بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Nervous System (NS) – Cerebral Cortex

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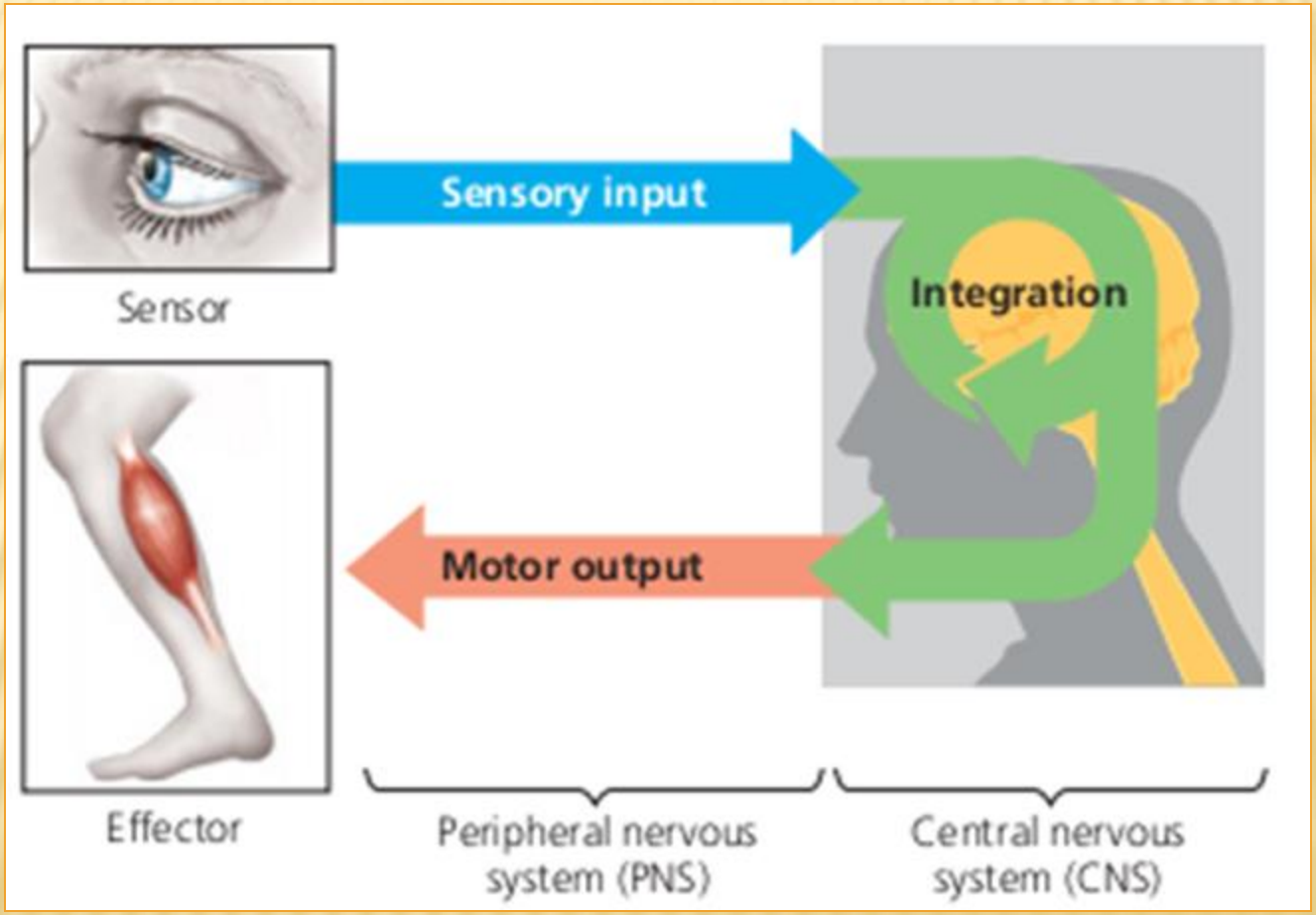
Organization of the Nervous System

- Based on differences in the structure, location, and functions, nervous system is subdivided into:

1. Central nervous system (CNS)
   - Brain and spinal cord
   - Contained within bone
2. Peripheral nervous system (PNS)
   - All nerve tissue outside CNS
   - Cranial and spinal nerves
   - Sensory & motor divisions

Generalized Model of Function of NS

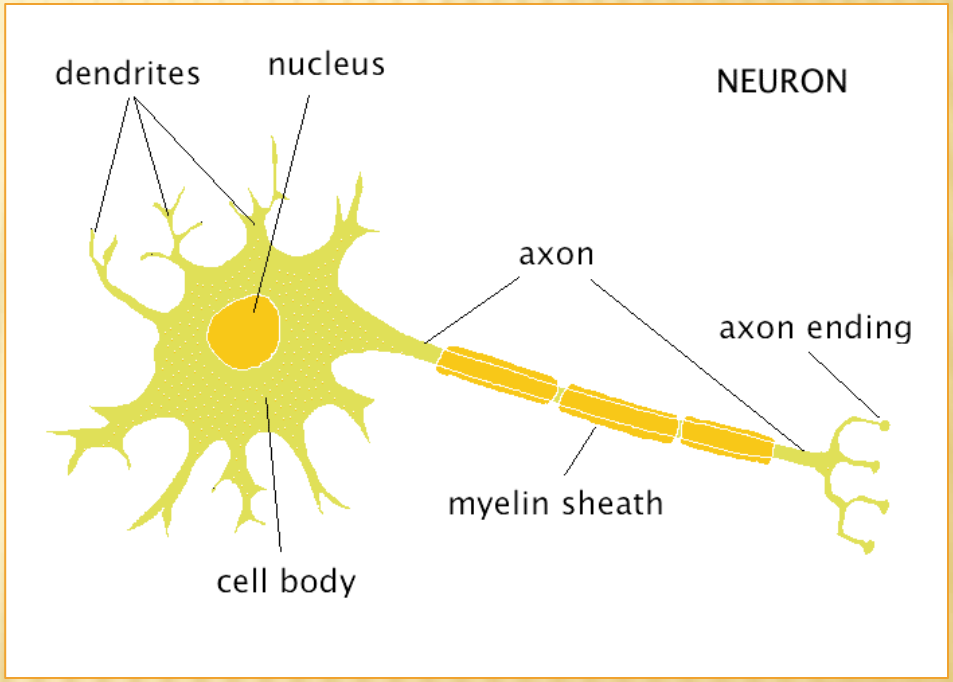


Cells of the Nervous System

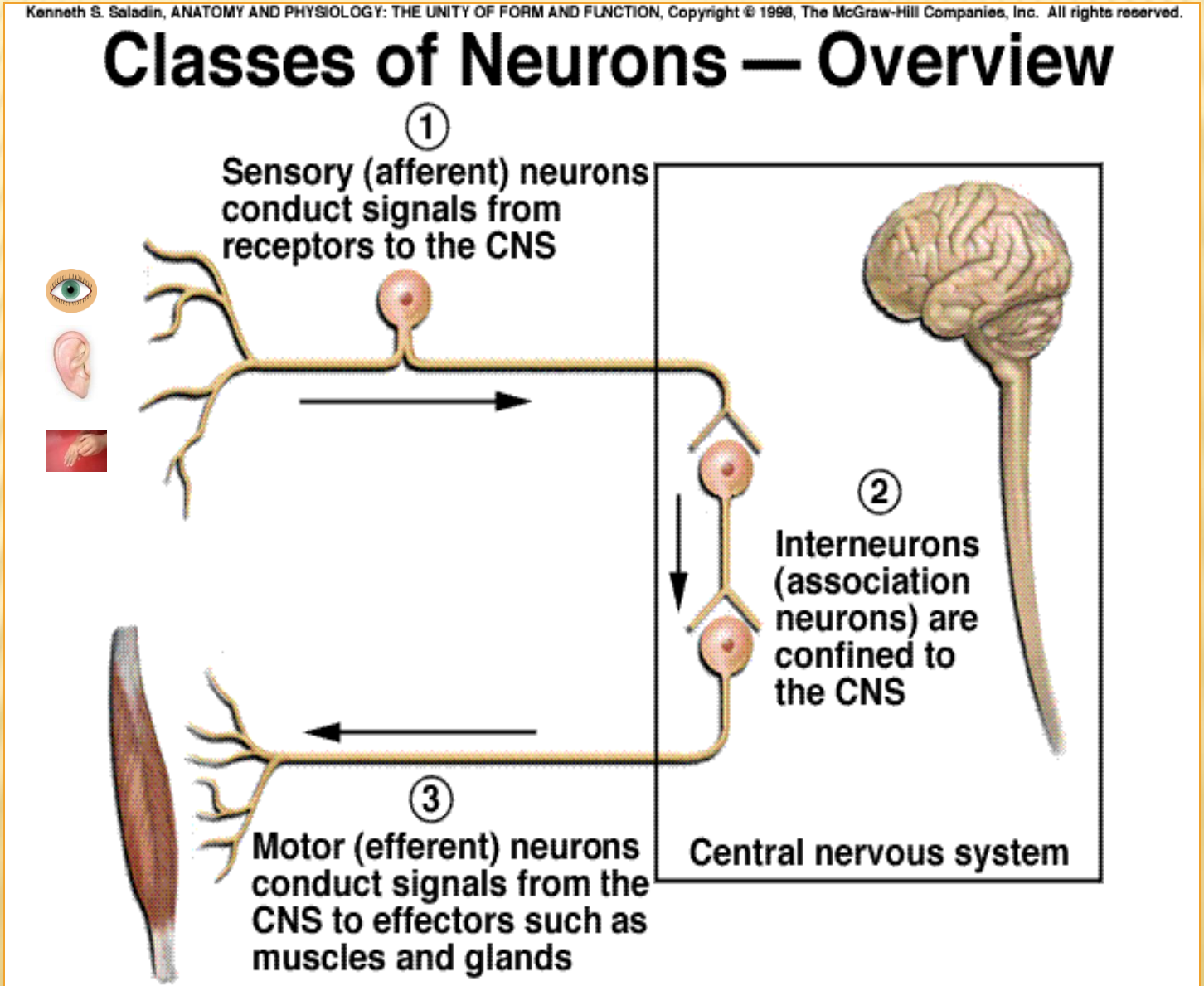
- Consists of 2 kinds of cells:
  - Neurons: functional units of NS
  - Supporting cells (= glial cells)
    - Maintain homeostasis
    - Are 5X more common than neurons
    - Schwann and satellite cells in the PNS
    - Oligodendrocytes, microglia, astrocytes and ependymal cells in the CNS

Neurons

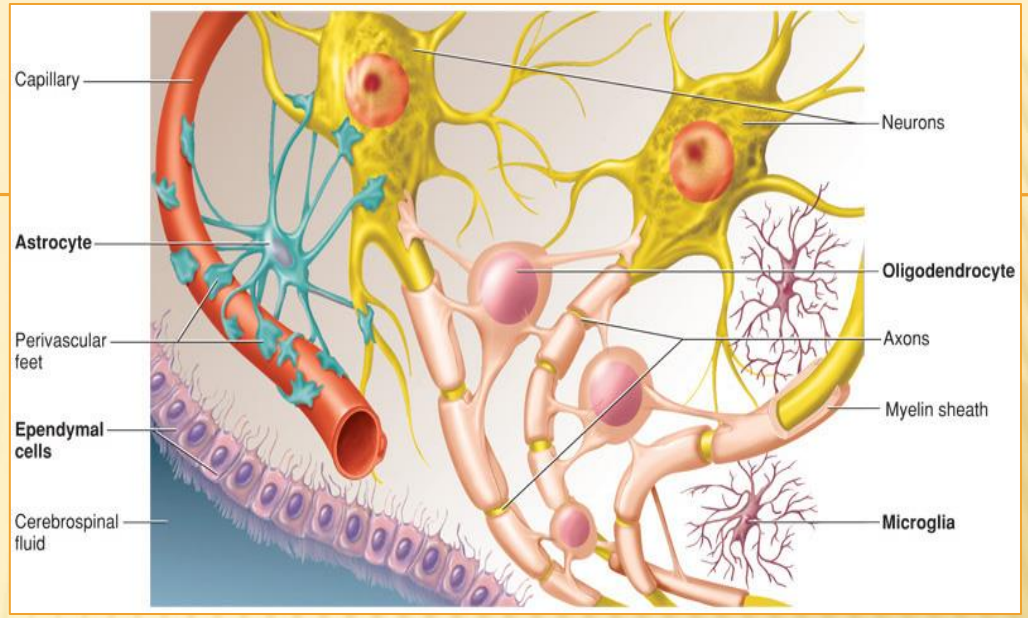
- **Gather and transmit information by:**
  - Responding to stimuli
  - Producing and sending electrochemical impulses
  - Releasing chemical messages
- **Have a cell body, dendrites and axon**
  - **Cell body**:
    - contains the nucleus
    - Cell body is the nutritional center and makes macromolecules
    - Groups of cell bodies in CNS are called nuclei; in PNS are called ganglia
  - **Dendrites** receive information, convey it to cell body
  - **Axons** conduct impulses away from cell body



Functional Classes of Neurons



Functions of the Glial Cells



Neuroglia	Function
Schwann Cells	surround axons of all peripheral nerve fibres, form the myelin sheath.
Oligodendrocytes	form myelin sheath around central axons producing the white matter of central nervous system.
Astrocytes	cover capillaries of brain to form the blood brain barrier and help regulate passage of molecules from blood to brain.
Ependyma	line the ventricles or brain cavities and central canal of spinal cord.
Microglia	phagocytic amoeboid cells in central nervous system that remove foreign and degenerate material from the brain.

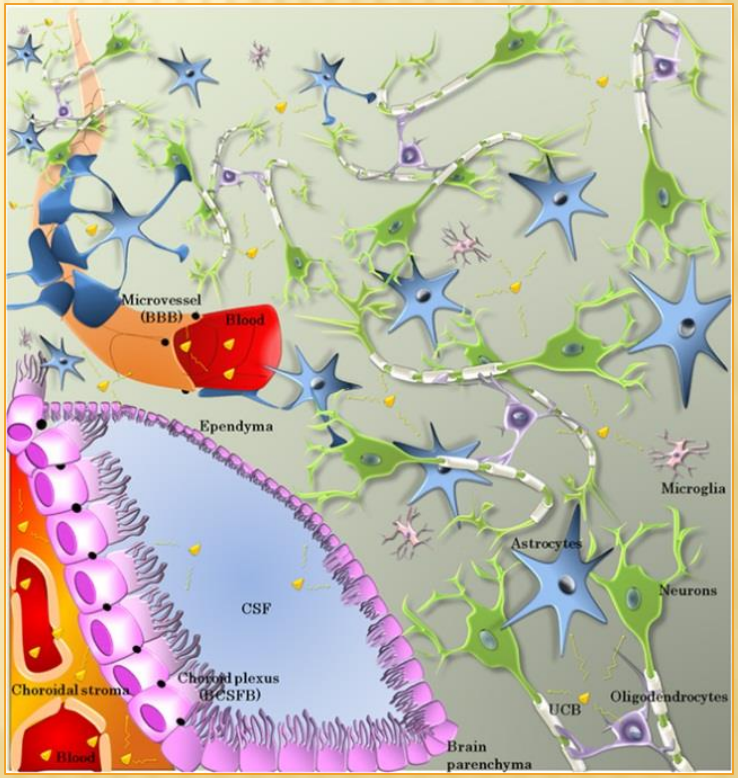
Protection of CNS

- Enclosed by hard, bony structures (skull bones)
- Wrapped by three protective and nourishing membranes – meninges
- Floats in cushioning fluid – cerebrospinal fluid (CSF)
- Blood-brain barrier (BBB) limits access of blood-borne materials into brain tissue

Cerebrospinal Fluid (CSF)

- Four major fluid compartments in the brain:

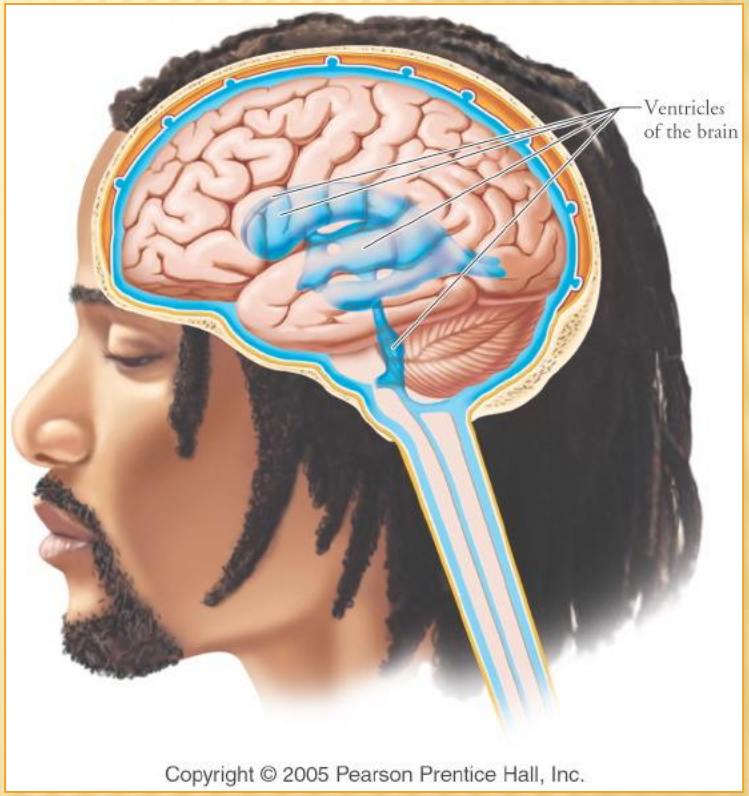
1. **blood** that flows through entire brain structures
2. **interstitial fluid** bathing neurons and neuroglia
3. **cerebrospinal fluid (CSF)**, circulates around brain ventricles, and spinal cord
4. **intracellular fluid** within brain cells



Gazzin et al., 2012

Cerebrospinal Fluid (CSF)

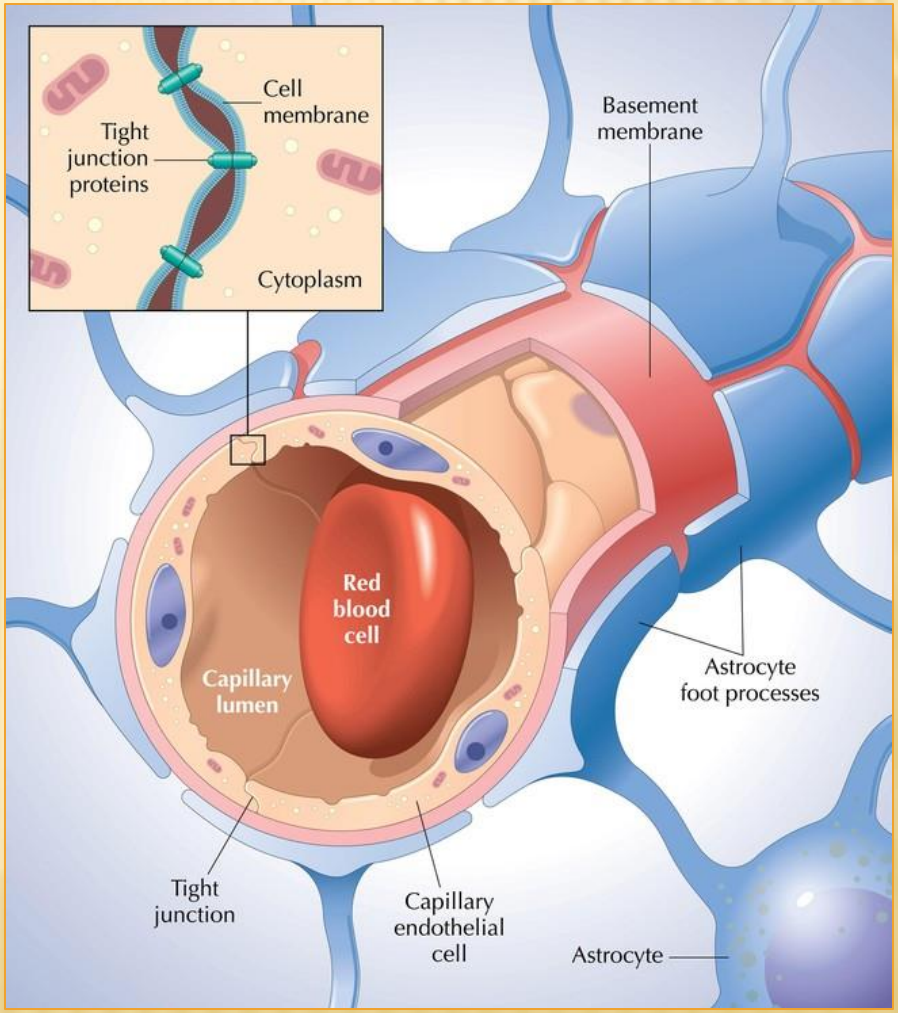
- **CSF**: colorless protein-poor serous plasma filtrate surrounding brain & spinal cord,
  - ≈ 150 mL
  - Occupying mainly the ventricular system, the subarachnoid space, and the central canal of the spinal cord



