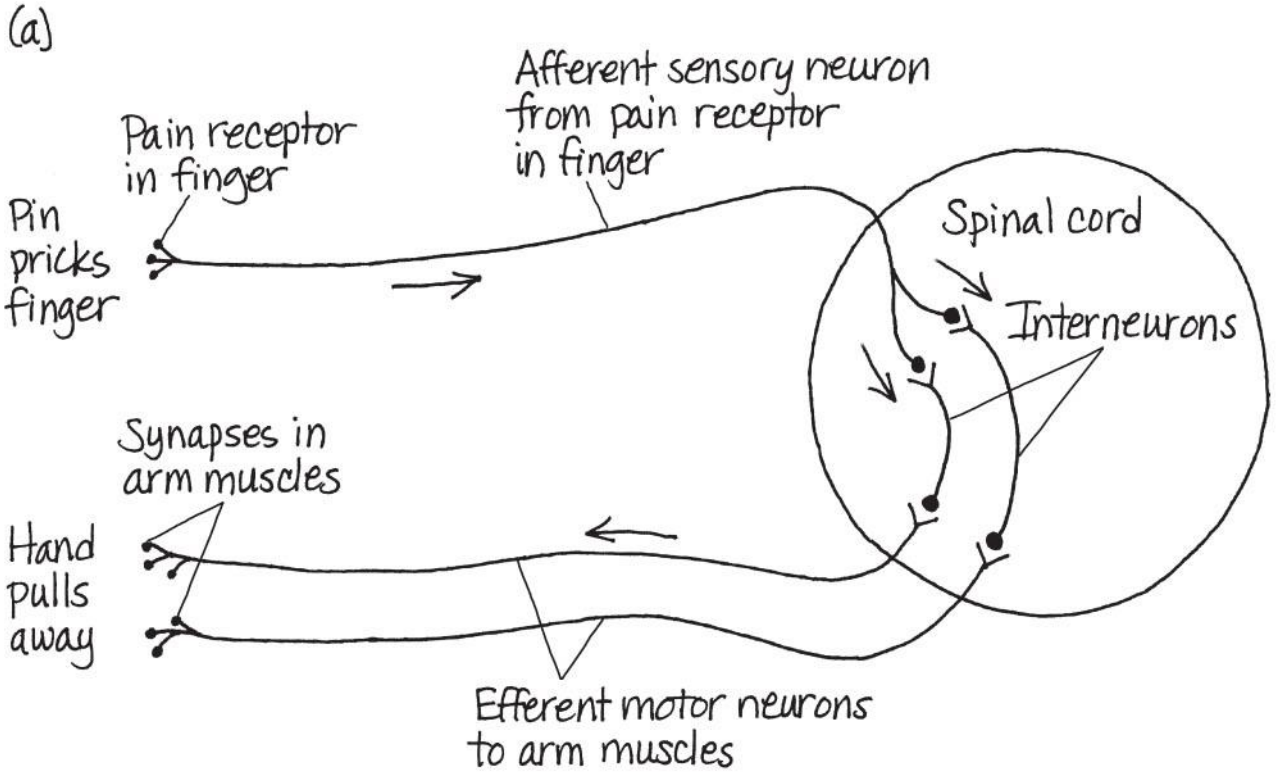
Chapter 49
Nervous Systems

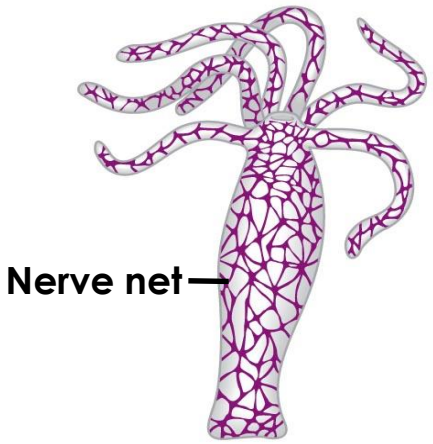
Concept 49.1

Nervous systems consist of circuits of neurons and supporting cells

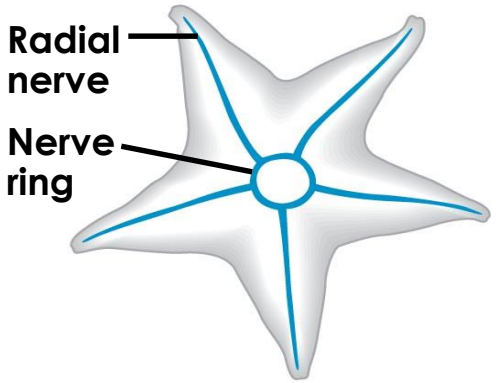


Nervous System Organization

- The simplest animals with nervous systems, the cnidarians, have neurons arranged in nerve nets
- A **nerve net** is a series of interconnected nerve cells
- More complex animals have **nerves** which are bundles that consist of the axons of multiple nerve cells
- Sea stars have a nerve net in each arm connected by radial nerves to a central nerve ring



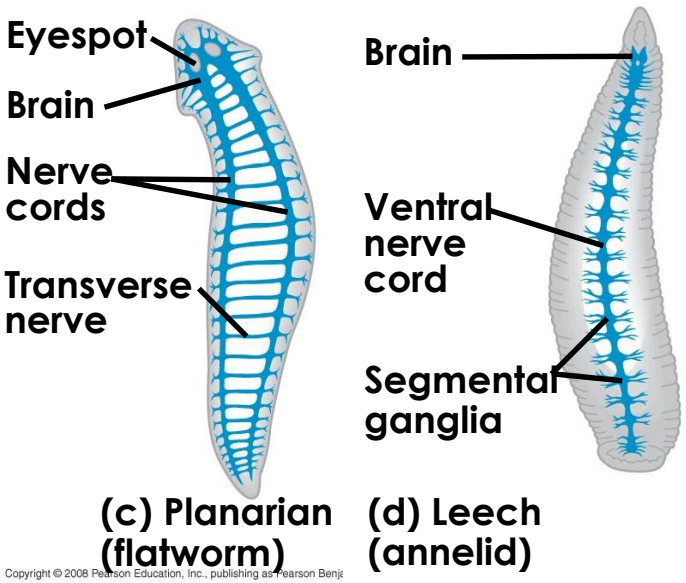
(a) Hydra (cnidarian)



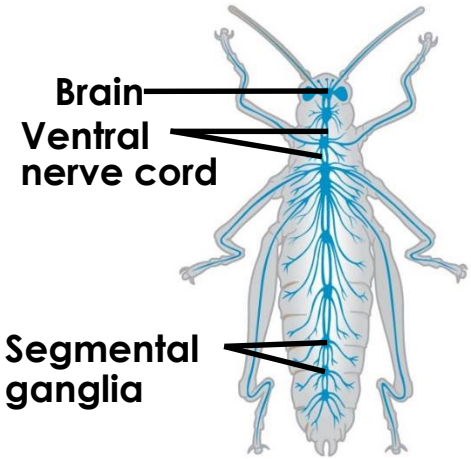
(b) Sea star (echinoderm)

Nervous System Organization

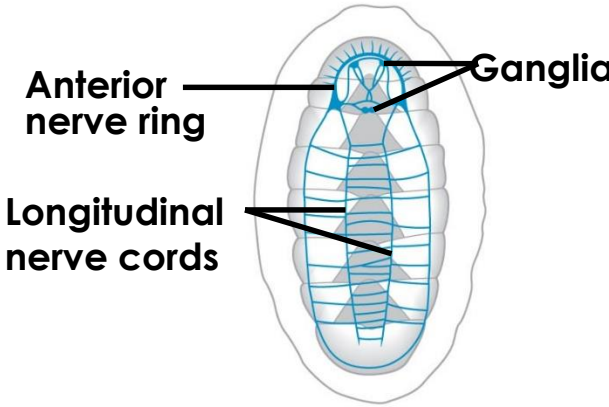
- Bilaterally symmetrical animals exhibit cephalization which is the clustering of sensory organs at the front end of the body
- Relatively simple cephalized animals, such as flatworms, have a *central nervous system (CNS)*
- The CNS consists of a brain and longitudinal nerve cords



