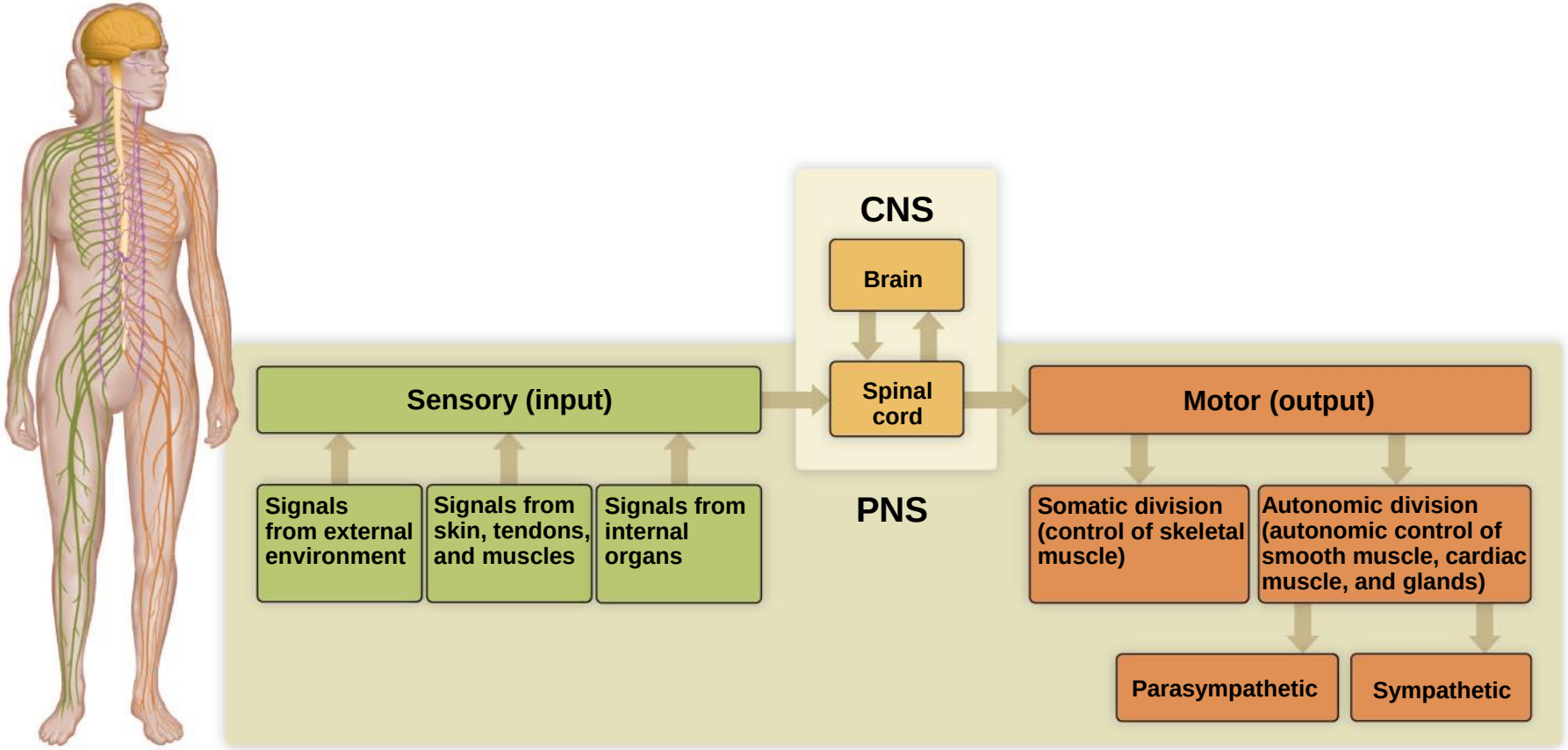
The Nervous System

Nervous System Has Two Principal Parts

- **Central nervous system** (CNS)
  - Components: brain and spinal cord
  - Functions: receives, processes, and transfers information
- **Peripheral nervous system** (PNS)
  - Components: nerves outside CNS
  - Sensory division: carries information toward the CNS
  - Motor division: carries information away from CNS

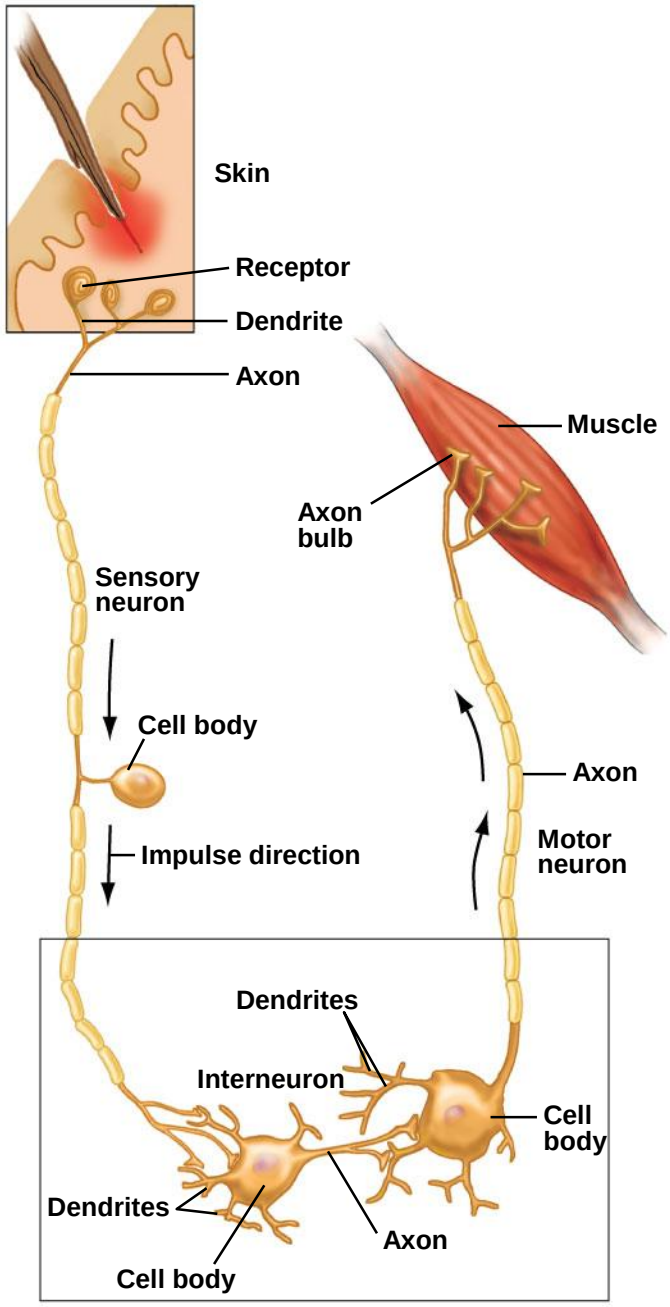

CNS
Brain
Spinal cord
Sensory (input)
Motor (output)
Signals from external environment
Signals from skin, tendons, and muscles
Signals from internal organs
PNS
Somatic division (control of skeletal muscle)
Autonomic division (autonomic control of smooth muscle, cardiac muscle, and glands)
Parasympathetic
Sympathetic

Neurons: Communication Cells of the Nervous System

- Neurons are specialized cells for communication
  - Generate and conduct electrical impulses
- Types of neurons
  - **Sensory neurons**: neurons found in the PNS that receive stimuli and transmit information to the CNS
  - **Interneurons**: transmit information between components of the CNS
  - **Motor neurons**: neurons found in the PNS that transmit information away from the CNS

Neurons: Cell Structure

- **Three parts of the neuron**
  - **Cell body**: main part of the cell, has the nucleus and most of the cytoplasm and organelles
  - **Dendrites**: small slender extensions of the cell body, receive incoming information
  - **Axon**: long slender extension, specialized to conduct electrical impulses away from the cell body


Skin
Receptor
Dendrite
Axon
Muscle
Axon bulb
Sensory neuron
Cell body
Impulse direction
Axon
Motor neuron
Dendrites
Interneuron
Cell body
Dendrites
Axon
Cell body
Brain and spinal cord

