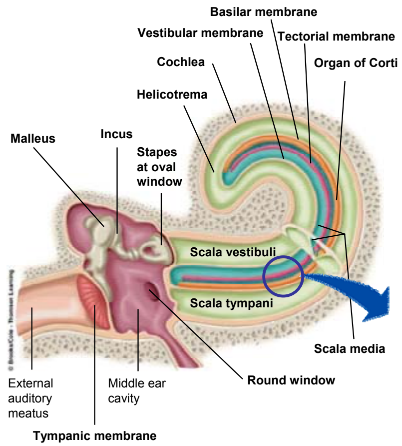
Hearing

- **Sound Wave Transmission**
  - Tympanic membrane
    - Vibrates when struck by sound waves
  - 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 stifness of the tympanic membrane
      - Protection mechanism
      - Slow action (40 msec) → protects only from prolonged sounds



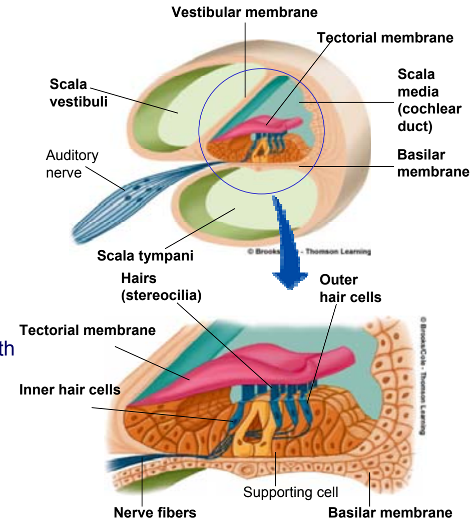
Hearing

- **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



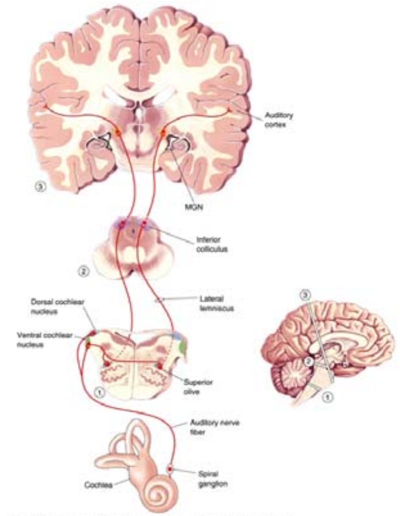
Hearing

- **Sound Transduction**
  - Organ of Corti
    - Hair cells with ~ 100 sterocilia 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



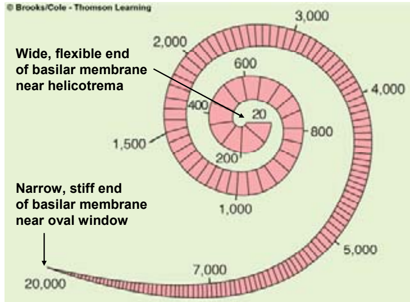
Hearing

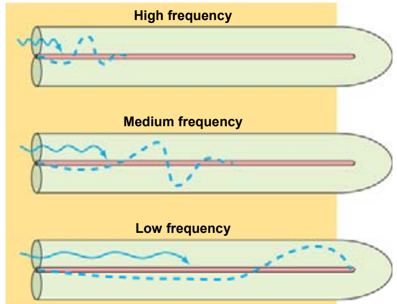
- **Auditory pathway**
  - Hair cells
  - Auditory nerve
  - Brain stem
    - Signals cross over to opposite site (unlike visual signals)
  - Thalamus
    - Sorts and relays signals to cortical regions
  - Cortex
- **Cortical Processing**
  - Primary auditory cortex in the temporal lobe
    - Tonotopically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



Hearing

- **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





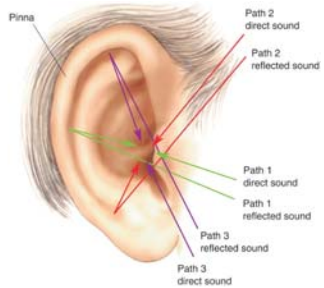
Hearing

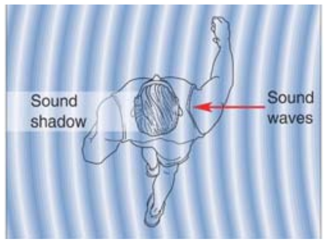
- **Loudness discrimination**
  - Exquisitely sensitive organ (motion less than a molecule of Hydrogen) → easily damaged
  - Wide range (every 10 dB means 10-fold increase in intensity)
  - Higher intensity causes larger basilar membrane movement
  - Stronger graded potential of hair cells
  - Faster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