- Annelids and arthropods have segmentally arranged clusters of neurons called ganglia



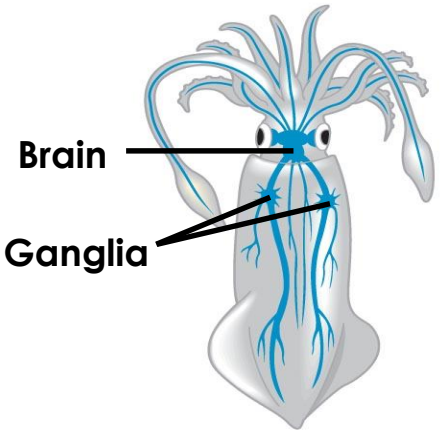
(e) Insect (arthropod)



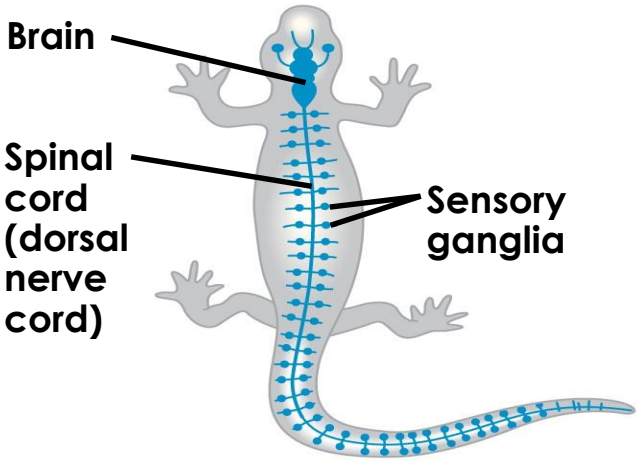
(f) Chiton (mollusc)

Nervous System Organization

- Nervous system organization usually correlates with lifestyle
- Sessile molluscs (e.g., clams and chitons) have simple systems, whereas more complex molluscs (e.g., octopuses and squids) have more sophisticated systems



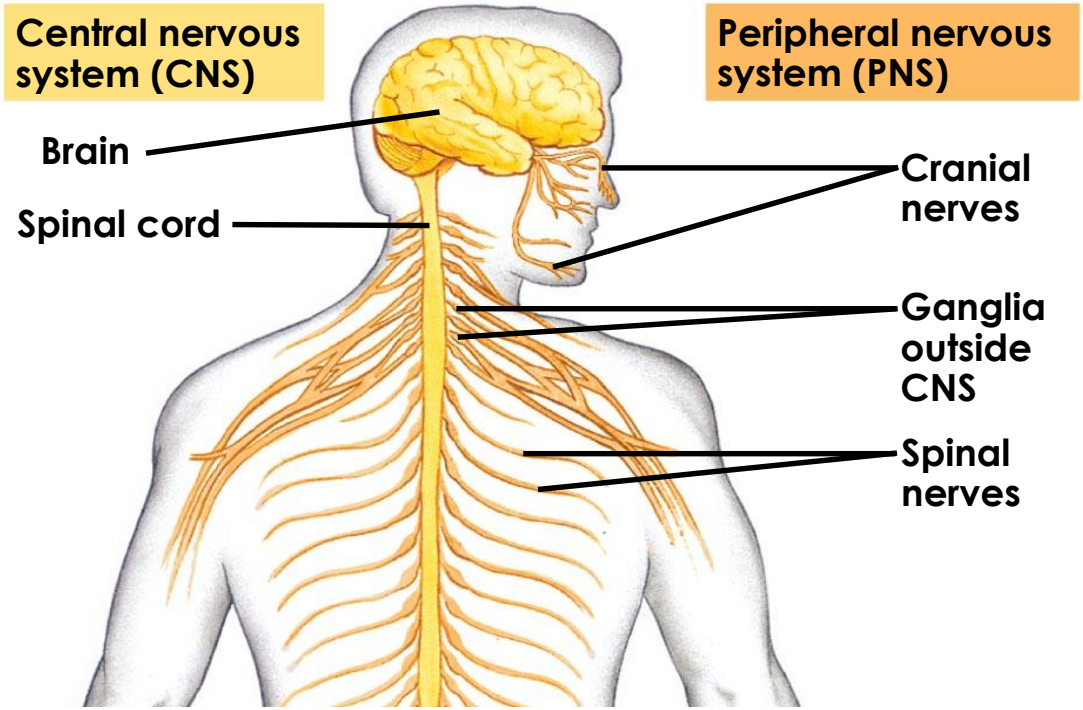
(g) Squid (mollusc)



(h) Salamander (vertebrate)

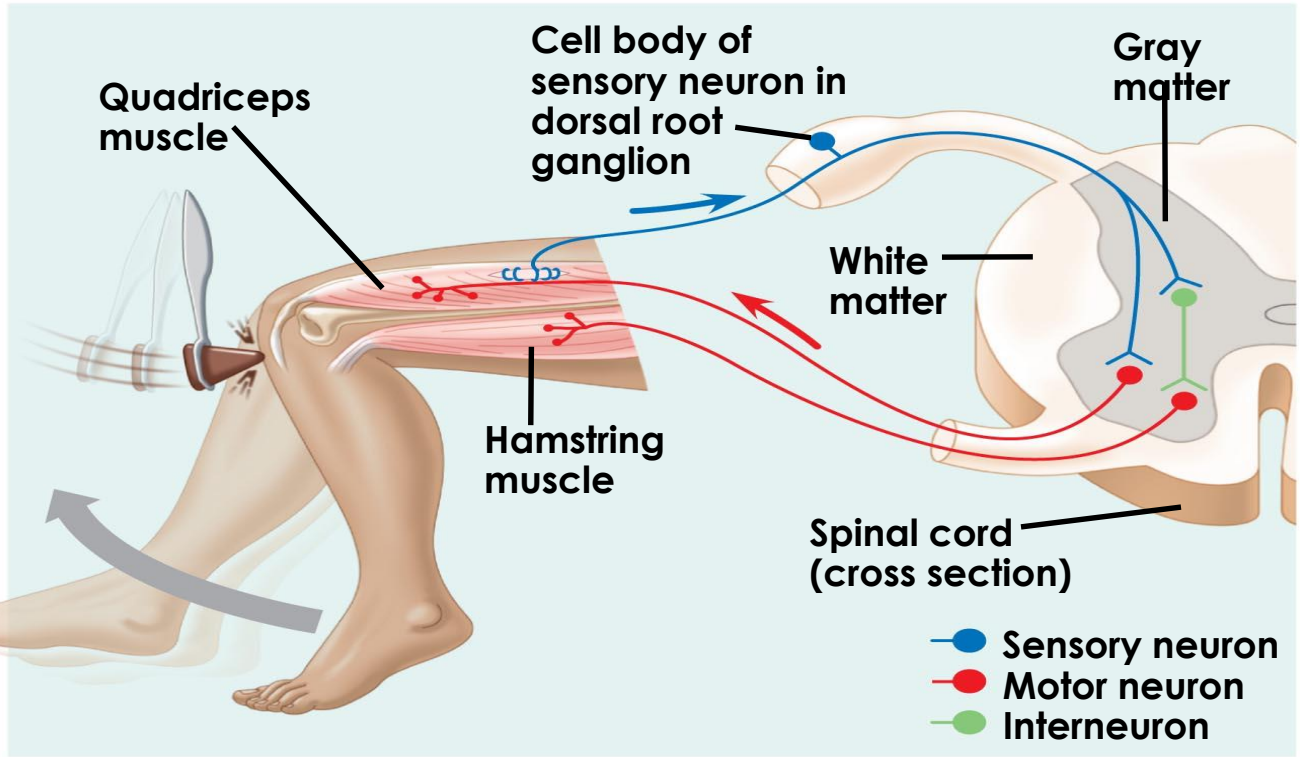
Nervous System Organization

- In vertebrates
  - The CNS is composed of the brain and spinal cord
  - The *peripheral nervous system* (*PNS*) is composed of nerves and ganglia