Neurons Initiate Action Potentials

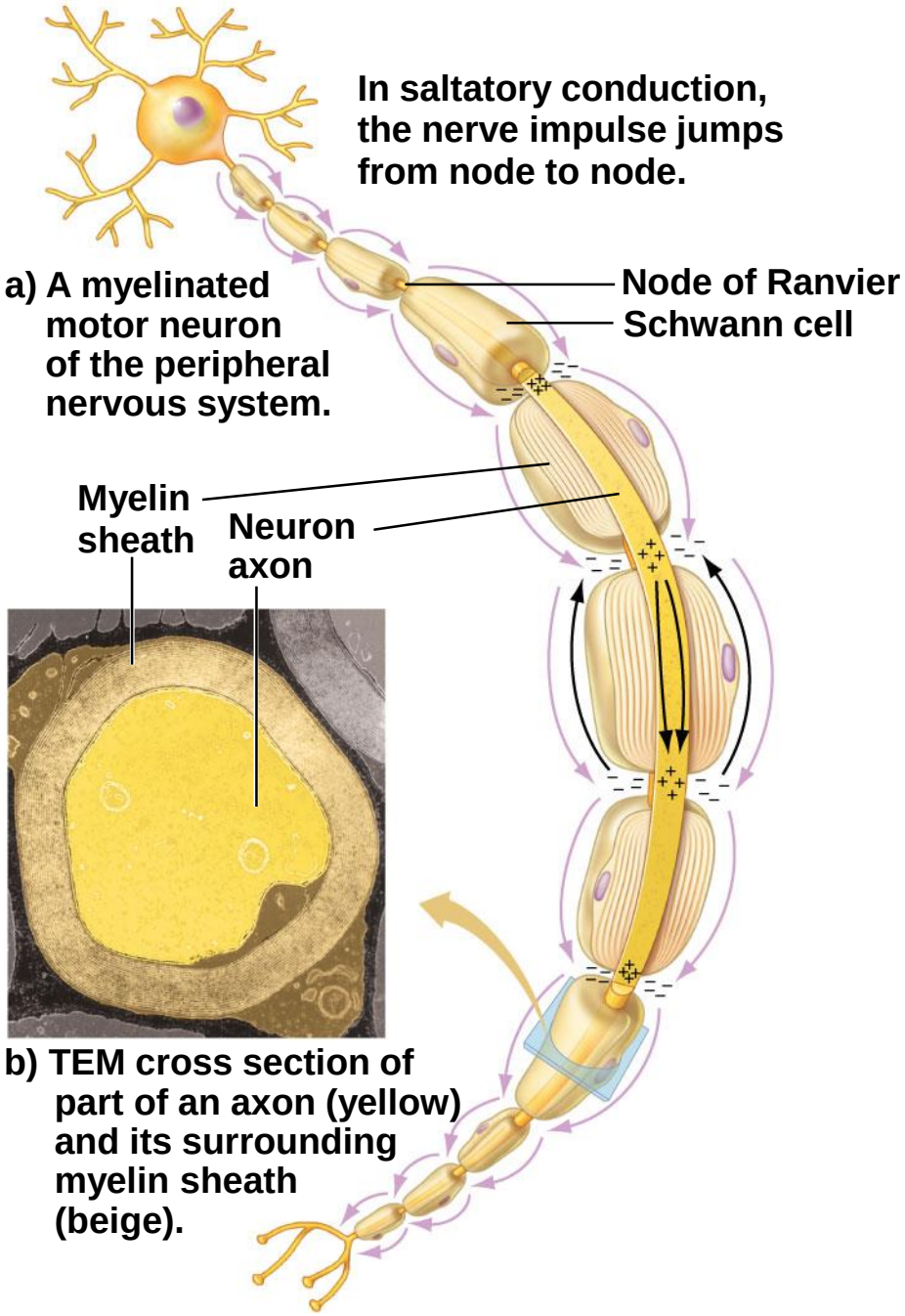
- Neurons generate and transmit action potentials
- An action potential is basically an electrical impulse
- Primary means of communication throughout the nervous system

Neuroglial Cells Support/Protect Axons

- Neuroglial cells make up 80% of nervous system
  - Function
    - Support
    - Protection
    - Do NOT transmit action potentials
  - Two types
    - Schwann cells
    - Oligodendrocytes

Neuroglial Cells: Form Myelin Sheath on Neurons

- **Schwann cells**
  - Form myelin sheath in PNS
  - Save the neuron energy
  - Speed up the transmission of impulses
    - **Saltatory conduction**: leaping pattern of action potential conduction
  - Help damaged or severed axons regenerate
- **Oligodendrocytes**
  - Form myelin sheath in CNS


In saltatory conduction, the nerve impulse jumps from node to node.
a) A myelinated motor neuron of the peripheral nervous system.
Node of Ranvier
Schwann cell
Myelin sheath
Neuron axon
b) TEM cross section of part of an axon (yellow) and its surrounding myelin sheath (beige).

Demyelinating Diseases

- Disorders associated with degeneration of myelin sheaths
  - **Multiple sclerosis** (MS)
    - Progressive damage to myelin sheaths in brain and spinal cord
    - Weakness, visual impairment, incontinence
  - **Amyotrophic lateral sclerosis** (ALS)
    - Lou Gehrig's disease
    - Progressive damage to myelin sheaths in motor area of spinal cord
    - Progressive weakening and wasting of skeletal muscle

Information Is Transferred from Neuron to Target

- Targets
  - another neuron, muscle cell, or gland
- **Synapse**
  - special junction between axon terminus and target cell
- Synaptic transmission
  - Process of transmission of impulse from sending (presynaptic neuron) across synaptic cleft to receiving (postsynaptic) target
  - Involves release and diffusion of chemical neurotransmitter

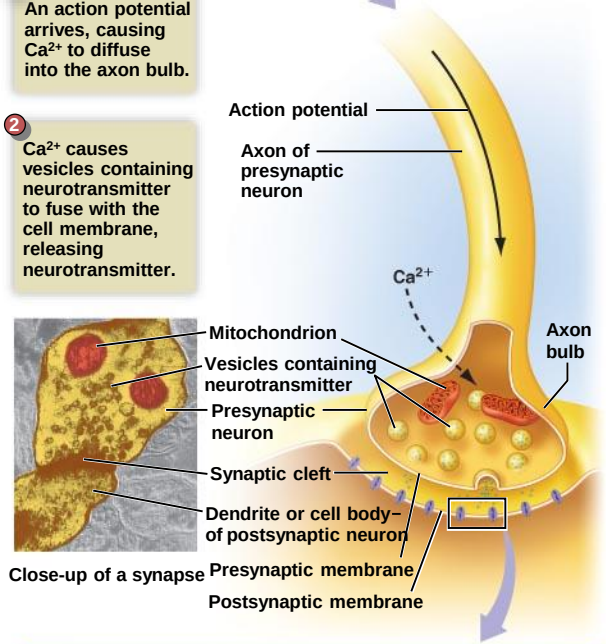
Synaptic Transmission: Neurotransmitter Release

- Action potential arrives at axon terminus, causing Ca^{2+} to diffuse into axon bulb
- Ca^{2+} causes release of neurotransmitter from vesicles
- Neurotransmitter diffuses across synaptic cleft
- Neurotransmitter binds to receptors on target (postsynaptic) membrane and opens gated channels

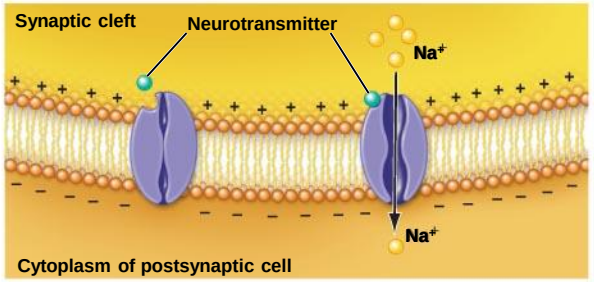
Axon bulbs form synapses with a postsynaptic neuron

1. An action potential arrives, causing Ca^{2+} to diffuse into the axon bulb.

2. Ca^{2+} causes vesicles containing neurotransmitter to fuse with the cell membrane, releasing neurotransmitter.



Close-up of a synapse



3. Neurotransmitter binds to receptors on chemically gated sodium channels, causing the channels to open.

4. Diffusion of sodium produces a graded potential in the local region of the synapse.

Neurotransmitters Exert Excitatory or Inhibitory Effects

- Response of postsynaptic target cell depends on
  - Type of neurotransmitter (>50 types)
  - Type of receptors
  - Type of gated ion channels

Table 11.1 Actions of common neurotransmitters

Neurotransmitter	Sites where released	Principal actions
Acetylcholine	Neuromuscular junctions, autonomic nervous systems, brain	Excitatory on skeletal muscles; excitatory or inhibitory at other sites, depending on receptors
Norepinephrine	Areas of brain and spinal cord, autonomic nervous system	Excitatory or inhibitory, depending on receptors; plays a role in emotions
Serotonin	Areas of brain, spinal cord	Usually inhibitory; involved in moods, sleep cycle, appetite
Dopamine	Areas of brain, parts of peripheral nervous system	Excitatory or inhibitory, depending on receptors; plays a role in emotions
Glutamate	Areas of brain, spinal cord	Usually excitatory; major excitatory neurotransmitter in brain
Endorphins	Many areas in brain, spinal cord	Natural opiates that inhibit pain; usually inhibitory
Gamma-aminobutyric acid	Areas of brain, spinal cord	Usually inhibitory; principal inhibitory neurotransmitter in brain
Somatostatin	Areas of brain, pancreas	Usually inhibitory; inhibits pancreatic release of growth hormone