Sound	Loudness in decibels (dB)	Comparison to faintest audible sound (hearing threshold)
Rustle of leaves	10 dB	10 x louder
Ticking of watch	20 dB	100 x
Hush of Library	30 dB	1000 x
Normal conversation	60 dB	1 million x
Food Blender	90 dB	1 billion x
Loud rock concert	120 dB	1 trillion x
Takeoff of jet plane	150 dB	1 quadrillion x

Hearing

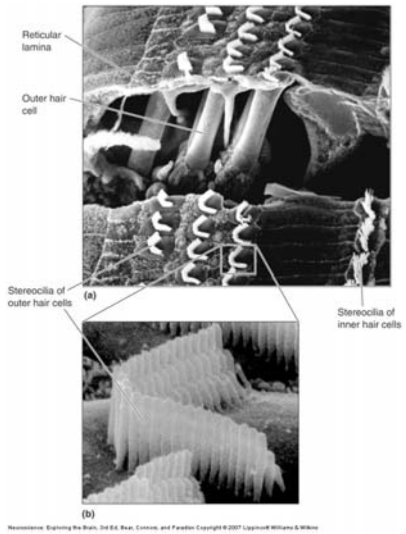
- **Localization**
  - Up-Down localization (elevation)
    - External ear (Pinna) shape changes sound timbre and intensity slightly according to elevation
  - Left-right localization (azimuth)
    - Sound arriving to proximal ear arrives
      - Slightly earlier (~ 0.5 msec)
      - Slightly stronger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





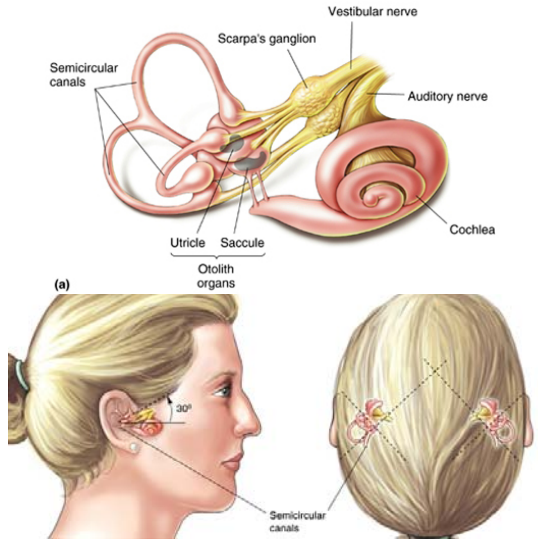
Hearing

- **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
  - Senosineural
    - 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



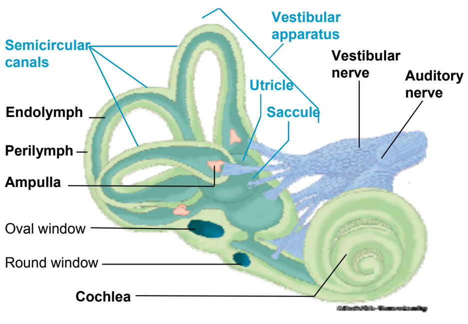
Equilibrium

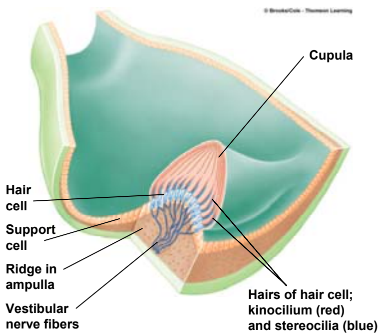
- **Detection of position and motion**
  - Posture and coordination
- **Vestibular apparatus**
  - Fluid filled tunnels In the inner ear
  - Semicircular canals
    - Three circular tunnels arranged on perpendicular planes
  - Otolith organs (Utricle and saccule)
    - Two bulges arranged in perpendicular directions