- **CSF functions:**
  - Shock absorption; fluid cushion for the brain and spinal cord
  - Second circulatory fluid; delivering oxygen and nutrients to the nervous tissue
  - Major route for removing potentially harmful brain metabolites; Serves as a lymphatic system for the brain
  - Allows the brain to float, thereby reducing its effective weight in situ
  - Conduit for hormones that are secreted by hypothalamic neurons and act at remote sites in the brain

Blood Brain Barrier (BBB)

- Between the blood and brain fluid (at capillaries)
- All over the brain except some areas e.g., hypothalamus
- Allows only certain compounds to enter brain
- Capillaries are not as leaky as those in body
  - Gaps between adjacent cells are closed by tight junctions
- Consists of:
  - capillary endothelial cells + their basement membranes
  - the processes of astrocytes (astrocytic endfeet)



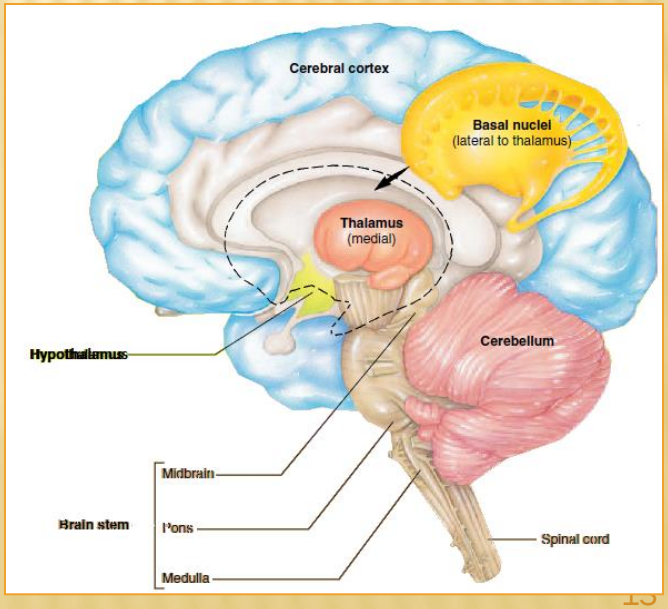
The Central Nervous System (CNS)

- Consists of:
  1. The brain
  2. Spinal cord

The Brain

- **Major brain functions (Brain functions as a whole (neurons linked via synapsis):**
  - ✓ Regulates internal environment
  - ✓ Experiences emotions
  - ✓ Voluntarily controls movements
  - ✓ Perceives own body and surroundings
  - ✓ Engages in other higher cognitive processes (e.g. thought and memory)

- **Brain Regions**
  1. Brain stem (Medulla, pons, midbrain)
  2. Cerebellum
  3. Forebrain
     a. Diencephalon
        - Hypothalamus
        - Thalamus
     b. Cerebrum
        - Basal nuclei
        - Cerebral cortex

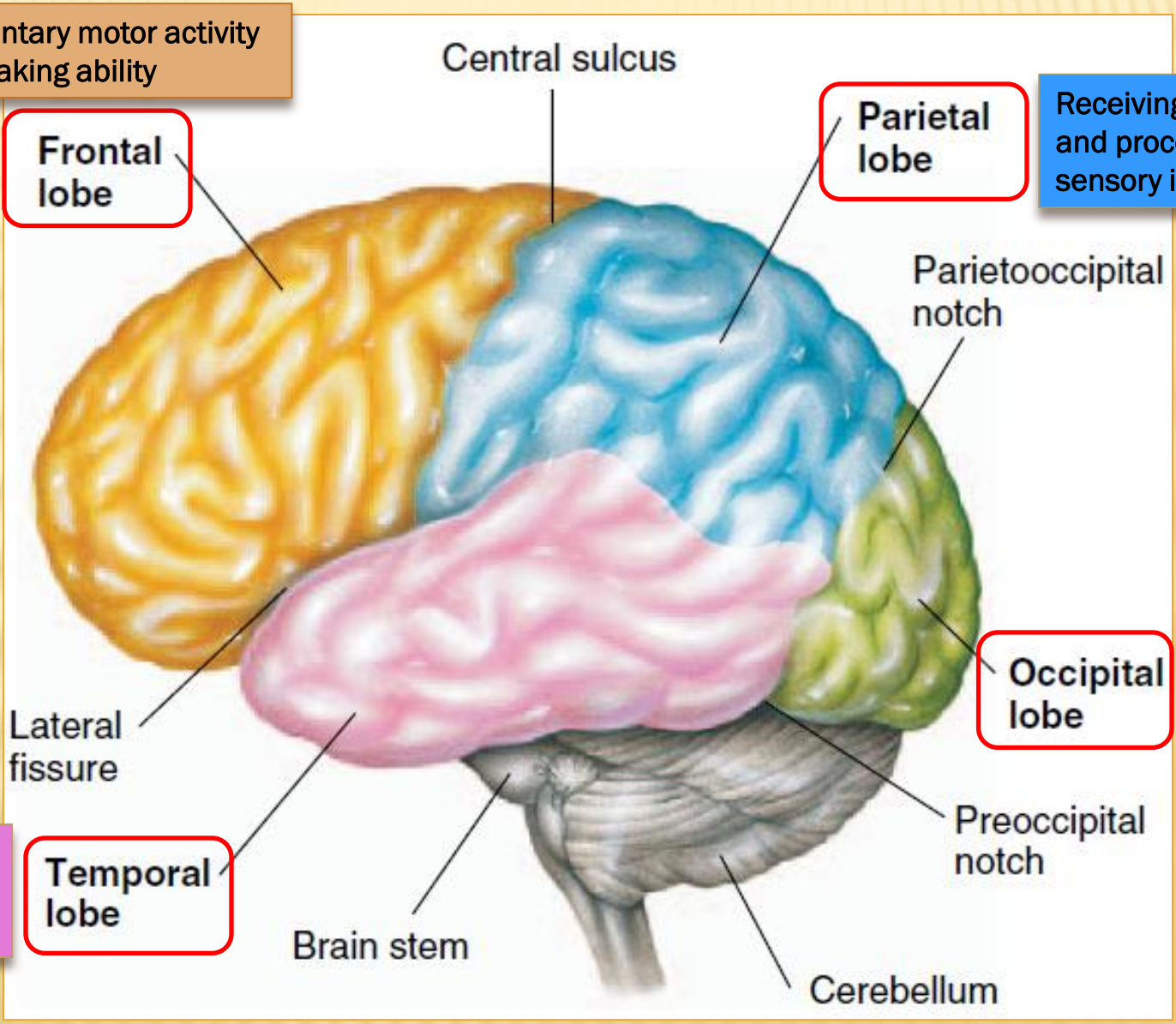


Cerebral Cortex

- The outermost sheet of neural tissue (gray matter) of the cerebrum of the brain
  - Convoluted
  - Total surface area: 2200 cm2 (2.5 ft2)
  - Thickness: 1.5 mm - 4.5 mm
  - Weight: 600 gm (40 % of total brain weight)
  - 180 gm --------- neurons (10-15 billion neurons)
  - 420 gm --------- glial cells
- Function: motor control of the body & information processing center

Functions of Cortical Lobes

- Voluntary motor activity
- Speaking ability



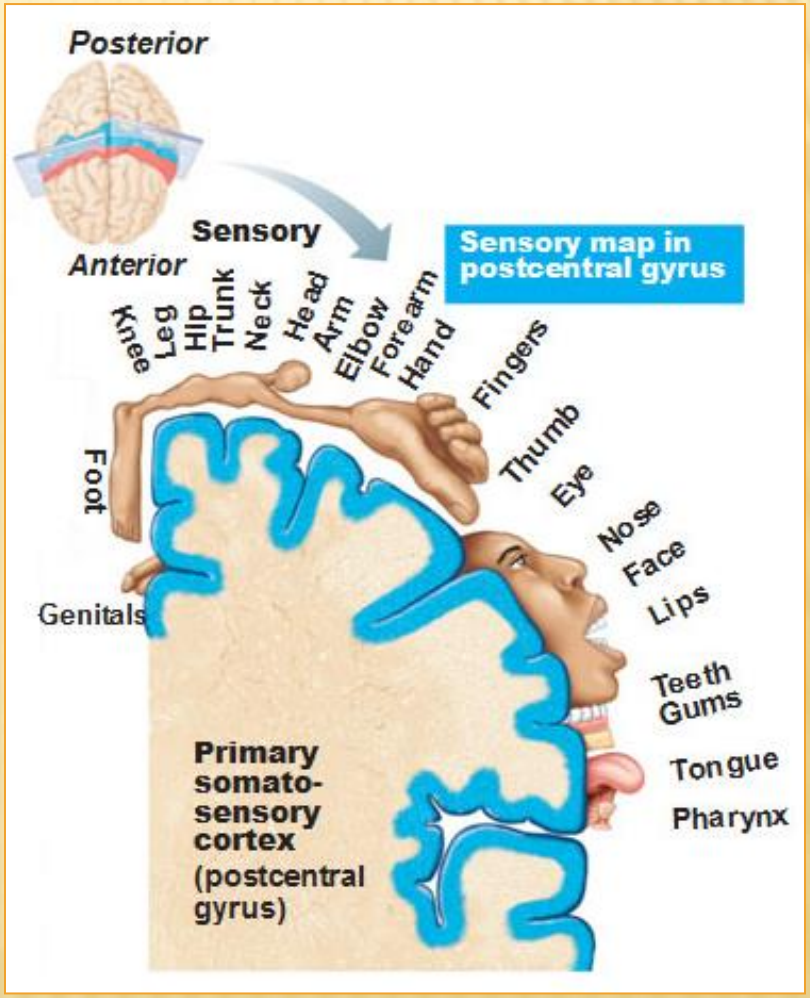
Receiving and processing sensory input

Initial processing of visual input

sound (auditory) sensation

Somatosensory Cortex

- The somatosensory cortex:
  - ✓ located in the front portion of each parietal lobe
  - ✓ Immediately behind the central sulcus
  - ✓ Post-central gyrus
- It is the site for initial cortical processing and perception of:
  - Somesthetic input (sensations from the surface of the body, such as touch, pressure, heat, cold, and pain)
  - Proprioceptive input (awareness of body position)
- Each region within the somatosensory cortex receives input from a specific area of the body.
- Different parts of the body are not equally represented
- The size of each body part in this homunculus indicates the relative proportion of the somatosensory cortex devoted to that area. (e.g., fingers >>> trunk)
- Reception of opposite side inputs

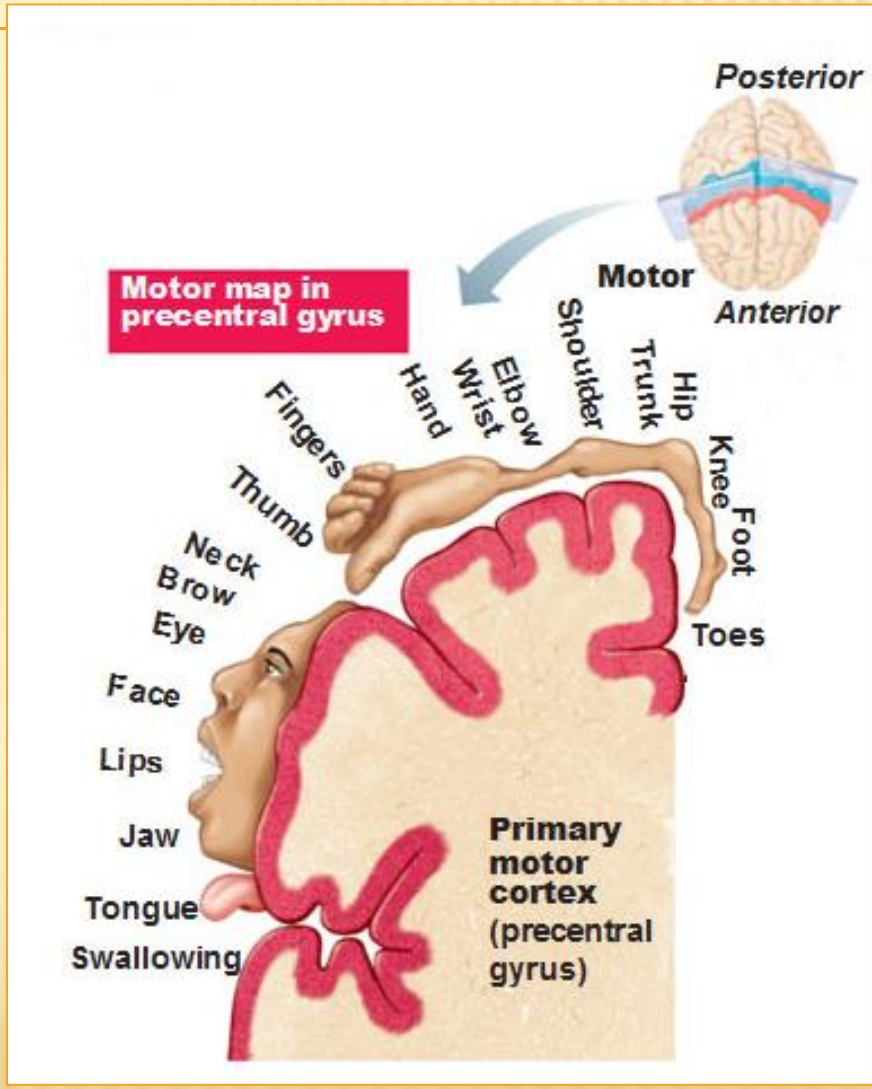


Sensory Homunculus

Proportional representation of the different body parts and areas in brain hemispheres

Primary Motor Cortex

- **Primary motor cortex:**
  - ✓ Immediately in front of the central sulcus
  - ✓ Pre-central gyrus
  - ✓ Next to the somatosensory cortex
- Confers voluntary control over movement produced by skeletal muscles.
- Controls opposite side muscles of the body
- The extent of representation in the motor cortex is proportional to the precision and complexity of motor skills required of the respective part
- **E.g., lips are >>> trunk area**



Motor Homunculus

Proportional representation of the different body parts and areas in brain hemispheres

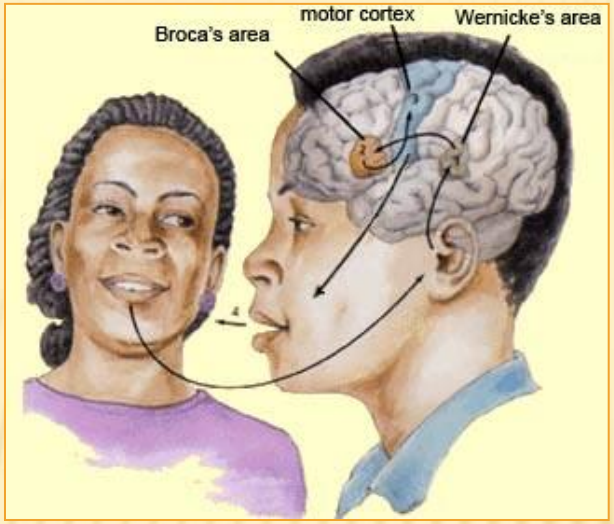
Brain Plasticity

- When an area of the brain associated with a particular activity is destroyed, other areas of the brain may gradually assume some or all of the functions of the damaged region

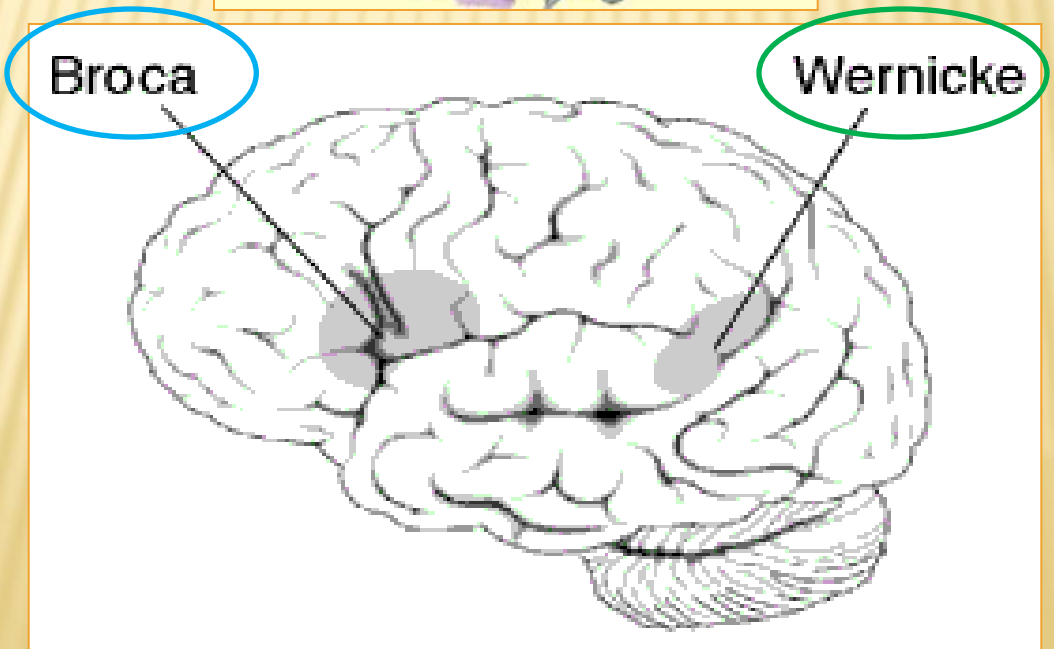
- Mechanism:

??? formation of new neural pathways (not new neurons, but new connections between existing neurons)