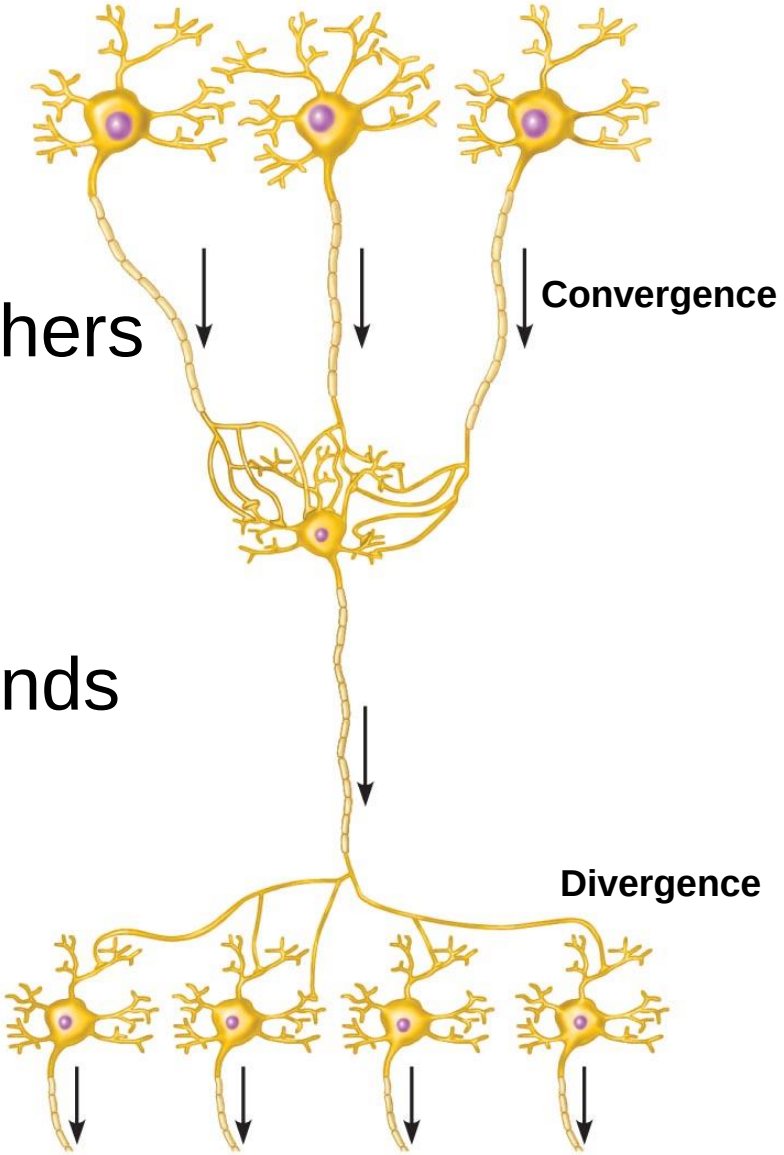
- This is just to show the names of some neurotransmitters
  - Do not worry about the ‘site where released’ or ‘principal actions’

Postsynaptic Neurons Integrate and Process Information

- Response in postsynaptic cell depends on
  - How many neurons are forming synapses with it
  - Whether the neurons forming synapses with it are excitatory or inhibitory

Postsynaptic Neurons Integrate and Process Information

- Convergence
  - occurs when one neuron receives input from many others
- Divergence
  - occurs when one neuron sends action potentials to multiple other neurons



Peripheral Nervous System Relays Information Between Tissues and CNS

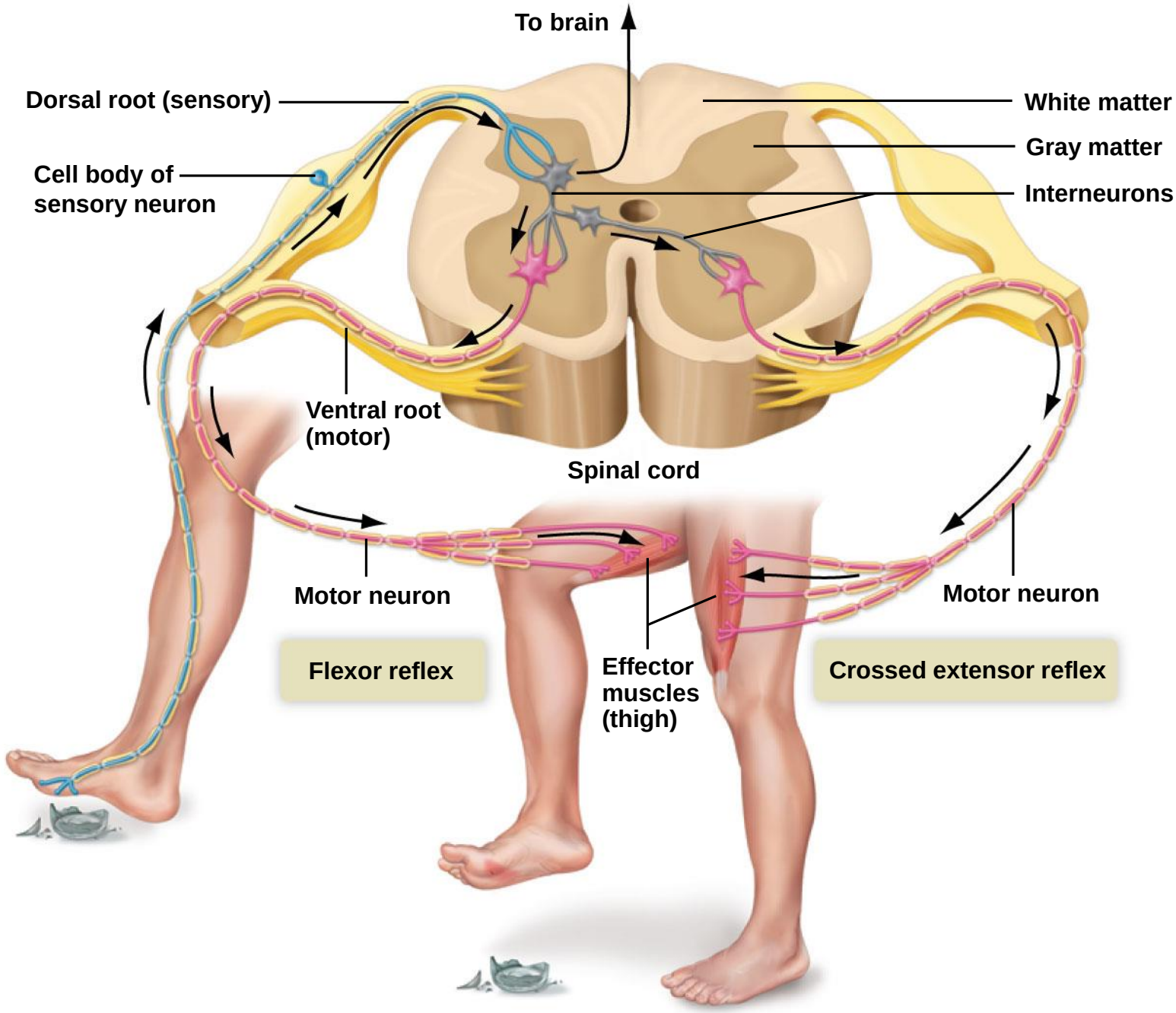
- Nerve
  - contains axons of many neurons wrapped together in a protective sheath
  - Carries information to and from the CNS
- Cranial nerves
    - 12 pairs
    - Connect directly to brain
- Spinal nerves
    - 31 pairs
    - Connect to spinal cord

Sensory Neurons Provide Information to the CNS

- Provide information for both the somatic and autonomic motor divisions of the PNS
- Incoming information arrives at the CNS as action potentials from sensory neurons located throughout the body

Somatic Division Controls Skeletal Muscles

- Functions
  - Voluntary
    - Conscious control of skeletal muscles
  - Involuntary (Reflexes)
    - **Spinal reflexes**: Involuntary responses mediated primarily by spinal cord and spinal nerves, with little brain involvement
      - flexor (withdrawal) reflex
      - crossed extensor reflex
      - stretch reflex: important in maintaining upright posture, movement


To brain
Dorsal root (sensory)
White matter
Gray matter
Cell body of sensory neuron
Interneurons
Ventral root (motor)
Spinal cord
Motor neuron
Motor neuron
Flexor reflex
Effector muscles (thigh)
Crossed extensor reflex

The Autonomic Division

- Part of the motor output of the PNS
- Controls automatic body functions of many internal organs
- Consists of two divisions
  - Sympathetic division
  - Parasympathetic division
- Both sympathetic and parasympathetic neurons enervate each organ