Equilibrium

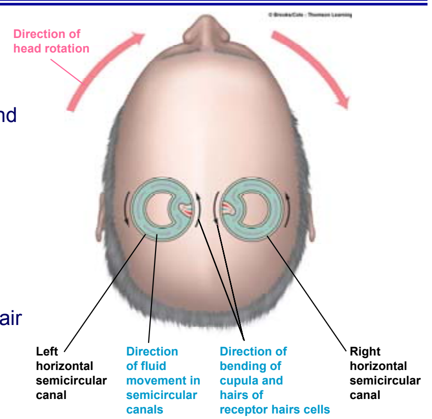
- **Semicircular canals**
  - Three circular tunnels arranged on perpendicular planes
  - Detect rotational acceleration or deceleration in any direction
  - Hair cells
    - On a ridge in the ampulla
    - Have on kinocilium and several sterocilia (mikrovilli)
    - Embedded in gelatinous material, the cupula

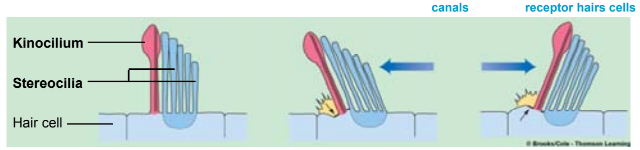




Equilibrium

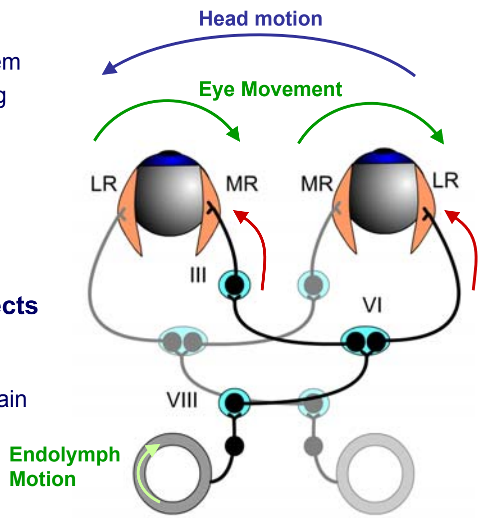
- **Semicircular canals**
  - Signal transduction
    - Head is rotated
    - Two of the canals are rotated around their axis in opposite directions
    - Endolymph moves opposite to the direction of motion (inertia)
    - Cupula leans in that direction
    - Cilia bent and K^+ channels open or close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





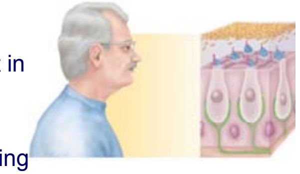
Equilibrium

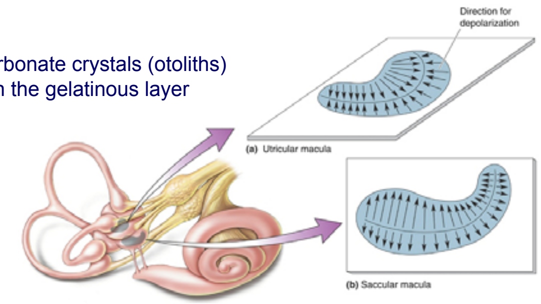
- **Vestibular pathway**
  - Vestibular nuclei in brain stem
  - Motor neurons for controlling eye movement, perceiving motion and orientation
    - E.g. vestibuloocular reflex
  - Cerebellum for use in maintaining balance and posture,
- **The vestibular system detects acceleration**
  - Speed is calculated by integrating circuitry in the brain stem



Equilibrium

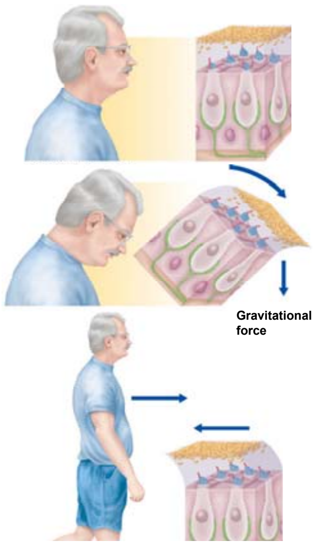
- **Otolith Organs**
  - Detect changes in rate of linear movement in any direction
  - Arranged in perpendicular directions
  - Provide information important for determining head position in relation to gravity
  - Hair cells
    - As described before
    - In addition, calcium carbonate crystals (otoliths) 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 haircells are depolarized or hyperpolarized
    - Neurotransmitter realize from the hair cells is modified
    - Firing of the vestibular nerve is modified