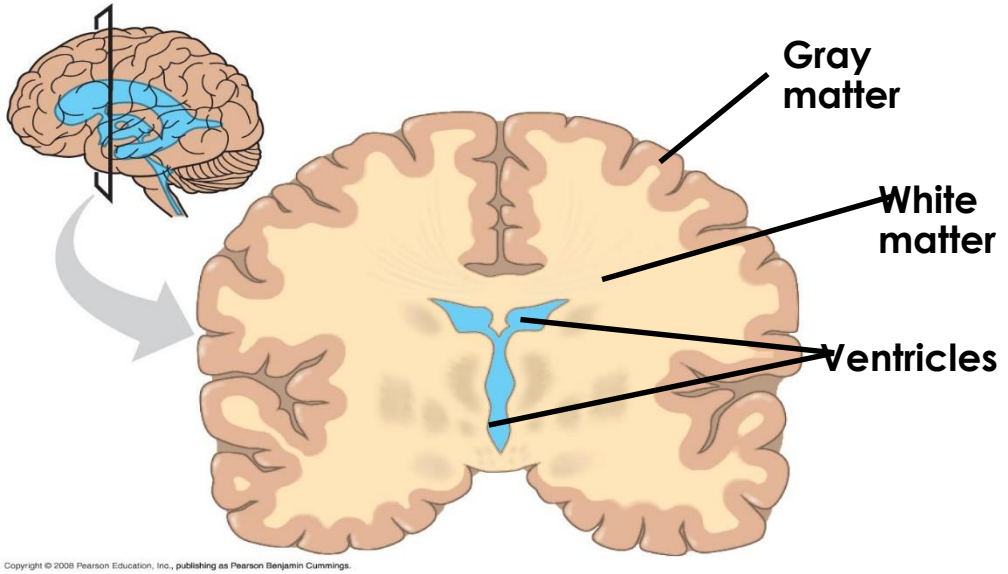
Organization of the Vertebrate Nervous System

- The spinal cord conveys information from the brain to the PNS
- The spinal cord also produces reflexes independently of the brain
- A **reflex** is the body's automatic response to a stimulus
  - For example, a doctor uses a mallet to trigger a knee-jerk refle



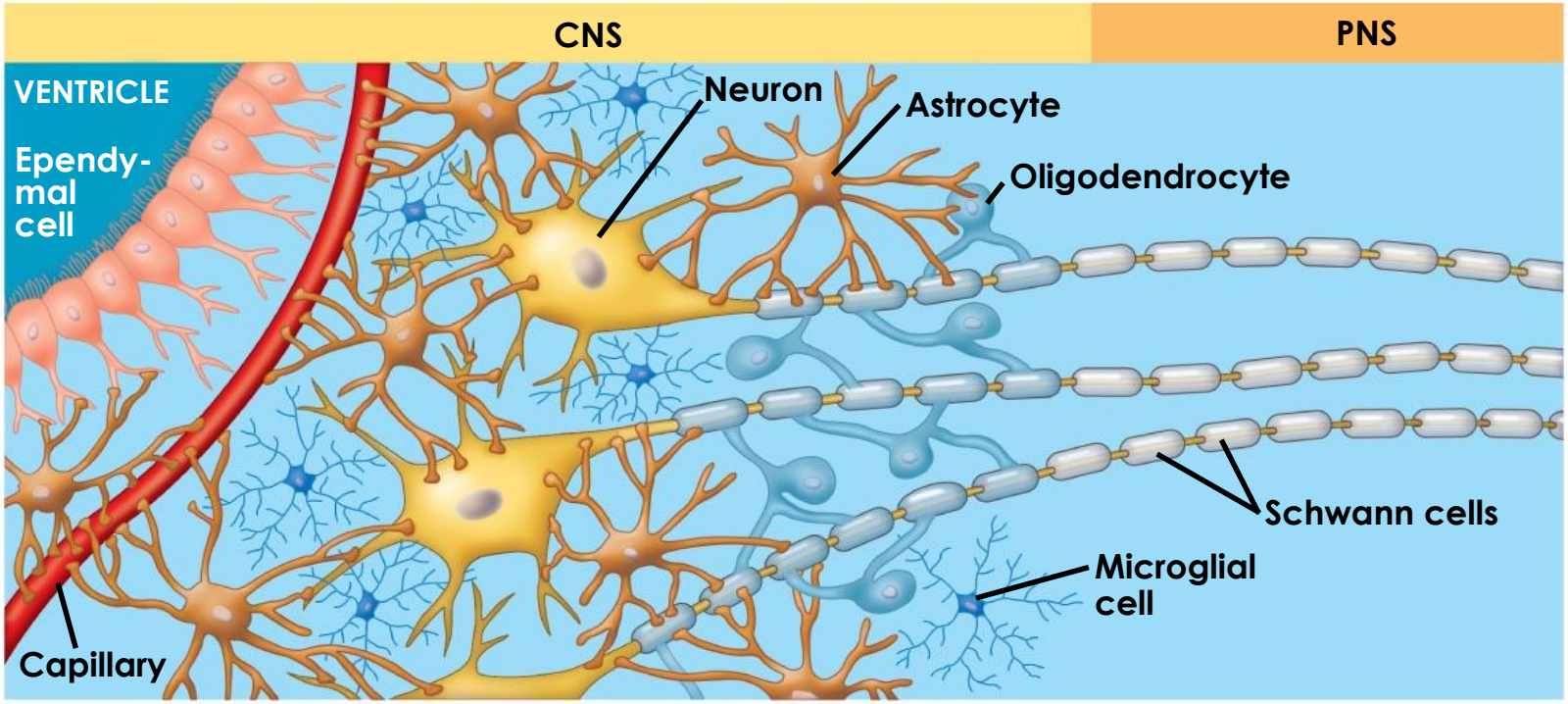
Central Nervous System

- The **central canal** of the spinal cord and the **ventricles** of the brain are hollow and filled with **cerebrospinal fluid**
- The cerebrospinal fluid is filtered from blood and functions to cushion the brain and spinal cord
- The brain and spinal cord contain
  - **Gray matter**, which of neuron cell bodies, dendrites, and unmyelinated axons
  - **White matter**, which consists of bundles of myelinated axons

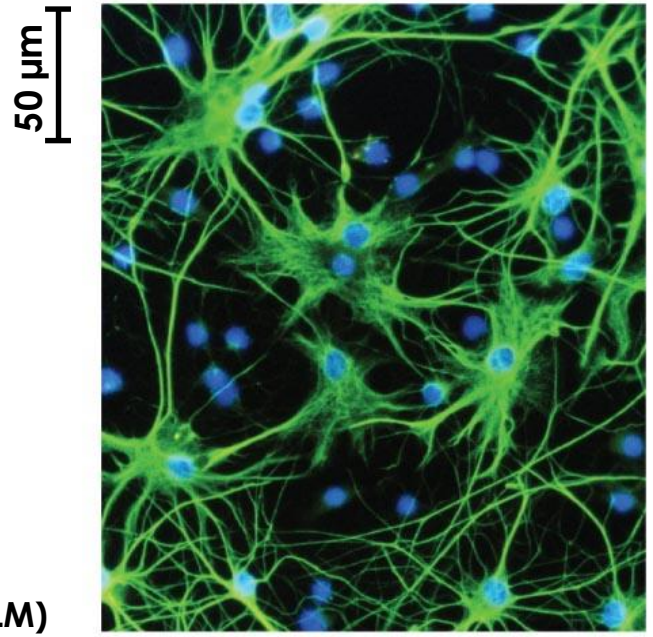


Glia in the CNS

- Glia have numerous functions
  - Ependymal cells promote circulation of cerebrospinal fluid
  - Microglia protect the nervous system from microorganisms
  - Oligodendrocytes and Schwann cells form the myelin sheaths around axons
- Glia have numerous functions
  - **Astrocytes** provide structural support for neurons, regulate extracellular ions and neurotransmitters, and induce the formation of a **blood-brain barrier** that regulates the chemical environment of the CNS
  - **Radial glia** play a role in the embryonic development of the nervous system