The Sympathetic and Parasympathetic Autonomic Divisions Oppose Each Other

- Sympathetic division
  - Prepares the body for emergencies
  - Norepinephrin is the key neurotransmitter
  - Produces fight-or-flight response
    - Increases heart rate and respiration
    - Raises blood pressure
    - Dilates pupils
    - Slows digestion and urine production
  - Generally produces a unified response in all organs at once
  - Opposes parasympathetic division

The Sympathetic and Parasympathetic Autonomic Divisions Oppose Each Other

- Parasympathetic division
  - Relaxes the body
  - Opposes sympathetic division
  - Acetylcholine is the key neurotransmitter
  - Actions:
    - lowers heart rate and respiration
    - increases digestion
    - permits defecation and urination
- Sympathetic and parasympathetic divisions work antagonistically to maintain homeostasis

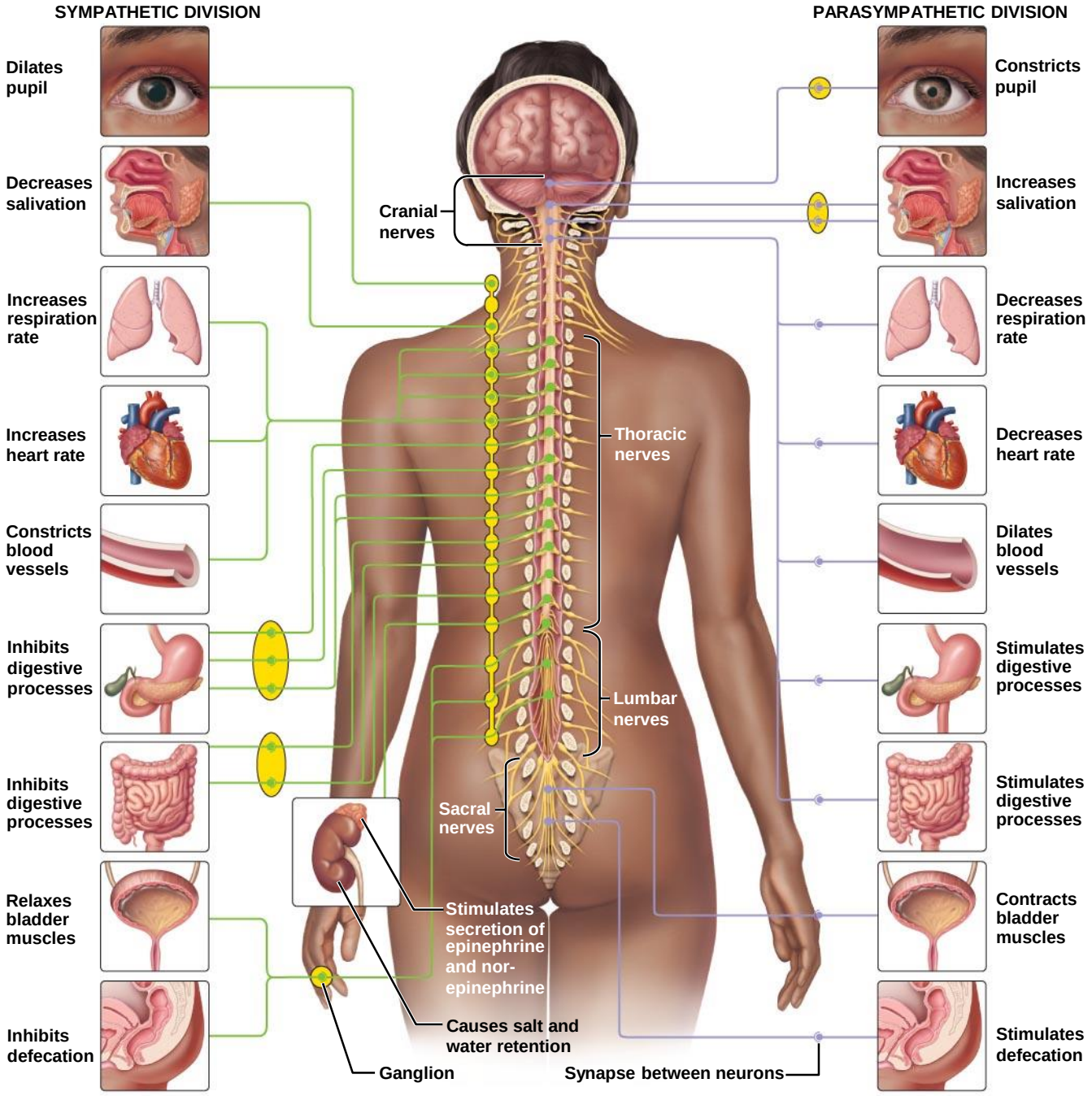
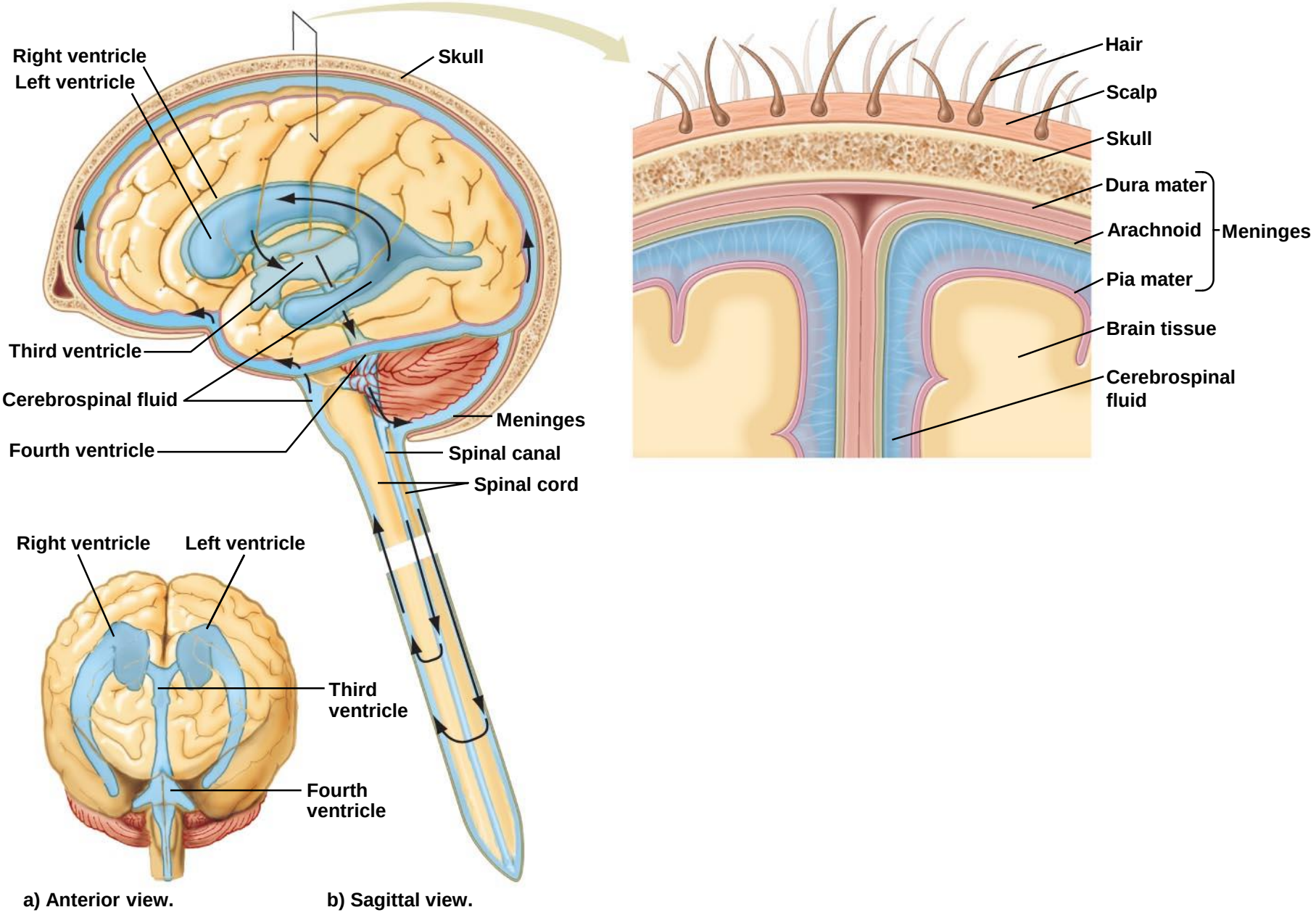