Control of Language



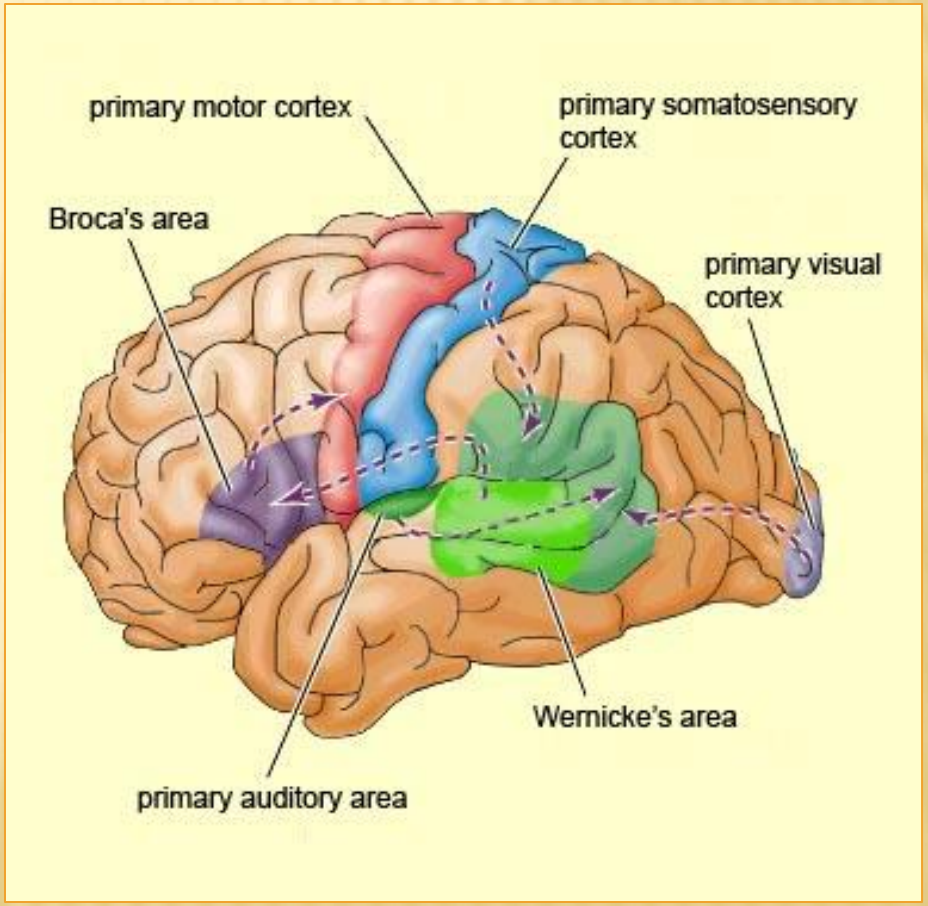
motor output
(language output)
- vocalization



sensory input
(language input)
- Vision
- Hearing

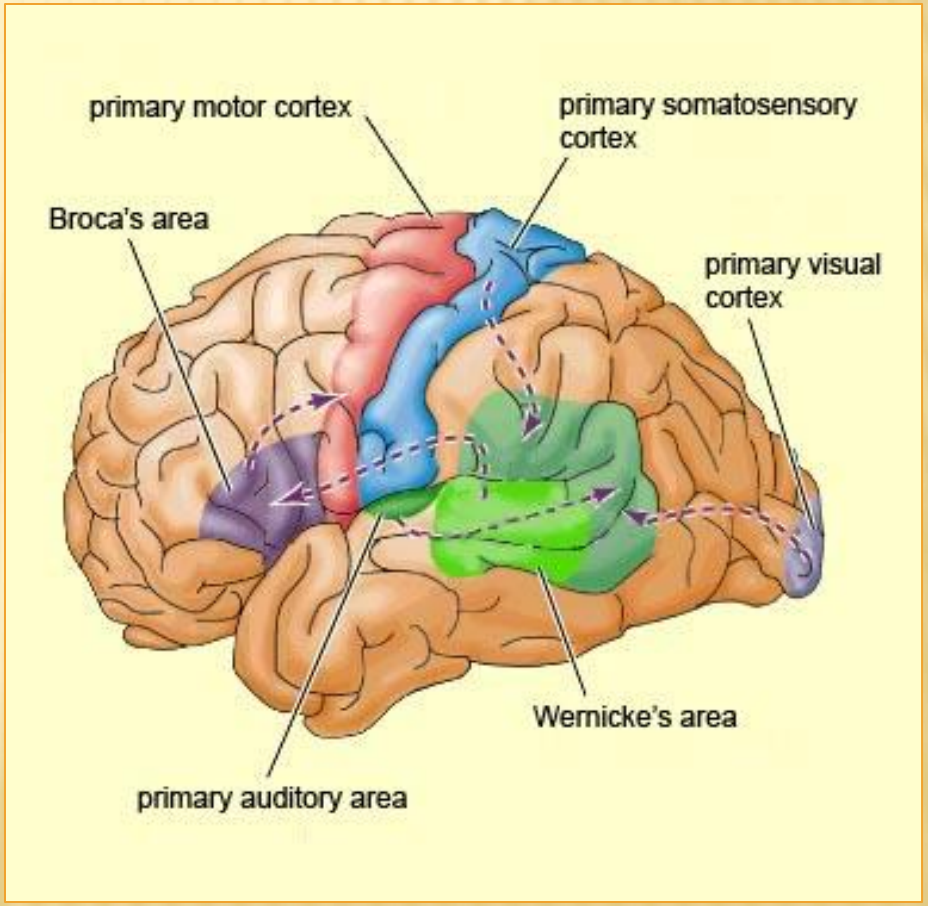
Wernicke's Area

- Role with the language comprehension;
  - ✓ Formulating coherent patterns of speech that are transferred via a bundle of fibers to broca's area
  - ✓ Understanding both spoken and written messages
  - ✓ Inputs from
    - i. Visual cortex
    - ii. Auditory cortex
- Damage: patient looses the ability to arrange read or heard words into coherent thought "Wernicke's Aphasia"



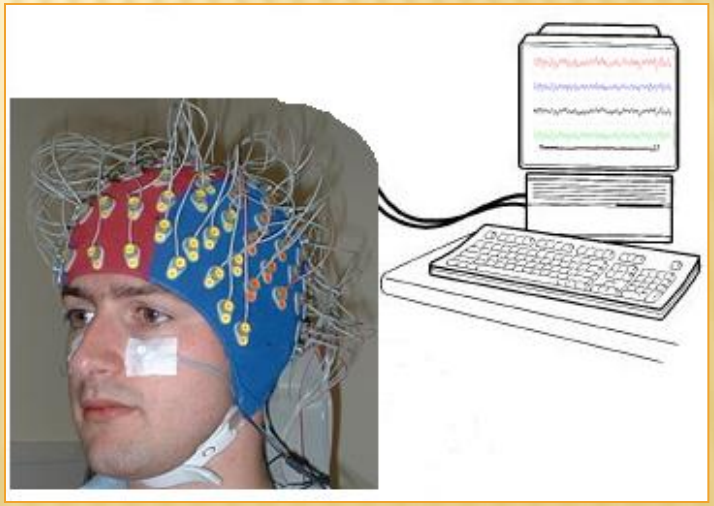
Broca's area

- Initiates and executes the expression of individual words or even short phrases (i.e., word formation)
  - ✓ Responsible for formation of words by exciting simultaneously the laryngeal muscles, respiratory muscles, and muscles of the mouth (via it's connection with motor cortex)
  - ✓ Near motor area for mouth, tongue & vocal cords
  - ✓ Damage; patient is capable of deciding what he or she wants to say but cannot make the vocal system emit words "Motor or Broca's Aphasia"



Electroencephalogram (EEG)

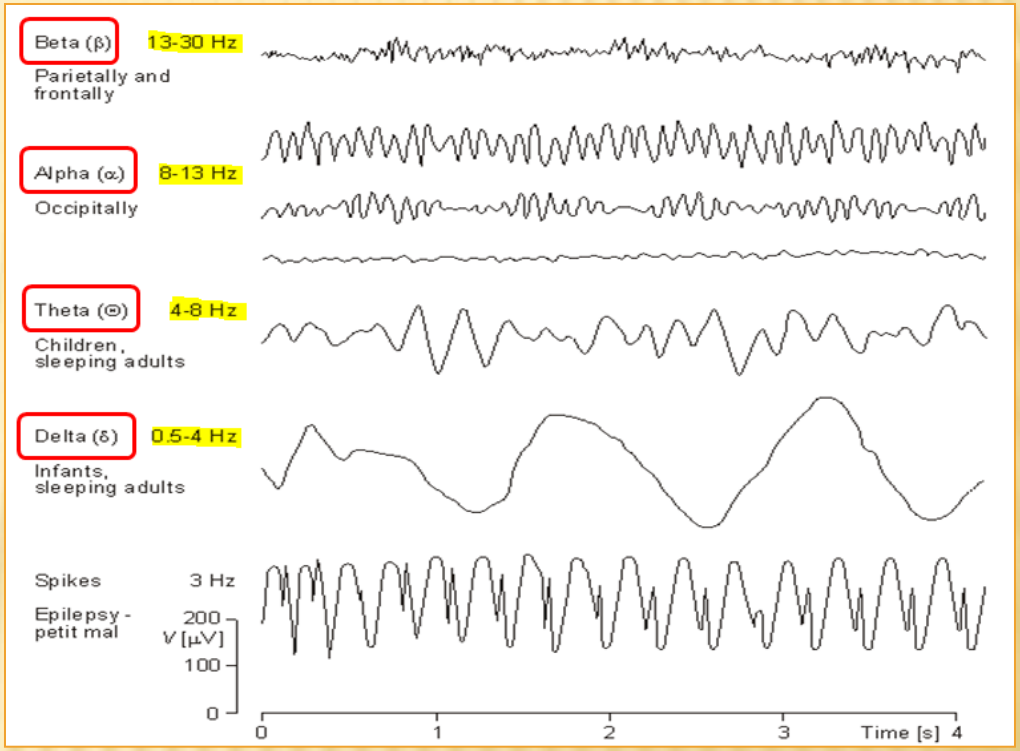
- The recording of electrical activity (potentials) along the scalp
- A tracing (measurement) of voltage fluctuations resulting from ionic current flows within the neurons of the brain versus time recorded from electrodes placed over scalp in a specific array
- Deep parts of the brain are not well sampled
- EEG Elements:
  - ✓ Active electrodes: Attached to the scalp
  - ✓ Reference electrode: Mastoid, nose, ear lobe…
  - ✓ Amplifier



- The EEG records differences in voltage – difference in electrical potential from one electrode to another

EEG Rhythms

- **Beta (β) waves**
  - ✓ Small in amplitude
  - ✓ More evident anteriorly
  - ✓ Drugs, such as barbiturates and benzodiazepines, augment beta waves
- **Alpha (α) waves**
  - ✓ Most common in adults.
  - ✓ Posteriorly (occipital) more than anteriorly
  - ✓ Especially prominent with closed eyes and with relaxation.
  - ✓ Disappears normally with attention (e.g., mental arithmetic, stress, opening eyes).
  - ✓ In most instances, it is regarded as a normal waveform.
- **Theta (θ) waves**
  - ✓ Normally seen in sleep
  - ✓ In awake adults, these waves are abnormal if they occur in excess.
- **Delta (δ) waves**
  - ✓ Normally seen in deep sleep.
  - ✓ Delta waves are abnormal in the awake adult.
  - ✓ Often, they have the largest amplitude of all waves. **Theta** and **delta** waves are known collectively as **slow waves**.

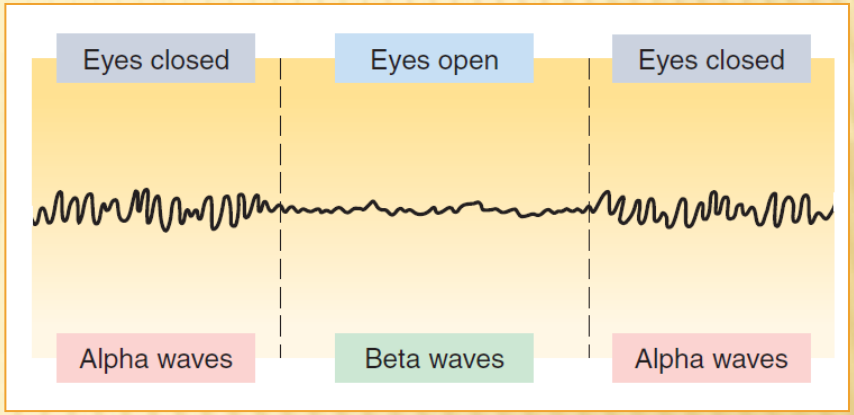


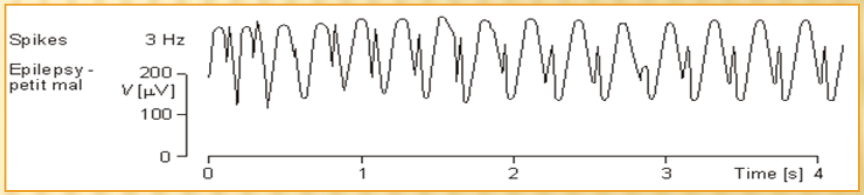
EEG Uses

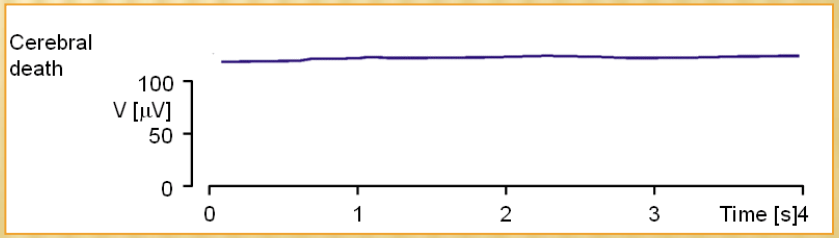
1. To distinguish various stages of sleep

2. A clinical tool in the diagnosis of cerebral dysfunction (e.g. **Epilepsy**)

3. Legal determination of brain death





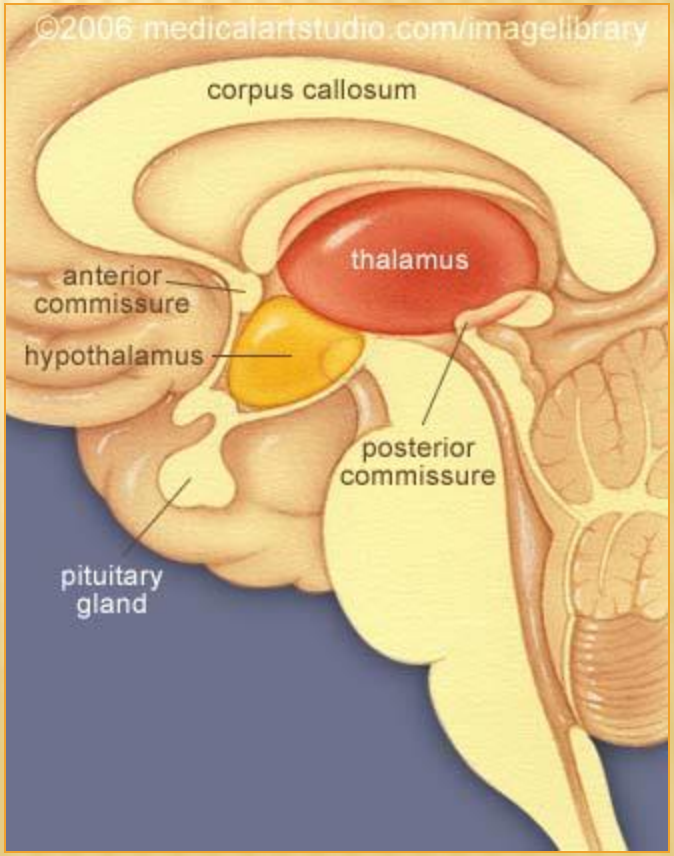


Nervous System – Brain & cranial nerves

The Thalamus

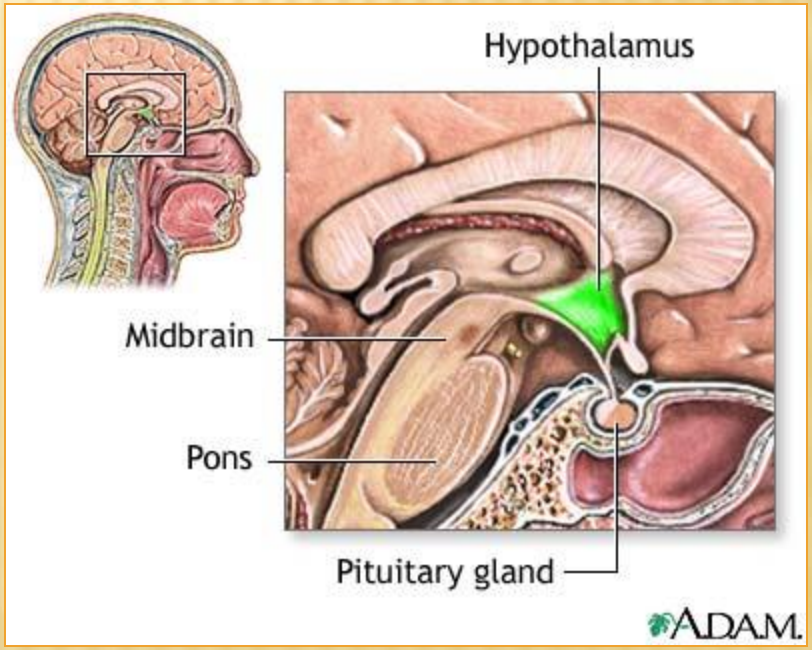
- "Relay station" and synaptic integrating center for preliminary processing of all sensory input on its way to the cortex

- It screens out insignificant signals and routes the important sensory impulses to appropriate areas of the somatosensory cortex (e.g., attention to stimuli of interest)



The Hypothalamus

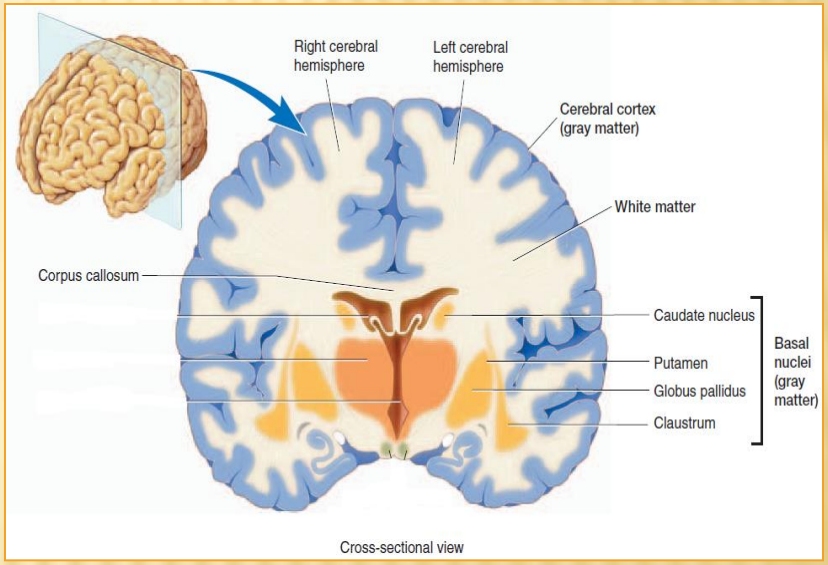
- Important **link** between the autonomic nervous system and the endocrine system via the pituitary gland
- Brain area most involved in directly regulating internal environment
  - Controls body temperature
  - Controls thirst and urine output
  - Controls food intake
  - Controls anterior pituitary hormone secretion
  - Produces posterior pituitary hormones
  - Controls uterine contractions and milk ejection
  - Serves as a major ANS coordinating center
  - Plays role in emotional and behavioral patterns
  - Participates in sleep-wake cycle



The Basal Nuclei

- Masses of gray matter (neuron cell bodies) located deep within the cerebral white matter

- Functions:
  - modifying ongoing activity in motor pathways
  - Fine tuning muscle tone; inhibiting muscle tone throughout the body



❖ Proper muscle tone is normally maintained by a balance of excitatory and inhibitory inputs to the neurons that innervate skeletal muscles)

The Basal Nuclei

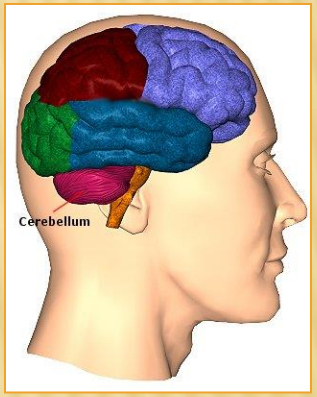
- Improper function: **Parkinson's disease**
- Deficiency of dopamine, an important neurotransmitter in the basal nuclei

- Signs and symptoms:
  - ✓ Increased muscle tone, or rigidity
  - ✓ Involuntary, useless, & unwanted movements, such as **resting tremors** (e.g., hands rhythmically shaking)
  - ✓ Slowness in initiating and carrying out different motor behaviors

Cerebellum

- Attached to the back of the upper portion of the brain stem, Lies underneath the occipital lobe of the cortex

- Does not initiate movement, but contributes to coordination, precision, and accurate timing.