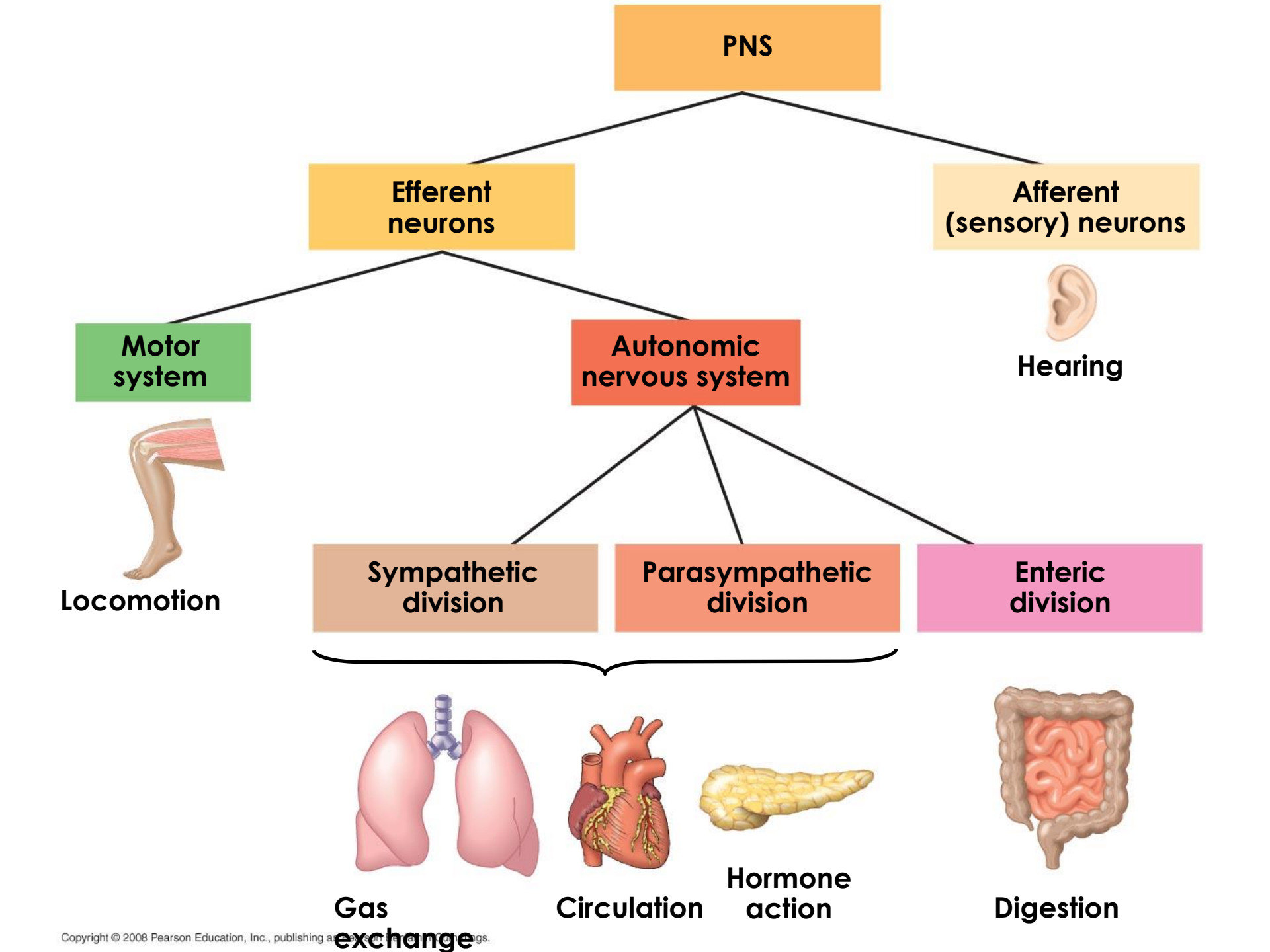
(a) Glia in vertebrates



(b) Astrocytes (LM)

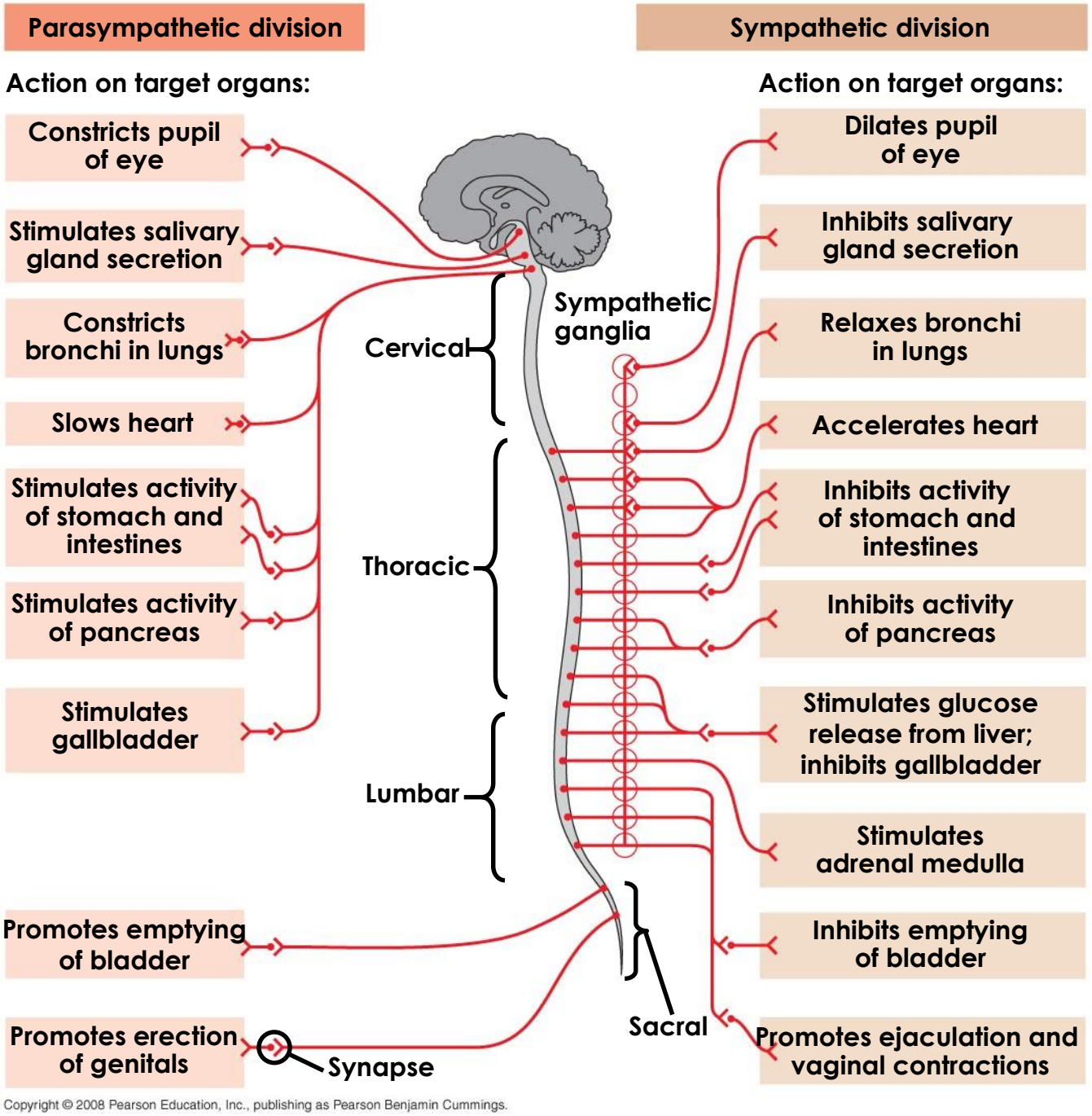
The Peripheral Nervous System

- The PNS transmits information to and from the CNS and regulates movement and the internal environment
- In the PNS, *afferent* neurons transmit information to the CNS and *efferent* neurons transmit information away from the CNS
- **Cranial nerves** originate in the brain and mostly terminate in organs of the head and upper body
- **Spinal nerves** originate in the spinal cord and extend to parts of the body below the head