SYMPATHETIC DIVISION
PARASYMPATHETIC DIVISION
Dilates pupil
Decreases salivation
Increases respiration rate
Increases heart rate
Constricts blood vessels
Inhibits digestive processes
Inhibits digestive processes
Relaxes bladder muscles
Inhibits defecation
Constricts pupil
Increases salivation
Decreases respiration rate
Decreases heart rate
Dilates blood vessels
Stimulates digestive processes
Stimulates digestive processes
Contracts bladder muscles
Stimulates defecation
Cranial nerves
Thoracic nerves
Lumbar nerves
Sacral nerves
Stimulates secretion of epinephrine and nor-epinephrine
Causes salt and water retention
Ganglion
Synapse between neurons

Table 11.2 The somatic and autonomic divisions of the PNS

	Somatic division	Autonomic division	
		Sympathetic	*Parasympathetic*
Functions	Serves skeletal muscles	Fight or flight; arouses body to deal with situations involving physical activity, mental alertness	Relaxes body; promotes digestion and other basic functions
Neurotransmitter	Acetylcholine	Norepinephrine	Acetylcholine
Number of neurons required to reach the target cell	One	Two (preganglionic and postganglionic)	Two (preganglionic and postganglionic)

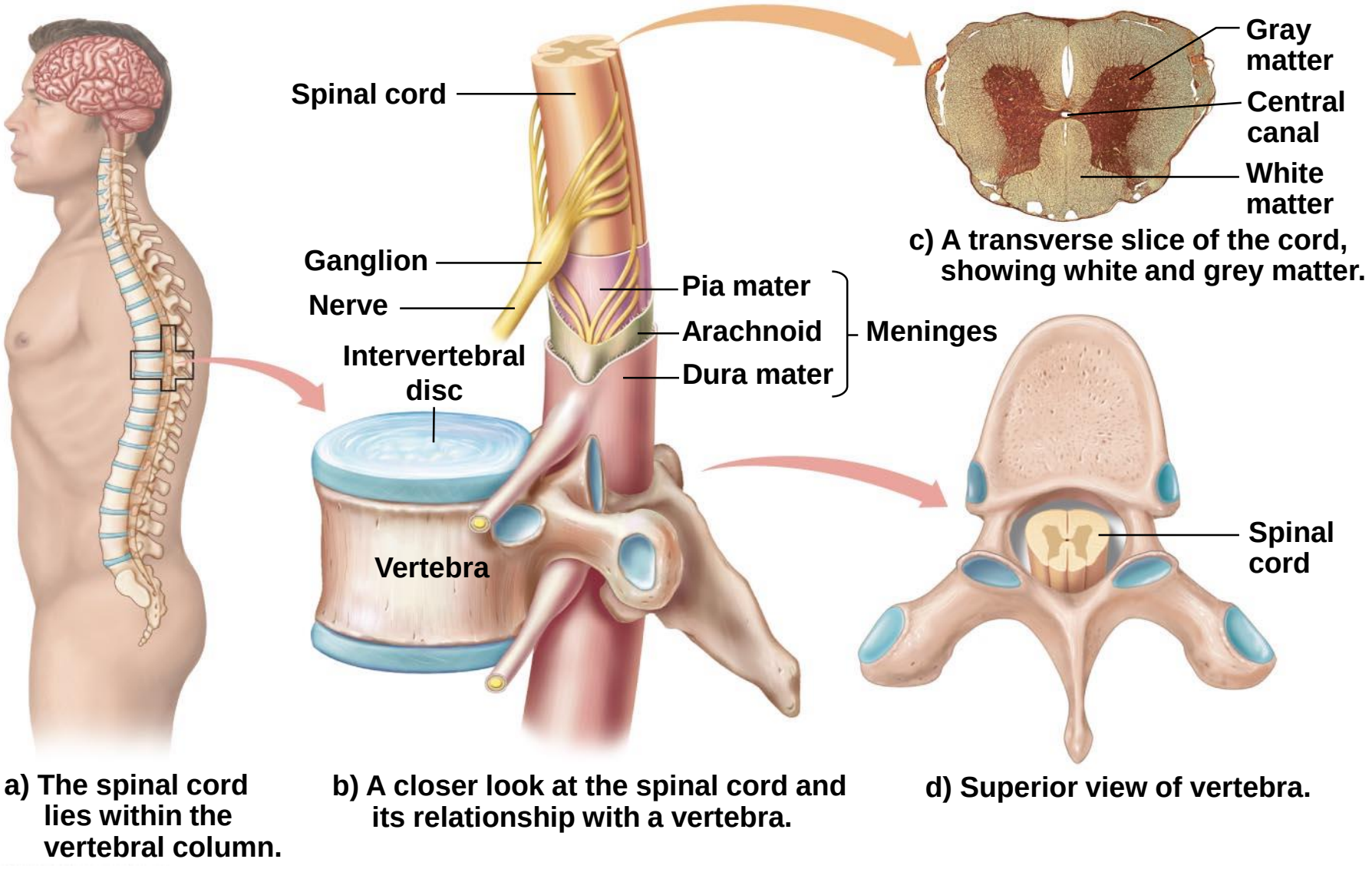
Brain and Spinal Cord Constitute the CNS

- CNS protection
  - **Bone**: skull and vertebrae
  - **Meninges**: protective membranes
    - Dura mater, arachnoid, and pia mater
  - **Cerebrospinal fluid**: bathes the brain, spinal cord
    - Shock absorber
    - Produced within the ventricles of the brain
  - **Blood-brain barrier**: prevents entry of certain chemicals and pathogens


Right ventricle
Left ventricle
Skull
Third ventricle
Cerebrospinal fluid
Fourth ventricle
Meninges
Spinal canal
Spinal cord
Right ventricle
Left ventricle
Third ventricle
Fourth ventricle
a) Anterior view.
b) Sagittal view.
Hair
Scalp
Skull
Dura mater
Arachnoid
Pia mater
Meninges
Brain tissue
Cerebrospinal fluid

The Spinal Cord Relays Information

- Spinal cord is a superhighway for action potentials between the brain and the rest of the body
- White matter
  - Outer portion of spinal cord
  - Consists of myelinated ascending (sensory) and descending (motor) nerve tracts
- Gray matter
  - Center portion of spinal cord
  - Contains cell bodies, dendrites



a) The spinal cord lies within the vertebral column.

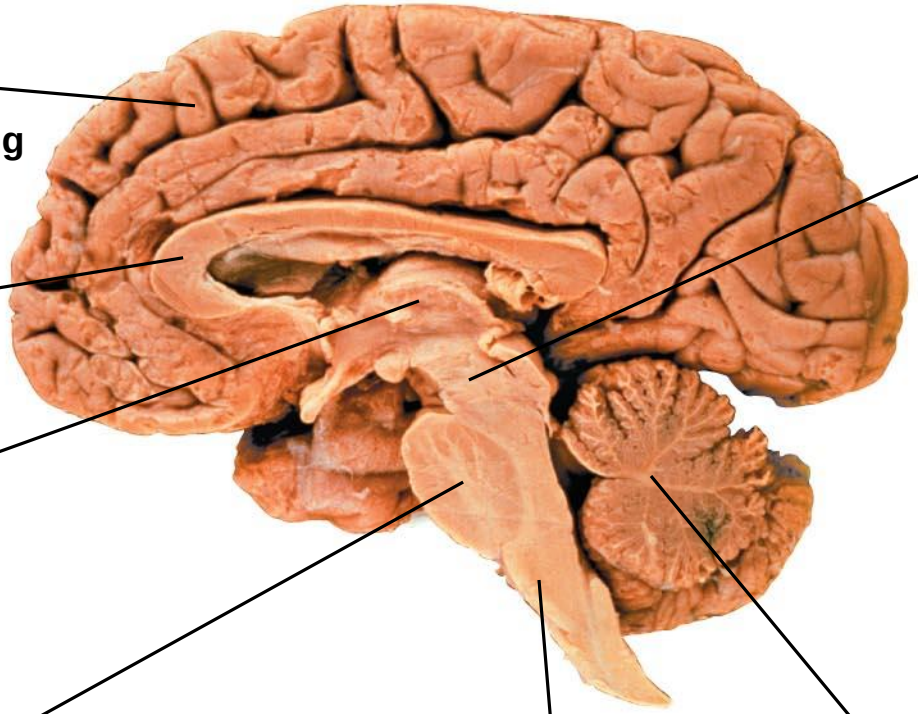
b) A closer look at the spinal cord and its relationship with a vertebra.

c) A transverse slice of the cord, showing white and grey matter.

d) Superior view of vertebra.