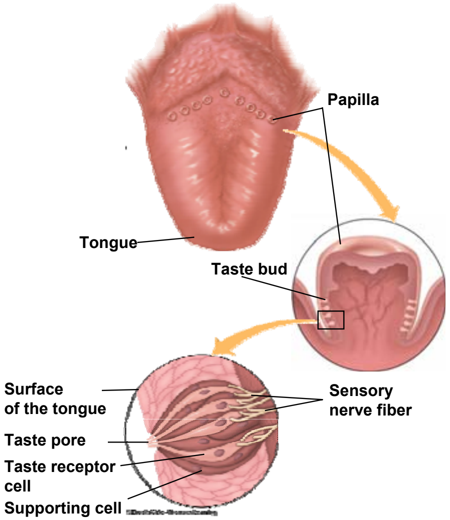


Taste and Smell

- **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

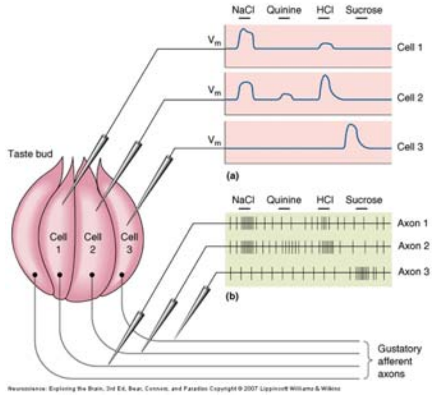
Taste (Gustation)

- **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



Taste (Gustation)

- **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



Taste (Gustation)

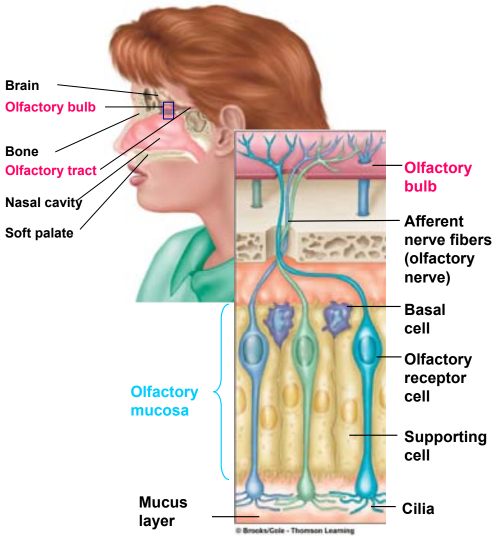
- **Five primary tastes**
  - Salty
    - Stimulated by chemical salts, especially NaCl
  - Sour
    - Caused by acids which contain a free hydrogen ion, H^+
  - Sweet
    - Evoked by configuration of glucose
  - Bitter
    - Brought about by more chemically diverse group of tastants
    - Examples –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

Taste (Gustation)

- **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

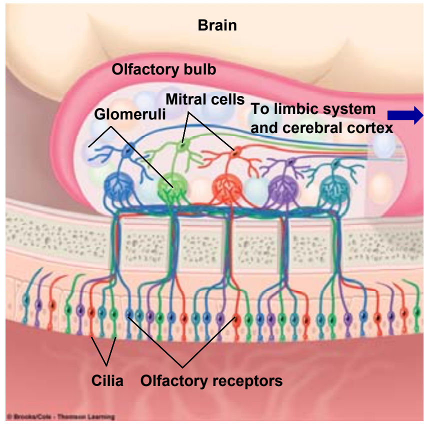
Smell (Olfaction)

- **Olfactory receptors in nose are specialized endings of renewable afferent neurons**
- **Olfactory mucosa**
  - 3cm^2 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
    - Secrete mucus
  - Basal cells
    - Precursors of new olfactory receptor cells (replaced about every two months)