- Three different parts
  1. **Vestibulocerebellum**
     - Important in maintaining balance and controls eye movements
  2. **Spinocerebellum**
     - Enhances muscle tone and coordinates skilled, voluntary movements
  3. **Cerebrocerebellum**
     - Plays role in planning and initiating voluntary activity by providing input to cortical motor areas
     - Stores procedural memories

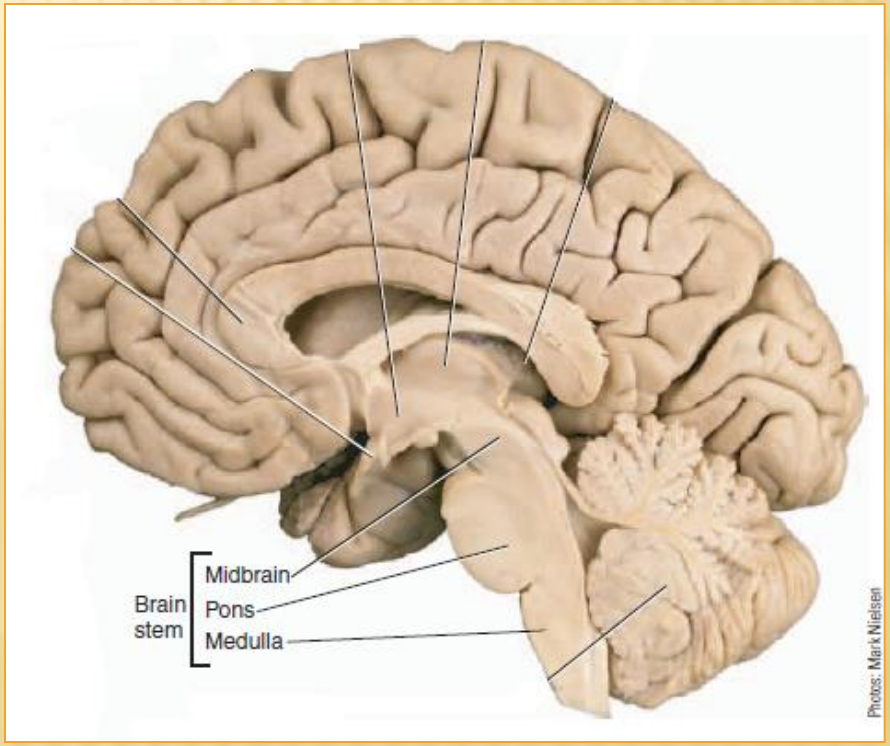
- Damage to the cerebellum does <u>not cause paralysis</u>, but instead produces disorders in fine movement, equilibrium & posture (**<u>intention tremor</u>**; oscillating to-and-fro movements of a limb as it approaches its intended destination)

Brain Stem

- The brain stem is a vital link between the spinal cord and higher brain regions

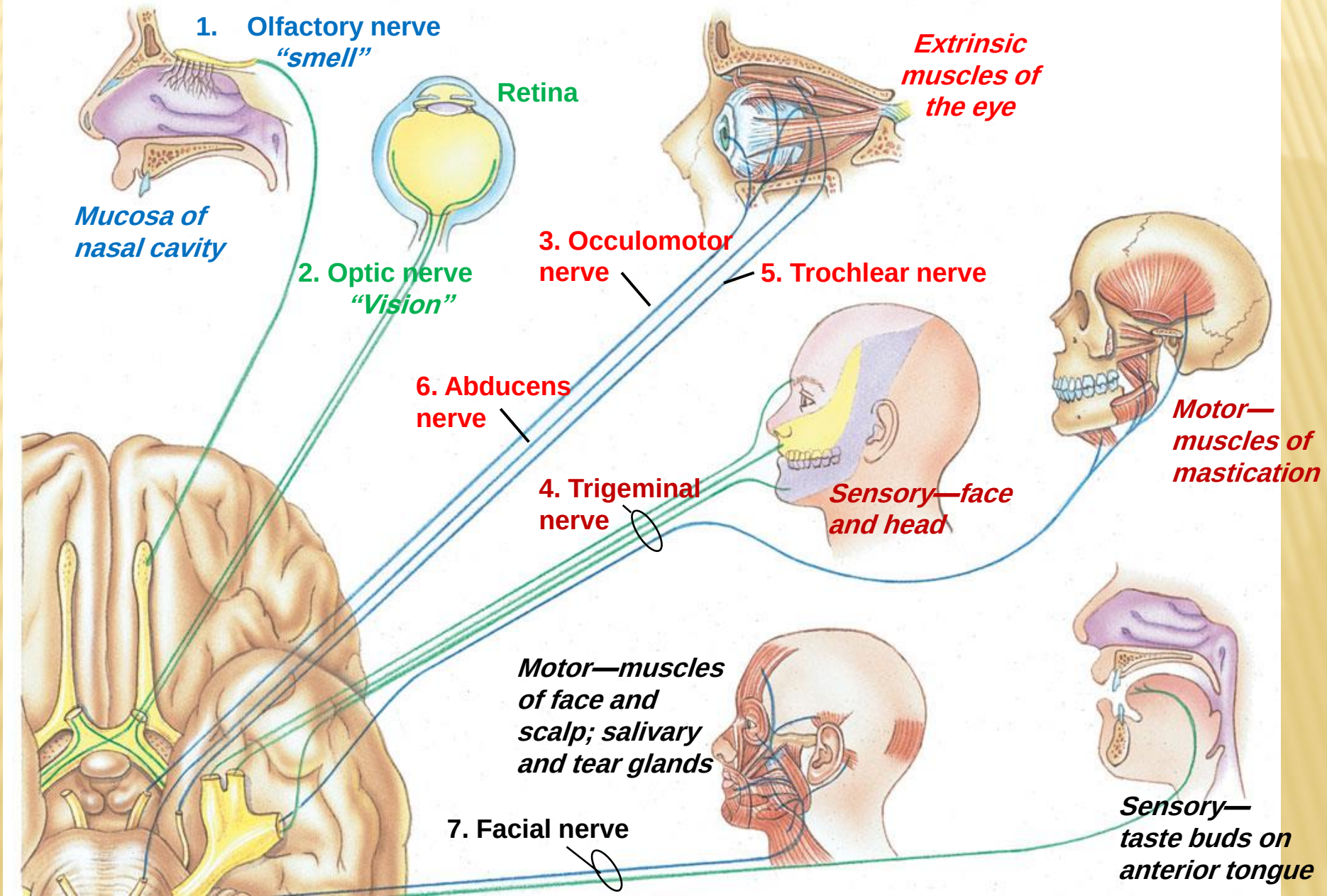
- Main functions:

- ✓ The majority of the 12 pairs of **cranial nerves** arise from the brain stem
- ✓ Centers that control heart and blood vessel function, respiration, and many digestive activities
- ✓ Plays role in regulating muscle reflexes involved in equilibrium and posture
- ✓ Reticular formation within brain stem receives and integrates all incoming sensory synaptic input; important for brain arousal (being awake & alert)
- ✓ Centers that govern sleep



= Motor fibers

= Sensory fibers

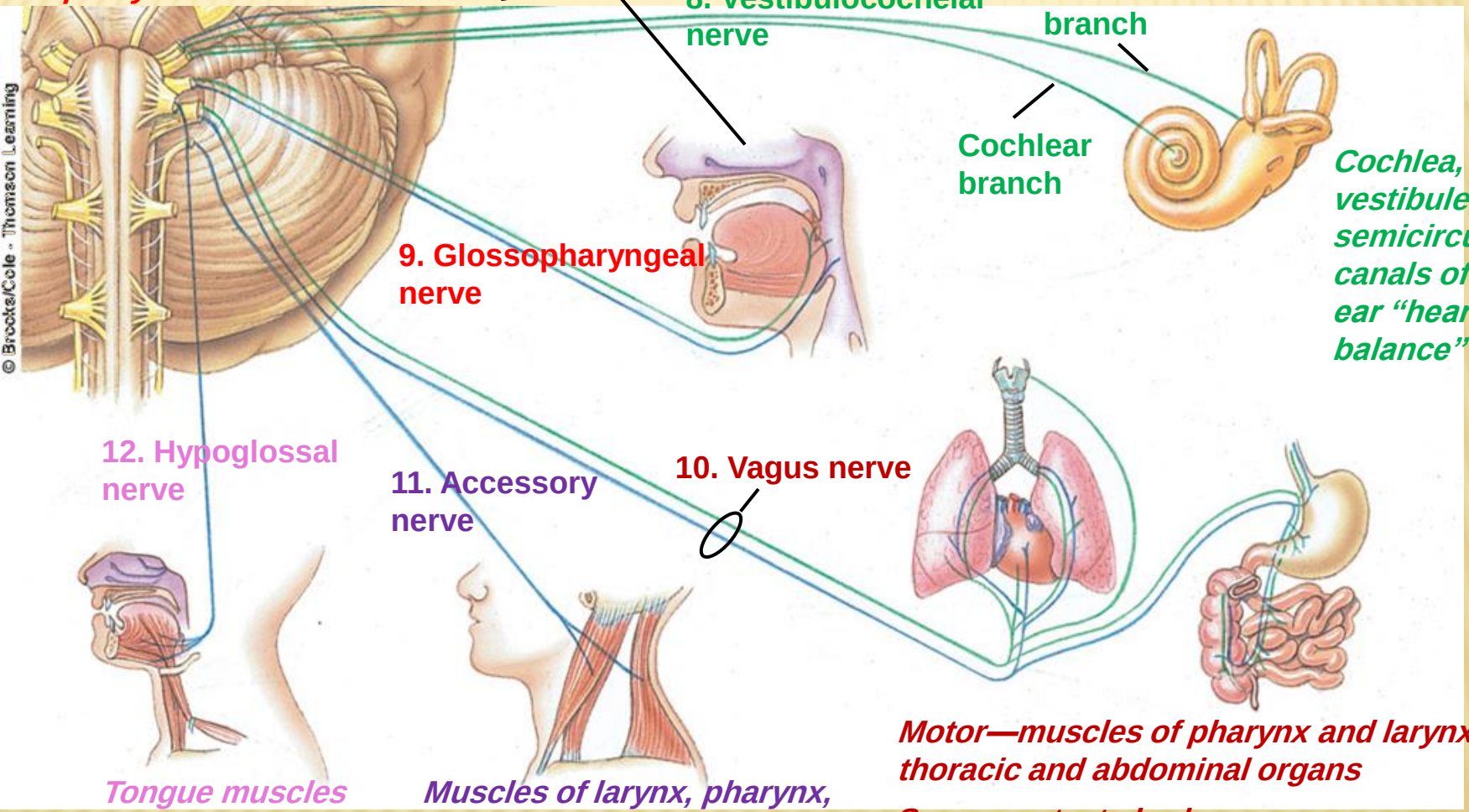


= Motor fibers

= Sensory fibers

Motor—muscles of pharynx; parotid gland

Sensory—taste buds on posterior tongue; receptors in pharynx and carotid sinus



Cochlea, vestibule, and semicircular canals of inner ear "hearing & balance"

Tongue muscles

Muscles of larynx, pharynx, soft palate, shoulder, and neck

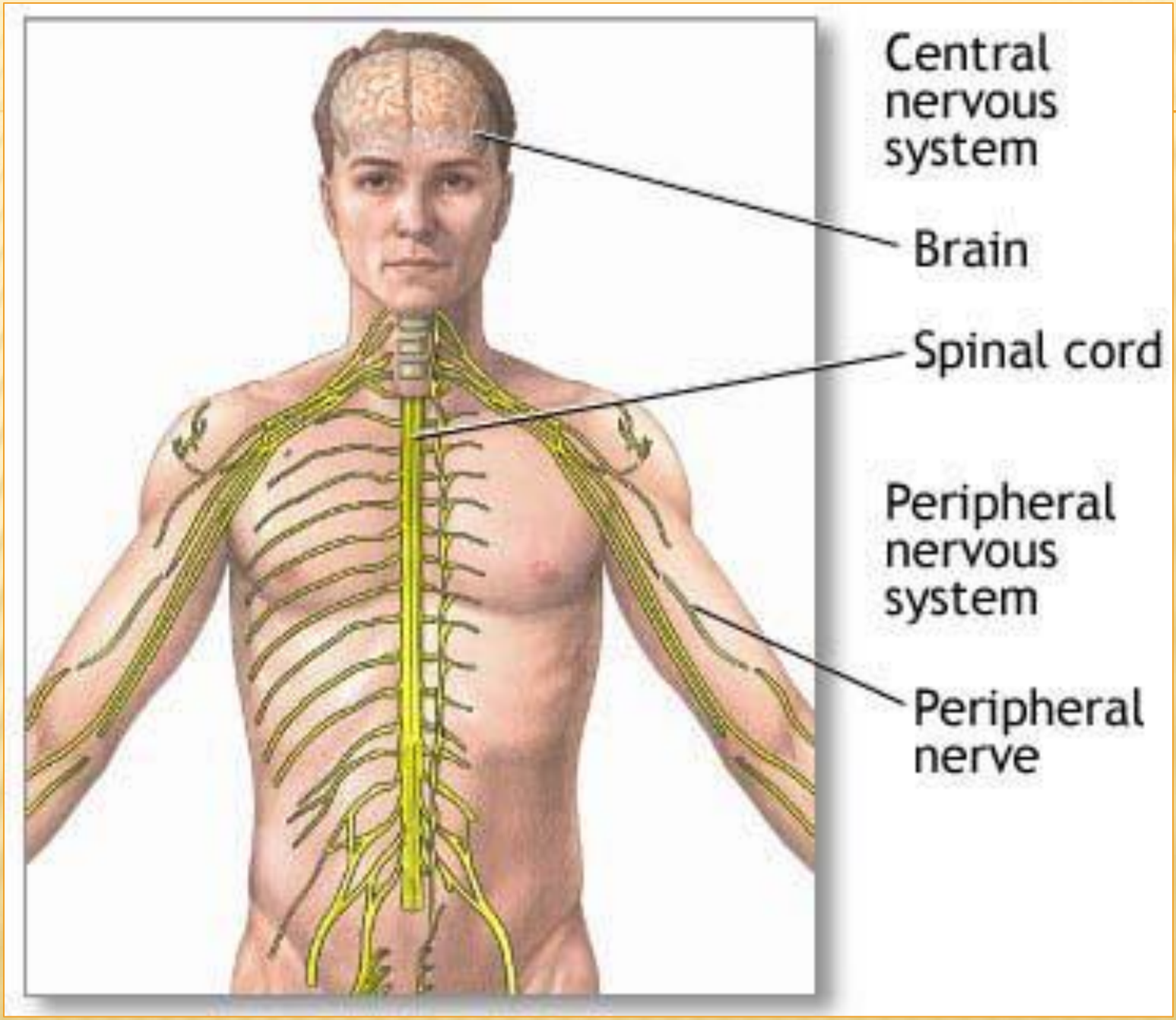
Motor—muscles of pharynx and larynx; thoracic and abdominal organs

Sensory—taste buds on anterior tongue and pharynx; thoracic and abdominal organs

Limbic System

- Includes portions of the hypothalamus and other forebrain structures that encircle brain stem
- Responsible for
  - Emotion
  - Basic, inborn behavioral patterns related to survival and perpetuation of the species
  - Plays important role in motivation and learning

Peripheral Nervous System (PNS)


Central nervous system
Brain
Spinal cord
Peripheral nervous system
Peripheral nerve

Peripheral Nervous System

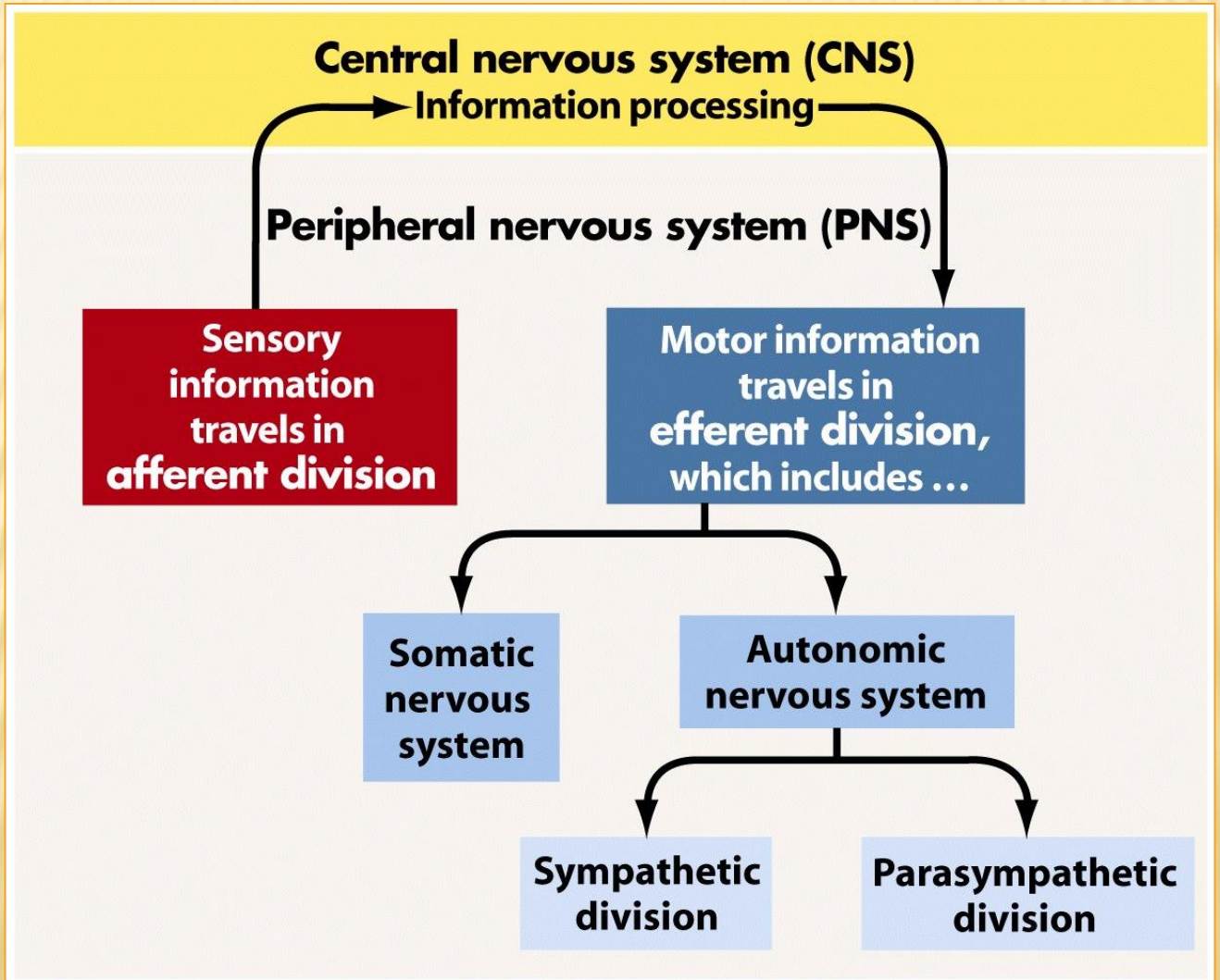


Figure 45-19 Biological Science, 2/e

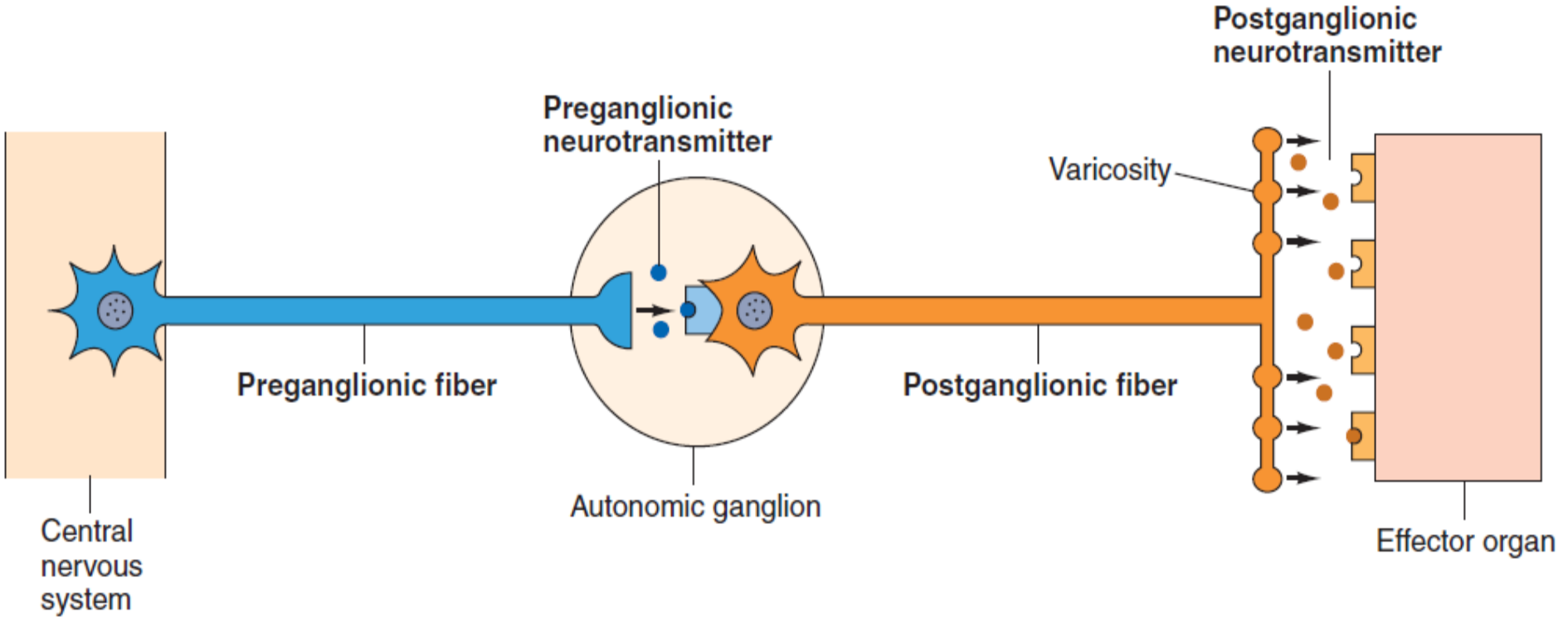
Autonomic Nervous System (ANS)