The Brain Processes and Acts on Information

- Brain: command center of the body
- Three major anatomical/functional divisions
  - **Hindbrain**: coordinates basic, automatic, and vital tasks
  - **Midbrain:** coordinates muscle groups and responses to sight and sound
  - **Forebrain**: receives, integrates sensory input, determines complex behavior



FOREBRAIN

Cerebrum
- Coordinates language
- Controls decision making
- Produces conscious thought

Corpus callosum
- Bridges the two cerebral hemispheres

Thalamus
- Receives, processes and transfers information

MIDBRAIN
- Relays visual and auditory inputs
- Coordinates movement

HINDBRAIN

Pons
- Connects cerebellum, spinal cord with higher brain centers
- Aids medulla in regulating respiration

Medulla oblongata
- Controls automatic functions of internal organs

Cerebellum
- Controls basic and skilled movements

Hindbrain: Medulla Oblongata

- Connects to spinal cord
- Controls vital automatic functions of internal organs
  - Cardiovascular center: regulates heart rate and blood pressure
  - Respiratory center: adjusts respiration in response to CO_2 and O_2 levels
- Motor nerves cross over in medulla oblongata
  - Right forebrain controls left side of body
  - Left forebrain controls right side of body

Hindbrain: Cerebellum

- Coordinates basic body movements
- Stores and replicates sequences of skilled movements
  - Examples
    - Tying a shoe
    - Swinging a bat
    - Using a keyboard

Hindbrain: Pons

- Connects higher brain centers and the spinal cord
- Coordinates the flow of information between the cerebellum and higher brain centers
- Aids medulla oblongata in regulating respiration

Midbrain: Vision and Hearing

- Coordinates movements of the head related to vision and hearing
- Controls movement of eyes and size of pupils

Forebrain: Emotions and Conscious Thought

- Receives and integrates information concerning emotions and conscious thought
- **Hypothalamus**
  - Helps regulate homeostasis
- **Thalamus** (“Grand Central Station”)
  - Receiving, processing, and transfer center
- **Limbic system**
  - Pathways involved in emotions and memory
- **Cerebrum**
  - Language, decision making, conscious thought

Forebrain: Cerebrum

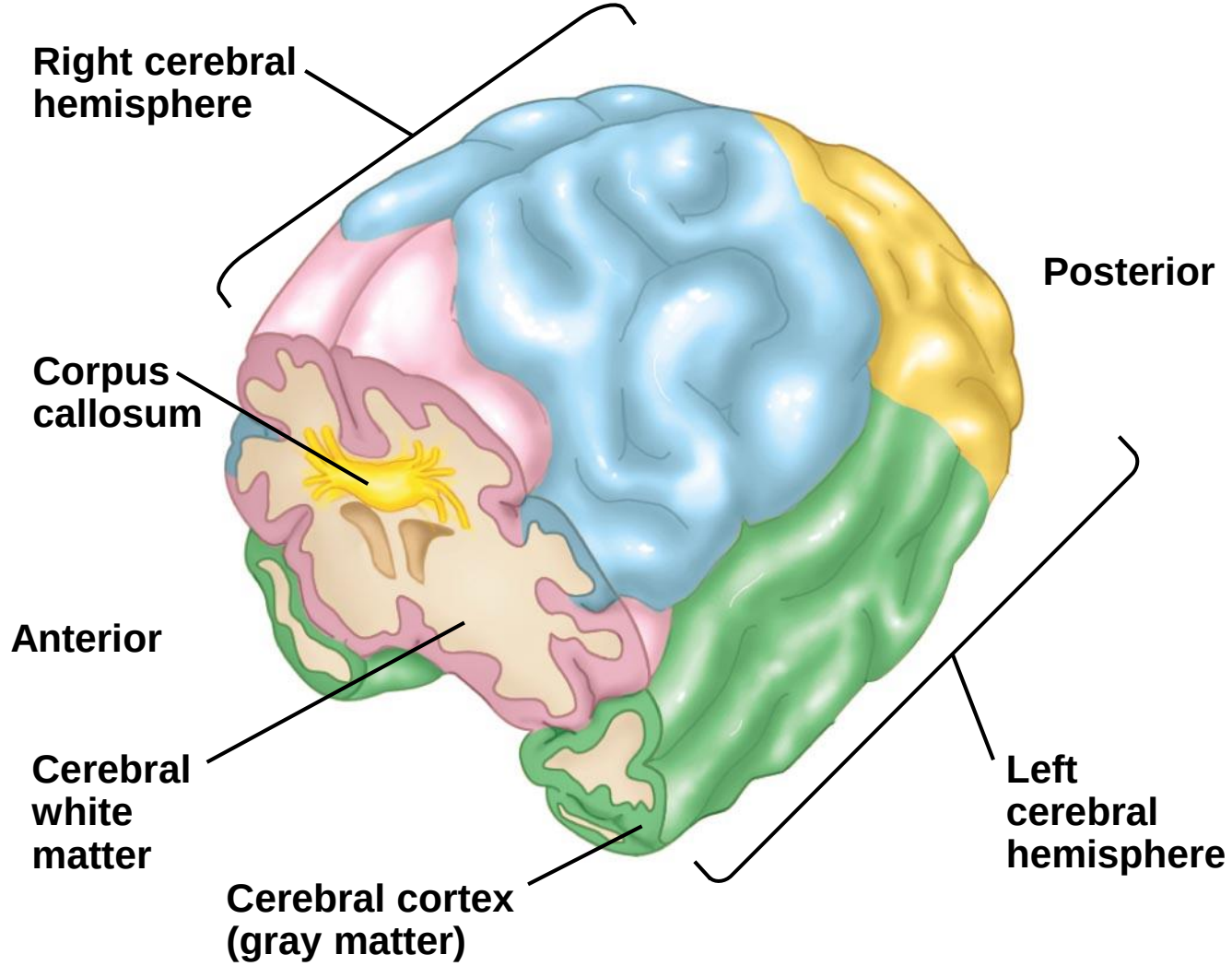
- Structure
  - Right and left **hemispheres**
  - Hemispheres connected by **corpus callosum**
    - Nerve tracts in corpus callosum allow two hemispheres to share information
  - Cerebral cortex
    - gray matter, the outer layer of the cerebrum

A Closer Look at the Cerebral Cortex

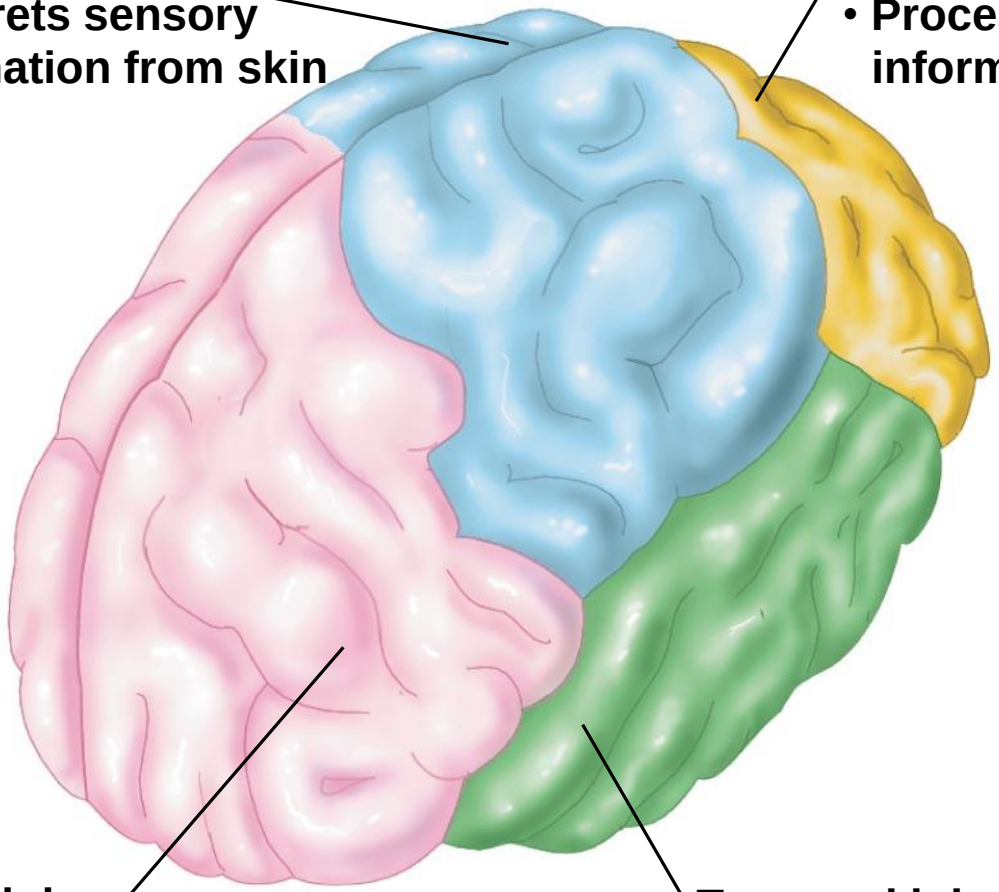
- **Functions**
  - memory storage
  - abstract thought
  - conscious awareness
  - conscious control of skeletal muscle

