Human Anatomy & Physiology II

ANP1106

Exam Notes

Physiology of Nervous System

March 9-10

Introduction

- Nerve impulses
- compare graded potentials and action potential
- Review the mechanisms of synaptic transmission
- describe the major classes and function of neurotransmitters

Neurons

- cell that transmits nerve impulses
- excitable (responsive to stimuli by showing depolarization)
- Nerve impulses (action potentials) are generated in the cell body (axon hillcock) and carried down the axon (region where impulse-generated)

Biological Electrical Potentials

- some molecules in body have electrical charge (ions; Na+, K+, Ca++, Cl-)
- ions are unevenly distributed in cells

Voltage

- potential energy created by a charge separation (across the cell membrane) due to uneven distribution of ions
- biological potentials have voltages from -90 to -70 mV
- under special circumstances can jump briefly to +55 mV (i.e. reversible electrical potentials)

Current

- flow of charge (from point A to B) resulting from potential
- depends on resistance (the impediment to current flow)

Ohms law

current (I) = Voltage (V)/ resistance (R)

- insulators have very large resistance
- conductors have low resistance
- decrease in resistance = increase in conductance that permits current flow

Electrical Force

- separation of positive and negative charges can produce an electrical force
- force increases with quantity of charge
- force increases with decreasing distance of charge separation

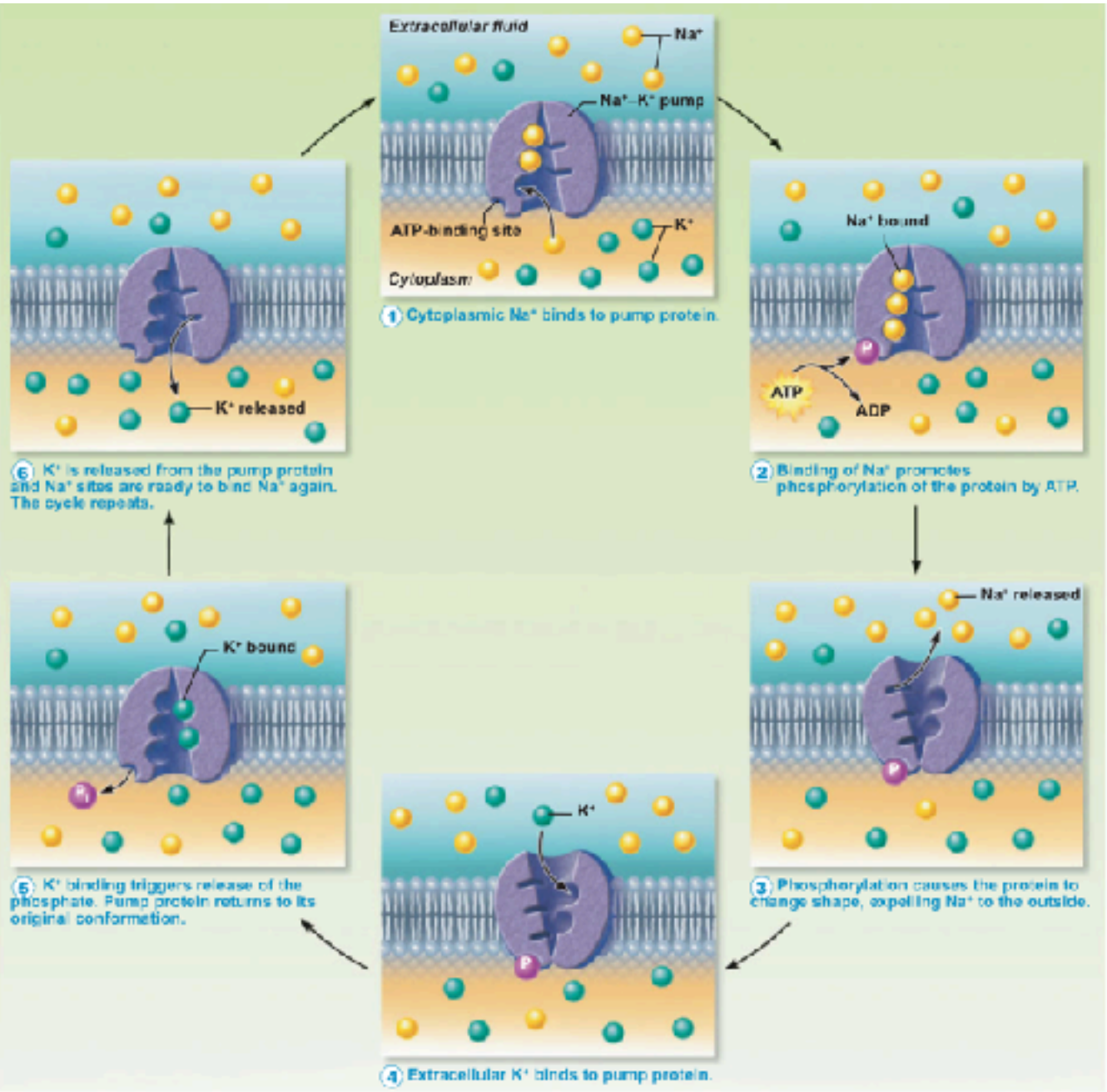
Polarized membrane

- negative on inside, positive on outside
- provides the electrical gradient that drives ion movement across the membranes of excitable cells

- sodium-potassium ATPase pump creates the gradient that produces this potential by primary active transport

Primary Active Transport: The Na^+-K^+ Pump

- Na+-K+ pumps maintain the concentration gradients of Na+ and K+ across the membrane
- Na+-K+ Pump exchanges ions 100 times per second
- concentrations of Na+ and K+ on each side of the membrane are different
- Na+ concentration is higher on the outside (140mM) and K+ is lower inside the cell (140nM)

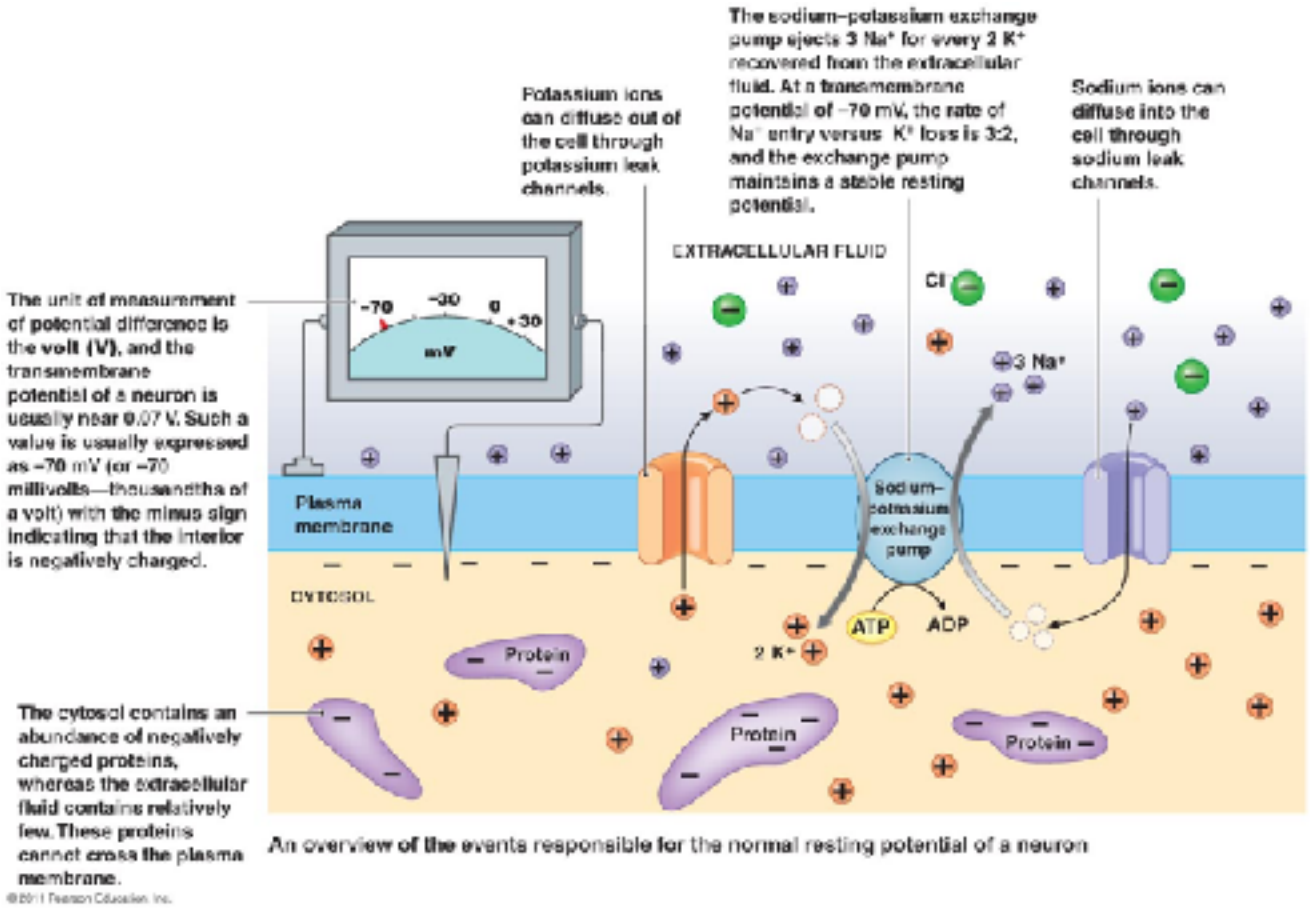


Plasma membrane

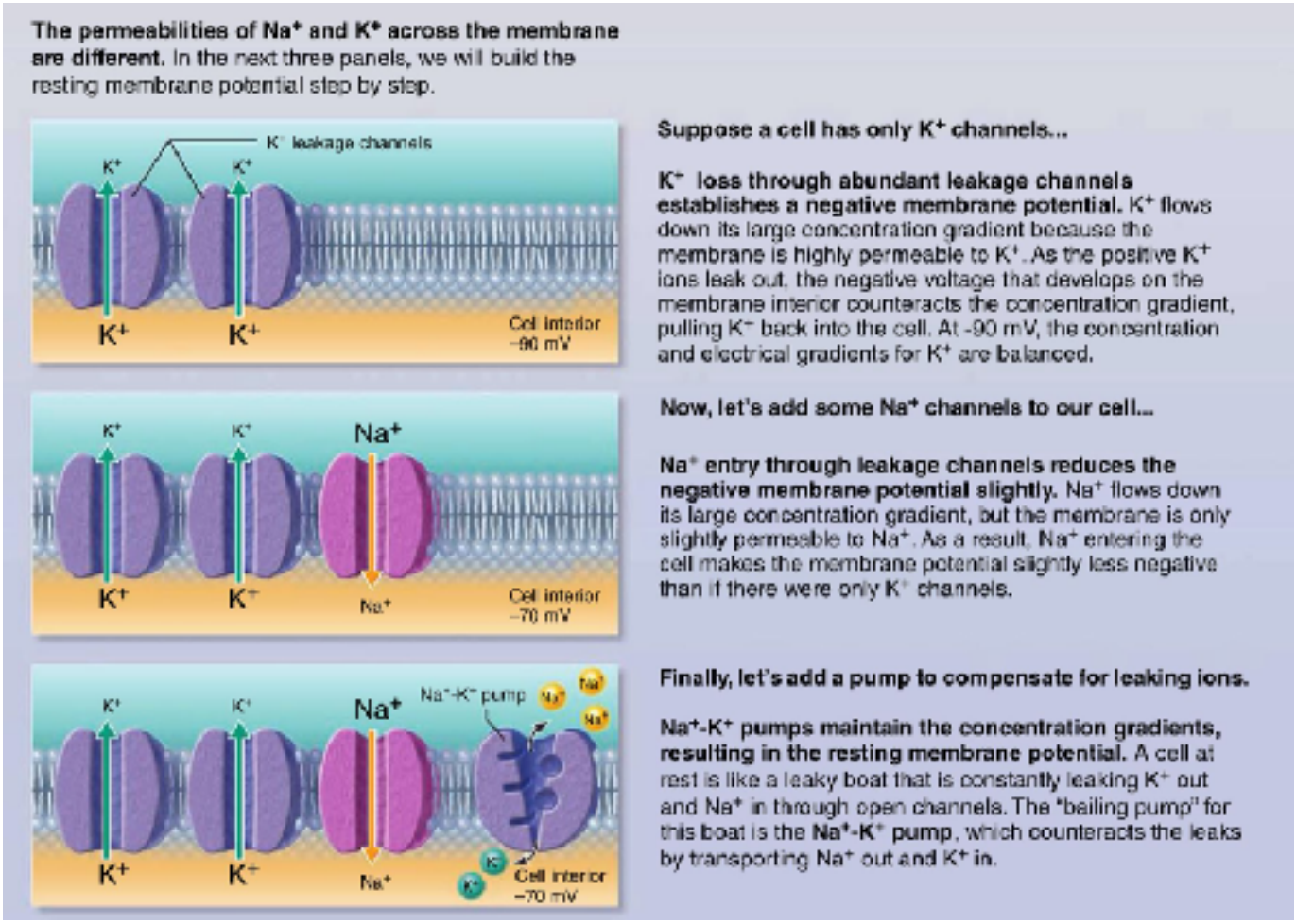
- good insulator (very high resistance)
- ions cross membrane through specialized transmembrane proteins called channels
- current has to flow for there to be a membrane voltage so not all ions will contribute to the voltage
- Channels are specific for Na, Cl, K, Ca
- most cells have only K channels that are open and therefore only K+ currents can exist (these are small in number and create a leakage current)

Membrane Potential

- only K+ potential contributes to the membrane potential
- membrane potential is typically -70 mV (resting membrane potential) based on the K leakage current
- In a neuron at rest, only K channels are open, so only K+ currents and therefore only K+ potential contributes to the membrane potential
- Differences in charge plus concentration results in an electrochemical gradient but it will only influence the membrane if there as a conductance (low R) for that ion
- excitable tissues can show huge changes in membrane potential
- In neurons and a few other types of excitable cells the membrane potential can swing from negative values to positive values based on the opening of protein ion channels such as Na channels
- Stimuli can cause membrane potential to become more negative hyper polarizing or more positive depolarizing



An overview of the events responsible for the normal resting potential of a neuron



Resting Potential - Only K+ channel open
Depolarized - voltage-gated Na+ channel open
Hyper-polarized - chemically gated K+ channel open

Graded Potentials (short distances)

- short lived localized changes in membrane potential
- current flow decreases with distance (decremental)
- they are graded because current flow varies with stimulus strength

Action Potentials (long distances)

- voltage gated ion channels, basis of the ability of action potential being carried down axons
- voltage gated ion channels only found in the membrane of excitable tissues action potentials are also known as nerve impulses
- strength does not decrease with distance because it is constantly being regenerated
- action potential moves in one direction down the axon due to the absolute refractory period
- an increase in stimulus intensity can overcome the relative refractory period

Myelinated Axons

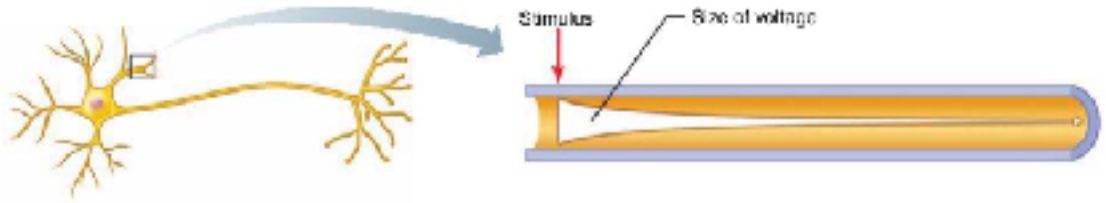
- segments of the axon are wrapped in myelin (thick sheets of lipid membrane)
- Myelin is an electrical insulator that increases conduction of nerve impulses