- Composed of:

1. Sympathetic Nervous System
2. Parasympathetic Nervous System

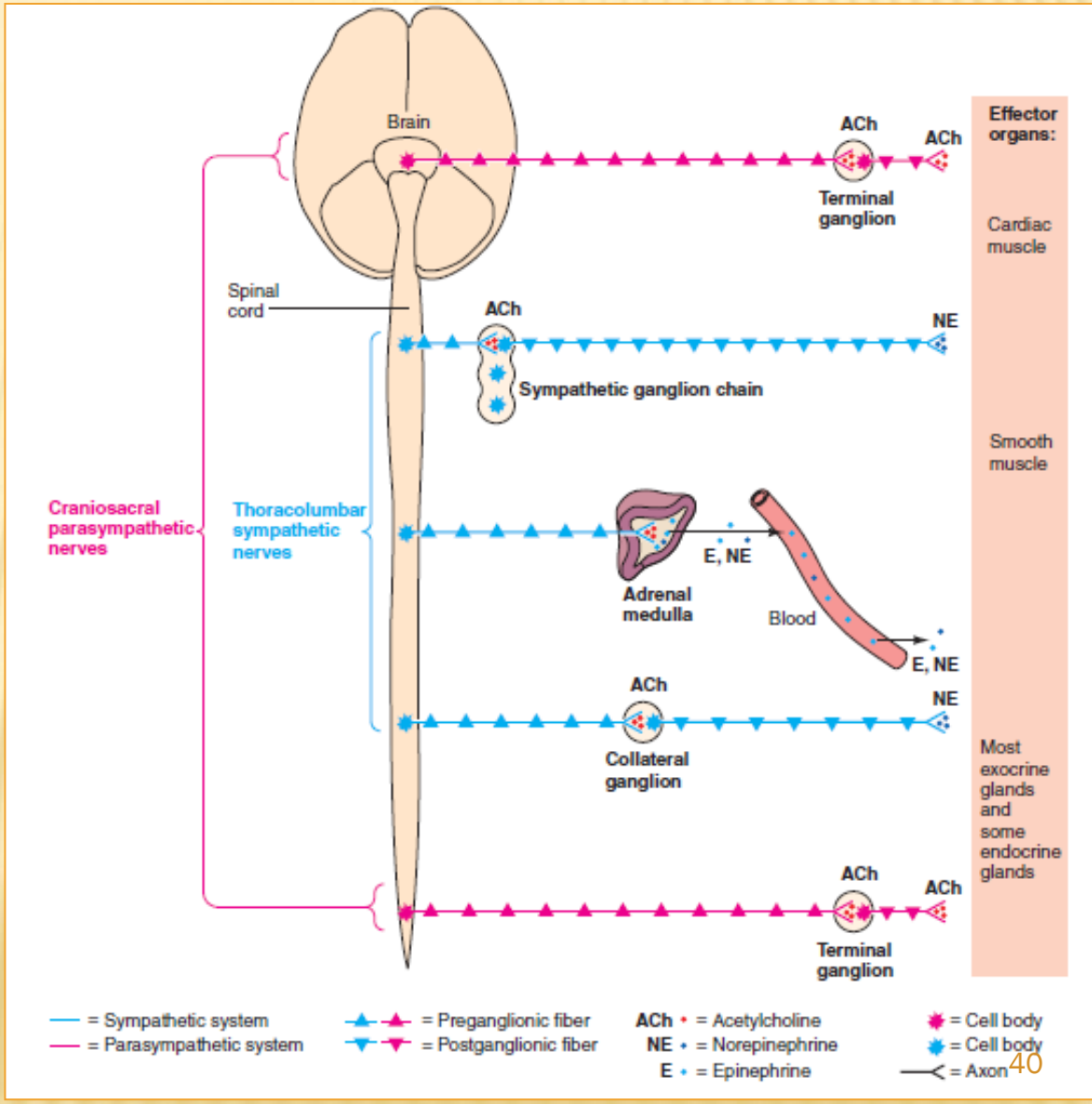
Autonomic Nerve Pathway

- Two-neuron chain



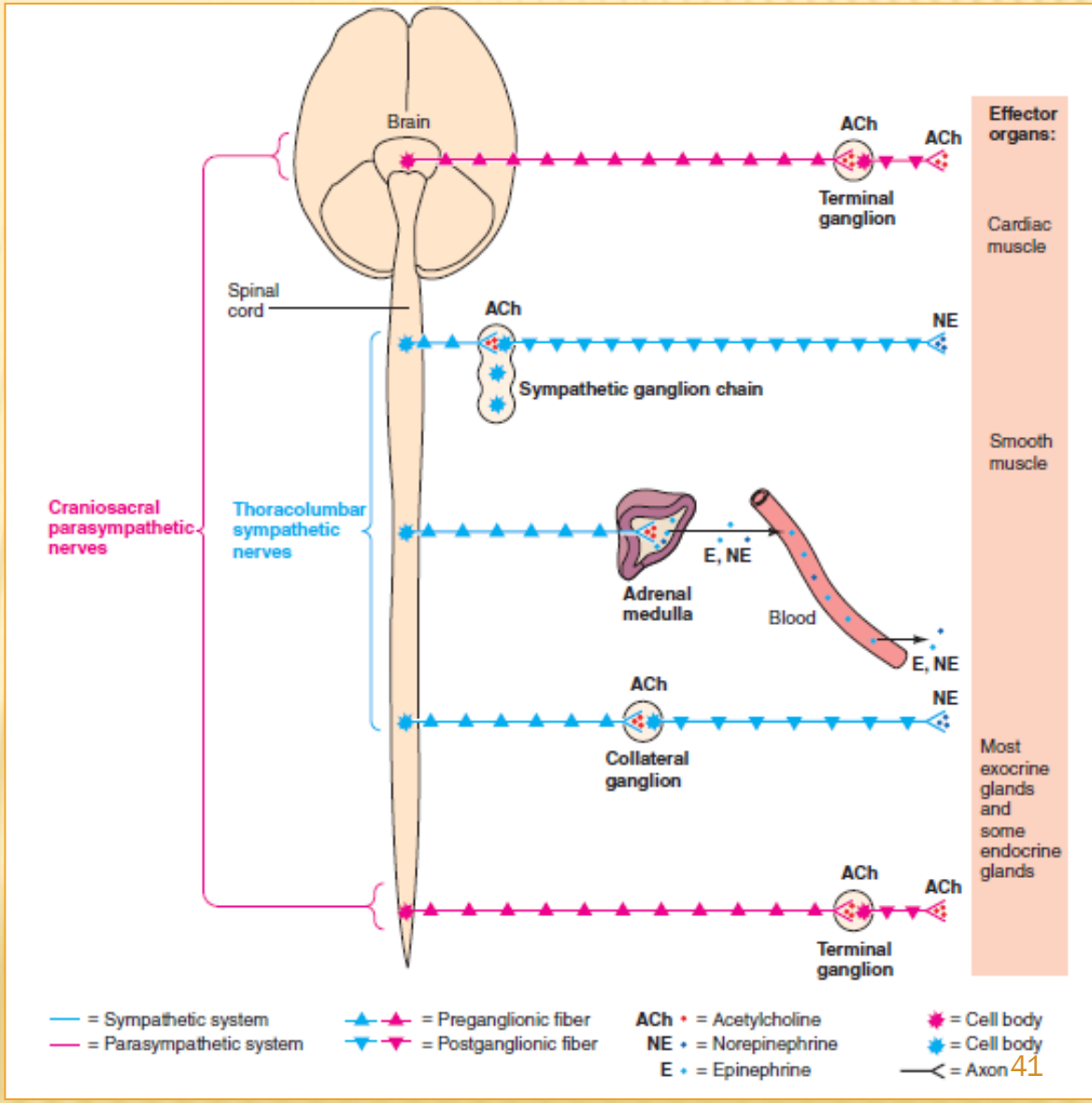
Sympathetic Nerve Pathway

- Sympathetic nerve fibers originate in the thoracic and lumbar regions of the spinal cord
- Short preganglionic fibers



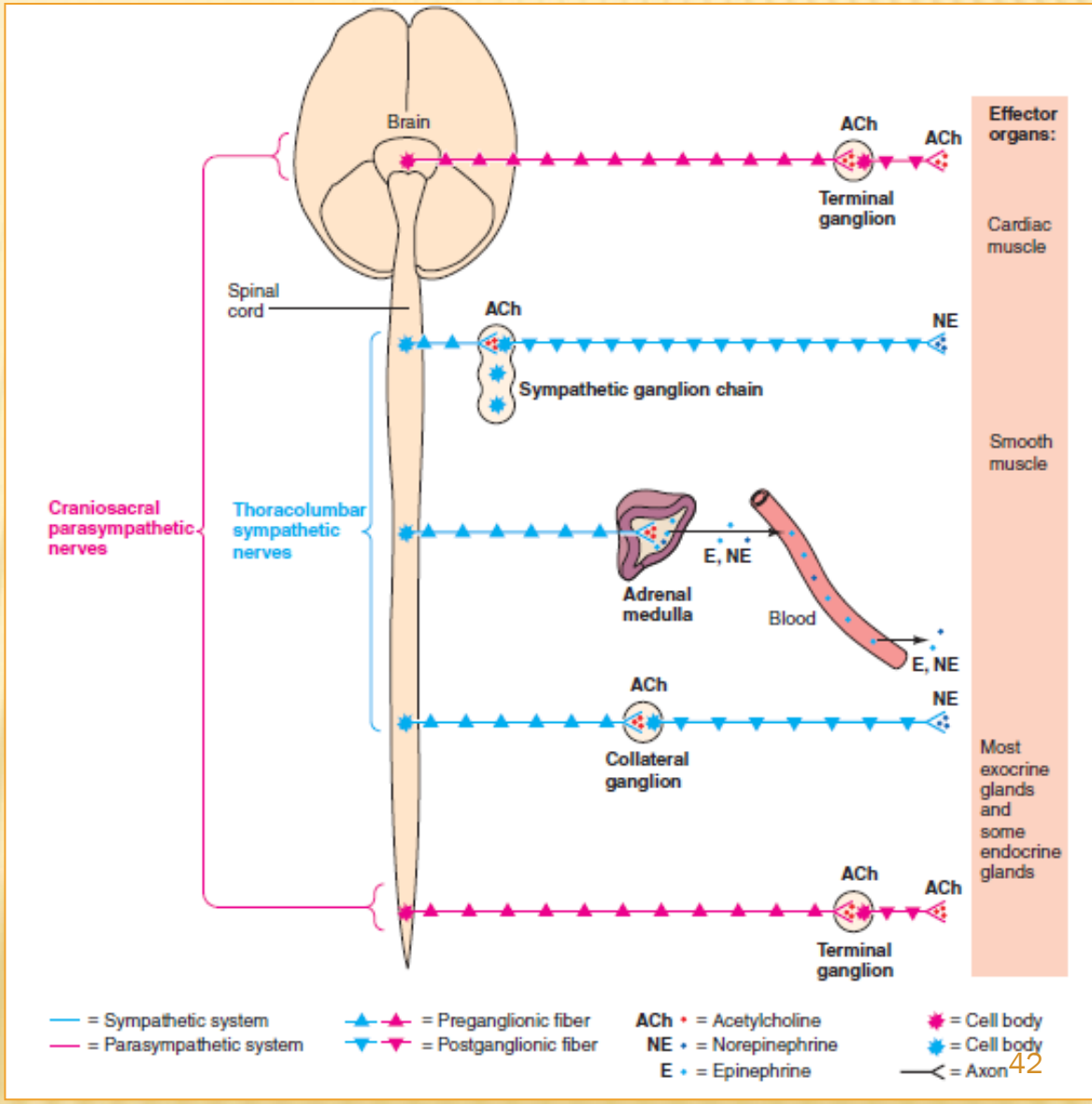
Parasympathetic Nerve Pathway

- **Parasympathetic** preganglionic fibers arise from the cranial (brain) and sacral (lower spinal cord) areas of the CNS
- Long preganglionic fibers

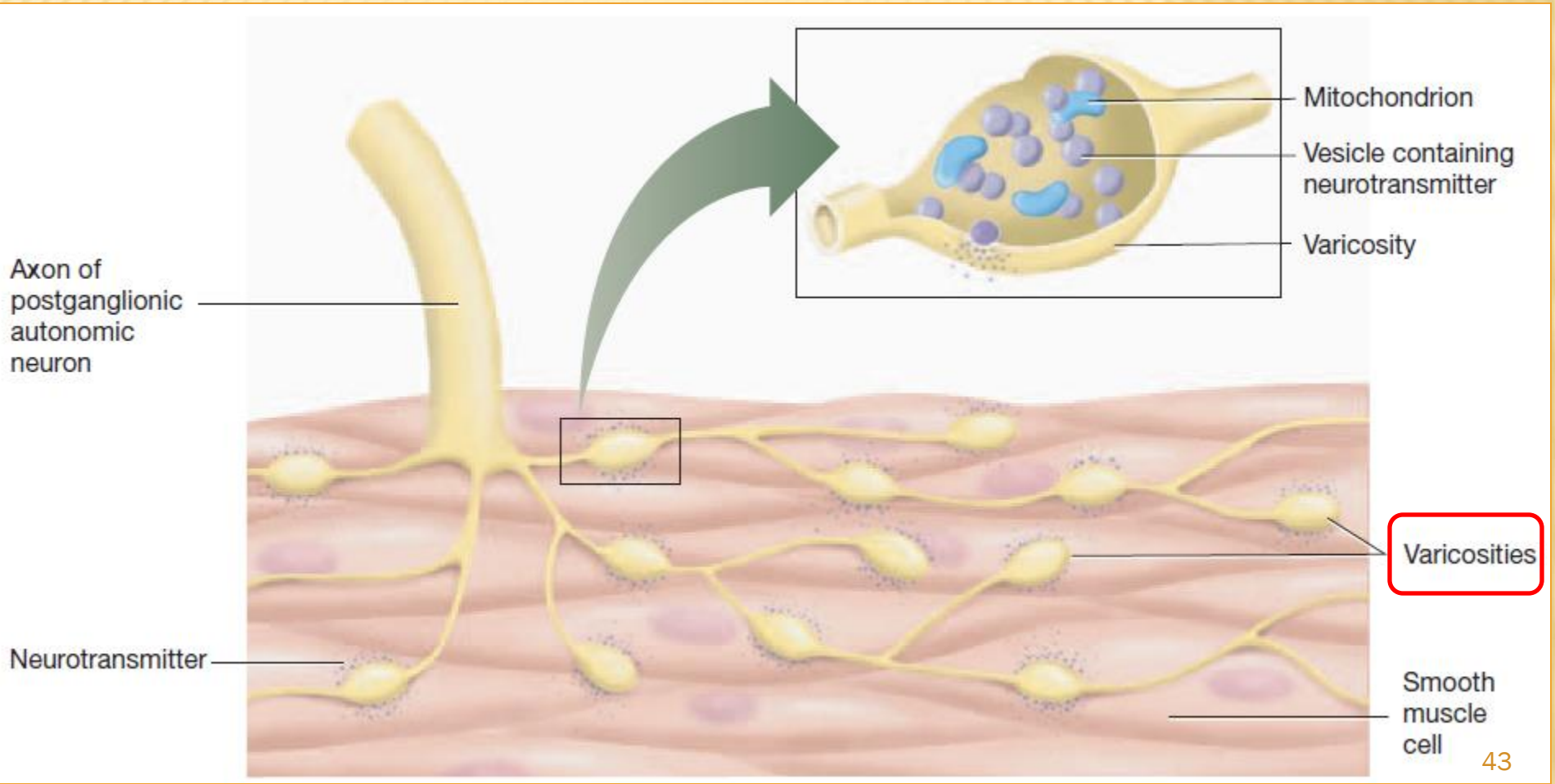


Neurotransmitters of the ANS

- All preganglionic fibers release Ach
- Sympathetic postganglionic fibers release NE/E mainly
- Parasympathetic postganglionic fibers release Ach

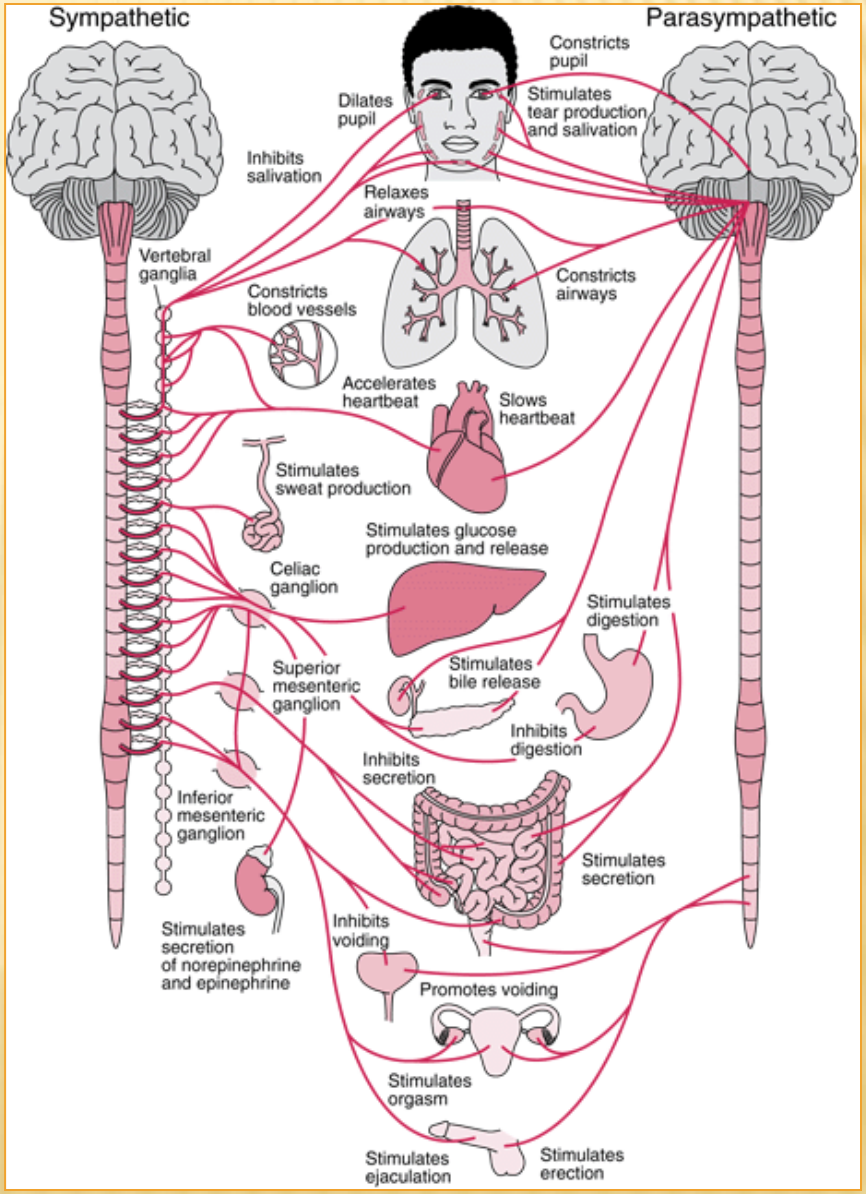


Postganglionic Nerve Terminals



Dual innervation of sympathetic and parasympathetic nervous systems

- Sympathetic and parasympathetic nervous systems generally exert **opposite effects** in a particular organ
- Both systems increase the activity of some organs and reduce the activity of others.
- Usually both systems are partially active; **sympathetic** or **parasympathetic tone** or **tonic activity, but** activity of one division can dominate over the other



Advantage Of Dual Autonomic Innervation

- Enables precise control over an organ's activity

Dual innervation of sympathetic and parasympathetic nervous systems

- Exceptions to general rule of dual reciprocal innervation by the two branches of autonomic nervous system
  - Most arterioles and veins receive only sympathetic nerve fibers (arteries and capillaries are not innervated)
  - Most sweat glands are innervated only by sympathetic nerves
  - Salivary glands are innervated by both ANS divisions but activity is not antagonistic – both stimulate salivary secretion

Sympathetic dominance

- **Fight-or-flight response**

in emergency or stressful situations, such as a physical threat from the outside

- **Heart**: beats more rapidly and more forcefully,
- **Blood pressure** is elevated by generalized constriction of the blood vessels,
- **Respiratory airways** open wide to permit maximal air flow,
- **Glycogen** (stored sugar) and **fat stores** are broken down to release extra fuel into the blood,

Sympathetic dominance

- **Blood vessels supplying skeletal muscles** dilate (open more widely).