A Closer Look at the Cerebral Cortex

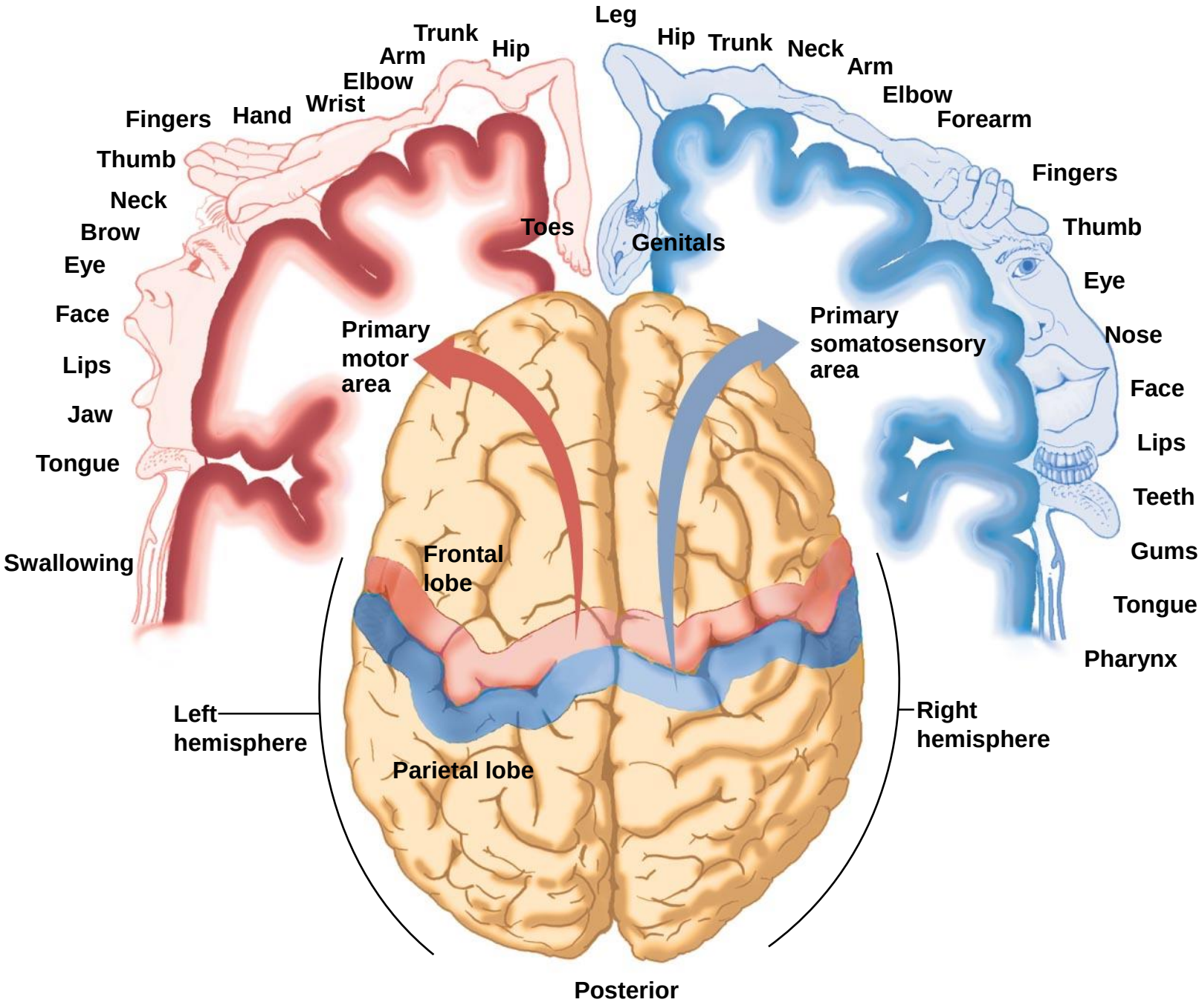
- Divided into four lobes
  - **Occipital lobe**
    - processes visual information
  - **Temporal lobe**
    - interprets auditory information, comprehends spoken/written language
  - **Parietal lobe**
    - receives and interprets sensory information from the skin
  - **Frontal lobe**
    - initiates motor activity, responsible for speech, conscious thought
- All four lobes: memory storage



a) The cerebral cortex (gray matter; outer layer, shown in four colors) consists of interneurons that integrate and process information. White matter (inner core) consists of ascending and descending nerve tracts. The two separate hemispheres are joined by the corpus callosum.

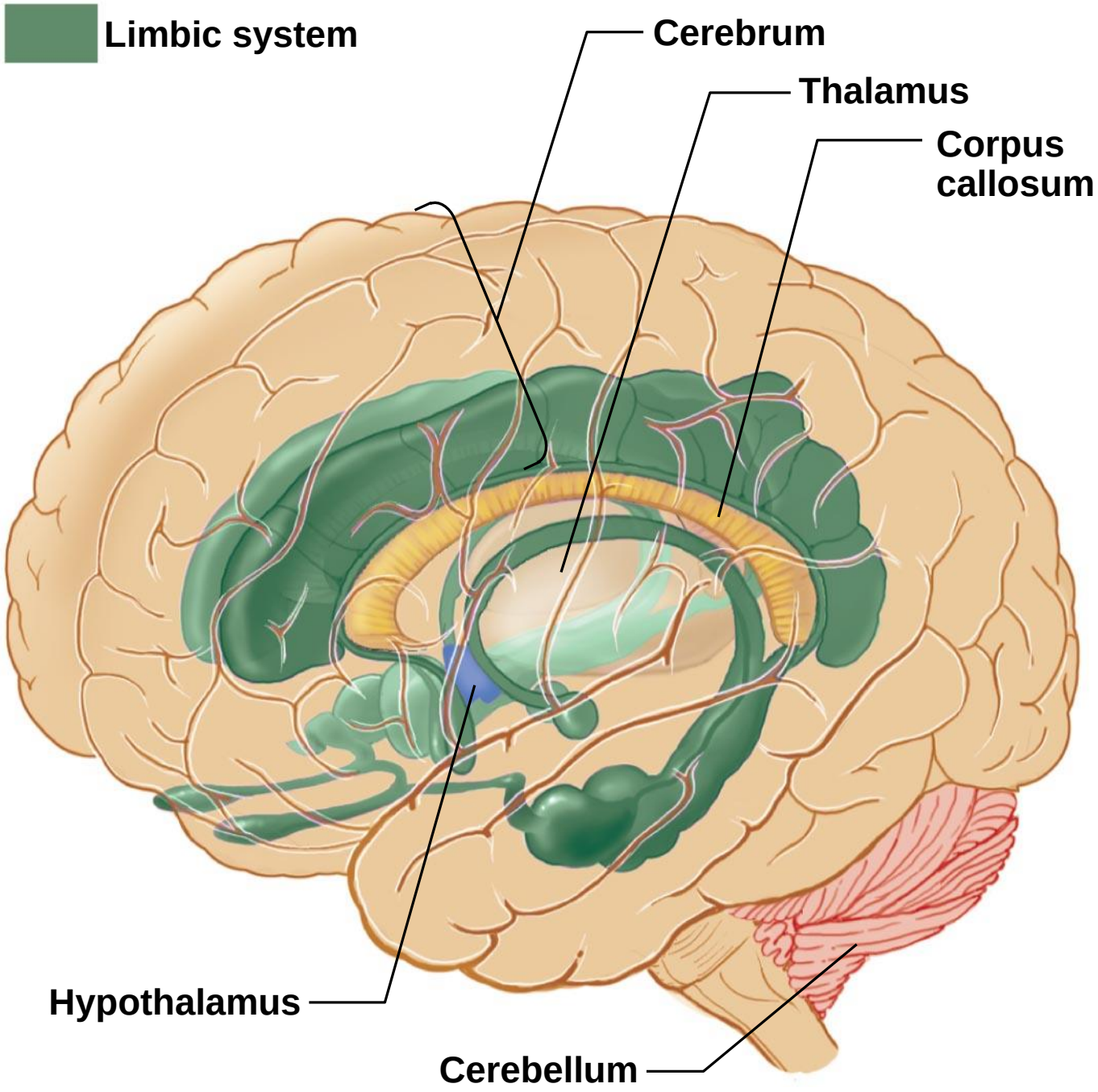


b) The functions of the four lobes of the cerebral cortex are location-specific.