- Action potentials can occur only at the un-insulated nodes of Ranvier (myelin sheath gaps)
- Current spreads between nodes of Ranvier by graded potential
- At the next node of Ranvier a new action potential is generated etc.
- Myelin in the CNS is formed from living oligodendrocytes
- Myelin in the PNS is formed from living Schwann cells

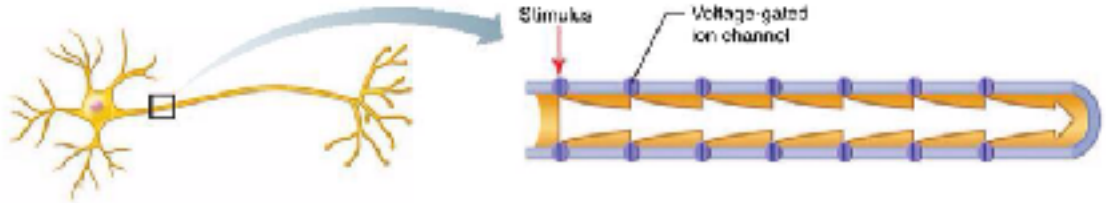
- Blockade of voltage gated sodium channels prevents peripheral nerve conduction (death by paralysis)

Tetrodotoxin
- neurotoxin also found in pufferfish and some poison dart frogs
- 200 times more toxic than cyanide

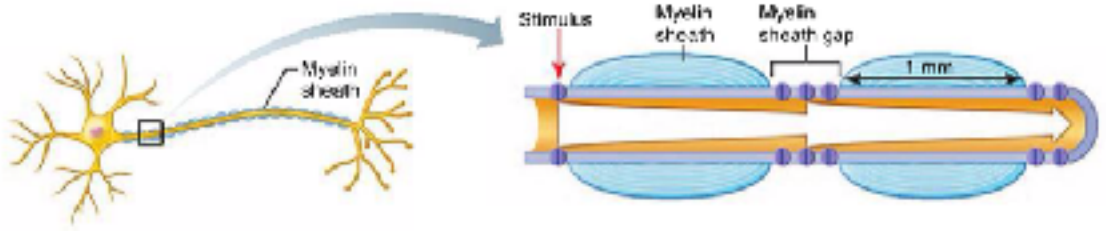
- The intensity of the stimulus does not increase the height of the action potential, it does in increase the frequency of action potentials



(a) In bare plasma membranes, voltage decays. Without voltage gated channels, as on a dendrite, voltage decays because current leaks across the membrane.



(b) In nonmyelinated axons, conduction is slow (continuous conduction). Voltage-gated Na^+ and K^+ channels regenerate the action potential at each point along the axon, so voltage does not decay. Conduction is slow because it takes time for ions and for gates of channel proteins to move, and this must occur before voltage can be regenerated.



(c) In myelinated axons, conduction is fast (saltatory conduction). Myelin keeps current in axons (voltage doesn't decay much). APs are generated only in the myelin sheath gaps and appear to jump rapidly from gap to gap.

Dendrites

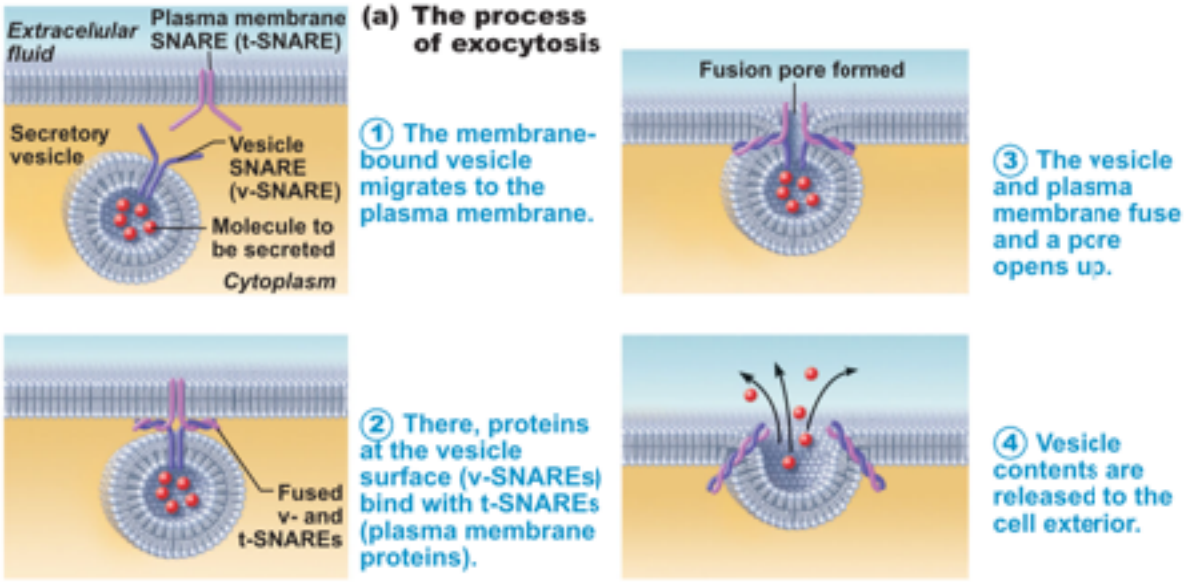
- short extensions of motor neurons
- convey incoming messages toward the cell body
- ligand gated channels are activated by neurotransmitters

Axons

- conducting region of the neutron (generates and transmits nerve impulses)
- voltage gated channels are activated by depolarization

Synaptic terminals - voltage gated calcium channels open to allow neurotransmitter release

Exocytosis



Botulinum Toxin

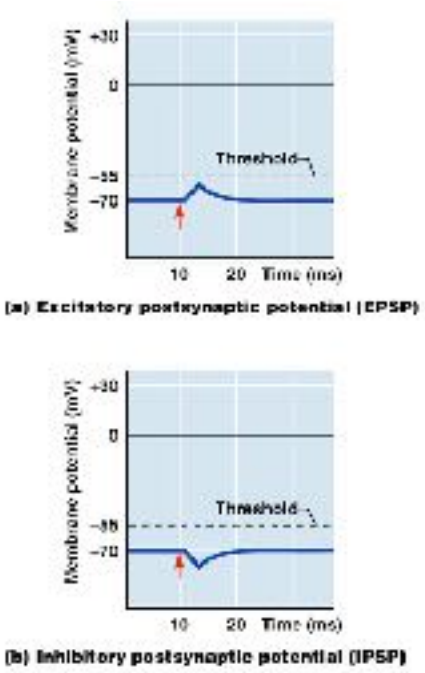
- among the most deadly naturally occurring neurotoxins
- produced by clostridium botulinum
- causes fatal disease, Botulism
- Minute doses of the toxin can be fatal "a single gram of crystalline toxin, evenly dispersed and inhaled, would kill more than 1 million people'
- Despite its impressive toxicity the botulinum toxin marketed under the trade name "Botox", has a variety of cosmetic and medical uses
- botox degrades a SNARE protein required for vesicle fusion that releases neurotransmitters from the axon endings

Gating of Ion Channels

- ion channels can be opened or closed by cellular events
- membrane voltage can open ion channels
- chemical agents can open or close ion channels

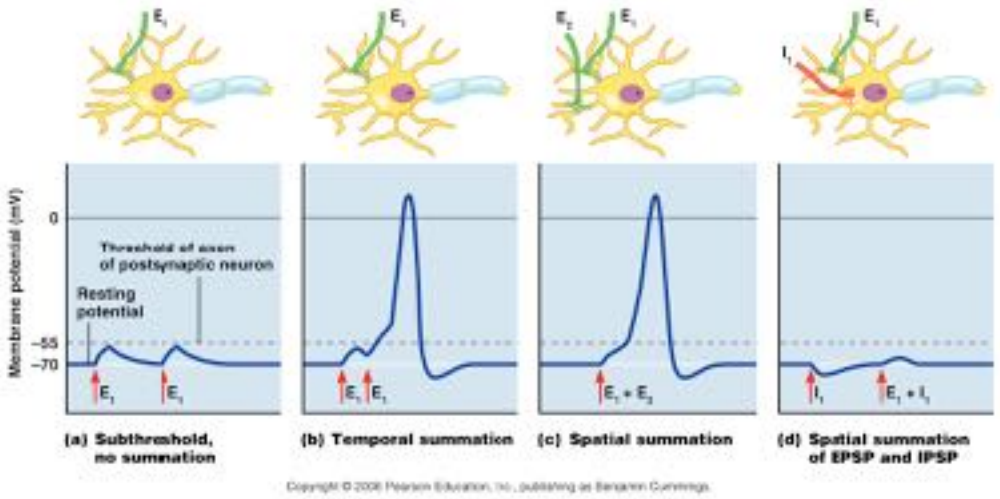
- this is the basis of neurotransmitter action through
    - ionotropic channels (both depolarizing and hyper polarizing actions)
    - metabotropic actions

- Neurotransmitters can hyper polarize (inhibitory action) or depolarize (excitatory action) depending on the ion channels that they open
- Metabotropic receptors are G protein coupled receptors
- 30% of the modern drugs target GPCRs
- The human genome encodes roughly 800 G protein-coupled receptors
- ACh at nicotinic receptors open channels permeable to both sodium and potassium, giving rise to an average of their two reversal potentials, is excitatory
- At G protein muscarinic receptor may be either excitatory or inhibitory depending on the tissue



(a) Excitatory postsynaptic potential (EPSP)

(b) Inhibitory postsynaptic potential (IPSP)



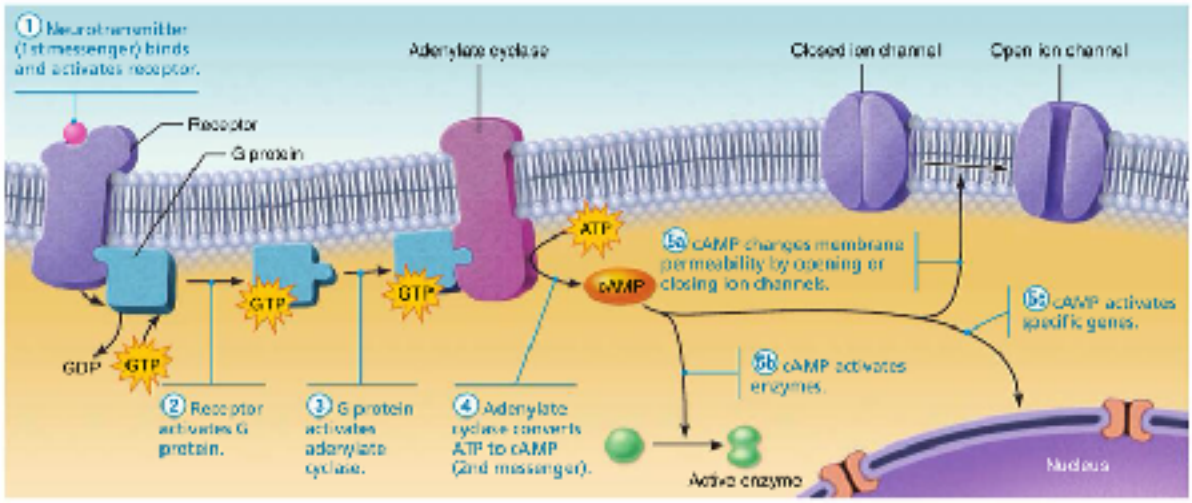


Figure 11.21 **Indirect neurotransmitter receptor mechanism: G protein–linked receptors.** These receptors cause the formation of intracellular second messengers—cyclic AMP (cAMP) in this example—that, indirectly bring about the cell's response.

TABLE 11.2 Comparison of Action Potentials with Postsynaptic Potentials

		POSTSYNAPTIC POTENTIAL (A TYPE OF GRADED POTENTIAL)	
CHARACTERISTIC	ACTION POTENTIAL (AP)	EXCITATORY (EPSP)	INHIBITORY (IPSP)
Function	Long-distance signaling; constitutes the nerve impulse	Short-distance signaling; depolarization that spreads to axon hillock; moves membrane potential toward threshold for generation of AP	Short-distance signaling; hyperpolarization that spreads to axon hillock; moves potential away from threshold for generation of AP
Stimulus for opening of ion gates	Voltage (depolarization)	Chemical (neurotransmitter)	Chemical (neurotransmitter)
Initial effect of stimulus	First opens Na^+ channels, then K^+ channels	Opens channels that allow simultaneous Na^+ and K^+ fluxes	Opens K^+ or Cl^- channels
Repolarization	Voltage regulated; inactivation of Na^+ channels together with opening of K^+ channels	Voltage independent; occurs when neurotransmitter is no longer present	
Conduction distance	Not conducted by local current flows; continually regenerated (propagated) along entire axon; intensity does not decline with distance	0.1–1 mm; local electrical events; intensity declines with distance	
Positive feedback cycle	Present	Absent	Absent
Peak membrane potential	+30 to +50 mV	Becomes depolarized, moves toward 0 mV	Becomes hyperpolarized, moves toward −90 mV
Summation	None; an all-or-none phenomenon	Present; temporal or spatial	Present; temporal or spatial
Refractory period	Present	Absent	Absent

TABLE 11.3 Neurotransmitters and Neuromodulators *(continued)*

NEUROTRANSMITTER	FUNCTIONAL CLASSES	SITES WHERE SECRETED
AMINO ACIDS		
GABA (γ-aminobutyric acid) $H_2N-CH_2-CH_2-CH_2-COOH$	Generally inhibitory Direct and indirect actions via second messengers	CNS: cerebral cortex, hypothalamus, Purkinje cells of cerebellum, spinal cord, granule cells of olfactory bulb, retina
Glutamate $H_2N-CH(COOH)-CH_2-CH_2-COOH$	Generally excitatory Direct action	CNS: spinal cord; widespread in brain where it represents the major excitatory neurotransmitter

TABLE 11.3 Neurotransmitters and Neuromodulators

NEUROTRANSMITTER	FUNCTIONAL CLASSES	SITES WHERE SECRETED
ACETYLCHOLINE		
• At nicotinic ACh receptors (on skeletal muscles, autonomic ganglia, and in the CNS)	Excitatory Direct action	CNS: widespread throughout cerebral cortex, hippocampus, and brain stem
• At muscarinic ACh receptors (on visceral effectors and in the CNS)	Excitatory or inhibitory depending on subtype of muscarinic receptor Indirect action via second messengers	PNS: all neuromuscular junctions with skeletal muscle; some autonomic motor endings (all preganglionic and parasympathetic postganglionic fibers)

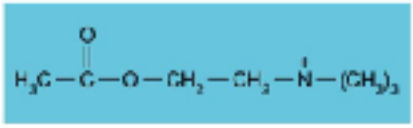


TABLE 11.3 Neurotransmitters and Neuromodulators (continued)