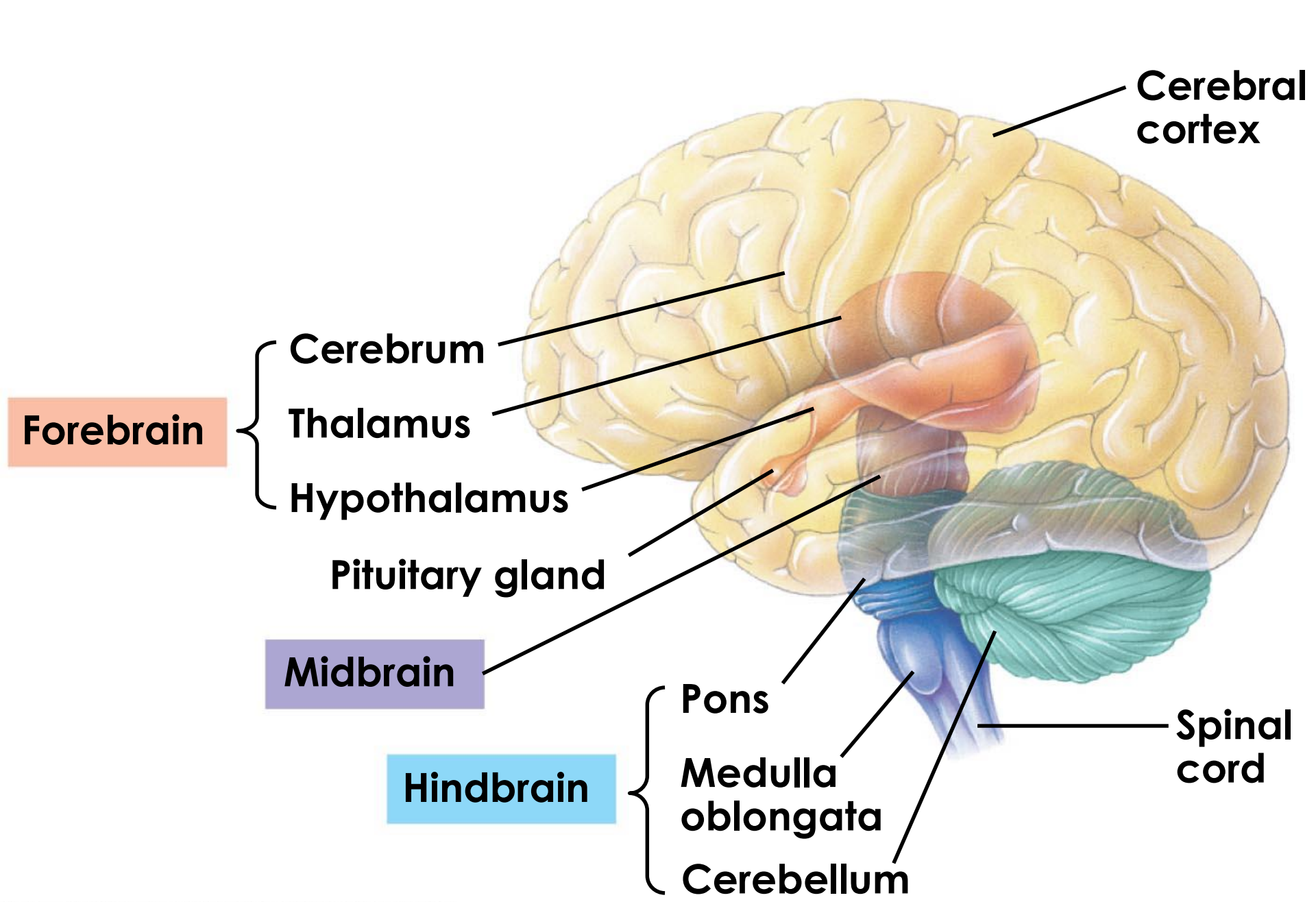
The PNS

- The PNS has two functional components: the motor system and the autonomic nervous system
- The **motor system** carries signals to skeletal muscles and is voluntary
- The **autonomic nervous system** regulates the internal environment in an involuntary manner
- The autonomic nervous system has sympathetic, parasympathetic, and enteric divisions
- The sympathetic and parasympathetic divisions have antagonistic effects on target organs
- The **sympathetic division** correlates with the "fight-or-flight" response
- The **parasympathetic division** promotes a return to "rest and digest"
- The **enteric division** controls activity of the digestive tract, pancreas, and gallbladder



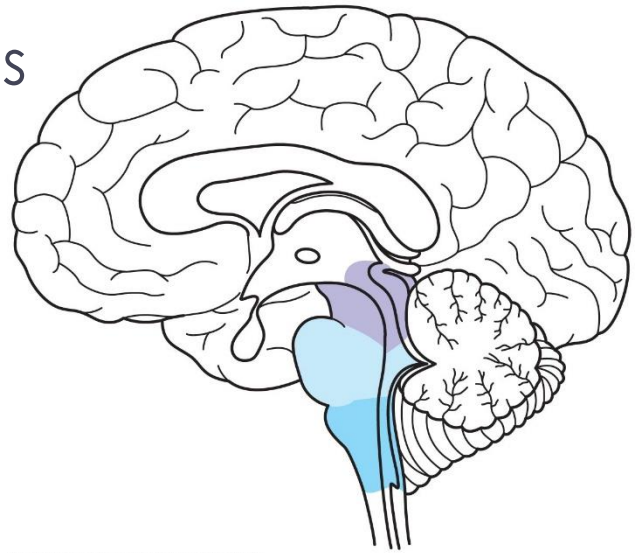
Concept 49.2
The vertebrate brain is regionally specialized

- All vertebrate brains develop from three embryonic regions: **forebrain**, **midbrain**, and **hindbrain**
- By the fifth week of human embryonic development, five brain regions have formed from the three embryonic regions
- As a human brain develops further, the most profound change occurs in the forebrain, which gives rise to the **cerebrum**
- The outer portion of the cerebrum called the **cerebral cortex** surrounds much of the brain



The Brainstem

- The **brainstem** coordinates and conducts information between brain centers
- The brainstem has three parts: the midbrain, the **pons**, and the **medulla oblongata**
- The midbrain contains centers for receipt and integration of sensory information
- The pons regulates breathing centers in the medulla
- The medulla oblongata contains centers that control several functions including breathing, cardiovascular activity, swallowing, vomiting, and digestion



The Brainstem: Arousal and Sleep

- The brainstem and cerebrum control arousal and sleep
- The core of the brainstem has a diffuse network of neurons called the **reticular formation**
- This regulates the amount and type of information that reaches the cerebral cortex and affects alertness
- The hormone melatonin is released by the pineal gland and plays a role in bird and mammal sleep cycles

The Brainstem: Arousal and Sleep

- Sleep is essential and may play a role in the consolidation of learning and memory
- Dolphins sleep with one brain hemisphere at a time and are therefore able to swim while "asleep"