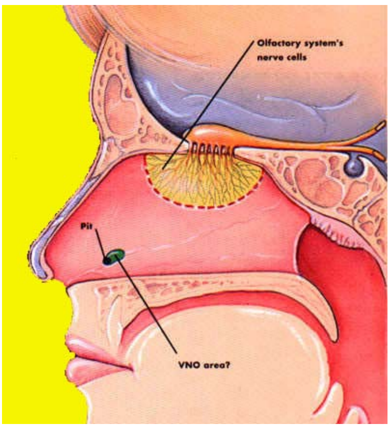
Smell (Olfaction)

- **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)**



Smell (Olfaction)

- **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"

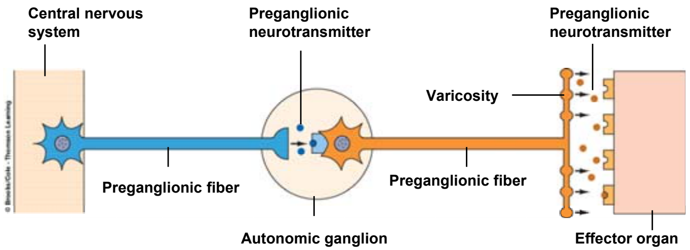


PNS – Efferent Division

- **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

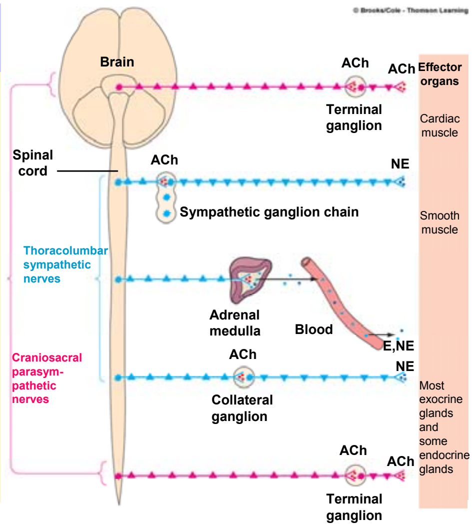
Autonomic Nervous System

- **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



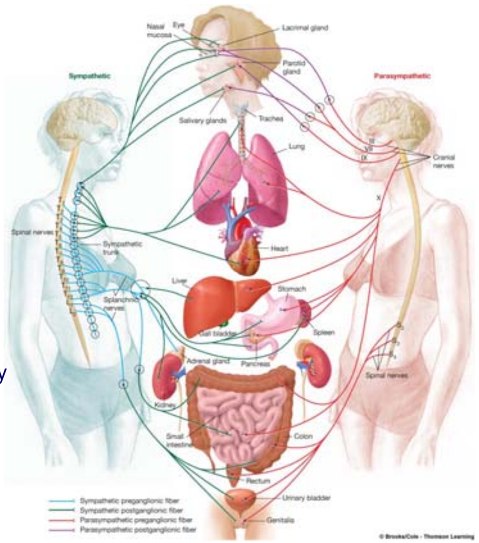
Autonomic Nervous System

Sympathetic Nervous System	Parasympathetic Nervous System
Fibers originate in thoracic and lumbar regions of spinal cord	Fibers originate from cranial and sacral areas of CNS
Most preganglionic fibers are short	Preganglionic fibers are longer
Long postganglionic fibers	Very short postganglionic fibers
Preganglionic fibers release acetylcholine (Ach)	Preganglionic fibers release acetylcholine (Ach)
Most postganglionic fibers release noradrenaline (norepinephrine)	Postganglionic fibers release acetylcholine