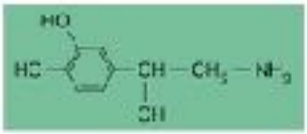
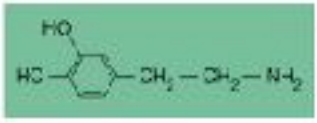
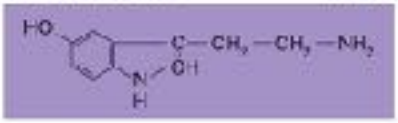
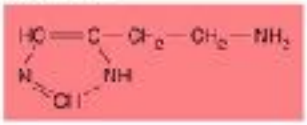
NEUROTRANSMITTER	FUNCTIONAL CLASSES	SITES WHERE SECRETED	COMMENTS
BIOGENIC AMINES			
Norepinephrine 	Excitatory or inhibitory, depending on receptor type bound Indirect action via second messengers	CNS: brain stem, particularly in the locus coeruleus of the midbrain; limbic system; some areas of cerebral cortex PNS: main neurotransmitter of ganglionic neurons in the sympathetic nervous system	A "feel-good" neurotransmitter; release enhanced by amphetamines; removal from synapse blocked by tricyclic antidepressants [amitriptyline (Elavil) and others] and cocaine; brain levels reduced by reserpine (an antihypertensive drug), leading to depression
Dopamine 	Excitatory or inhibitory depending on the receptor type bound Indirect action via second messengers	CNS: substantia nigra of midbrain, hypothalamus; is the principal neurotransmitter of extrapyramidal system PNS: some sympathetic ganglia	A "feel-good" neurotransmitter; release enhanced by L-dopa and amphetamines; reuptake blocked by cocaine; deficient in Parkinson's disease; may be involved in pathogenesis of schizophrenia
Serotonin (5-HT) 	Mainly inhibitory Indirect action via second messengers; direct action at 5-HT$_3$ receptors	CNS: brain stem, especially midbrain; hypothalamus; limbic system; cerebellum; pineal gland; spinal cord	Activity blocked by LSD and enhanced by ecstasy (MDMA); may play a role in sleep, appetite, nausea, migraine headaches, and regulation of mood; drugs that block its uptake [fluoxetine (Prozac)] relieve anxiety and depression
Histamine 	Indirect action via second messengers	CNS: hypothalamus	Increases acid secretion in the stomach; acid secretion blocked by histamine H_2 receptor blockers (cimetidine); also released by mast cells during inflammation and acts as powerful vasodilator

TABLE 11.3 Neurotransmitters and Neuromodulators *(continued)*

NEUROTRANSMITTER	FUNCTIONAL CLASSES	SITES WHERE SECRETED
PEPTIDES		
Endorphins, e.g., dynorphin, enkephalins (illustrated) 	Generally inhibitory Indirect action via second messengers	CNS: widely distributed in brain; hypothalamus; limbic system; pituitary; spinal cord
Tachykinins: Substance P (illustrated), neurokinin A (NKA)	Excitatory Indirect action via second messengers	CNS: basal nuclei, midbrain, hypothalamus, cerebral cortex PNS: certain sensory neurons of dorsal root ganglia (pain afferents)
DISSOLVED GASES		
Nitric oxide (NO)	Excitatory Indirect action via second messengers	CNS: brain; spinal cord PNS: adrenal gland; nerves to penis
Carbon monoxide (CO)	Excitatory Indirect action via second messengers	Brain and some neuromuscular and neuroglandular synapses

March 14-15

Physiology of the Nervous System

Somatosensory pages - 484 - 494

Define sensation and discuss the underlying processes

- Sensory receptors
- Explain signal transduction; define generator and receptor potentials, and describe the patterns of nerve impulses that they generate
- Explain the concept of adaptation; describe phasic and tonic receptors
- Classify the sensory receptors according to their structure, location and function

  Somatic sensation
- Describe the properties and location of tactile receptors
- Describe the properties and location of thermoreceptors
- Describe the properties and location of nociceptors; compare somatic and visceral pain; explain the concept of referred pain
- Describe the location and functions of proprioceptors
- Sensory properties of intensity coding acuity and adaptation

Peripheral Nervous System
(all neural structures outside brain + spinal cord)

- provides links to/from the external environment
- includes all neural structures outside the brain; sensory receptors, peripheral nerves, associated ganglia, autonomic nervous system, and efferent motor endings
- enables CNS to receive information and carry out decisions

Input from PNS
(function of CNS is critically dependant on input from PNS)

- PNS receives inputs from peripheral sensory receptors
- Sensation - awareness of changes in internal/external environment
- Perception - conscious interpretation of those stimuli
- Receptor level sensory receptors/Circuit level ascending pathways/ perception level cerebral cortex

Homeostatic Imbalance
Trigeminal Neuralgia

- inflammation of trigeminal nerve
- considered to produce must excruciating pain known
- provoked by sensory stimulus (brushing teeth, breeze hitting face)
- severe cases, surgery moves the compressing vessel or destroys the nerve
- nerve destruction results in loss of sensation on that side of the face

Sensory Receptors

- structures specialized to respond to stimuli
- activation results in graded depolarizations that trigger action potential impulses along the nerve axon to CNS
- Reflex activity takes place in the spinal cord
- sensation and perception, occur in the cerebral cortex
- either specialized endings of afferent neurons or separate cells that signal the afferent neuron
- type of sensation perceived (modality) is a specific to the type of receptor being activated
- Three ways to classify: type of stimulus they detect, body location, structural complexity

Transduction

- conversion of the environmental physical property (stimulus) into a neuronal electrochemical property
- key to process of sensation

Receptor Class by Location

Exteroceptors

- Respond to stimuli arising outside the body
- found near body surface

- sensitive to touch, pressure, pain, and temperature
- include the special sense organs

Interoceptors
- Respond to stimuli arising within the body
- Found in internal viscera and blood vessels
- Sensitive to chemical changes, stretch, and temperature changes

Proprioceptors
- respond to degree of stretch of the organs they occupy
- found in skeletal muscles, tendons, joints, ligaments and connective tissue coverings of bone and muscles
- constantly "advise" the brain of one's movement
- give information concerning movements and position of the body
- Proprioception ("sense of self")

Types of Proprioceptors
- In limbs, proprioceptors provide information about joint angle, muscle length, and muscle tension, which is integrated to give information about the position of limb in space
- muscle spindle is one type of proprioceptor that provides information about changes in muscle length
- the Golgi tendon organ is another type of proprioceptor that provides information about changes muscle tension

Receptor Classification by Stimulus Type

- Mechanoreceptors - respond to touch, pressure, vibration, stretch, and itch
- Thermoreceptors - sensitive to changes in temperature
- Photoreceptors - respond to light energy (e.g. retina)
- Chemoreceptors - respond to chemicals (e.g. smell, taste, changes in blood chemistry)
- Nociceptors - sensitive to pain-causing stimuli

Thermoreceptors
- transient receptor potential (TRP) family of proteins
- free nerve endings with membrane channels that change their permeability (and therefore axon firing rates) across specific temperature ranges

Receptor Classification by Receptor Structure

- receptors are structurally classified as either simple or complex
- most receptors are simple and include encapsulated and unencapsulated varieties (free nerve endings)

- general sensory receptors are involved in tactile sensation (mix of touch, pressure, stretch, and vibration), temperature monitoring, pain, and "muscle sense" provided by proprioceptors
- receptors for special senses (vision, hearing, equilibrium, smell, and taste) are housed in complex sense organs (in contact with a free nerve ending)

Adaptation of Sensory Receptors

- receptors responding to pressure, touch, and smell adapt quickly (phasic)
- receptors responding slowly include Merkel's discs, Ruffini's corpuscles, and interoceptors that respond to chemical levels in the blood
- Pain receptors and proprioceptors do not exhibit adaption (tonic)

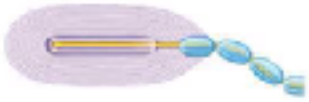
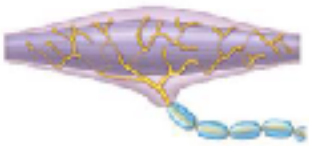
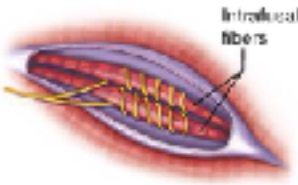
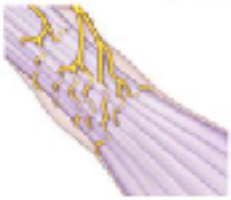
STRUCTURAL CLASS	ILLUSTRATION	ACCORDING TO LOCATION (L) AND STIMULUS TYPE (S)	BODY LOCATION
Encapsulated			
Tactile (Meissner's) corpuscles		L: Exteroceptors S: Mechanoreceptors (light pressure, discriminative touch, vibration of low frequency); rapidly adapting	Dermal papillae of hairless skin, particularly nipples, external genitalia, fingertips, soles of feet, eyelids
Lamellar (Pacinian) corpuscles		L: Exteroceptors, interoceptors, and some proprioceptors S: Mechanoreceptors (deep pressure, stretch, vibration of high frequency); rapidly adapting	Dermis and hypodermis; periosteum, mesentery, tendons, ligaments, joint capsules; most abundant on fingers, soles of feet, external genitalia, nipples
Bulbous corpuscles (Ruffini endings)		L: Exteroceptors and proprioceptors S: Mechanoreceptors (deep pressure and stretch); slowly or nonadapting	Deep in dermis, hypodermis, and joint capsules
Muscle spindles		L: Proprioceptors S: Mechanoreceptors (muscle stretch, length)	Skeletal muscles, particularly in the extremities
Tendon organs		L: Proprioceptors S: Mechanoreceptors (tendon stretch, tension)	Tendons
Joint kinesthetic receptors		L: Proprioceptors S: Mechanoreceptors and nociceptors	Joint capsules of synovial joints

Table 13.1 General Sensory Receptors Classified by Structure and Function

STRUCTURAL CLASS	ILLUSTRATION	FUNCTIONAL CLASSES ACCORDING TO LOCATION (L) AND STIMULUS TYPE (S)	BODY LOCATION
Nonencapsulated			
Free nerve endings of sensory neurons		L: Exteroceptors, interoceptors, and proprioceptors S: Thermoreceptors (warm and cool), chemoreceptors (itch, pH, etc.), mechanoreceptors (pressure), nociceptors (pain, heat, cold, pinch, and chemicals)	Most body tissues; most dense in connective tissues (ligaments, tendons, dermis, joint capsules, periosteal and epithelia (epidermis, cornea, mucosae, and glands)
Modified free nerve endings: Tactile (Merkel) discs		L: Exteroceptors S: Mechanoreceptors (light pressure); slowly adapting	Basal layer of epidermis
Hair follicle receptors		L: Exteroceptors S: Mechanoreceptors (hair deflection); rapidly adapting	In and surrounding hair follicles

Pain Perception

Nociception

- the perception of stimuli (thermal, mechanical or anoxic) that have potential to produce tissue damage
- we avoid stimuli by relax and conscious responses

Responses to stimuli

- histamine, K+, ATP, acid, and/or bradykinin are released by stressed or damaged issue and they depolarize the free nerve endings of pain sensory endings

Mechanisms of pain relief

- electrical stimulation of specific areas of the CNS
- Pharmacological agents (NSAIDS like Tylenol inhibits prostaglandin synthesis) and morphine (opioids)
- Some of the neutrons in these inhibitory pathways release morphine-like endogenous opioids
- Acupuncture (seems to be linked to activation of the endogenous opioid pathways)

- There are active mechanisms promoting axon regrowth after damage in the PNS but inhibiting axon regrowth after damage in the CNS

March 16-17

Physiology of the Nervous System Somatosensory

pp. 435-436, 438, 468-469, 472-474, 516-521
- Processing of sensation at the circuit level
- Describe the chain of neurons in the ascending pathways
- Describe the principal ascending pathways
- Processing of sensation at the perceptual level
- Describe and discuss the principal features of perceptions

Organization of the Somatosensory System
- Input comes from: exteroceptors, proprioceptors, and interceptors
- Main levels of Neural Integration of SS
    1. Receptor Level - the sensor receptors
    2. Circuit level - ascending pathways
    3. Perceptual level - neuronal circuits in the cerebral fluid

Second Order Sensory Neurons
- receive synapses from primary sensory neurons
- send out axons that immediately crosses the midline and projects to the appropriate nucleus of the thalamus
- Second order neurons for pain are in the spinal cord gray matter
- second order neurons for fine touch are in brain stem nuclei (dorsal column nuclei in the medulla).

- Afferent pain pathways differ afferent "non-pain" sensory pathways
- Both sets of second order neurons send out axons that cross the midline and project to the thalamus

First Order Neurons
- cell body in a peripheral ganglion
- projects to the CNS and innervates a second order neuron which immediately crosses the midline and projects to the thalamus

Spinothalamic Pathway
- provides conscious sensations of poorly localized ("crude") touch, pressure, pain and temperature
- axons of 1st order neurons enter spinal cord and synapse on 2nd order neurons within the posterior gray horns
- axons cross to opposite side of spinal cord before ascending to the thalamus
- 3rd order neurons synapse in the primary sensory cortex

Sensory Homunculus

- "little human"
- functional map of primary sensory cortex
- area of sensory cortex devoted to a particular body region is proportional to the number of sensory receptors it contains

Posterior Column Pathway

- Also known as the dorsal column-medial lemniscus
- carries sensations of highly localized ("fine") touch, pressure, vibration, and proprioception
- begins at a peripheral receptor and ends at primary sensory cortex of the cerebral hemispheres

Processing at the Circuit Level

- chains of three neutrons conduct sensory impulses upward to the brain
- First-order neutrons - soma reside in dorsal root or cranial ganglia, and conduct impulses from the skin to the spinal cord or brain stem
- Second-order neutrons - soma reside in the dorsal horn of the spinal cord or medullary nuclei and transmit impulses to the thalamus or cerebellum
- Third-order neutrons - located in the thalamus and conduct impulses to the somatosensory cortex of the cerebrum

TABLE 12.2 Major Ascending (Sensory) Pathways and Spinal Cord Tracts

SPINAL CORD TRACT	LOCATION (FUNICULUS)	ORIGIN	TERMINATION	FUNCTION
Dorsal Column–Medial Lemniscal Pathways				
Fasciculus cuneatus and fasciculus gracilis (dorsal white column)	Dorsal	Central axons of sensory (first-order) neurons enter dorsal root of the spinal cord and branch; branches enter dorsal white column on same side without synapsing	By synapse with second-order neurons in nucleus cuneatus and nucleus gracilis in medulla; fibers of medullary neurons cross over and ascend in medial lemniscus to thalamus, where they synapse with third-order neurons; thalamic neurons then transmit impulses to somatosensory cortex	Both tracts transmit sensory impulses from general sensory receptors of skin and proprioceptors, which are interpreted as discriminative touch, pressure, and "body sense" (limb and joint position) in opposite somatosensory cortex. Cuneatus transmits afferent impulses from upper limbs, upper trunk, and neck. Gracilis carries impulses from lower limbs and inferior body trunk.

TABLE 12.2 Major Ascending (Sensory) Pathways and Spinal Cord Tracts (continued)

SPINAL CORD TRACT	LOCATION (FUNICULUS)	ORIGIN	TERMINATION	FUNCTION
Anterolateral Pathways				
Lateral spinothalamic	Lateral	Interneurons (second-order neurons) of dorsal horn; fibers cross to opposite side before ascending	By synapse with third-order neurons in thalamus; impulses then conveyed to somatosensory cortex by thalamic neurons	Transmits impulses concerned with pain and temperature to opposite side of brain for interpretation by somatosensory cortex.
Ventral spinothalamic	Ventral	Interneurons (second order neurons) in dorsal horns; fibers cross to opposite side before ascending	By synapse with third order neurons in thalamus; impulses eventually conveyed to somatosensory cortex by thalamic neurons	Transmits impulses concerned with crude touch and pressure to opposite side of brain for interpretation by somatosensory cortex.