Key

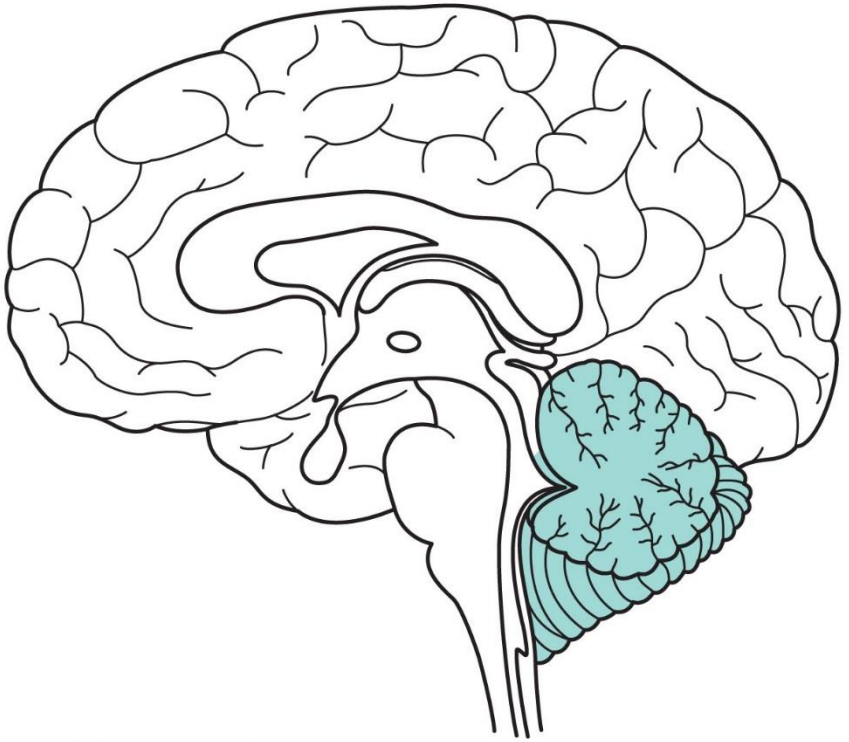
Low-frequency waves characteristic of sleep

High-frequency waves characteristic of wakefulness

Location	Time: 0 hours	Time: 1 hour
Left hemisphere		
Right hemisphere		

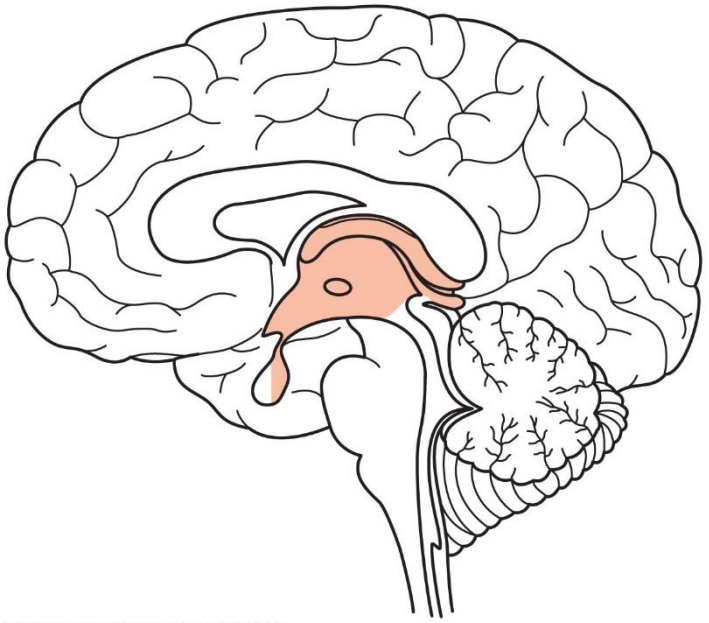
The Cerebellum

- The **cerebellum** is important for coordination and error checking during motor, perceptual, and cognitive functions
- It is also involved in learning and remembering motor skills



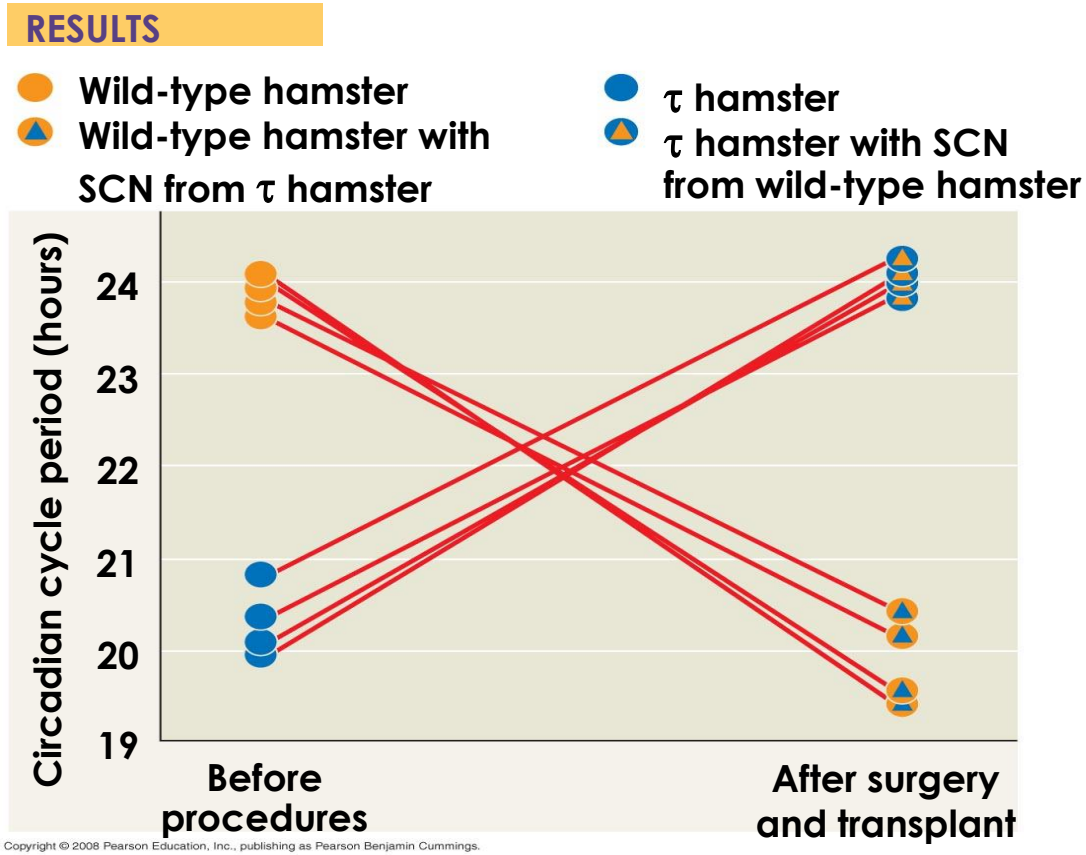
The Diencephalon

- The diencephalon develops into three regions: the epithalamus, thalamus, and hypothalamus
- The *epithalamus* includes the pineal gland and generates cerebrospinal fluid from blood
- The **thalamus** is the main input center for sensory information to the cerebrum and the main output center for motor information leaving the cerebrum
- The **hypothalamus** regulates homeostasis and basic survival behaviors such as feeding, fighting, fleeing, and reproducing



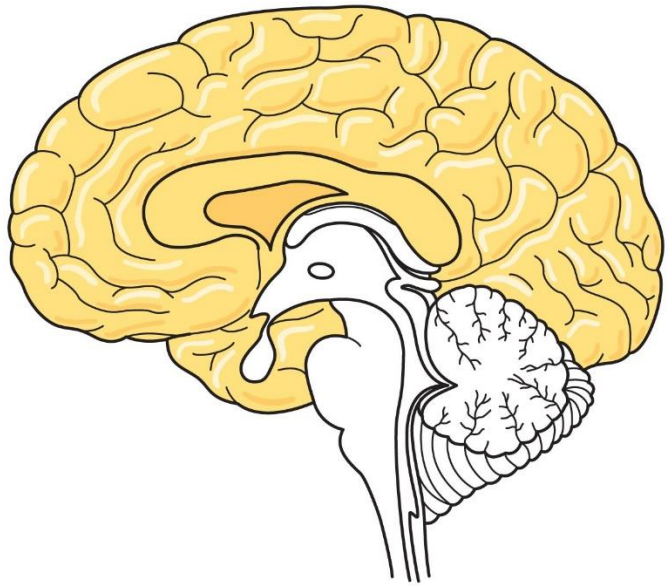
The Diencephalon: Biological Clock Regulation by the Hypothalamus