→ Providing increased flow of oxygenated, nutrient-rich blood to the skeletal muscles in anticipation of strenuous physical activity.

- **The pupils** dilate and the eyes adjust for far vision, letting the person visually assess the entire threatening scene.

- **Sweating** is promoted in anticipation of excess heat production by the physical exertion.

Sympathetic dominance

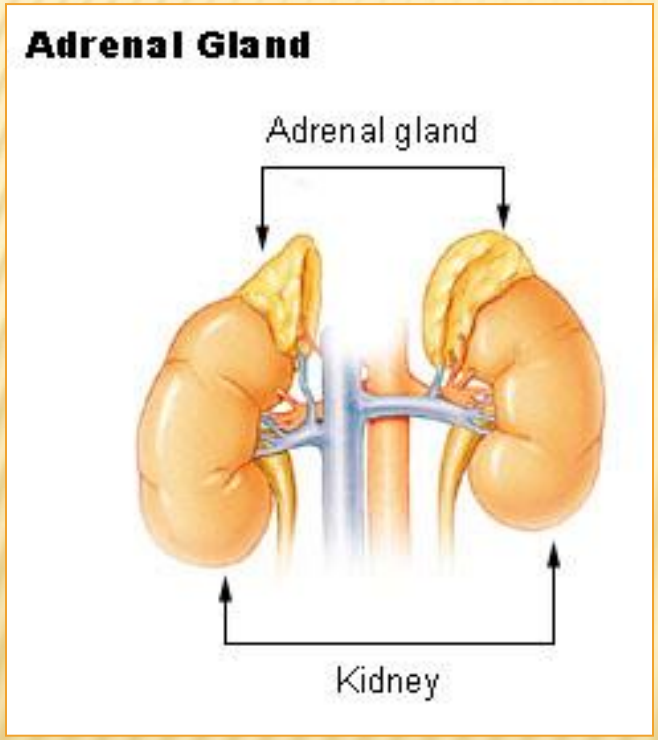
- Inhibition of **digestive and urinary activities**; not essential in meeting the threat

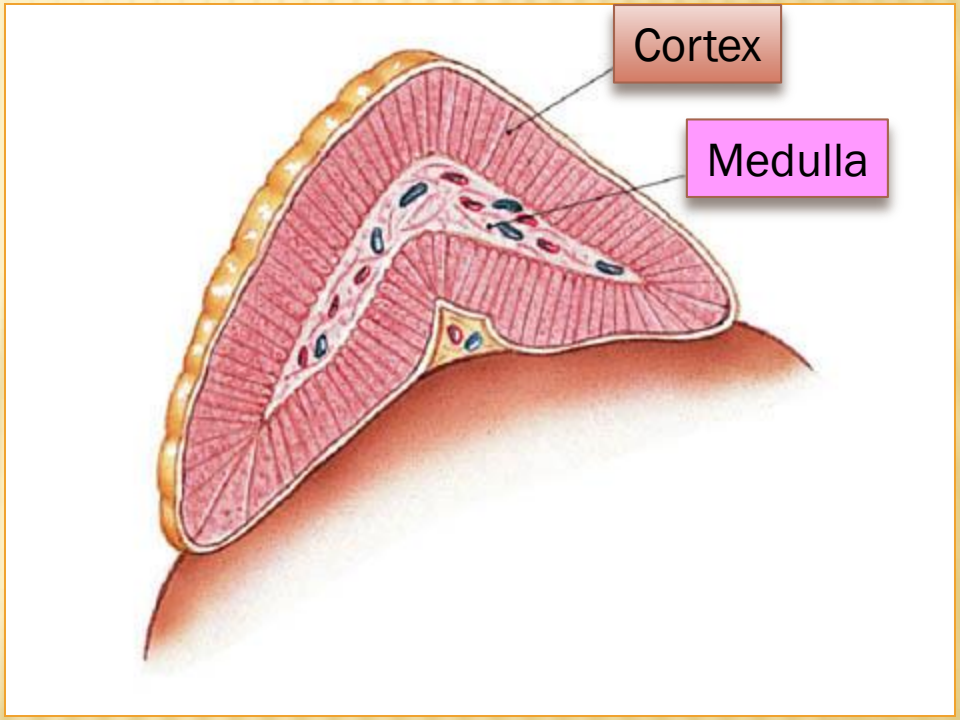
Parasympathetic dominance

- Rest-and-digest

in quiet, relaxed situations

The Adrenal Medulla

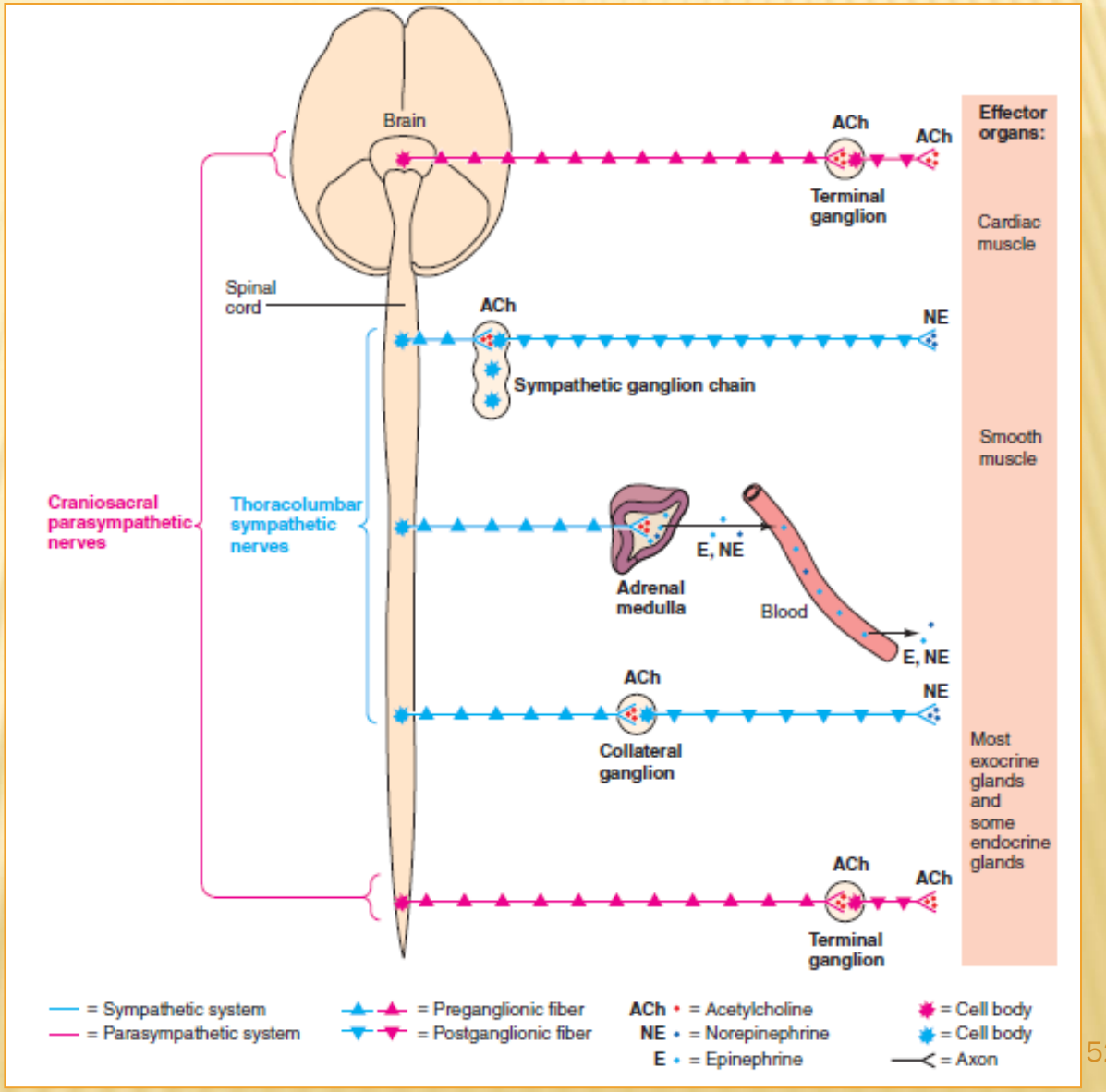




Medulla secretes:
Epinephrine (mainly) & Norepinephrine

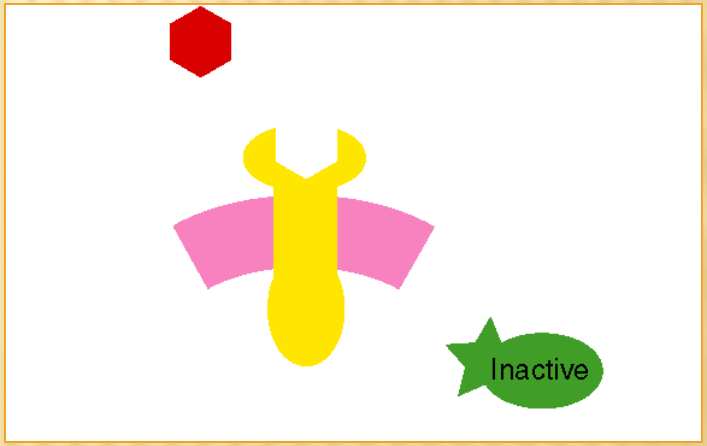
The Adrenal Medulla

- Part of the sympathetic nervous system
- Receives preganglionic fibers
- Does not have postganglionic fibers
- Instead, releases E & NE into the blood



Receptor Types For Autonomic Neurotransmitters

- Specific neurotransmitter action results from specificity of receptors
- 2 types of receptors in ANS:
  - **Cholinergic**
  - **Adrenergic**



Cholinergic Receptors

- **Nicotinic receptors:**

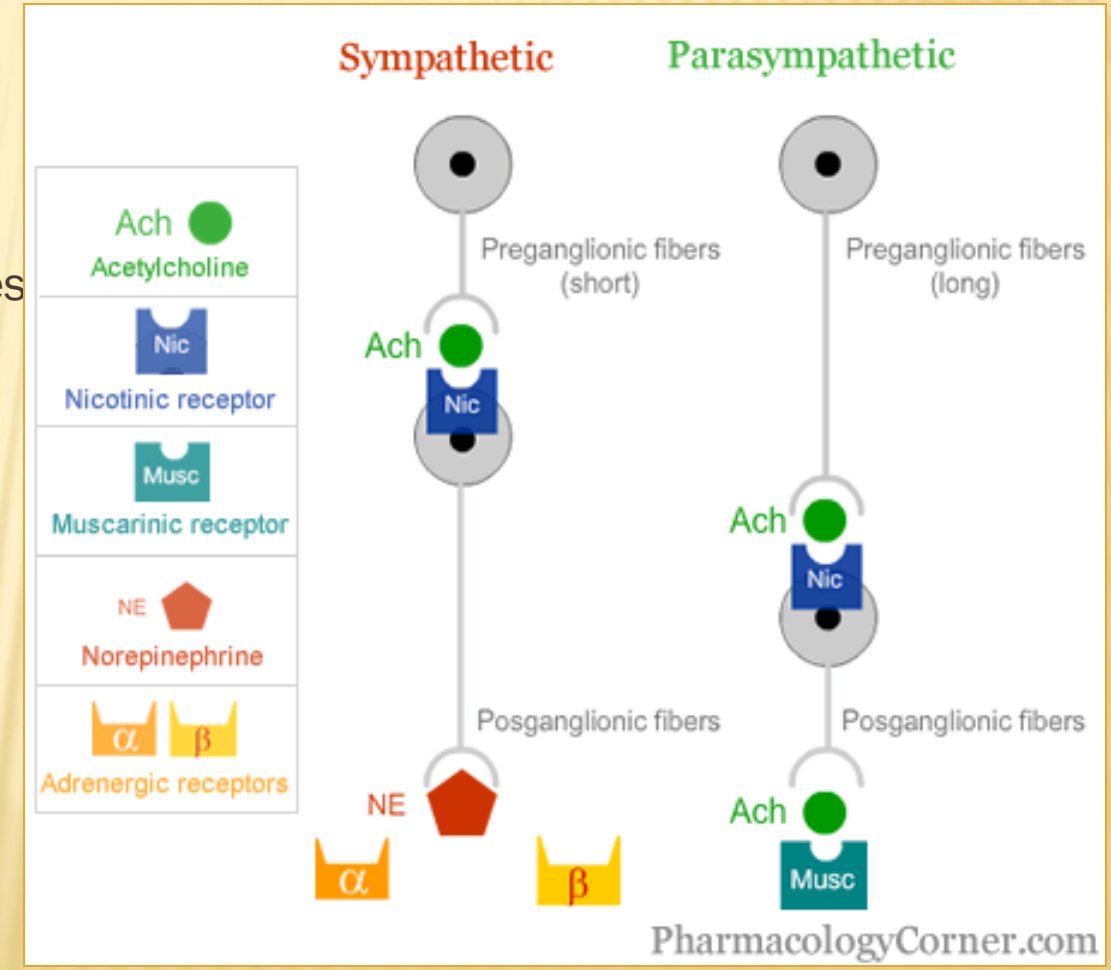
found on the postganglionic cell bodies in all autonomic ganglia

Bind ACh

- **Muscarinic receptors:**

found on effector cell membranes (smooth muscle, cardiac muscle, and glands).

Bind ACh



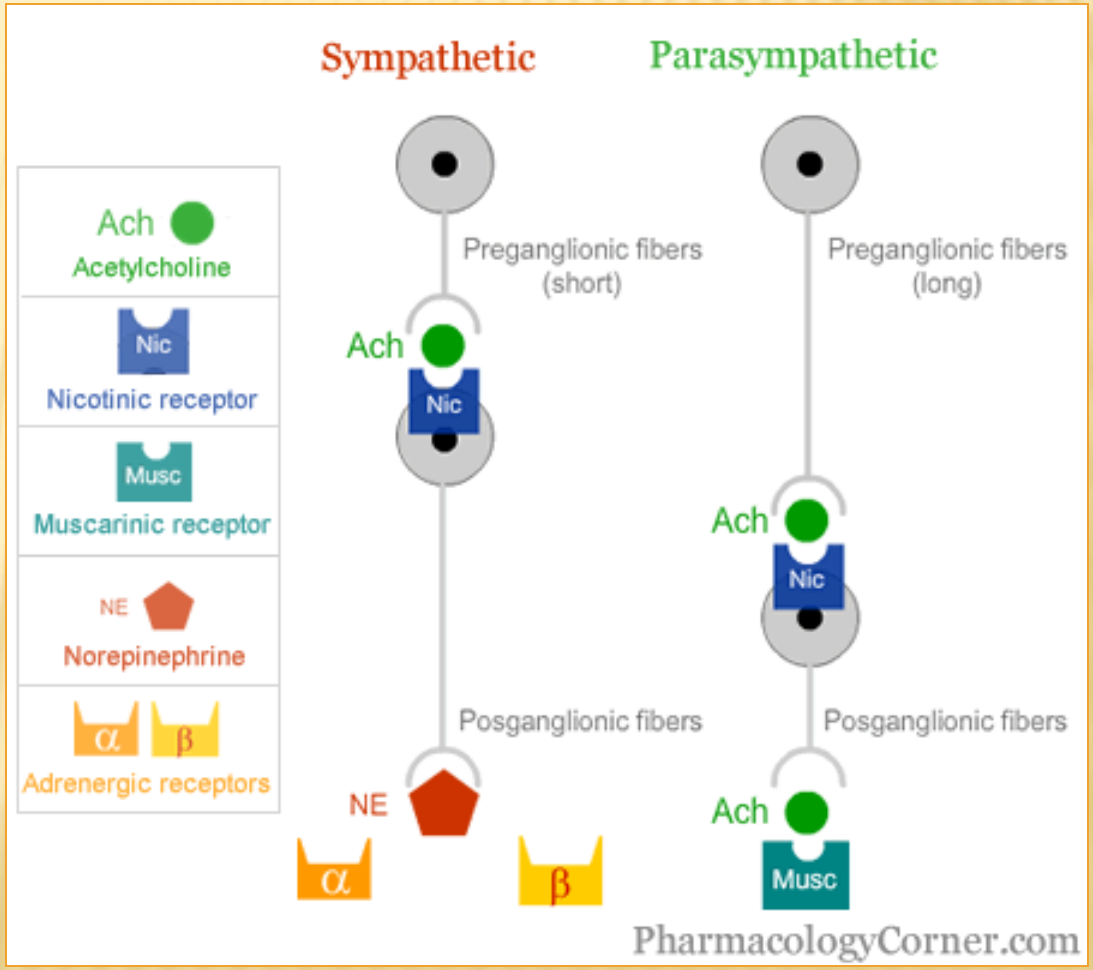
Adrenergic Receptors

- Found on effector cell membranes

1. **alpha (α):**
   - α1
   - α2

   } NE > E

2. **beta (β)**
   - B1 → NE = E
   - B2 → E > NE



Adrenergic Receptors

- α1 → Excitatory; e.g., arteriolar constriction
- α2 → Inhibitory; e.g., GI smooth muscle
- β1 → Excitatory; e.g., increased rate and force of cardiac contraction
- β2 → Inhibitory; e.g., arteriolar & bronchiolar (dilation)