Fine Touch Vs Pain Pathways

Fine Touch

- Fine touch primary afferent axons enter the spinal cord
- ascend in the dorsal columns (white matter bundles) of the spinal cord
- synapse on second order neurons in the medulla

Pain Pathways

- Pain afferent neurons enter the spinal cord and synapse on second order neurons in the dorsal horn

- Pain and temperature/fine touch are carried on opposite sides of the spinal cord because one ascends as the first order neuron and the other ascends as the second order (crossed) neuron

Sensory for the Face

- fine touch component for the face which ends the principle sensory nucleus of the trigeminal
- similar to the dorsal column nuclei
- pain component for face which ends in the spinal nucleus of the trigeminal (similar to spinal cord grey matter)
- one to one mapping of sensory receptive fields on the body surface to the corresponding area of the sensory cortex
- the body is mapped onto the sensory cortex (somatotopy)
- Body regions with higher density of sensory receptive fields occupy proportionally greater areas of sensory cortex

Processing at Perceptual Level

- Thalamus projects fibres to:
  - the somatosensory cortex
  - -sensory association areas

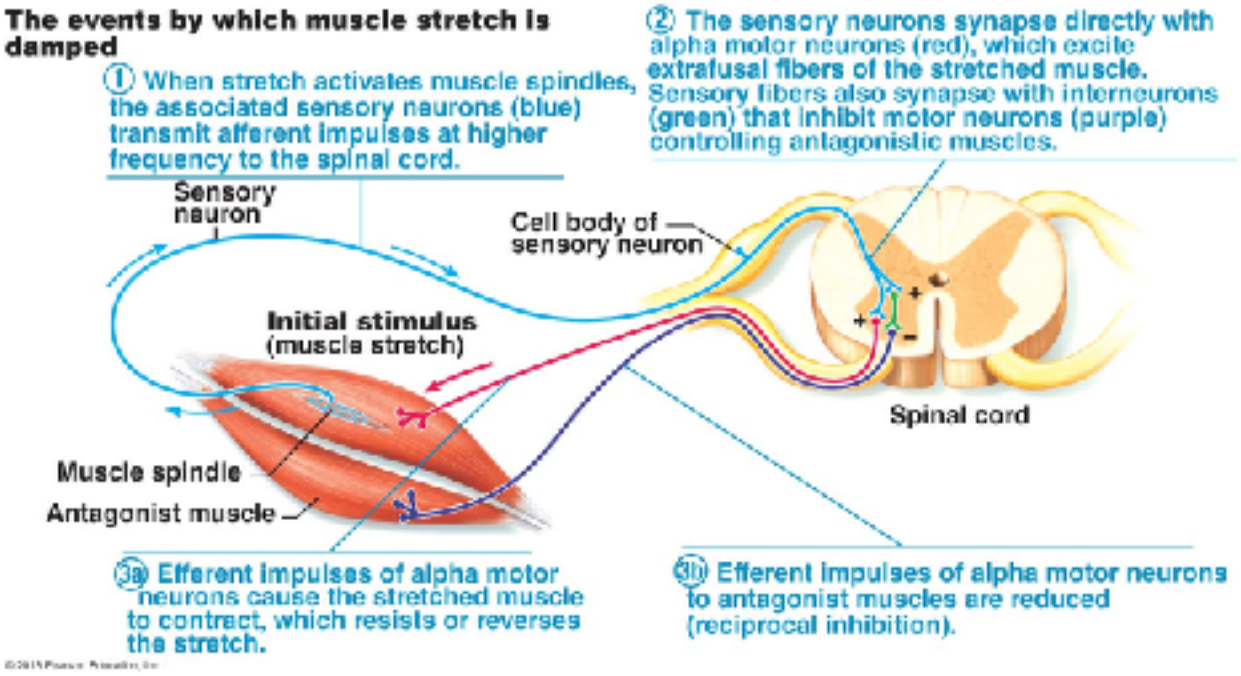
Main Aspects of Sensory Perception

- Perceptual detection - detecting that a stimulus has occurred
- Magnitude estimation - how much of a stimulus is acting
- Spatial discrimination - identifying the site or pattern of the stimulus (example IMR)
- Feature abstraction - used to identify a substance that has specific texture or shape
- Quality discrimination - ability to identify sub modalities of a sensation (e.g. sweet/sour tastes)
- Pattern recognition - ability to recognize patterns in stimuli (e.g. melody, familiar face)

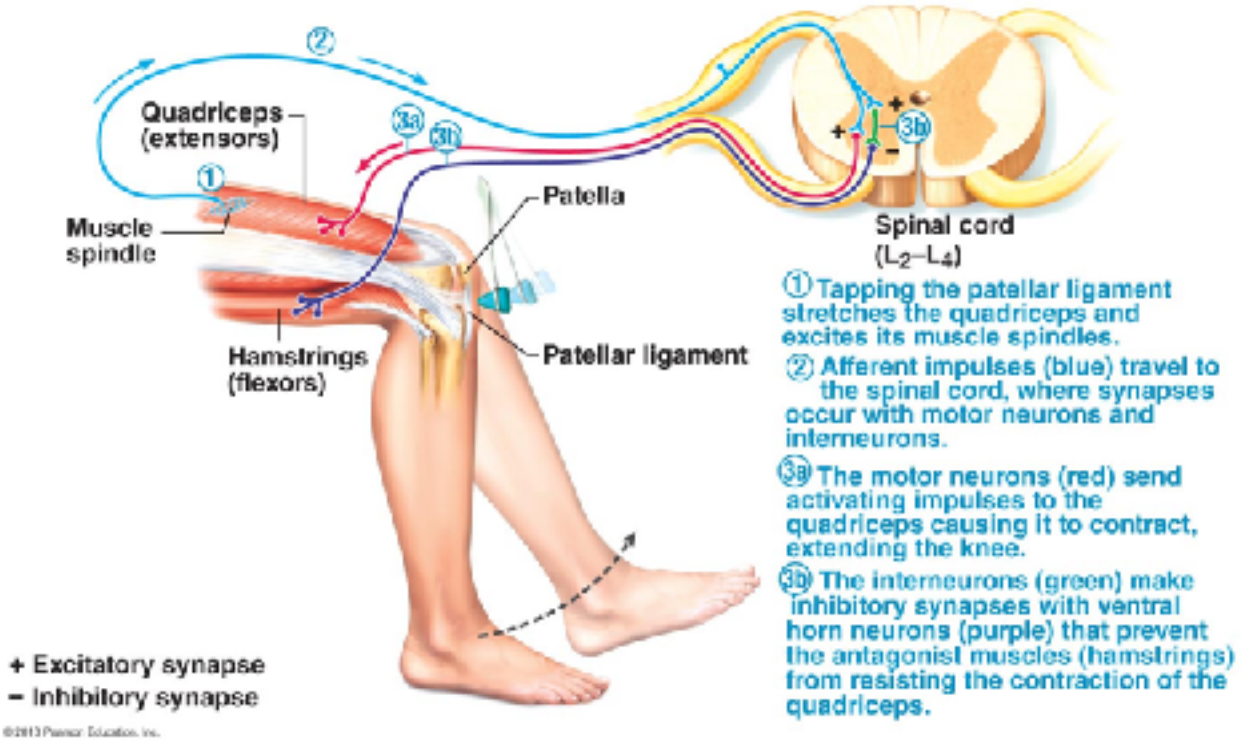
Somatosensory (Somasthetic) input from the body

- fine touch component for face which ends in the principle sensory nucleus of the trigeminal (similar to the dorsal column nuclei)
- pain component for the face which ends in the spinal nucleus of the trigeminal (similar to the spinal cord grey matter)

- There are active mechanisms promoting axon regrowth after damage in the PNS and active mechanisms inhibiting axon regrowth after damage in the CNS



The patellar (knee-jerk) reflex—an example of a stretch reflex



① Tapping the patellar ligament stretches the quadriceps and excites its muscle spindles.

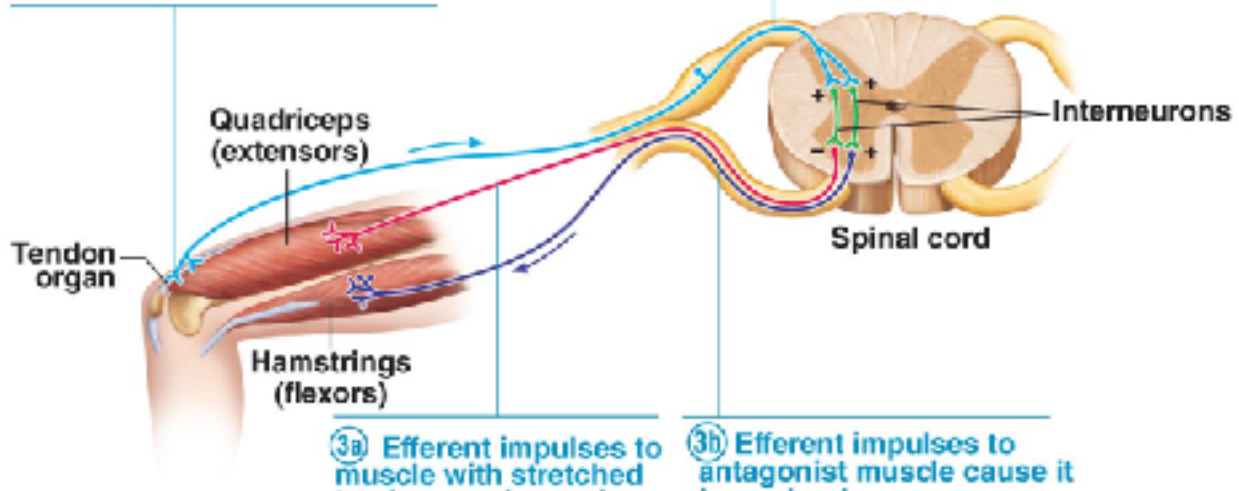
② Afferent impulses (blue) travel to the spinal cord, where synapses occur with motor neurons and interneurons.

3a The motor neurons (red) send activating impulses to the quadriceps causing it to contract, extending the knee.

3b The interneurons (green) make inhibitory synapses with ventral horn neurons (purple) that prevent the antagonist muscles (hamstrings) from resisting the contraction of the quadriceps.

① Quadriceps strongly contracts. Tendon organs are activated.

② Afferent fibers synapse with interneurons in the spinal cord.



3a Efferent impulses to muscle with stretched tendon are damped. Muscle relaxes, reducing tension.

3b Efferent impulses to antagonist muscle cause it to contract.

Previous Exams

1. Membrane potential in excitable tissues depends on ___ and ion conductance
    A) open Na+ channels
    B) open Cl- channels
    C) open Ca++ channels
    D) Transmembrane ion gradient

ANSWER: D) Transmembrane ion gradient

2. Gradient potentials do not
    A) act over short distances
    B) produce self regenerating changes in membrane potential
    C) produce current flow which decreases with distance
    D) produce current flow which varies with stimulus strength

ANSWER: B) Produce self regenerating changes in membrane potential

3. Second order neutrons of the ascending sensory pathways project to:
    A) the spinal cord
    B) the medulla
    C) the thalamus
    D) the cerebral cortex

ANSWER: B) the medulla

4. A flexor reflex in one limb is often accompanied by extension in the opposite limb in the
    A) quadriceps reflex
    B) crossed extensor reflex
    C) the thalamus
    D) the cerebral cortex

ANSWER: B) Crossed extensor reflex

March 21-22

Physiology of Smell and Taste

Pages 569-574, 496, 499, 501
- Taste: describe the gustatory receptors and the neural pathway for taste
- Smell: describe the olfactory receptors and the neural pathway for smell

Chemical sense

- gustation (taste) and olfaction (smell)
- chemoreceptors respond to chemicals in aqueous solution

- taste - to substances dissolved in saliva
- smell - to substances dissolved in fluids of the nasal membranes

The Olfactory Nerves
- arise from olfactory receptor cells located in olfactory epithelium of nasal cavity
- carry afferent impulses for sense of smell

Olfactory Epithelium
- specialized part of the nasal epithelium
- found in the roof of the nasal cavity

Olfactory Receptor Cells (Olfactory Neurons)
- olfactory epithelium contains olfactory neurons
- unique
- replaced by new neurons after 4-8 weeks
- have a dendrite directed towards the mucus overlying the olfactory epithelium (within mucus dendrite branches into olfactory cilia)
- mucus captures airborn oderants (chemicals capable of detection by the receptors)
- about 1000 unique receptors capable of differentiating about 10000 odors

Physiology of Smell

- axons of the olfactory receptor cell ascend up through roof of nasal cavity via tiny holes in the cribriform plate of the ethmoid bone into the cranial cavity
- they reach the olfactory bulbs and synapse with neurons called mitral cells
- axons of mitral cells form the olfactory nerve (olfactory tracts - not a true nerve)
- olfactory tracts have two destinations
    1. the olfactory cortex (inferior frontal lobe), smells are interpreted and identified
    2. the limbic system, memories and emotions associated with the smell are activated

Transduction
- olfactory receptors respond to several different oder-causing chemicals
- when bound to ligand these proteins initiate a mechanism which produces cAMP as a second messenger
- cAMP opens Na^+ and Ca^{2+} channels, causing depolarization of the receptor membrane of olfactory sensory neurons of the olfactory epithelium cells (receptor neurons) that then triggers an action potential in these neurons

Olfactory Transduction Process
1. Odorant binds to its receptor
2. Receptor activates G protein
3. G protein activates adenylate cyclase
4. Adenylate cyclase converts ATP to cAMP

5. cAMP opens a cation channel allowing Na^+ and Ca^{2+} influx and causing depolarization (Ca^{2+} potential = +140 mV)

Transmission

- the sense of smell is the only input to the cerebral cortex that does not pass through the thalamus

Olfactory Pathway

- Mitral cells activated, impulses flow from the olfactory bulbs via the olfactory tracts to the piriform lobe of the olfactory cortex
- from there, two major pathways take information to various parts of the brain
- cerebral activations with the two odourants
- main clusters are seen bilaterally in the amygdala and neighbouring cortex and in the right insult and orbital gyrus

Physiology of Taste

- in order to be tasted, a chemical:
  - must be dissolved in saliva
  - must contact gustatory hairs
- binding of the chemical:
  - depolarizes the taste cell membrane, releasing neurotransmitter
  - initiates a generator potential that elicits an action potential

Taste Organ

- 10,000 or so taste buds (sensory organs for taste) are located mostly in papillae on the surface of the tongue
- each taste bud is composed of >50 epithelial cells consisting of two types:
- gustatory epithelial cells (sensory taste cells) and basal epithelial cells (stem cells)
- Taste reception depends on specialized gustatory receptor cells that detect the taste signal and relay it to gustatory afferent nerve terminals CN VII or CN IX

The Glossopharyngeal Nerves

- mixed nerves that innervate part of tongue and pharynx
- emerge from medulla and leave via jugular foramen to run to throat
- provide somatic motor fibres to, and carry proprioceptors fibres from, a superior pharyngeal muscle (stylopharyngeus) which elevates the pharynx in swallowing
- sensory neuron cell bodies are located in superior and inferior ganglia
- injury/inflammation impairs swallowing and taste

Taste Sensations

- There are five basic taste sensation
  - sweet - sugars, saccharin, alcohol, some amino acids
  - salt - metal ions
  - sour - hydrogen ions
  - bitter - alkaloids such as quinine and nicotine
  - Umami - elicited by the amino acid glutamate

Gustatory Cells (taste cells)

- have microvillar called gustatory hairs that extend through the taste pore into the saliva to detect chemicals
- the gustatory hairs have membrane receptors for gustatory chemicals
- gustatory receptor cells are replaced every 7 days
- a tasting (gustatory equivalent of an oderant) binds to specialized receptors on gustatory hairs and causes release of neurotransmitter which activates the gustatory afferent fibres
- Not responsible for the "Mechanism of Taste Transduction"

Taste Transduction

- the stimulus energy of taste is converted into a nerve impulse by:
  - Na^+ influx in salty tastes
  - H^+ in sour tastes (by directly entering the cell, by opening cation channels, or by blockade of K^+ channels)
  - Gustducin in sweet and bitter tastes

Taste Receptor Type 1 Member 1

- protein that is encoded by the *TAS1R1* gene
  - which encoded by a G protein-coupled receptor
  - component of the heterodimeric amino acid taste receptor T1R1+3
- The T1R1+3 receptor responds to L-amino acids but not to D-enantiomers or other compounds
- Most amino acids that are perceived as sweet activate T1R1+3,
- activation is strictly dependent on an intact T1R1+3 heterodimer

Taste Buds

- most of the 10,000 or so taste buds are found on the tongue
- taste buds are found in papilla (bumps) on the tongue (ignore the rest of the paragraph 'localization and structure of taste buds')

Structure of a Taste Bud

- Each gourd-shaped taste bud consists of three major cell types
  - supporting cells - insulate the receptor
  - Basal cells - dynamic stem cells
  - Gustatory cells - taste cells

Gustatory Pathway

- Cranial Nerves VII and IX carry impulses from taste buds to the solitary nucleus of the medulla
- impulses then travel to the thalamus, and fibres branch to the:
  - gustatory cortex (taste)
  - hypothalamus and limbic system (appreciation of taste)

Influence of Other Sensations on Taste

- taste is 80% smell

- thermoreceptors, mechanoreceptors, nociceptors also influence tastes
- temperature and texture enhance or detract from taste

Taste Pathway

- afferent fibers are found primarily in two cranial nerve pairs
    - Facial nerve (VII) - carries information from the anterior 2/3 of the tongue
    - Glossopharyngeal nerve (IX) - carries information from the posterior 1/3
- impulses from the epiglottis and lower pharynx are conducted primarily by the vagus nerve (X)
- All of these cranial nerves project to the solitary nucleus in the medulla
- Projections from the solitary nucleus cross the midline, innervate the thalamus and then thalamic neurons project to the gustatory cortex in the insula
- Also projections to hypothalamus
- Taste from the anterior 2/3 of the tongue CN VII and from the posterior 1/3 CN IX of the tongue along with a minor component from the vagus
- nerve project to second order neurons in the solitary nucleus in the medulla
- Projections from the solitary nucleus cross the midline, innervate the thalamus and then thalamic neurons project to the gustatory cortex in the insula

"Taste is also important when it comes to the development of dietary habits and the sequencers discovered mutations in the panda's T1R1 gene which may affect its ability to taste meat, one possible explanation for why a potential carnivore would rely on a strict bamboo diet."