- The hypothalamus also regulates circadian rhythms such as the sleep/wake cycle
- Mammals usually have a pair of **suprachiasmatic nuclei** (**SCN**) in the hypothalamus that function as a **biological clock**
- Biological clocks usually require external cues to remain synchronized with environmental cycles



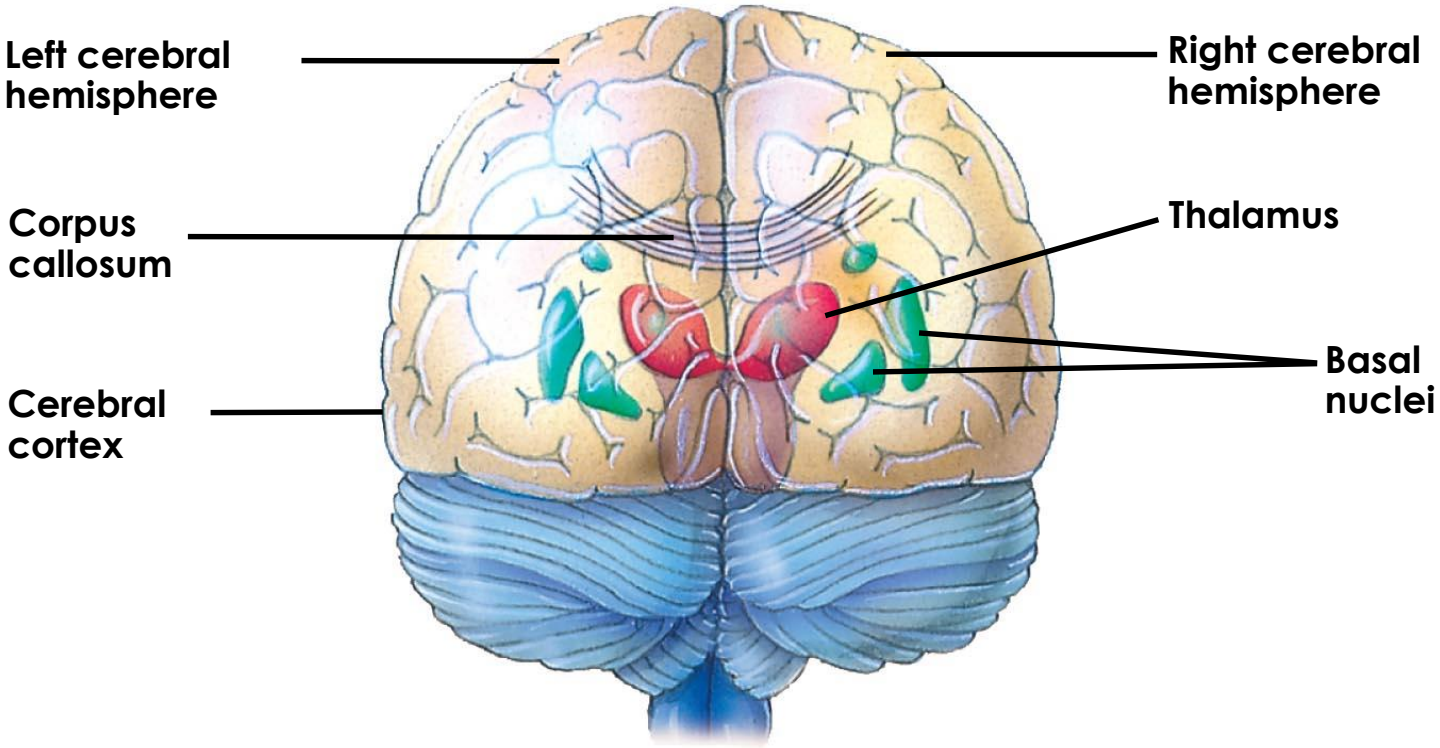
The Cerebrum

- The cerebrum develops from the embryonic telencephalon
- The cerebrum has right and left **cerebral hemispheres**
- Each cerebral hemisphere consists of a cerebral cortex (gray matter) overlying white matter and basal nuclei
- In humans, the cerebral cortex is the largest and most complex part of the brain
- The basal nuclei are important centers for planning and learning movement sequences



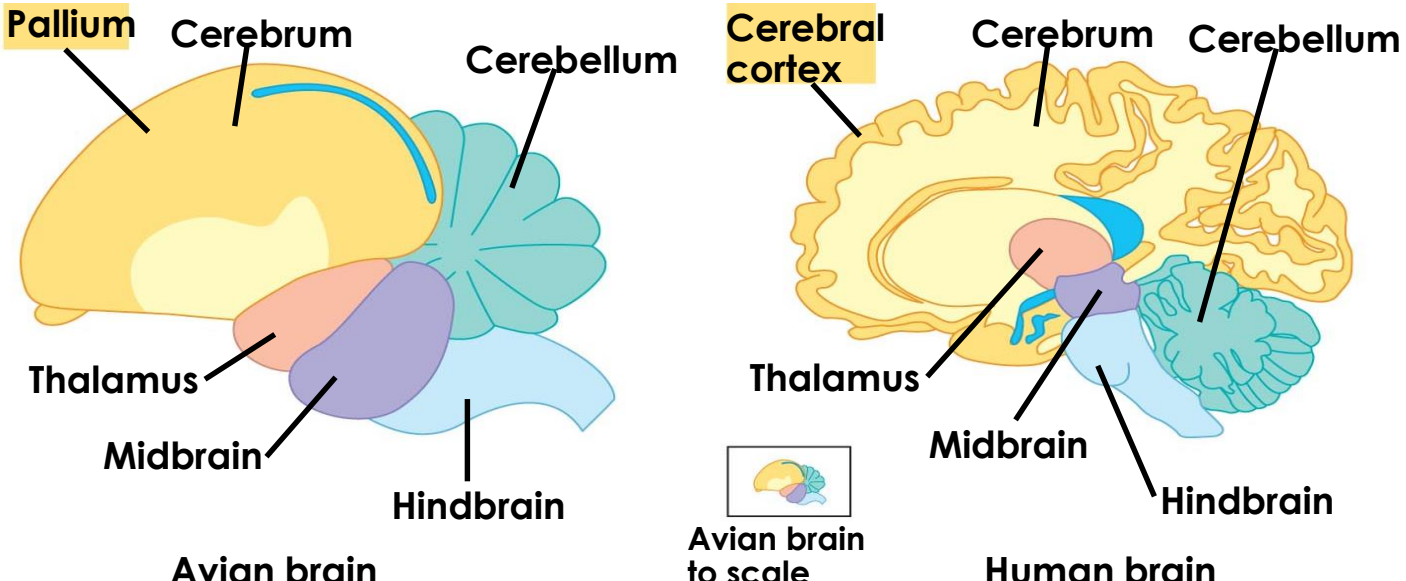
The Cerebrum

- A thick band of axons called the **corpus callosum** provides communication between the right and left cerebral cortices
- The right half of the cerebral cortex controls the left side of the body, and vice versa