Trunk
Hip
Arm
Elbow
Wrist
Fingers
Hand
Thumb
Neck
Brow
Eye
Face
Lips
Jaw
Tongue
Swallowing
Toes
Leg
Hip
Trunk
Neck
Arm
Elbow
Forearm
Fingers
Thumb
Eye
Nose
Face
Lips
Teeth
Gums
Tongue
Pharynx
Genitals
Primary motor area
Primary somatosensory area
Frontal lobe
Parietal lobe
Left hemisphere
Right hemisphere
Posterior

Limbic System: Site of Emotions and Basic Behaviors

- Includes all neuronal structures that together control emotional behavior and motivational drives
- Hypothalamus serves as a gateway to and from limbic system
- Emotions
  - Fear, anger, sorrow, love, etc.
- Basic behavior
  - Seeking food, satisfying thirst
  - Sexual gratification
- Behaviors modified by cerebrum
- Short-term memory


Limbic system
Cerebrum
Thalamus
Corpus callosum
Hypothalamus
Cerebellum

Memory: Storing and Retrieving Information

- Short-term
  - Working memory
  - Information from previous few hours
  - Stored in the limbic system
- Long-term
  - Information from previous days to years
  - Involves permanent changes in neurons and synapses in the cerebral cortex

Psychoactive Drugs Affect Higher Brain Functions

- Psychoactive drugs
  - Affect states of consciousness, emotions, or behavior
- Action
  - Able to cross blood-brain barrier
  - Influence concentrations or actions of neurotransmitters
  - Affect higher brain functions

Psychoactive Drugs

- Psychological dependence
  - User craves the feeling associated with the drug
- Tolerance
  - Requires more of the substance to achieve the same effect
- Addiction
  - The need to continue obtaining and using a substance
  - No free choice
- Withdrawal
  - Physical symptoms that occur upon stopping the drug

Disorders of the Nervous System

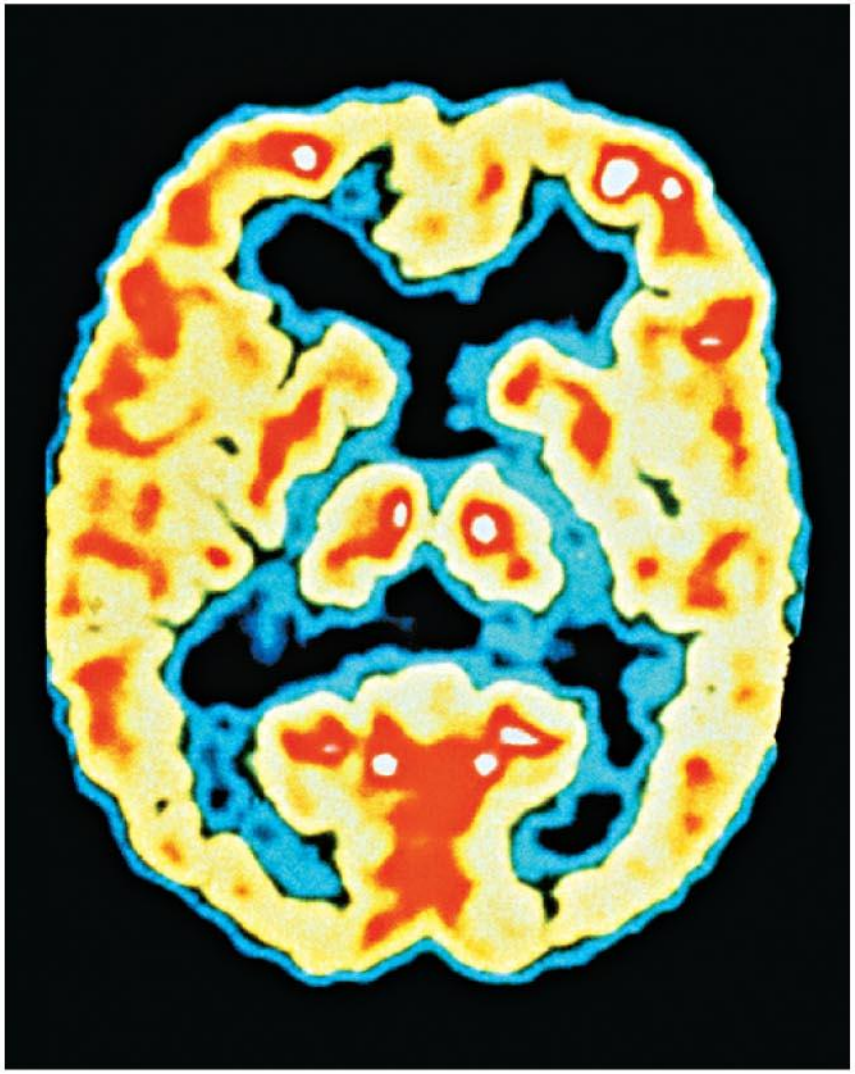
- Trauma
  - Physical injury to brain or spinal cord
  - Concussion
    - Blow to the head may lead to unconsciousness
    - Disruption of electrical activity in the brain
    - Risk of subdural hematoma
  - Spinal cord injuries
    - Impairment of sensation and function below site of injury

Disorders of the Nervous System

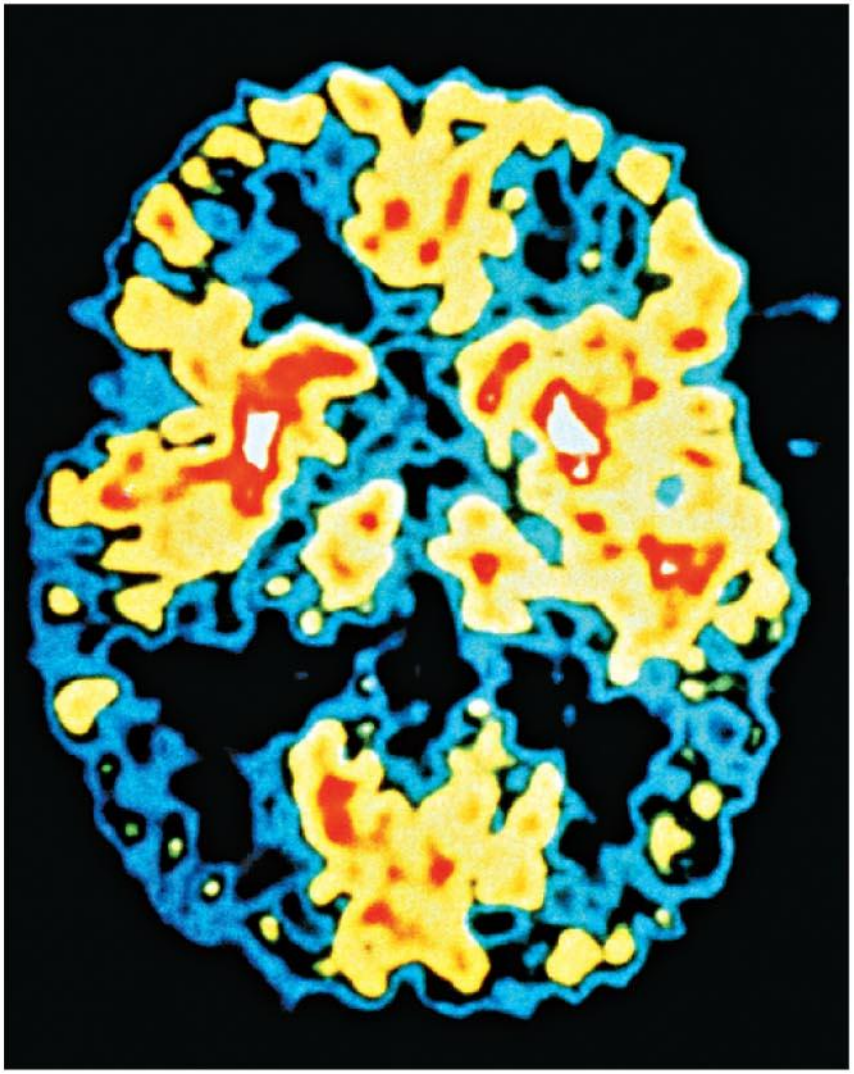
- **Infections**: Caused by viruses or bacteria that manage to pass through the blood-brain barrier
  - **Encephalitis**
    - Inflammation of the brain caused by viral infection
  - **Meningitis**
    - Inflammation of the meninges caused by viral or bacterial infection
  - **Rabies**
    - Infectious viral disease
    - Spread by bite or saliva of infected animal
    - Virus spreads from bite to brain via sensory neurons
- **Brain tumors:** abnormal growth in or on the brain

Disorders of the Nervous System

- Disorders of neural and synaptic transmission
  - **Epilepsy**
    - Recurring episodes of abnormal electrical activity (seizures)
  - **Alzheimer's disease**
    - Shortage of acetylcholine
    - Accumulation of abnormal protein, beta amyloid
    - Progressive memory lapses and dementia
  - **Parkinson's disease**
    - Loss of dopamine-releasing neurons
    - Progressive degenerative disorder affecting motor activity



a) A PET scan of a healthy brain.



b) A PET scan of a patient with Alzheimer's disease, showing decreased activity and an irregular pattern.