Umami

- basic taste associated with an amino acid common in protein heavy foods like meat
- is sensed through the T1R gene family in carnivores
- in pandas, the T1R gene family has experienced mutations causing the inactivation of the T1R1 gene

March 23-24

Physiology of Vision

pages 549-569, 496, 497, 499
- Describe the structural components of the eye
- Explain the concepts of refraction, image, formation, accommodation
- Describe the principal refraction abnormalities
- Describe the processing of visual signals in the retina
- Describe the neural pathway for vision

Eyebrows

- Coarse hairs that overlie the supraorbital margins
- Functions include:
    - -shading the eye

- -preventing perspiration from reaching the eye
- Orbicularis muscle- depresses the eyebrows
- Corrugator muscles- move the eyebrows medially

Palpebrae (Eyelids)

- Protect the eye anteriorly
- Palpebral fissure - separates eyelids
- Tarsal plates of connective tissue support the eyelids internally
- Levator palpeerde superioris - gives the upper eyelid mobility

Conjunctiva

- Transparent membrane that:
  - Lines the eyelids as the palpebral conjunctiva
  - covers the whites of the eyes as the ocular conjunctiva
  - lubricates and protects the eye

Conjunctivitis

- inflammation of the conjunctiva
- results in reddened, irritated eyes,
- pink-eye is a conjunctival infection caused by bacteria or viruses (highly contagious)

Structure of the Eyeball

- slightly irregular hollow sphere with anterior and posterior poles
- wall is composed of three tunics (layers): fibrous, vascular, and sensory
- internal cavity is filled with fluids called humours (aqueous anterior and vitrious posterior)
- lens separates the internal cavity into anterior and posterior segments

Lacrimal Apparatus

- Consists of the lacrimal gland and associated ducts
- lacrimal glands secrete tears

Tears

- contain mucus, antibodies, and lysozyme
- enter the eye via superolateral excretory ducts
- exit the eye medially via the lacrimal puncture
- drain into the nasolacrimal duct

Light

- Electromagnetic radiation - energy waves from short gamma rays to long radio waves
- our eyes respond to a small portion of this spectrum called the visible spectrum
- different cone receptor cells in the retina respond to different wavelengths of the visible spectrum

Focusing Light on the Retina

- Pathway of light entering the eye: cornea, aqueous humor, lens, vitreous humor, and the neural layer of the retina to the photoreceptors
- Light is refracted:
  - -at the cornea
  - -entering the lens
  - -leaving the lens
  - The lens curvature and shape allow for fine focusing of an image

Focusing for Distant Vision

- Light from a distance needs little adjustment for proper focusing
- Far point of vision - the distance beyond which the lens does not need to change shape to focus (20ft)

Lens

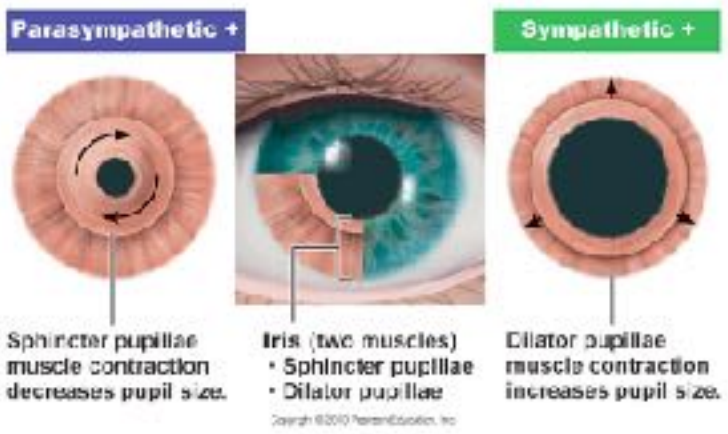
- biconvex, transparent, flexible avascular structure that:
  - Allows precise focusing of light onto the retina
  - is composed of epithelium and lens fibres
- lens epithelium- anterior cells that differentiate into lens fibres
- lens fibers - cells filled with the transparent protein crystallin
- With age, the lens becomes more compact, dense and loses its elasticity

Focusing for Close Vision

- Close Vision requires:
  - accommodations - changing the lens shape by ciliary muscles to increase refractory power
  - constriction - the pupillary reflex constricts the pupils to prevent divergent light rays from entering the eye
  - convergence - medial rotation of the eyeballs toward the object being viewed

Extrinsic Eye Muscles

- Six straplike extrinsic eye muscles
  - enable the eye to follow moving objects
  - maintain the shape of the eyeball
- Four rectus muscles originate from the annular ring
- Two oblique muscles move the eye in the vertical plane



Retina

- Light enters eye and passes through to the back wall of the orbit covered with a photosensitive sensory organ called the retina
- true photosensitive layer of the retina is the photoreceptor cell layer
- The sensory signals begun in the photoreceptors are carried back out through the layers of the retina in a direction opposite to the light path

The Retina: Ganglion Cells and the Optic Disc

- Ganglion cell axons:
  - Run along the inner surface of the retina
  - leave the eye as the optic nerve
- The optic disc:
  - is the site where the optic nerve leaves the eye
  - lacks photoreceptors (the blind spot)

- Sensory receptors are either specialized endings of afferent neutrons or separate cells that signal the afferent neuron

The Retina: Photoreceptors

Rods:

- Respond to dim light
- used for peripheral vision

Cones:

- Respond to bright light
- Have high-acuity color vision
- Are found in the macula lutea
- Are concentrated in the fovea centralism

Functional characteristics of Rods

- Sensitive to dim light and best suited for night vision
- absorb all wavelengths of visible light
- perceived input is in grey tones only
- sum of visual input from many rods feeds into a single ganglion cell
- results in fuzzy and indistinct images

Excitation of Rods

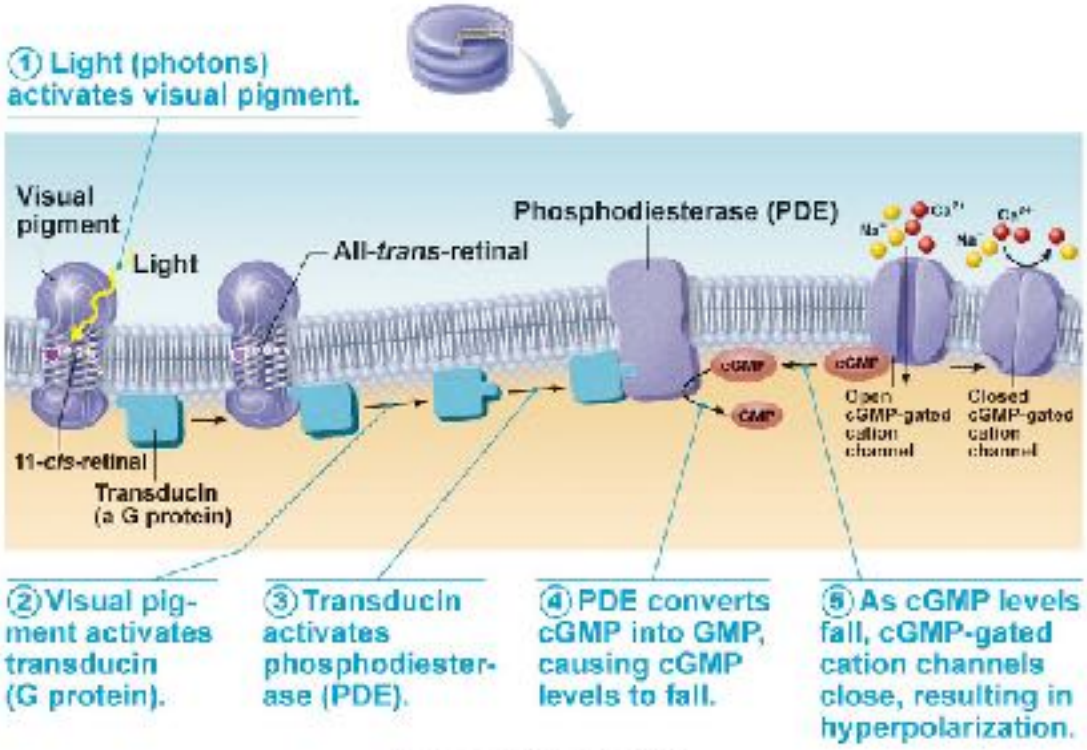
- the visual pigment of rods is rhodopsin (opsin +11-cis retinal)
- Light phase:
  - Rhodopsin breaks down into all-trans retinal + opsin (bleaching of the pigment)
- Dark phase:
  - All-trans retinal converts to 11-cis form
  - 11-cis retinal is also formed from vitamin A
  - 11-cis retinal + opsin regenerate rhodopsin

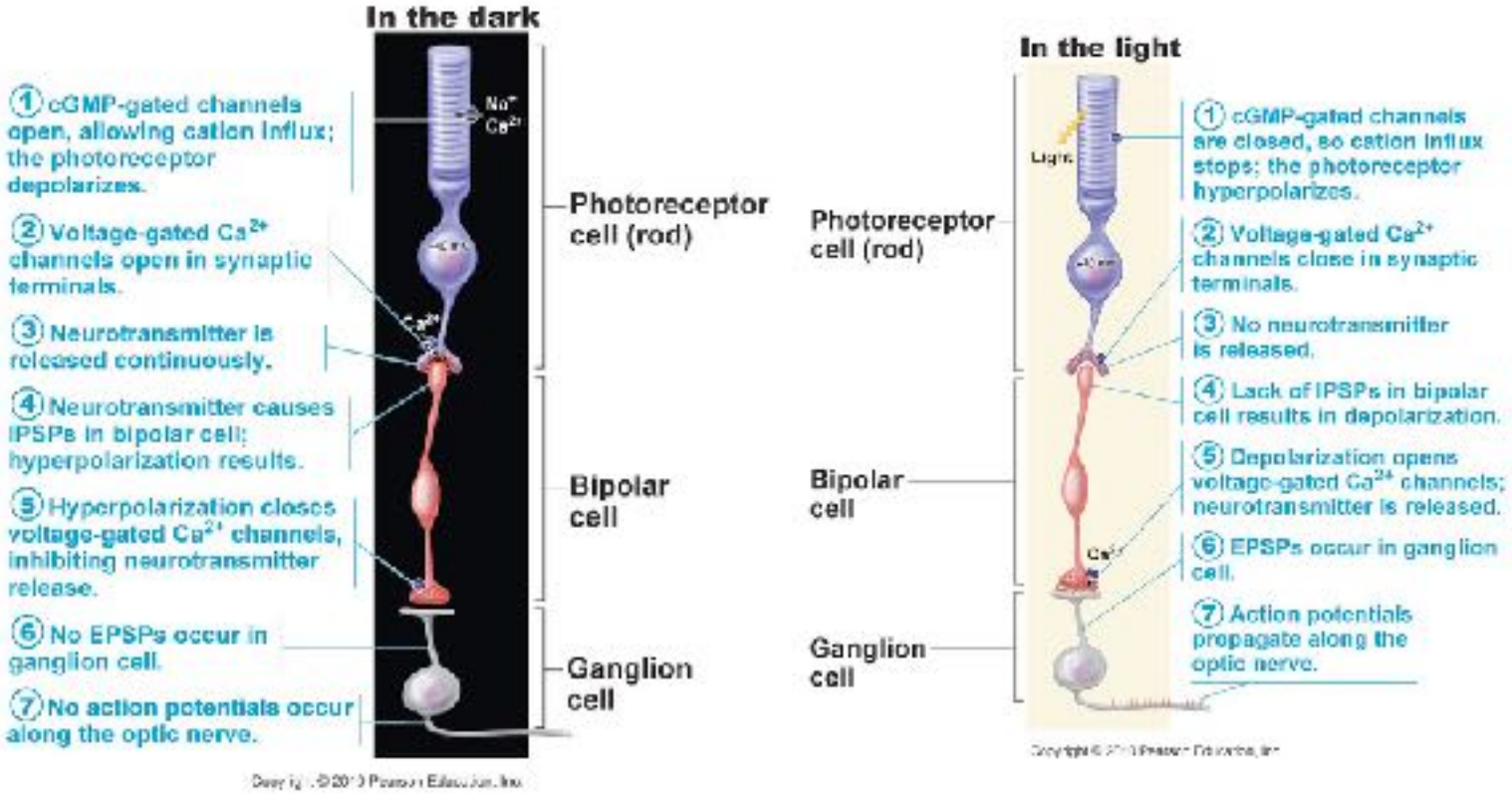
Photoreception - process by which the eye detects light energy

- Rods and cones contain visual pigments (photopigments)
- Arranged in a stack of dislike infoldings of the plasma membrane that change shape as they absorb light

Phototransduction

- light energy splits rhodopsin into all-trans retinal, releasing activated opsin
- the freed opsin activates the G protein transducer
- Transducin catalyzes activation of phosphodiesterase (PDE)
- PDE hydrolyzes cGMP to GMP and releases it from sodium channels
- Without bound cGMP, sodium channels close, the membrane hyperpolarizes, and neurotransmitter cannot be released





Chemistry of Visual Pigments

- Retinal is a light-absorbing molecule
  - combines with opsins to form visual pigments
  - similar to and is synthesized from vitamin A
  - Two isomers: 11-cis and all-trans
- Isomerization of retinal initiates electrical impulses in the optic nerve

Functional characteristics of Cones

- Need bright light for activation (have low sensitivity) moonlight
- Have pigments that furnish a vividly coloured view
- Each cone synapses with a single ganglion cell
- Vision is detailed and has high resolution