Autonomic Nervous System

- **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

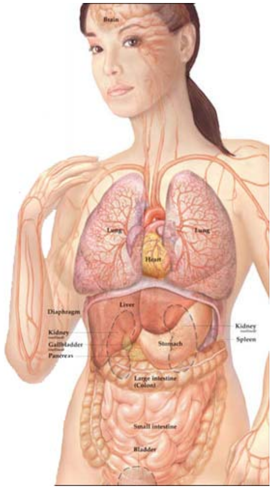


Autonomic Nervous System

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

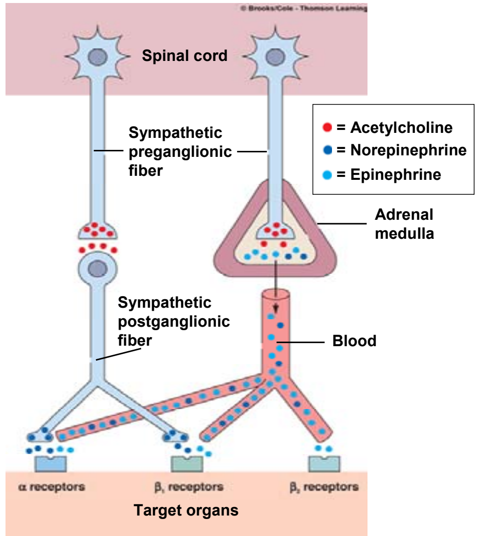
Autonomic Nervous System

- **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



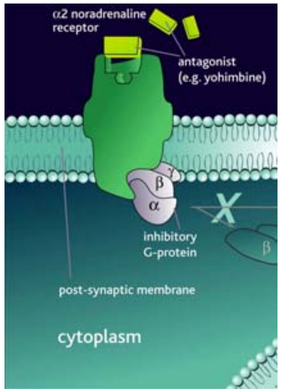
Autonomic Nervous System

- **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 → Na^+ flow is higher → AP
  - Muscarinic receptors (bind mushroom poison)
    - Found on effector cell membranes (e.g. smooth muscle, cardiac muscle, glands)
    - Several (five) types

Amanita muscaria

Autonomic Nervous System

- **Andrenergic receptors – bind to norepinephrine and epinephrine**
  - Alpha (α) receptors (α_1, α_2)
    - α_1 → excitatory
      - In most sympathetic target tissues
      - E.g. Constriction of skin and GI arterioles, dilation of pupils, etc.
    - α_2 → inhibitory
      - Decreased motility in digestive tract
  - Beta (β) receptors (β_1, β_2)
    - β_1 → excitatory
      - Primarily in the heart (increased heart rate and force of contraction)
    - β_2 → inhibitory
      - Dilation of skeletal muscle arterioles and bronchioles
    - β_3 → ıin adipose tissue
      - Lipolysis



	Sympathetic		Paraympathetic	
	Action	**Receptor**	**Action**	**Receptor**
General Homeostasis	-stress response (fight or flight) -expends energy		-maintains homeostasis -conserves energy	
Heart				
Cardiac muscle	-↑ rate -↑ contractility	β1 β1	-↓ rate (atria only) -↓ contractility (atria only)	M2 M2
Smooth muscle				
Blood vessels -skeletal m. -skin -penis and clitoris	 -dilation -constriction -constriction	 β2 α α	 -dilation	 M
Spleen	-contraction	α		
Bronchi	-dilation	β2	-constriction	M3
G.I. tract -walls -sphincters	 -↓ motility -contraction	 α2 & β2 α1	 -↑ motility -relaxes	 M3 M3
Genitourinary tract -bladder wall -sphincter -penis	 -relaxation -contraction -ejaculation	 β2 α2 α	 -contraction -relaxation -erection	 M3 M3 M
Glands				
Salivary	-↑viscous secretion (small amounts)	α1	-↑ watery secretion	
Sweat -Thermoregulation -Stress	 -↑ secretion -↑ secretion	 M α		
Metabolism				
Liver **Adipose** **Kidney**	-glycogenolysis -lipolysis -renin release	α, β2 β3 β1		
Eye				
Iris **Ciliary muscle**	-dilation	α1	-constriction -contraction	M3 M3

Autonomic Nervous System

- **Agonists**
  - Bind to same receptor as neurotransmitter
  - Elicit an effect that mimics that of neurotransmitter
  - E.g.
    - Salbutamol
      - Activates β_2 receptors
      - Treatment of asthma
    - Phenylephrine
      - Stimulates both α_1 & α_2 receptors
      - Vasoconstrictor
      - Used as nasal decongestant
    - Pilocarpine
      - Stimulates muscarinic receptors
      - Useful for both narrow and wide angle glaucoma
      - Side effects include sweating.

Autonomic Nervous System

- **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 β_1 blocker
      - Blockage produces bradycardia and decrease in blood pressure

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

Next Lecture …

Neuromuscular Physiology
(240-249, 253-267,270-286,288-297)

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