Sympathetic vs. Parasympathetic

FEATURE	SYMPATHETIC SYSTEM	PARASYMPATHETIC SYSTEM
Origin of Preganglionic Fiber	Thoracic and lumbar regions of spinal cord	Brain and sacral region of spinal cord
Origin of Postganglionic Fiber (location of ganglion)	Sympathetic ganglion chain (near spinal cord) or collateral ganglia (about halfway between spinal cord and effector organs)	Terminal ganglia (in or near effector organs)
Length and Type of Fiber	Short cholinergic preganglionic fibers Long adrenergic postganglionic fibers	Long cholinergic preganglionic fibers Short cholinergic postganglionic fibers
Effector Organs Innervated	Cardiac muscle, almost all smooth muscle, most exocrine glands, and some endocrine glands	Cardiac muscle, most smooth muscle, most exocrine glands, and some endrocrine glands
Types of Receptors for Neurotransmitters	For preganglionic neurotransmitter: nicotinic For postganglionic neurotransmitter: $\alpha_1, \alpha_2, \beta_1, \beta_2$	For preganglionic neurotransmitter: nicotinic For postganglionic neurotransmitter: muscarinic
Dominance	Dominates in emergency "fight-or-flight" situations; prepares body for strenuous physical activity	Dominates in quiet, relaxed situations; promotes "general housekeeping" activities such as digestion

Somatic Nervous System

Somatic Nervous System

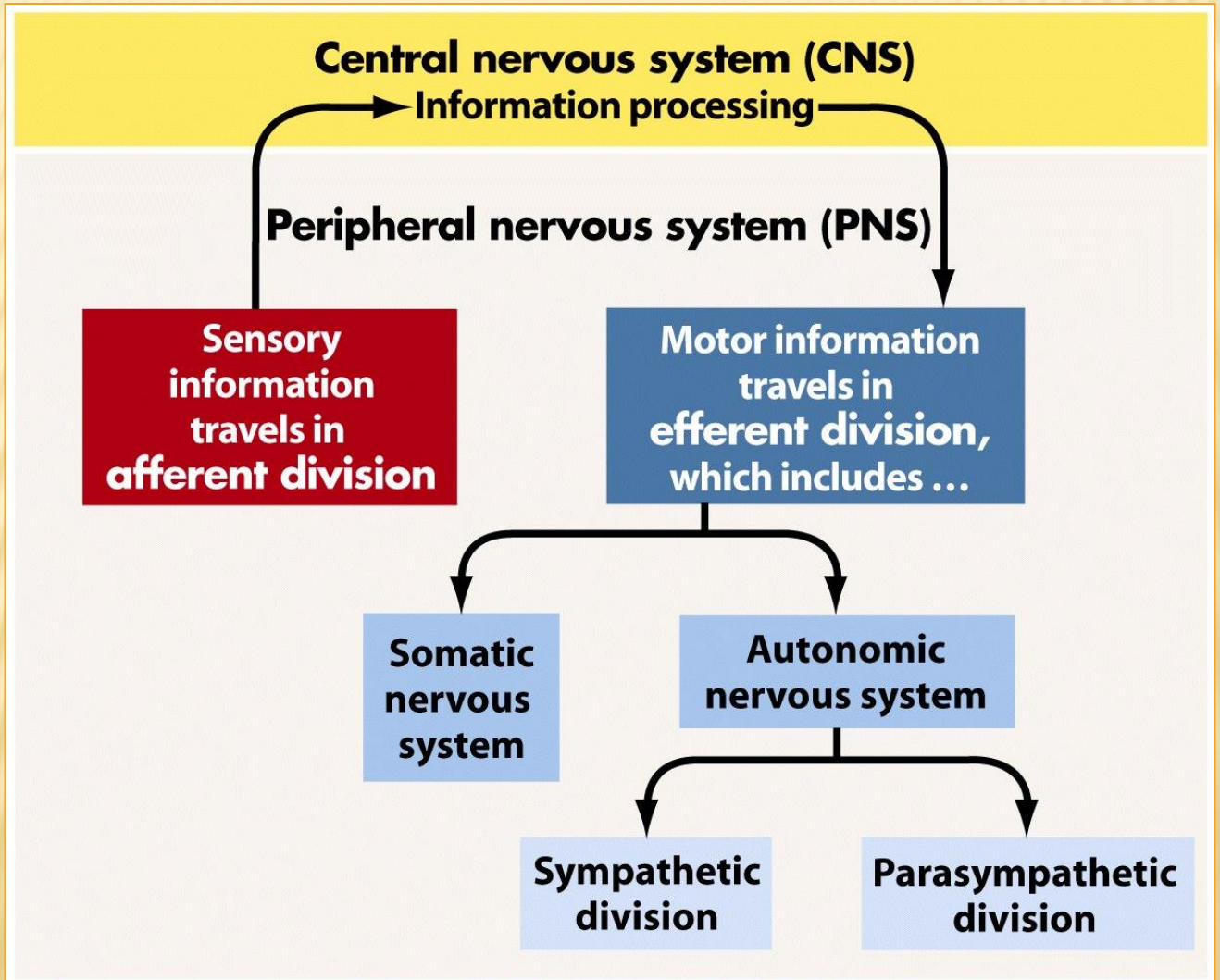
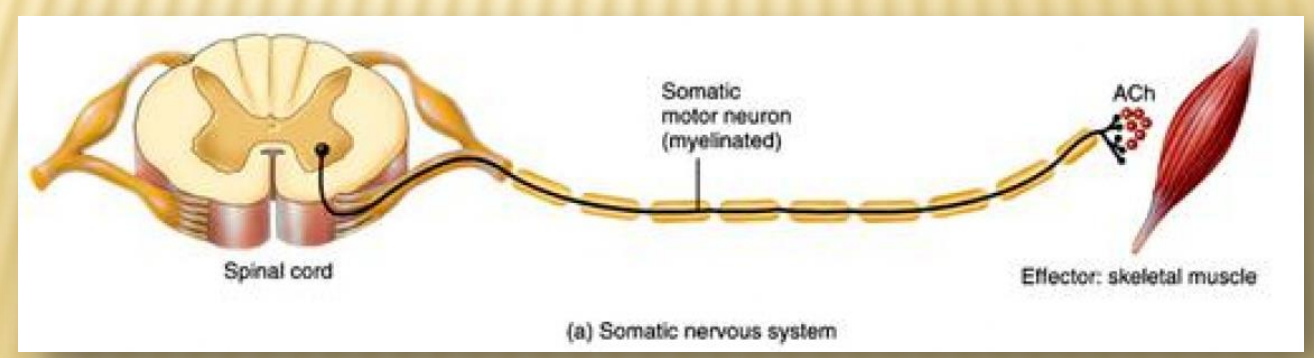


Figure 45-19 Biological Science, 2/e

Somatic Nervous System

- Composed of the axons of the motor neurons which innervate skeletal muscles

- Motor neurons:
  - ✓ The cell bodies are within the spinal cord. (except motor neurons supplying muscles in the head, they are in the brain stem)
  - ✓ Release acetylcholine (ACh)
  - ✓ Can <u>only stimulate</u> skeletal muscles (no inhibition)

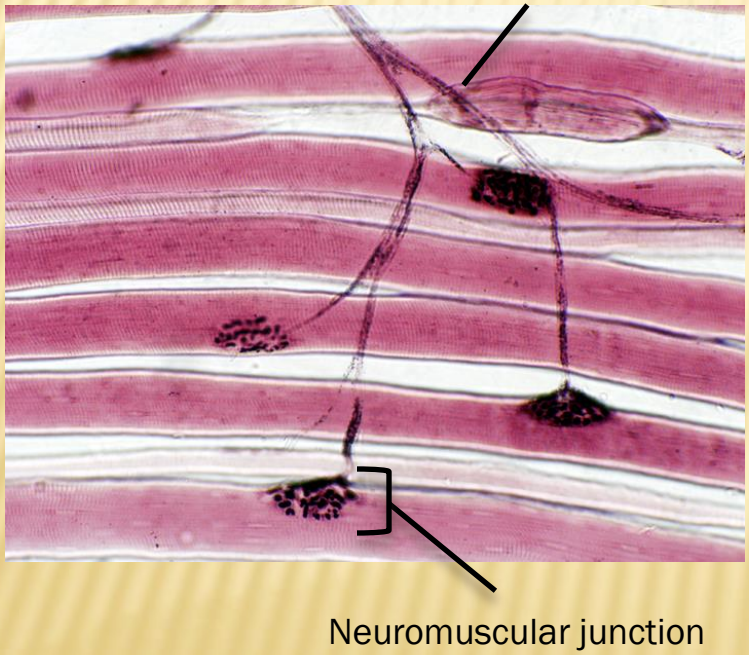


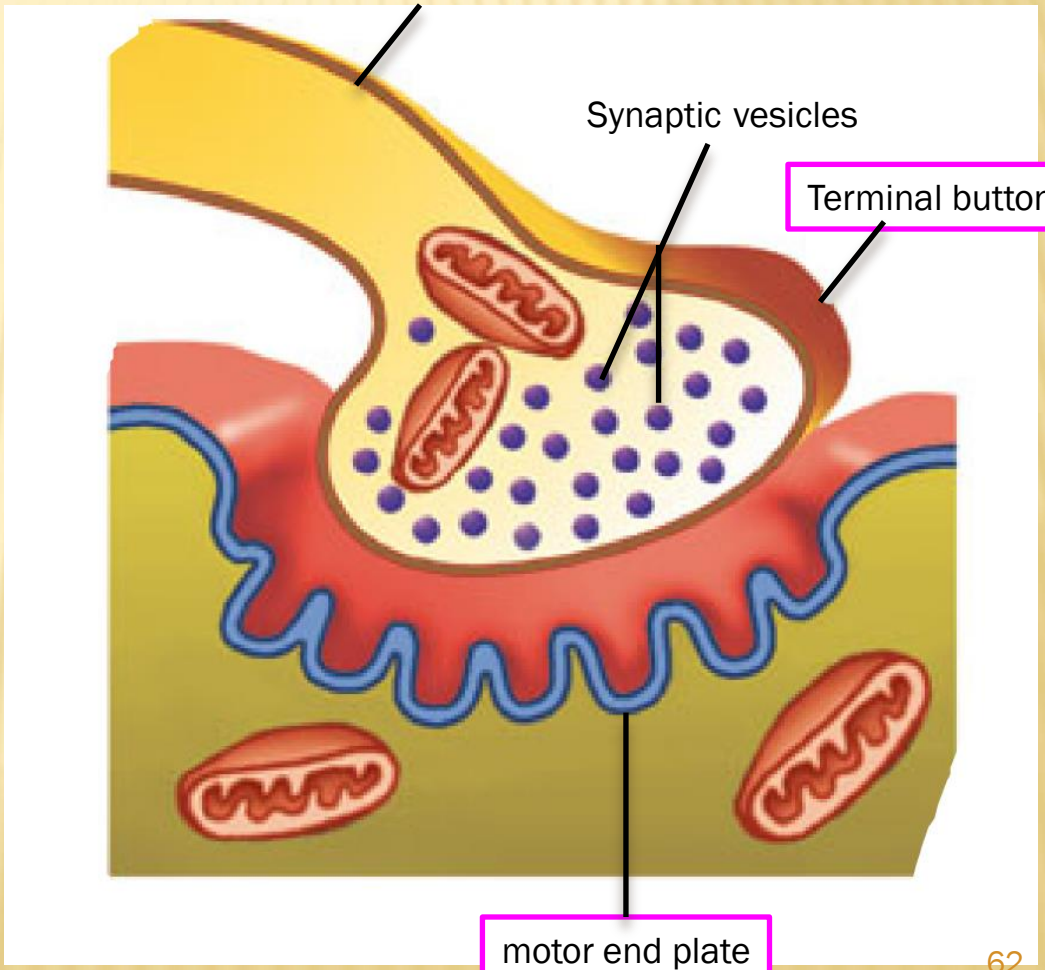
Somatic Nervous System

- The somatic system is under voluntary control

However, much of the skeletal muscle activity involving posture, balance, and stereotypical movements is subconsciously controlled

Neuromuscular Junction (NMJ)





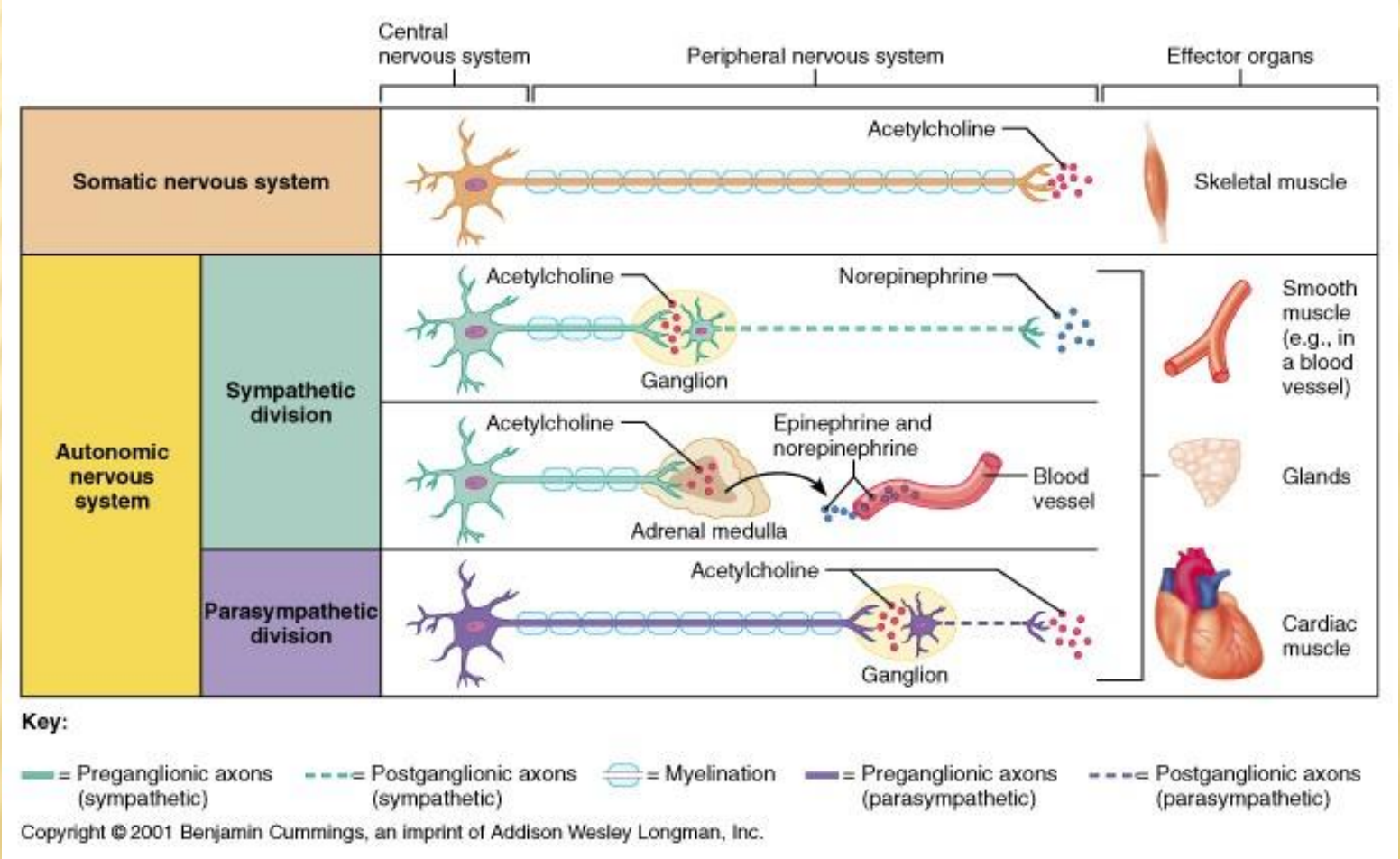
Neuromuscular Junction (NMJ)

- Nerve and muscle cells do not actually come into direct contact at a neuromuscular junction
- The space, or cleft, between these two structures is too large to permit electrical transmission of an impulse between them
- The chemical messenger is acetylcholine (ACh)

Somatic vs. Autonomic

FEATURE	AUTONOMIC NERVOUS SYSTEM	SOMATIC NERVOUS SYSTEM
Site of Origin	Brain or spinal cord	Spinal cord for most; those supplying muscles in head originate in brain
Number of Neurons from Origin in CNS to Effector Organ	Two-neuron chain (preganglionic and postganglionic)	Single neuron (motor neuron)
Organs Innervated	Cardiac muscle, smooth muscle, exocrine and some endocrine glands	Skeletal muscle
Type of Innervation	Most effector organs dually innervated by the two antagonistic branches of this system (sympathetic and parasympathetic)	Effector organs innervated only by motor neurons
Neurotransmitter at Effector Organs	May be acetylcholine (parasympathetic terminals) or norepinephrine (sympathetic terminals)	Only acetylcholine
Effects on Effector Organs	Either stimulation or inhibition (antagonistic actions of two branches)	Stimulation only (inhibition possible only centrally through IPSPs on dendrites and cell body of motor neuron)
Types of Control	Under involuntary control	Subject to voluntary control; much activity subconsciously coordinated
Higher Centers Involved in Control	Spinal cord, medulla, hypothalamus, prefrontal association cortex	Spinal cord, motor cortex, basal nuclei, cerebellum, brain stem

Somatic vs. Autonomic



Spinal Cord Reflexes

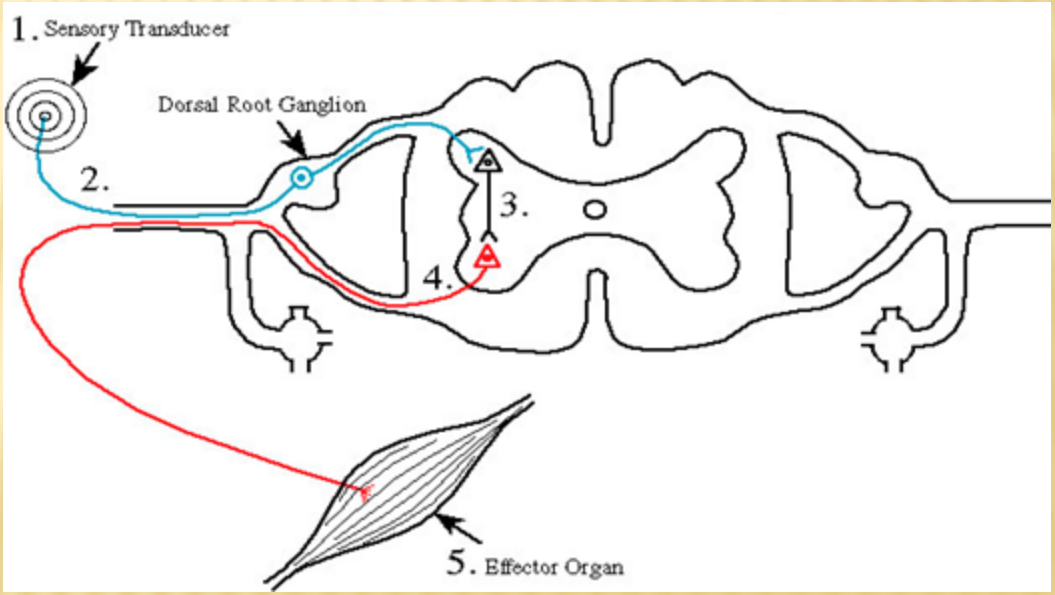
Reflex

- Any response that occurs automatically without conscious effort
- Motor response to a specific sensory stimulus

Reflex arc

- **Reflex arc:**
  - ✓ The neural pathway involved in accomplishing reflex activity

- **Five basic components:**
  1. Receptor
  2. Afferent pathway
  3. Integrating center
  4. Efferent pathway
  5. Effector



Types of Reflexes

A. Based on complexity:

1. **Simple,** or **basic reflexes,**
   - ✓ Built-in, unlearned responses
   - ✓ e.g., pulling the hand away from a burning hot object
   - ✓ Usually integrated in spinal cord or brain stem

2. **Acquired,** or **conditioned reflexes,**
   - ✓ Result of practice and learning
   - ✓ Usually integrated at higher brain levels