Excitation of Cones

- Visual pigments in cones are similar to rods (retinal + opsin)
- There are three types of cones: blue, green, and red
- Intermediate colours are perceived by activation of more than one type of cone
- Method of excitation is similar to rods

Adaptation

- Adaption to bright light (going from dark to light) involves:
  - dramatic decreases in retinal sensitivity (rod function is lost)
  - switching from the rod to the cone system (visual acuity is gained)
- Adaptation to dark is the reverse
  - cones stop functioning in low light
  - Rhodopsin accumulates in the dark and retinal sensitivity is restored

Visual Pathways

- Axons of retinal ganglion cells form the optic nerve
- Medial fibers of the optic nerve decussate at the optic chiasm
- Most fibers of the optic tracts continue to the lateral geniculate body of the thalamus
- Other optic tract fibers end in superior colliculi (initiating visual reflexes) and pretectal nuclei (involved with pupillary reflexes)
- Optic radiations travel from the thalamus to the visual cortex
- Some nerve fibers send tracts to the midbrain ending in the superior colliculi
- A small subset of visual fibers contain melanopsin (circadian pigment) which:
    - Mediates papillary light reflexes
    - Sets daily biorhythms'

Depth Perception

- Achieved by both eyes viewing the same image from slightly different angles
- three-dimensional vision results from cortical fusion of the slightly different images
- if only one eye is used, depth perception is lost and the observer must rely on learned clues to determine length

Retinal Processing: Receptive Fields of Ganglion Cells

- On-center fields
    - stimulated by light hitting the centre of the field
    - inhibited by light hitting the periphery of the field
- Off-center fields have the opposite effects
    - These responses are due to receptor types in the "on" and "off" fields

Thalamic Processing

- The lateral geniculate nuclei of the thalamus:
    - Relay information on movement
    - segregate the retinal axons in preparation for depth perception
    - emphasize visual inputs from regions of high cone density
    - sharpen the contrast information received by the retina

Cortical Processing

- Striate cortex processes
    - basic dark/bright and contrast information
- Prestriate cortices (association areas) processes
    - form, colour, and movement
- Visual information then proceeds anteriorly to the:
    - Temporal lobe - processes identification of objects
    - Parietal cortex and postcentral gyrus - processes spatial location

Reflex Functions

- Pupillary light reflex
    - pupil constricts in response to light-induced action potentials (CNII) reaching the pretectal nucleus in the midbrain

- projecting back to the eyeball (CNII) to cause constrictor papillae muscles to contract
- clinically significant because loss of this reflex can indicate compression CNIII and therefore compression of the midbrain

- Near reflex
  - focusing for close vision
    1. accommodation (elastic recoil thickening of the sense by contracting the ciliary muscle)
    2. pupillary constriction (again, but this time to increase focus)
    3. convergence (eyes become slightly crossed, activation of medial rectus (CNIII)
- Reflex postural
  - movements of the head, neck and upper torso and upper arms in response to visual stimuli, basis is retinal projections to the superior colliculus

March 28-29

Physiology of Balance and Hearing

Vestibulocochlear nerve - pages 574 – 588, 500
- Describe the anatomy of the three main regions of the ear
- Explain sound waves
- Describe the structure and function of outer and inner hair cells
- Explain the major events involved in hearing
- Describe the auditory pathway
- Compare static and dynamic equilibrium, and describe
- the structure and function of receptor organs for equilibrium
- Describe the equilibrium pathways

Properties of Sound

Sound is:
- a pressure disturbance (alternating areas of high and low pressure) originating from a vibrating object
- composed of areas of rarefaction and compression
- represented by a sine wave in wavelength, frequency, and amplitude

Amplitude - intensity of a sound measured in decibels (dB)
Loudness - subjective interpretation of sound intensity
Frequency - the number of waves that pass a given point in a given time
Pitch - perception of different frequencies (we hear from 20-20,000 Hz cycle/s)

Sound and Mechanisms of Hearing
- sound vibrations beat against the eardrum (tympanic membrane)

- eardrum pushes against the ossicles (little bones), which presses fluid in the inner ear against the oval and round windows
    - this movement sets up shearing forces that pull on hair cells
    - moving hair cells stimulates the cochlear nerve that sends impulses the brain

External Ear

- external (outer) ear collects sound waves and passes them inwards
- Structures of EE:
    - auricle (pinna) [cartilage covered with skin]
    - external auditory canal (acoustic meatus)
    - tympanic membrane or eardrum [skin and connective tissue]

Ear Ossicles

The tympanic cavity:

- contains three small bones:
    - malleus
    - incus
    - stapes
- transmit vibratory motion of the eardrum to the oval window
- dampened by the tensor tympani and stapedius muscles

- Damping muscles are an example of CNS control over sensory input (protects the auditory receptor cells), Innervated by cranial nerves

Inner Ear

- Bony labyrinth
    - tortuous channels worming their way through the temporal bone
    - contains the vestibule, the cochlea, and the semicircular canals
    - filled with perilymph (orange fluid)
- Membranous labyrinth (inside bony)
    - series of membranous sacs with the bony labyrinth
    - filled with a potassium-rich fluid (endolymph)

- differential pressure in your tympanic membrane (ears popping)

The Vestibule

- The central egg-shaped cavity of the bony labyrinth
- suspended in its perilymph are two sacs
- These sacs:
    - house equilibrium receptors called maculae
    - respond to gravity and changes in the position of the head

The Semicircular Canals

- three canals that each define two-thirds of a circle and lie in the three planes of space

- membranous semicircular ducts line each canal
- the ampulla is the swollen end of each canal band and it houses equilibrium receptors in a region called the crust ampullaris
- these receptors respond to angular movements of the head

The Cochlea

- Spiral, conical, bony chamber
- extends from the anterior vestibule
- coils around a bony pillar called the modiolus
- contains the cochlear duct, which ends at the cochlear apex
- contains the organ of the Court (hearing receptor)
- divided into three chambers:
    - Scala vestiboli
    - Scala media (cochlear duct)
    - Scala Tympani
- The "floor" of the cochlear duct is composed of:
    - the bony spiral lamina
    - the basilar membrane, which supports the organ of Corti
- The cochlear branch of nerve VIII runs from the organ of Corti to the brain

Scala Tympani

- terminates at the round window

Scalas Tympani and vestibuli

- filled with perilymph
- continuous with each other via the helicotrema

Scala media (cochlear duct)

- filled with endolymph

Transmission of Sound to the Inner Ear

The route of sound to the inner ear follows this pathway:

- outer ear - pinna, auditory canal, eardrum
- middle ear - malleus, incus, and stapes to the oval window
- inner ear - scales vestibule and tympani to the cochlear duct
    - stimulation of the organ of Corti
    - generation of impulses in the cochlear nerve

- each frequency that we hear corresponds to a specific place on the basilar membrane
- As a result, the brain determines the frequency of a sound wave by the location of the hair cells activated by the vibrating basilar membrane

Resonance of the Basilar Membrane

- sound waves of low frequency (inaudible):
    - travel around the helicotrema
    - do not excite hair cells

- sounds with high frequency (audible):
    - are transmitted through the cochlear duct
    - vibrates the basilar membrane
    - excite specific hair cells according to frequency of the sound

The Organ of Corti

- composed of supporting cells and outer and inner hair cells
- afferent fibers of the cochlear nerve attach to the base of hair cells
- the stereocilia (hairs):
    - protrude into the endolymph
    - touch the tectorial membrane

Excitation of Hair Cells in the Organ of Corti

- bending cilia does 2 things:
    - Opens mechanically gated ion channels (Ca and K)
    - Causes a graded potential and the release of a neurotransmitter (probably glutamate)
- the neurotransmitter causes cochlear fibers to transmit impulses to the brain, where sound is perceived

Excitation of the Spiral Organ

- the spiral organ rests on top of the basilar membrane
- composed of supporting cells and outer and inner hair cells
- afferent fibers of the (a division of CN VIII) of the___
- the hair cells have:
    - numerous stereo cilia
    - single kinocilium (true cilium)
    - are linked together by tip links
- movement of the basilar membrane causes:
    - bending of the cilia of inner hair cells puts tension on the tip links
    - this opens mechanically gated ion channels (K+)
    - causes a graded depolarization
    - causes release of a neurotransmitter (glutamate)
- the neurotransmitter release causes cochlear fibres to transmit impulses to brain, where sound is perceived

Auditory Pathway to the Brain

- impulses from the cochlea pass via the spiral ganglion (in the periphery) to the cochlear nuclei (in the brain stem)
- from there, impulses are sent to the:
    - superior olivary nucleus
    - inferior colliculus (auditory reflex center)
- from there, impulses pass to the auditory cortex
- Auditory pathways decussate so that both cortices receive input from both ear
- Pitch is perceived by
    - the primary auditory cortex

    - cochlear nuclei
- Loudness is perceived by:
    - varying thresholds of cochlear cells
    - the number of cells stimulated
- localization is perceived by superior olivary nuclei that determine relative sound volume in the two ears
- goes to the inferior colliculus (auditory reflex center)
- impulses then project to the medial geniculate nucleus of the thalamus
- thalamic axons then project to the primary auditory cortex
- auditory pathways decussate so that both cortices receive input from both ears

Pitch - Perceived by primary auditory cortex
Loudness - perceived by varying thresholds of cochlear cells and the number of cells stimulated
Localization - perceived by the superior olivary nuclei that determine relative sound volume in the two ears and the time difference in the arrival of sound in the two ears

Deafness

- Conduction deafness - something hampers sound conduction to the fluids of the inner ear (e.g. impacted earwax, perforated eardrum, osteosclerosis of the ossicles)
- Sensorineural deafness - results from damage to the neural structures at any point from the cochlear hair cells to the auditory cortical cells (in part because of high K in endolymph)
- Tinnitus - ringing or clicking sound in the ears in the absence of auditory stimuli
- Meniere's syndrome - labyrinth disorder that affects the cochlea and the semicircular canals, causing vertigo, nausea, and vomiting

Anatomy of Maculae

- Maculae - sensory recectoprs for static equilibrium
    - contain supporting cells and hair cells
    - each hair cell has stereo cilia and kinocilium embedded in the otolithic membrane
- Otolithic membrane - jellylike mass studded with tiny $CaC0_3$ stones called otoliths
- Utricular hairs respond to horizontal movement
- Saccular hairs respond to vertical movement

Mechanisms of Equilibrium and Orientation

- Vestibular apparatus - equilibrium receptors in the semicircular canals and vestibule
    - maintains our orientation and balance in space
    - vestibular receptors monitor static equilibrium
    - semicircular canal receptors monitor dynamic equilibrium

- detection of head position by the macula

Activating Macula Receptors

- hair cells synapse with fibres of the vestibular nerve

- cell bodies of this are located in the superior and inferior vestibular ganglia

Effect of Gravity on Utricular Receptor Cells

- Otolithic movement in the direction of the kinocilia:
  - depolarizes vestibular nerve fibers
  - increase the number of action potentials generated
- Movement in the opposite direction:
  - hyperpolarizes vestibular nerve fibers
  - reduces the rate of impulse propagation
- From this information, the brain is informed of the changing position of the head

Crista Ampullaris and Dynamic Equillibrium

- The crista ampullaris (or crista):
  - is the receptor for dynamic equilibrium
  - is located in the ampulla of each semicircular canal
  - responds to angular movements
- each crista has support cells and hair cells that extend up into a gel-like mass called the Cupula
- Dendrites (actually sensory nerve endings) of vestibular nerve fibres encircle the base of the hair cells

Activating Crista Ampullaris Receptors

- Cristae respond to changes in velocity of rotatory movements of the head
- directional bending of hair cells in the cristae causes:
  - depolarizatons, and rapid impulses reach the brain at a faster rate
  - hyperpolarizations, and fewer impulses reach the brain
- the result is that the brain is informed of rotational movements of the head

Balance and Orientation Pathways

- three modes of input for balance and orientation:
  - vestibular receptors
  - visual receptors
  - somatic receptors
- these receptors allow our body to respond reflexively

Cyclic nucleotide gated ion channels are a general feature of the sense of_____

A) touch
B) Vision
C) hearing
D) balance

Olfactory receptor cells (which is NOT true)

A) are found in the roof of the nasal cavity
B) are replaced by new neutrons after 4-8 weeks

C) have a dendrite which branches into a number of olfactory cilia capturing operant
D) send axons traveling with the facial nerve into the brain stem

The receptor membranes of gustatory cells are located on____
A) Basal cells
B) gustatory hairs
C) nasoepithelial cells
D) thermoreceptors
ANSWER: B

The olfactory receptor neutrons innervate:
A)Primary olfactory afferents
B) the olfactory bulbs
C) the thalamus
D) the olfactory cortex
ANSWER: B

March 30-31

Physiology of the Motor System

Descending systems - pages 469-474, 513-522
- Discuss the levels of motor control
- Describe the direct and indirect pathways of upper motor neurons
- Explain the functions of the precommand systems: cerebellum and basal nuclei
- Reflex activity:
  - Define reflex and describe the classifications of reflexes
  - Describe the basic components of a reflex arc
- Somatic spinal reflexes:
  - Describe the functional anatomy of muscle spindles and Golgi tendon organs
  - Describe the stretch reflex
  - Describe the Golgi tendon reflex
  - Describe the withdrawal and cross-extensor reflexes
  - Discuss spinal cord reflexes that cause muscle spasms

- The cortex sends direct (corticospinal) and indirect (corticobulbar/bulbospinal) projections to the spinal cord: paralysis

Movement
- intimated in the basal ganglia which then projects to the motor cortex (lesions: akinesia)

- regulated by the cerebellum which then project to the motor cortex (lesions: dyskinesia)

Primary Motor Cortex
- precentral gyrus of frontal lobe
- note its relationship to the primary somatosensory cortex (3,2,1)

Premotor Cortex
- anterior to precentral gyrus coordinates movement of several muscle groups simultaneously

Broca's Area
- one side only (usually left)
- motor speech area

Frontal Eye Field
- voluntary movements of the eyes

Descending Motor Pathways
- Descending tracts deliver efferent impulses from the brain to the spinal cord, and are divided into two groups
    - direct pathways equivalent to the pyramidal tracts
    - indirect pathways, essentially all others
- Motor pathways involve two neurons (upper and lower)
    - upper motor neuron is in the motor cortex
    - lower motor neuron is a spinal motor neuron or a cranial nerve motor neuron

The Direct (Pyramidal) System
- Direct pathways originate with the pyramidal neurons in the precentral gyri
- Impulses are sent through the corticospinal tracts and synapse in the anterior horn
- Stimulation of anterior horn neurons activates skeletal muscles
- Parts of the direct pathway, called corticobulbar tracts, innervate cranial nerve nuclei
- direct pathway regulates fast and fine (skilled) movements
- 90 % are in the lateral corticospinal pathway; 10 % are in the anterior corticospinal pathway (bilateral innervation of midline muscles)

Motor Unit
- consists of efferent branches of the axon of a spinal (cranial) motor neuron and all of the muscle fibres it innervates (3-5 extraocular muscles versus 1000 in quadraceps)

Innervation of Skeletal Muscle
- Takes place at a neuromuscular junction
- Acetylcholine is the neurotransmitter that diffuses across the synaptic cleft
- ACh binds to receptors resulting in:
    - Movement of Na^+ and K^+ across the membrane
    - Depolarization of the interior of the muscle cell
    - An end-plate potential that triggers an action potential

TABLE 12.3 Major Descending (Motor) Pathways and Spinal Cord Tracts

SPINAL CORD TRACT	LOCATION (FUNICULUS)	ORIGIN	TERMINATION	FUNCTION
Direct (Pyramidal)				
Lateral corticospinal	Lateral	Pyramidal neurons of motor cortex of the cerebrum; decussate in pyramids of medulla	By synapse with ventral horn interneurons that influence motor neurons and occasionally with ventral horn motor neurons directly	Transmits motor impulses from cerebrum to spinal cord motor neurons (which activate skeletal muscles on opposite side of body). A voluntary motor tract.
Ventral corticospinal	Ventral	Pyramidal neurons of motor cortex; fibers cross over at the spinal cord level	Ventral horn (as above)	Same as lateral corticospinal tract.

TABLE 12.3 Major Descending (Motor) Pathways and Spinal Cord Tracts *(continued)*

SPINAL CORD TRACT	LOCATION (FUNICULUS)	ORIGIN	TERMINATION	FUNCTION
Indirect (Extrapyramidal) Pathways				
Tectospinal	Ventral	Superior colliculus of midbrain of brain stem (fibers cross to opposite side of cord)	Ventral horn (as above)	Turns neck so eyes can follow a visual object
Vestibulospinal	Ventral	Vestibular nuclei in medulla of brain stem (fibers descend without crossing)	Ventral horn (as above)	Transmits motor impulses that maintain muscle tone and activate ipsilateral limb and trunk extensor muscles and muscles that move head; in this way it helps maintain balance during standing and moving.
Rubrospinal	Lateral	Red nucleus of midbrain of brain stem (fibers cross to opposite side just inferior to the red nucleus)	Ventral horn (as above)	In experimental animals, transmits motor impulses concerned with muscle tone of distal limb muscles (mostly flexors) on opposite side of body. In humans, functions are largely assumed by corticospinal tracts.
Reticulospinal (ventral, medial, and lateral)	Ventral and lateral	Reticular formation of brain stem (medial nuclear group of pons and medulla); both crossed and uncrossed fibers	Ventral horn (as above)	Transmits impulses concerned with muscle tone and many visceral motor functions. May control most unskilled movements.

Trigeminal Mandibular Branch

- innervates the skin and teeth of the lower jaw for sensation
- supplies motor impulses to the temporal and master muscles for chewing

Cranial Nerve Nuclei Motor Neurons

- CN III, IV and VI innervate extra ocular muscles
- CN V innervates muscles of mastication (chewing)
- CN VII innervates muscles of facial expression
- CN IX
- CN XI
- CN XII innervates muscles of the tongue

Spinal Cord Trauma: Paralysis

- Cross sectioning of the spinal cord at any level result in total motor and sensory loss in regions of inferior to the cut
- Paraplegia - transection between T1 and L1
- Quadriplegia - transection in the cervical region
- Paralysis - loss of motor function
- Flaccid paralysis - severe damage to the ventral root or anterior horn cells
    - lower motor neurone are damaged and impulses do not reach muscles
    - there is no voluntary or involuntary control of muscles
- Spastic paralysis - only upper motor neuron of the primary motor cortex are damaged
    - spinal neurons remain intact and muscles are stimulated irregularly
    - there is no voluntary control of muscles

Poliomyelitis

- Destruction of the anterior horn motor neurons by the poliovirus
- Early symptoms - fever, headache, muscle pain and weakness, and loss of somatic reflexes
- Vaccines are available and can prevent infection

Amyotrophic Lateral Sclerosis (ALS)

- Lou Gehrig's disease - neuromuscular condition involving destruction of anterior horn motor neurone and fibres of the pyramidal tract
- Symptoms - loss of the ability to speak, swallow, and breathe
- Death occurs within five years
- linked to malfunctioning goes for glutamate transporter and/or superoxide dismutase

Indirect (Extrapyramidal) System

- Includes the brain stem, motor nuclei, and all motor pathways not part of the pyramidal system
- this system includes the rubrospinal, vestibulospinal, reticulospinal, and tectospinal tracts
- These motor pathways are complex and multi synaptic, and regulate:
    - -axial muscles that maintain balance and posture
    - -muscles controlling coarse movements of the proximal portions of limbs
    - -head, neck, and eye movement
- Reticulospinal tracts - maintain balance
- Rubrospinal tracts - control flexor muscles
- Superior colliculi and tectospinal tracts mediate head movements

The Basal Ganglia

- movement initiation
- receive inputs from widespread regions of the cortex
- relay information (via VA thalamus) back to premotor cortex
- Requires dopamine from substantial nigra (Parkinson's disease)

Cerebellar Processing

- cerebellum receives data from the cortex on the intent to initiate voluntary movement
- Proprioceptors and visual signals "inform" the cerebellum of the body's condition
- Cerebellar cortex calculates the best way to perform a movement
- A "blueprint" of coordinated movements is sent to the cerebral motor cortex

Neocerebellum - lateral lobes/dentate nucleus connections to and from the cerebral cortex dysmetria and ataxia (intention tremor)

Midline Cerebellum - spinal inputs, posture, and balance

Vestibulocerebellum - flocculonodular lobe/fastigial nucleus, vertigo and nystagmus

- Lateral geniculate receives visual information and projects to vital cortex
- Ventral posterior receives somatosensory information and protects to sensory cortex
- Ventral lateral receives cerebellar inputs and relays to motor cortex
- Ventral anterior receives basal ganglia input and relays to premotor cortex

Final Common Pathway

-Lower motor neurone receive signals from both direct & indirect upper motor neurone
-sum total of all inhibitory & excitatory signals determines the final response of the lower motor neurone & the skeletal muscles

April 4-5

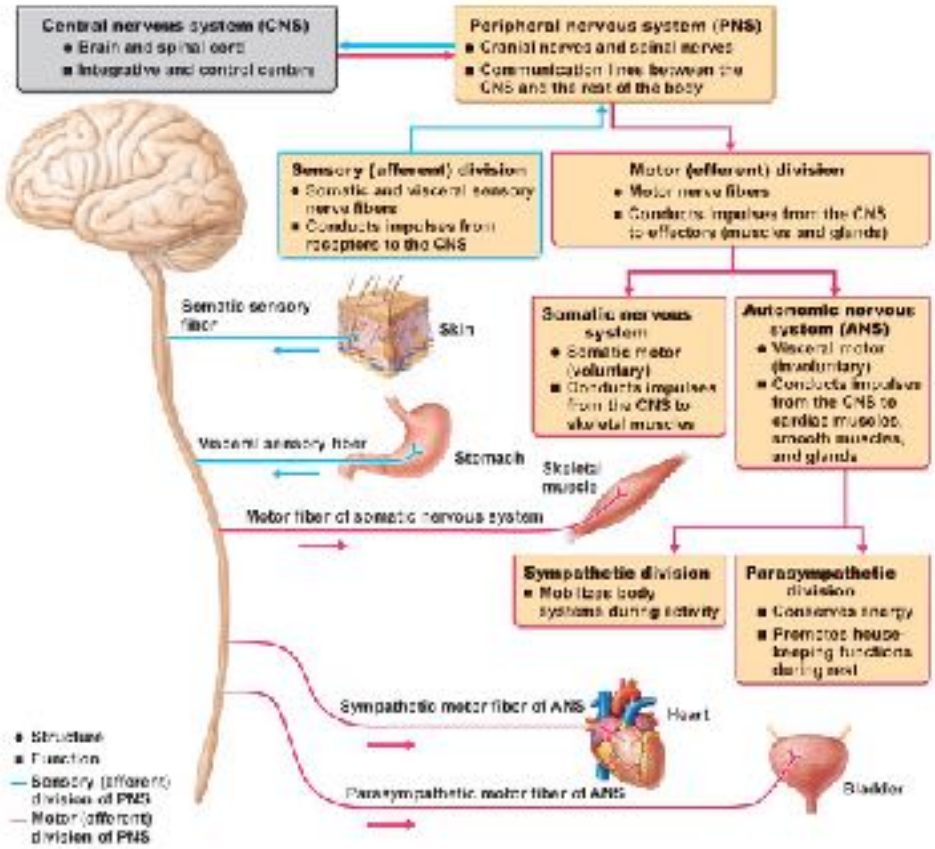
Physiology of the Nervous System Autonomic Nervous System

pages 528-543

- Compare the structural and functional differences between the somatic and autonomic nervous systems
- Compare the anatomical and functional differences between the sympathetic and parasympathetic divisions of the autonomic nervous system
- Describe the neurotransmitters and receptors involved in autonomic responses
- Describe the levels of control of the autonomic nervous system

Autonomic Nervous System (ANS)

- Consists of motors neutrons that:
    - innervate smooth and cardiac muscle and glands
    - make adjustments to ensure optimal support for body activities
    - operate via subconscious control
    - have viscera as most of their effectors
- viscera= stomach, intestine, liver, spleen, pancreas, kidney, etc.
- Axons of ANS are a two-neutron chain
    - The preganglionic (first) neuron has a lightly myelinated axon and extends to a ganglion
    - the postganglionic (second) neuron (unmyelinated) extends to an effector organ
    - ganglion = collection of neuronal cell bodies in the periphery (except for the CNS basal ganglion)



Divisions of the ANS

- sympathetic and parasympathetic
- sympathetic mobilizes the body during extreme situations
- parasympathetic performs maintenance activities and conserves body energy-two divisions counterbalance each other

Role of the Sympathetic Division

- "fight-or-flight" system
- involves E activities (exercise, excitement, emergency, and embarrassment)
- promotes adjustments during exercise (blood flow to organs is reduced, flow to muscles is increased)
- its activity is illustrated by a person who is threatened
    - heart rate increases
    - breathing is rapid and deep
    - skin is cold and sweaty
    - pupils dilate

Sympathetic Outflow

- arises from spinal cord segments T1 through L2
- sympathetic neurons make up the lateral horns the spinal cord
- preganglionic fibres pass through the white rami communicates and synapse in the chain (paravertebral) ganglia
- fibers from T5-L2 form splanchnic nerves and synapse with collateral ganglia
- postganglionic fibres innervate the numerous organs of the body

Sympathetic Trunks an Pathways

- a preoganglionic fiber follows one of three pathways upon entering the paravertebral ganglia
    1. Synapse with the ganglionic neuron within the same ganglion
    2. Ascend or descend the sympathetic chain to synapse in another chain ganglion
    3. Pass through the chain ganglion and emerge without synapsing

Role of the Parasympathetic Division

- concerned with keeping body energy
- involves the D activities - digestion, defecation, and diuresis
- its activity is illustrated in a person who relaxes after a meal
    - blood pressure, heart rate, and respiratory rates are low
    - gastrointestinal tract activity is high
    - the skin is warm and the pupils are constricted

Parasympathetic Division Outflow

Cranial Outflow	Cranial Nerve	Ganglion	Effector Organ(s)
	Oculomotor (III)	Ciliary	Eye
	Facial (VII)	Pterygopalatine Submandibular	Salivary, nasal, and lacrimal glands
	Glossopharyngeal (IX)	Otic	Parotid salivary glands
	Vagus (X)	Located within the walls of target organs	Heart, lungs, and most visceral organs
Sacral Outflow	S_2-S_4	Located within the walls of the target organs	Large intestine, urinary bladder, ureters, and reproductive organs

Division	Origin of Fibers	Length of Fibers	Location of Ganglia
Sympathetic	Thoracolumbar region of the spinal cord	Short preganglionic and long postganglionic	Close to the spinal cord
Parasympathetic	Brain and sacral spinal cord (craniosacral)	Long preganglionic and short postganglionic	In the visceral effector organs

Neurotransmitters and Receptors

Neurotransmitter Effects

- All somatic motor neurons release acetylcholine (ACh), which has an excitatory effect
- In the ANS:
  - Preganglionic fibers release ACh
  - Postganglionic fibers release norepinephrine or ACh and the effect is either stimulatory or inhibitory
  - ANS effect on the target organ is dependent upon the neurotransmitter released and the receptor type of the effector

Neurotransmitters and Receptors

- Acetylcholine (ACh) and norepinephrine (NE) are the two major neurotransmitters of the ANS
- ACh is released by all preganglionic axons and all parasympathetic postganglionic axons
- Cholinergic fibers - parasympathetic postganglionic ACh-releasing fibers
- Adrenergic fibers - sympathetic postganglionic axons that release NE
- Neurotransmitter effects can be excitatory or inhibitory depending upon the receptor type

Cholinergic Receptors

- two types of receptors that bind ACh are nicotinic and muscarinic
- these are named after drugs that bind to them and mimic Each effects

Nicotinic Receptors

- Nicotinic receptors are found on:
  - motors end plates (somatic targets)
  - all ganglionic neutrons of both sympathetic and parasympathetic divisions
  - the hormone-producing cells of the adrenal medulla
- the effect of ACh binding to nicotinic receptors is always stimulatory

Muscarinic Receptors

- Muscarinic receptors occur on all effector cells innervated by postganglionic cholinergic fibres (all parasympathetic a sympathetic to sweat glands)
- The effect of ACh binding:
    - can be either inhibitory or excitatory
    - depends on the receptor type of the target organ

Effects of Drugs

- Atropine: blocks parasympathetic effects
- Neostigmine: inhibits acetylcholinesterase and is used to treat myasthenia gravis
- Tricyclic antidepressants: prolong the activity of NE on postsynaptic membranes
- Over-the-counter drugs (for colds, allergies, and nasal congestion): stimulate α-adrenergic receptors
- Beta-blockers: attach mainly to β_1 receptors and reduce heart rate and prevent arrhythmias (beta blockers and performance anxiety in musicians)

Interactions of the Autonomic Divisions

- most visceral organs are innervated by both sympathetic and parasympathetic fibres
- this results in dynamic antagonisms that precisely control visceral activity
- sympathetic fibres increase heart and respiratory rates, and inhibit digestion and elimination
- parasympathetic fibers decrease and heart and respiratory rates, and allow for digestion and the discarding of wastes

Sympathetic Tone

- the sympathetic division controls blood pressure and keeps the blood vessels in a continual state of partial constriction
- this sympathetic tone (vasomotor tone):
    - constricts blood vessels and causes blood pressure to rise as needed
    - prompts vessels to dilate if blood pressure is to be decreased
- Alpha-blocker drugs interfere with vasomotor fibres and are used to treat hypertension

Parasympathetic Tone

- Parasympathetic tone:
    - slows the heart
    - dictates normal activity levels of the digestive and urinary systems
- the sympathetic division can override these effects during times of stress
- drugs that block parasympathetic responses increase heart rate and block focal urinary retention

Thermoregulatory Responses to Heat

- Applying heat to the skin causes reflex dilation of blood vessels
- Systemic body temperature elevation results in widespread dilation of blood vessels
- This dilation brings warm blood to the surface and activates sweat glands to cool the body

- When temperature falls, blood vessels constrict and blood is retained in deeper vital organs

Referred Pain

- Pain stimuli arising from the viscera are perceived as somatic in origin
- this may be due to the fact that visceral pain afferents travel along the same pathways as somatic pain fibres

TABLE 14.1 Anatomical and Physiological Differences Between the Parasympathetic and Sympathetic Divisions

CHARACTERISTIC	PARASYMPATHETIC	SYMPATHETIC
Origin	Craniosacral outflow: brain stem nuclei of cranial nerves III, VII, IX, and X; spinal cord segments S_2–S_4.	Thoracolumbar outflow: lateral horns of gray matter of spinal cord segments T_1–L_2.
Location of ganglia	Ganglia (terminal ganglia) are within the visceral organ (intramural) or close to the organ served.	Ganglia are within a few centimeters of CNS: alongside vertebral column (sympathetic trunk ganglia) and anterior to vertebral column (collateral, or prevertebral, ganglia).
Relative length of pre- and postganglionic fibers	Long preganglionic; short postganglionic.	Short preganglionic; long postganglionic.
Rami communicantes	None.	Gray and white rami communicantes. White rami contain myelinated preganglionic fibers; gray contain unmyelinated postganglionic fibers.
Degree of branching of preganglionic fibers	Minimal.	Extensive.
Functional role	Maintenance functions; conserves and stores energy: "rest and digest."	Prepares body for activity: "fight-or-flight."
Neurotransmitters	All preganglionic and postganglionic fibers release ACh (are cholinergic fibers).	All preganglionic fibers release ACh. Most postganglionic fibers release norepinephrine (are adrenergic fibers); postganglionic fibers serving sweat glands and some blood vessels of skeletal muscles release ACh. Neurotransmitter activity is augmented by release of adrenal medullary hormones (norepinephrine and epinephrine).