Types of Reflexes

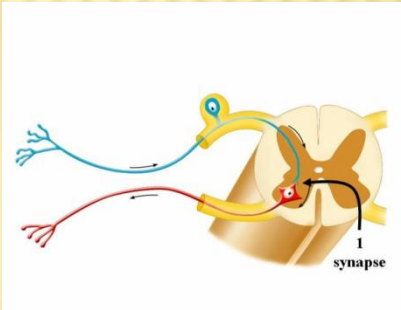
B. Based on neural processing level:

1. Cranial reflexes
   e.g., Pupillary reflex

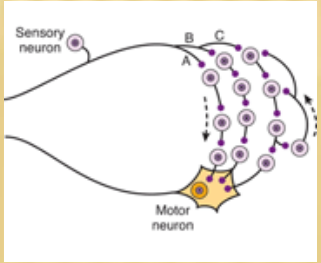
2. Spinal reflexes
   * Reflex activity between afferent input and efferent output without involving the brain
   * The controlling center of the spinal reflex is located in one or more spinal cord segments
   e.g., Skeletal muscle stretch reflex

C. Based on synapse number

1. Monosynaptic reflexes
   A. Two neurons (one synapse)



2. Polysynaptic reflexes
   A. Many neurons (many synapses)



Types of Reflexes

D. Based on effector

1. **Autonomic [visceral] reflexes**
   Smooth muscle, cardiac muscle, glands

2. **Somatic [muscle] reflexes**
   Skeletal muscles

E. Based on side of effect

1. **Ipsilateral reflexes**
   The response is on the same side of the body as the stimulus

2. **Contralateral [crossed extensor] reflexes**
   The response is on the opposite side of the body as the stimulus

Spinal Reflexes

- Integrating center for the reflex activity between afferent input and efferent output is located in one or more spinal cord segments
- The brain can facilitate or inhibit them
- Examples:
    1. Stretch reflex

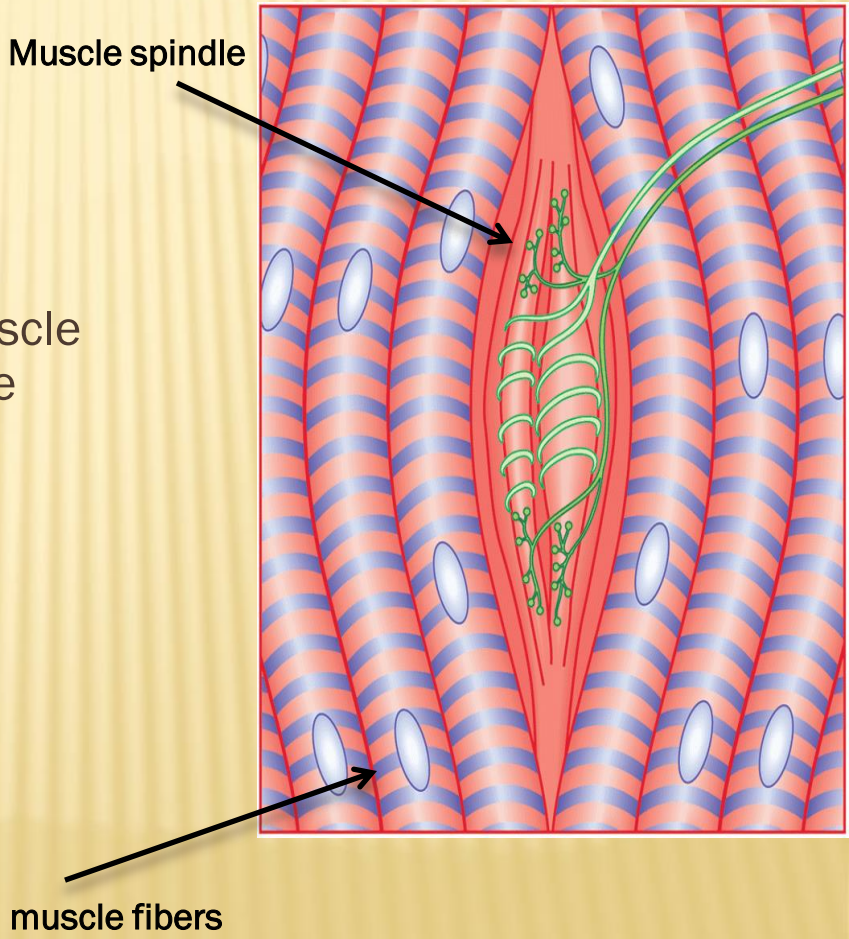
Stretch reflex

- Two muscle receptors are important for proprioceptive inputs:

1. ***Muscle spindles*** *(monitor changes in muscle* ***length****)*
2. ***Golgi tendon organs*** *(monitor changes in muscle* ***tension****)*

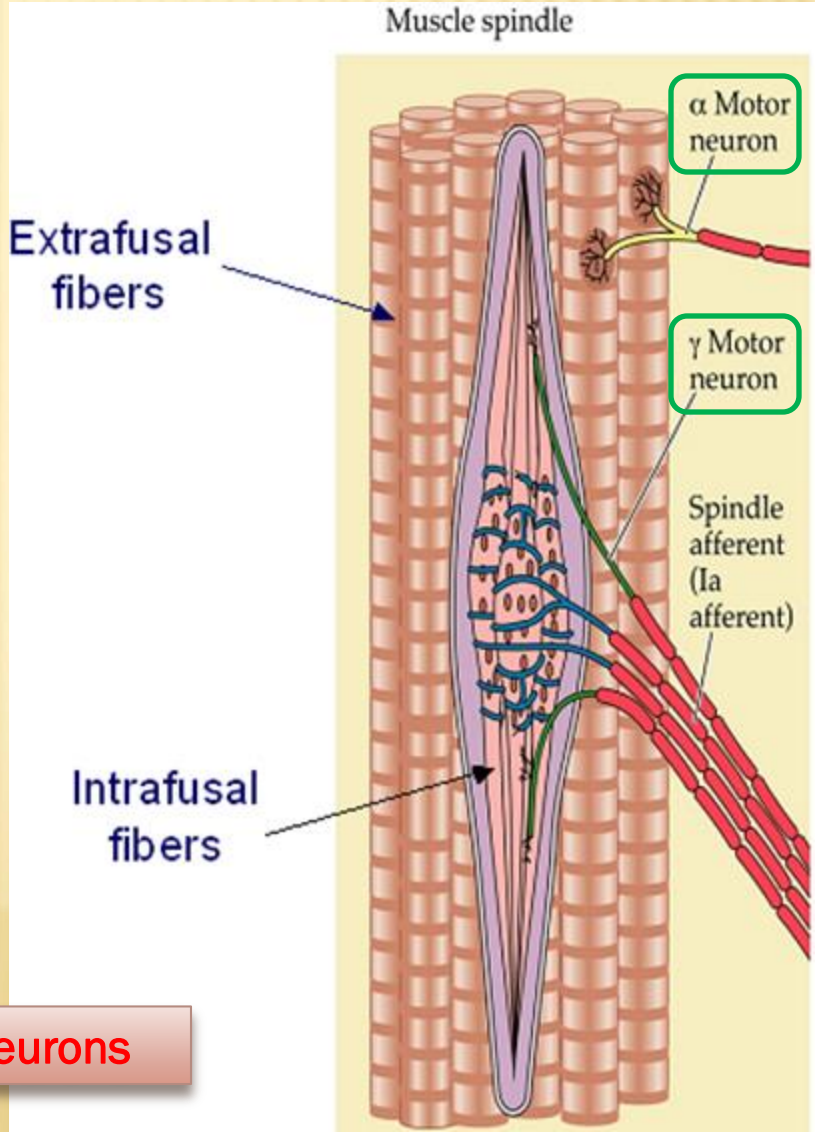
Muscle Spindles

- Distributed throughout skeletal muscle fibers
- Each spindle consists of 3-10 specialized muscle fibers enclosed in a connective tissue capsule (intrafusal fibers)
- Each intrafusal fiber has
  - ✓ Noncontractile central portion
  - ✓ Contractile ends



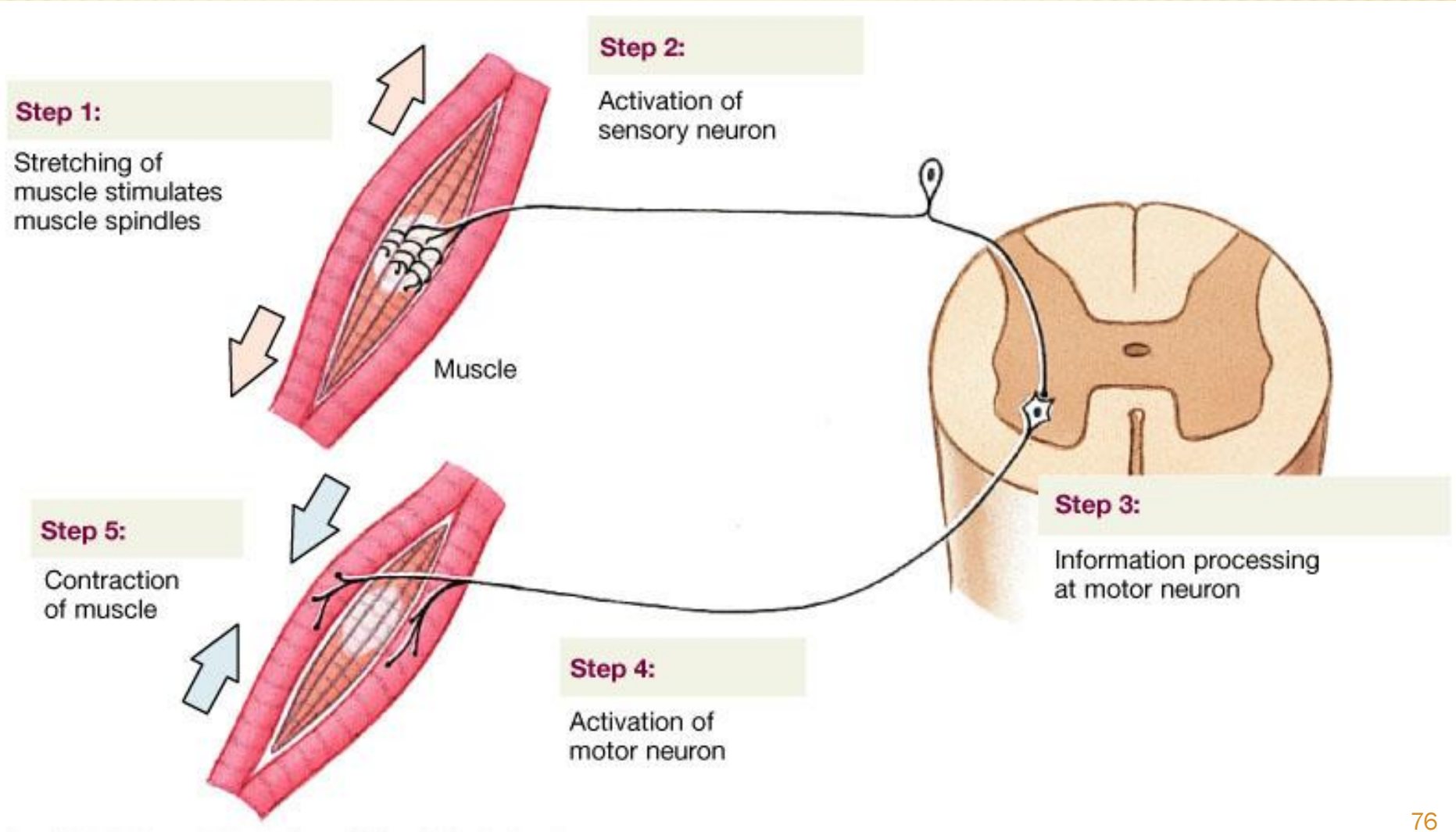
Muscle Spindles

- Each spindle has:
  - ✓**Afferent** nerve supply
    sensory nerve endings
    detect change in muscle <u>length</u> and <u>speed</u>
  - ✓**Efferent** nerve supply
    motor, gamma neurons

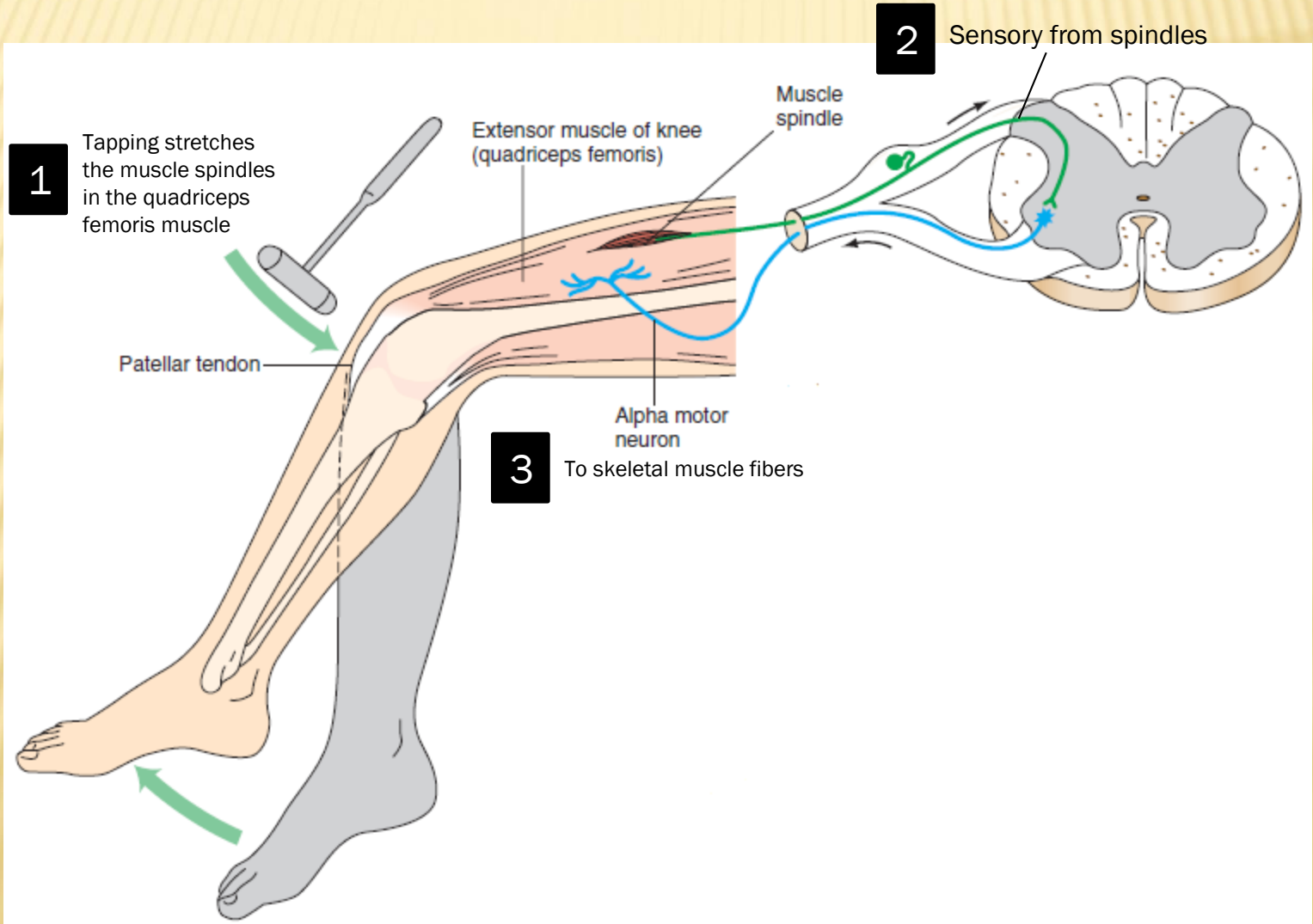


Skeletal muscle fibers are supplied via α motor neurons

Action of Muscle Spindles



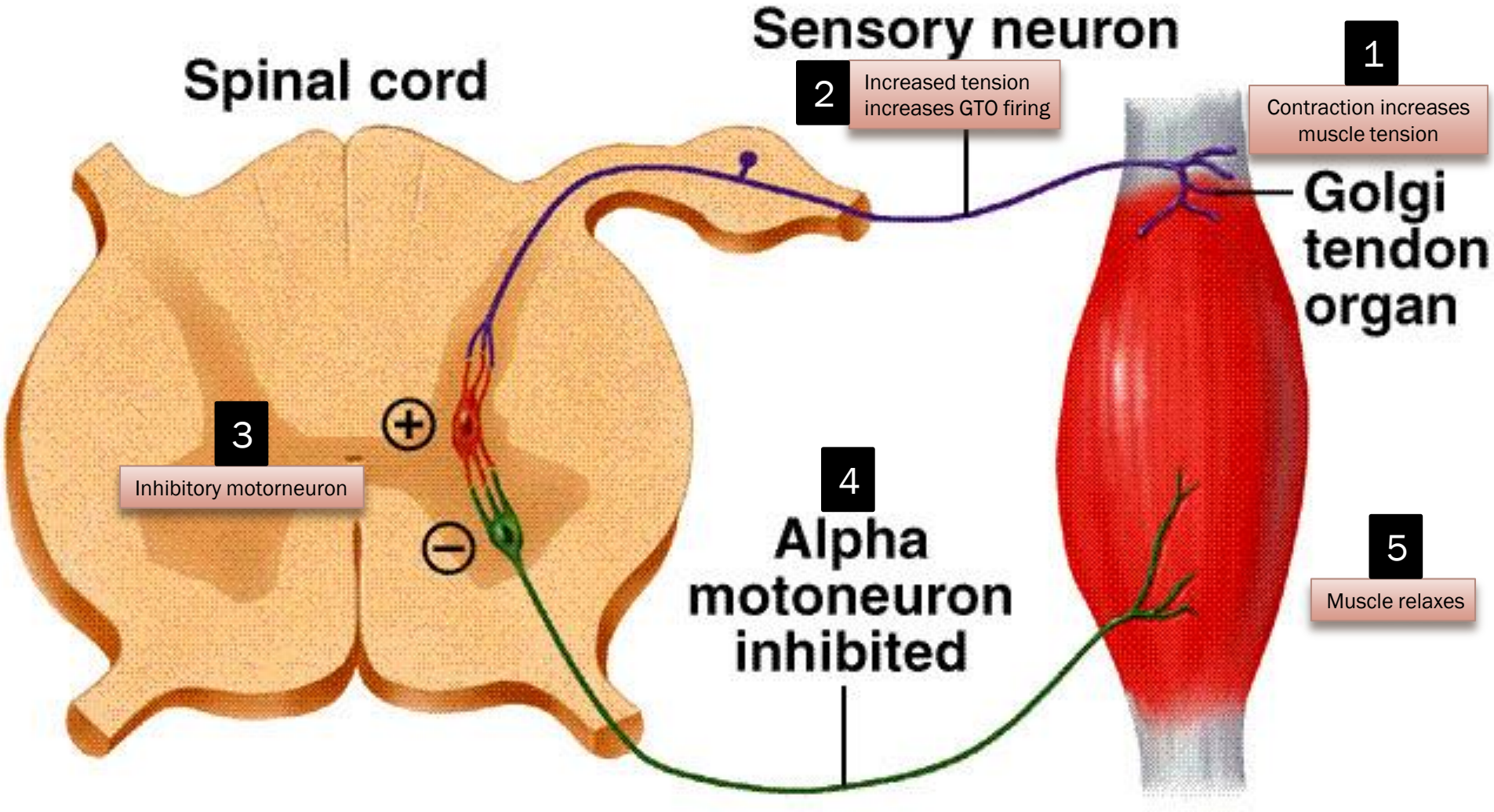
Patellar Tendon Reflex (A Stretch Reflex)



Golgi Tendon Organs

- In the tendons of the muscle
- Respond to changes in the muscle's **tension**
- Increased firing with increased muscle tension
- Its firing leads to inhibition of α motorneuron and thus relaxation of skeletal muscle

Action of Golgi Tendon Organ (Disynaptic Reflex)



Golgi Tendon Reflex

- Opposite of those elicited by muscle spindle reflexes
- Golgi tendon organs help ensure smooth onset and termination of muscle contraction
- Particularly important in activities involving rapid switching between flexion and extension such as in running

The END