TABLE 14.2 Cholinergic and Adrenergic Receptors

NEUROTRANSMITTER	RECEPTOR TYPE	MAJOR LOCATIONS*	EFFECT OF BINDING
Acetylcholine	**Cholinergic**		
	Nicotinic	All ganglionic neurons; adrenal medullary cells (also neuromuscular junctions of skeletal muscle)	Excitation
	Muscarinic	All parasympathetic target organs	Excitation in most cases; inhibition of cardiac muscle
		Limited sympathetic targets:	
		• Eccrine sweat glands	Activation
		• Blood vessels in skeletal muscles	Vasodilation (may not occur in humans)
Norepinephrine (and epinephrine released by adrenal medulla)	**Adrenergic**		
	β_1	Heart predominantly, but also kidneys and adipose tissue	Increases heart rate and strength; stimulates renin release by kidneys
	β_2	Lungs and most other sympathetic target organs; abundant on blood vessels serving the heart, liver and skeletal muscle	Effects mostly inhibitory; dilates blood vessels and bronchioles, relaxes smooth muscle walls of digestive and urinary visceral organs; relaxes uterus
	β_3	Adipose tissue	Stimulates lipolysis by fat cells
	α_1	Most importantly blood vessels serving the skin, mucosae, abdominal viscera, kidneys, and salivary glands; also, virtually all sympathetic target organs except heart	Constricts blood vessels and visceral organ sphincters; dilates pupils of the eyes
	α_2	Membrane of adrenergic axon terminals; pancreas; blood platelets	Inhibits NE release from adrenergic terminals; inhibits insulin secretion by pancreas; promotes blood clotting

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

TABLE 14.3 Selected Drug Classes That Influence the Activity of the Autonomic Nervous System

DRUG CLASS	RECEPTOR BOUND	EFFECTS	EXAMPLE	CLINICAL USE
Nicotinic agents (little therapeutic value, but important because of presence of nicotine in tobacco)	Nicotinic ACh receptors on all ganglionic neurons and in CNS	Typically stimulation of sympathetic effects; blood pressure increases	Nicotine	Used in smoking cessation products
Parasympathomimetic agents (muscarinic agents)	Muscarinic ACh receptors	Mimic effects of ACh, enhance parasympathetic effects	Pilocarpine	Glaucoma (opens aqueous humor drainage pores)
			Bethanechol	Difficulty urinating (increases bladder contraction)
Acetylcholinesterase inhibitors	None; bind to the enzyme (AChE) that degrades ACh	Indirect effect at all ACh receptors; prolong the effect of ACh	Neostigmine	Myasthenia gravis (increases availability of ACh)
			Sarin	Used as chemical warfare agent (similar to widely used insecticides)
Sympathomimetic agents	Adrenergic receptors	Enhance sympathetic activity by increasing NE release or binding to adrenergic receptors	Albuterol (Ventolin)	Asthma (dilates bronchioles by binding to β_2 receptors)
			Phenylephrine	Colds (nasal decongestant, binds to α_1 receptors)
Sympatholytic agents	Adrenergic receptors	Decrease sympathetic activity by blocking adrenergic receptors or inhibiting NE release	Propranolol	Hypertension (member of a class of drugs called *beta-blockers* that decrease heart rate and blood pressure)

TABLE 14.4 Effects of the Parasympathetic and Sympathetic Divisions on Various Organs

TARGET ORGAN OR SYSTEM	PARASYMPATHETIC EFFECTS	SYMPATHETIC EFFECTS
Eye (iris)	Stimulates sphincter pupillae muscles; constricts pupils	Stimulates dilator pupillae muscles; dilates pupils
Eye (ciliary muscle)	Stimulates muscle, which results in bulging of the lens for close vision	Weakly inhibits muscle, which results in flattening of the lens for far vision
Glands (nasal, lacrimal, gastric, pancreas)	Stimulates secretory activity	Inhibits secretory activity; causes vasoconstriction of blood vessels supplying the glands
Salivary glands	Stimulates secretion of watery saliva	Stimulates secretion of thick, viscous saliva
Sweat glands	No effect (no innervation)	Stimulates copious sweating (cholinergic fibers)
Adrenal medulla	No effect (no innervation)	Stimulates medulla cells to secrete epinephrine and norepinephrine
Arrector pili muscles attached to hair follicles	No effect (no innervation)	Stimulates contraction (erects hairs and produces "goosebumps")
Heart (muscle)	Decreases rate; slows heart	Increases rate and force of heartbeat
Heart (coronary blood vessels)	No effect (no innervation)	Causes vasodilation*
Urinary bladder/urethra	Causes contraction of smooth muscle of bladder wall; relaxes urethral sphincter; promotes voiding	Causes relaxation of smooth muscle of bladder wall; constricts urethral sphincter; inhibits voiding
Lungs	Constricts bronchioles	Dilates bronchioles*

*Effects are mediated by epinephrine release into the bloodstream from the adrenal medulla.

TABLE 14.4 Effects of the Parasympathetic and Sympathetic Divisions on Various Organs

TARGET ORGAN OR SYSTEM	PARASYMPATHETIC EFFECTS	SYMPATHETIC EFFECTS
Digestive tract organs	Increases motility (peristalsis) and amount of secretion by digestive organs; relaxes sphincters to allow movement of foodstuffs along tract	Decreases activity of glands and muscles of digestive system and constricts sphincters (e.g., anal sphincter)
Liver	Increases glucose uptake from blood	Stimulates release of glucose to blood*
Gallbladder	Excites (gallbladder contracts to expel bile)	Inhibits (gallbladder is relaxed)
Kidney	No effect (no innervation)	Promotes renin release; causes vasoconstriction; decreases urine output
Penis	Causes erection (vasodilation)	Causes ejaculation
Vagina/clitoris	Causes erection (vasodilation) of clitoris; increases vaginal lubrication	Causes contraction of vagina
Blood vessels	Little or no effect	Constricts most vessels and increases blood pressure; constricts vessels of abdominal viscera and skin to divert blood to muscles, brain, and heart when necessary; NE constricts most vessels; epinephrine dilates vessels of the skeletal muscles during exercise*
Blood coagulation	No effect (no innervation)	Increases coagulation*
Cellular metabolism	No effect (no innervation)	Increases metabolic rate*
Adipose tissue	No effect (no innervation)	Stimulates lipolysis (fat breakdown)

*Effects are mediated by epinephrine release into the bloodstream from the adrenal medulla.

April 6-7

Higher Mental Functions

pages 452-459
- Higher mental functions
- Explain the electroencephalogram and describe the brain waves
- Describe the stages of sleep and discuss their functions
- Describe the stages of memory, categories of memory, and discuss the processes involved in transfer of information

Consciousness
- encompasses perception of sensation, voluntary initiation and control of movement, and capabilities associated with higher mental processing
- involves simultaneous activity of large areas of the cerebral cortex
- is superimposed on other types of neural activity
- clinical consciousness is defined on a continuum that grades level of behaviour - alertness, drowsiness, stupor, coma

Reticular Formation
- Composed of three broad columns along the length of the brain stem
    - raphe nuclei
    - medial (large cell) group
    - lateral (smaal cell) group
- has far-flung axonal connections with hypothalamus, thalamus, cerebellum, and spinal cord
- crucial for maintaining the state of consciousness
- located in the brainstem
- bilateral damage can lead to permanent coma
- the area affected by many psychotropic coma
- general anesthetics, bar-biturates, alcohol, etc, affect the reticular formation

Reticular Formation: RAS and Motor Function
- RAS- Reticular Activating System
    - sends impulses to the cerebral cortex to keep it conscious and alert
    - filters out repetitive and weak stimuli
- Motor function
    - helps control coarse motor movements
    - autonomic enters regulate visceral motor functions - e.g., vasomotor, cardiac, and respiratory centres

Brain Waves

- Normal bran function involves continuous electrical activity
- An electroencephalogram (EEG) records this activity
- patterns of neuronal electrical activity recorded are called brain waves, originating from cortical post-synaptic responses
- each person's brain waves are unique
- continuous train of peaks and troughs
- wave frequency is expressed in Hertz (Hz)

Types of Brain Waves

- Alpha waves: regular, rhythmic, low-amplitude, slow, synchronous waves indicating an "idling" brain
- Beta waves: rhythmic, more irregular waves occurring during the awake and mentally alert state
- Theta waves: more irregular than alpha waves, common in children but abnormal in adults
- Delta waves: high-amplitude waves seen in deep sleep and when reticular activating system is damped, (amplitude= synchronization)

State of the Brain

- Change with age, sensory stimuli, brain disease, and the chemical state of the body
- EEGs used to diagnose and localize brain lesions, tumors, infarcts, infections, abscesses, and epileptic lesions
- a flat EEG (no electrical activity) is clinical evidence of death

Epilepsy

- A victim of epilepsy may lose consciousness, fall stiffly, and have uncontrollable jerking, characteristic of epileptic seizure
- epilepsy is not associated with, nor does it cause, intellectual impairments
- epilepsy occurs in 1% of the population

Epileptic Seizures

-absence seizures, or petit mal - mild seizures seen in young children where the expression goes blank
-grand mal seizures - victim loses consciousness, bones may be broken due to intense convulsions
-difference if spread of activation to motor cortex (Rolandic)

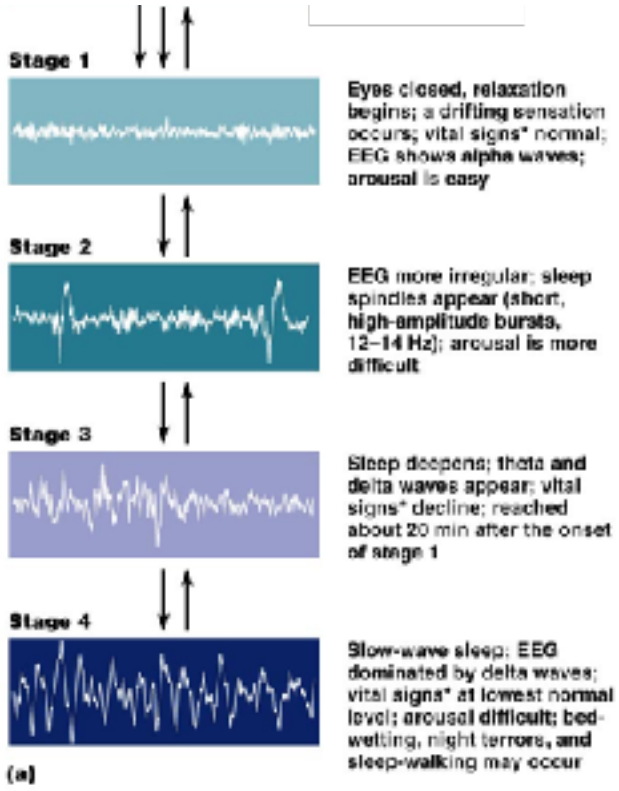
Control of Epilepsy

- epilepsy can usually be controlled with anti-convulsive drugs
- valproic acid, a nonsedatin drug, enhances GABA and is a drug of choice
- vagus nerve stimulators can be implanted under the skin of the chest and can keep electrical activity of the brain from becoming chaotic

Sleep

Types of Sleep

- There are two major types of sleep:
  - non-rapid eye movement (NREM)
  - rapid eye movement (REM)
- one passes through four stages of NREM during the first 30-45 minutes of sleep
- REM sleep occurs after the fourth NREM stage has been achieved



Types and Stages of Sleep: NREM

- NREM stages include:
  - **Stage 1**: eyes closed, relaxation begins, EEG shows alpha waves, one can be easily aroused
  - **Stage 2**: EEG pattern is irregular with sleep spindles (high-voltage wave bursts), arousal is more difficult
  - **Stage 3**: sleep deepens, theta + delta waves appear, vital signs decline, dreaming is common
  - **Stage 4**: EEG pattern is dominated by delta waves, skeletal muscles are relaxed, arousal is difficult

Types and Stages of Sleep: REM

- characteristics of REM sleep

- EEG pattern reverts through the NREM stages to the stage 1 pattern
- Vital signs increase
- Skeletal muscles (except ocular muscles) are inhibited
- most dreaming takes place

Sleep Patterns

- alternating cycles of sleep and wakefulness reflect a natural circadian rhythm
- although RAS activity declines in sleep, sleep is more than turning off RAS
- the brain is actively guided into sleep
- the nuclei of the hypothalamus regulate the sleep cycle: orexin receptor deficits - narcolepsy
- a typical sleep pattern alternates between REM and NREM sleep

Importance of Sleep

- slow-wave sleep is presumed to be the restorative stage
- those deprived of REM sleep become moody and depressed
- REM sleep may be a reverse learning process where superfluous information is purged from the brain
- daily sleep requirements decline with age
- "renormalizing synapses to a baseline level that is sustainable and ensures cellular homeostasis"

Sleep Disorders

- Narcolepsy - lapsing abruptly into sleep from the awake state
- Insomnia - chronic inability to obtain the amount or quality of sleep needed
- Sleep apnea - temporary cessation of breathing during sleep

Language

- involves all areas of the association cortex on the left side of the brain
- two critically important regions:
  - Broca's area - production of language
  - Wernicke's area - comprehension of language
- non-dominan hemisphere is involved in nonverbal emotional components of language - tone of our voice, gestures, ability to understand the emotional context of speech

Memory

- Memory is the storage and retrieval of information
- The three principles of memory are:
  - **Storage** - occurs in stages and is continually changing
  - **Processing** - accomplished by the hippocampus and surroundings structures
  - **Memory traces** - chemical or structural changes that encode memory

Stages of Memory

- the two stages of memory are short-term memory and long-term memory
- short-term memory (STM, or working memory) - a fleeting memory of the events that continually happen
- STM lasts seconds to hours and is limited to 7 to 8 pieces of information
- long-term memory (LTM) has limitless capacity

Transfer from STM to LTM

- factors that effect transfer of memory from STM to LTM include:
    - emotional state (we learn best when we are alert, motivated, and aroused)
    - Rehearsal (repeating or rehearsing material enhances memory)
    - Association (associating new information with old memories in LTM enhances memory)
    - Automatic memory (subconscious information stored in LTM)

Categories of Memory

- two categories of memory: fact memory and skill memory
- Fact (declarative) memory:
    - entails learning exploit information
    - is related to our conscious thoughts and our language ability
    - is stored with the context in which it was learned

Skill Memory

- skill memory is less conscious than fact memory and involves motor activity
- it is acquired through practice
- skill memories do not retain the context in which they were learned

Structures Involved in Fact Memory

- fact memory involves the following brain areas:
    - hippocampus and the amygdala, both limbic system structures
    - specific areas of the thalamus and hypothalamus of the diencephalon
    - ventromedial prefrontal cortex and the basal forebrain (releases ACh)

Structures Involved in Skill Memory

- skill memory involves:
    - Corpus striatum (basal ganglia) - mediates the automatic connections between a stimulus and a motor response
    - Portion of the brain receiving the stimulus
    - Premotor and motor cortex

Mechanisms of Memory

- Neuronal RNA content is altered
- Dendritic spines change shape
- Extracellular proteins are deposited at synapses involved in LTM
- Number and size of presynaptic terminals may increase
- More neurotransmitter is released by presynaptic neutrons
- New hippocampal neutrons appear