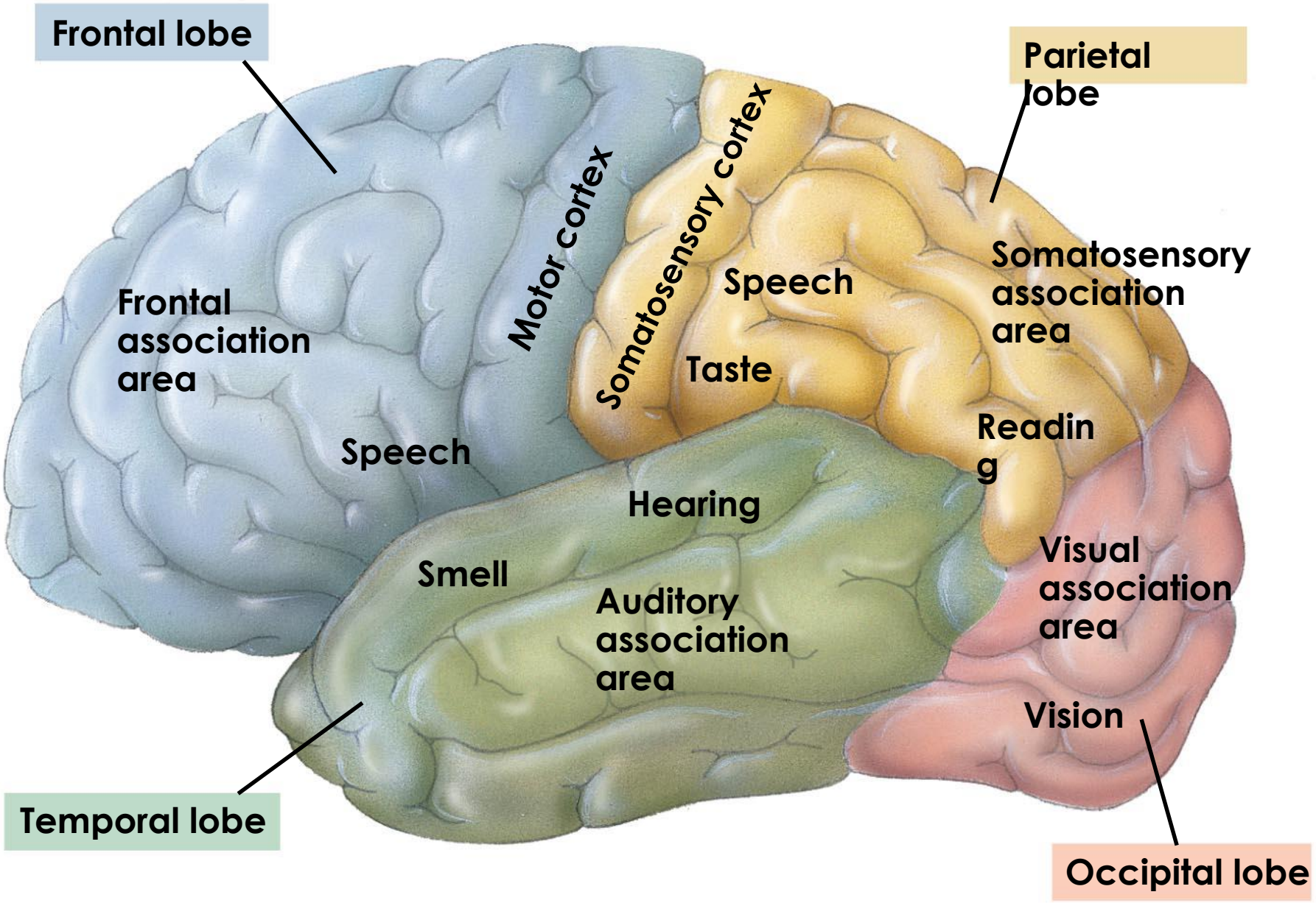
Evolution of Cognition in Vertebrates

- The outermost layer of the cerebral cortex has a different arrangement in birds and mammals
- In mammals, the cerebral cortex has a convoluted surface called the *neocortex*, which was previously thought to be required for cognition
- Cognition is the perception and reasoning that form knowledge
- However, it has recently been shown that birds also demonstrate cognition even though they lack a neocortex



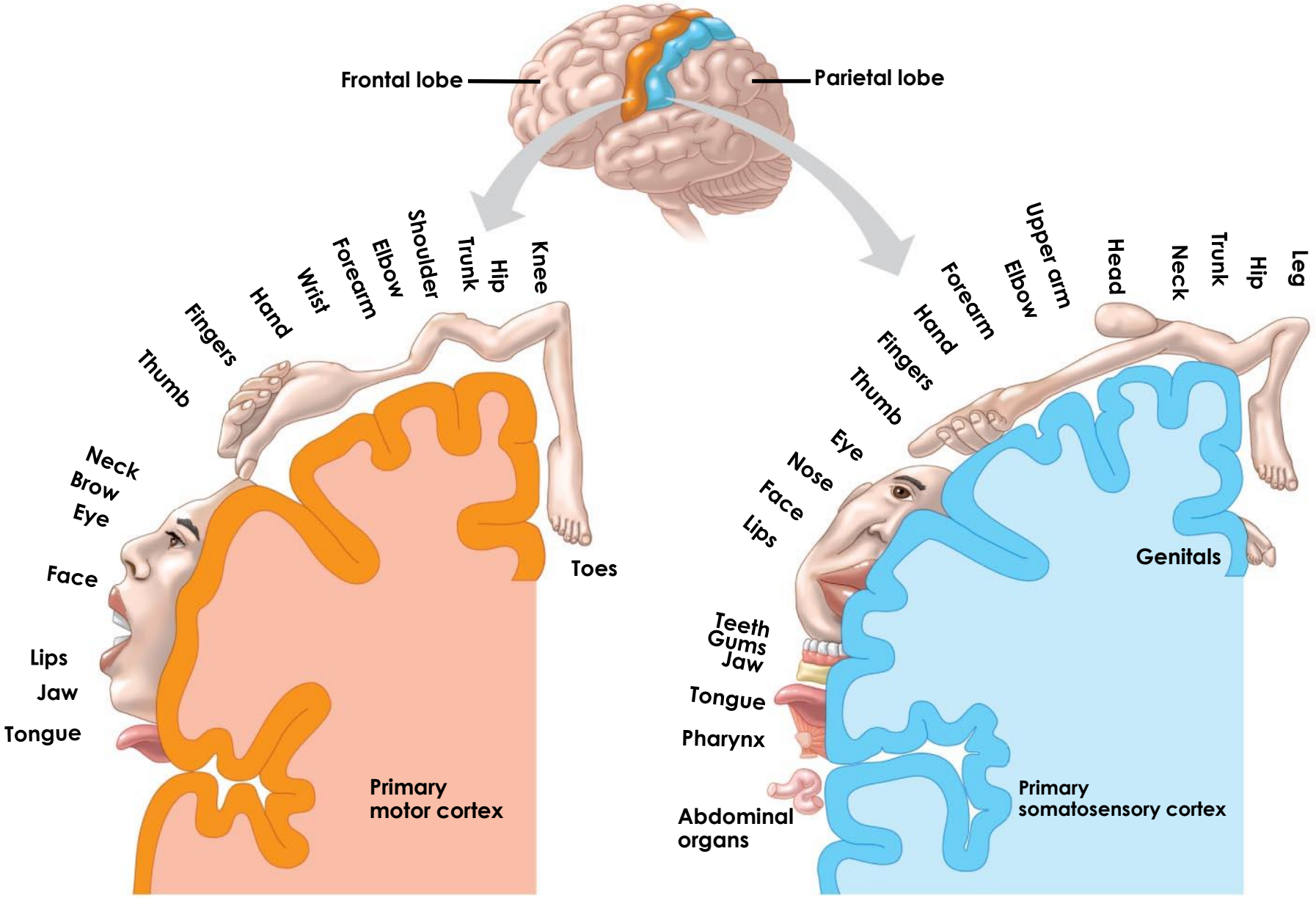
Concept 49.3
The cerebral cortex controls voluntary movement and cognitive functions

- Each side of the cerebral cortex has four lobes: frontal, temporal, occipital, and parietal
- Each lobe contains primary sensory areas and association areas where information is integrated



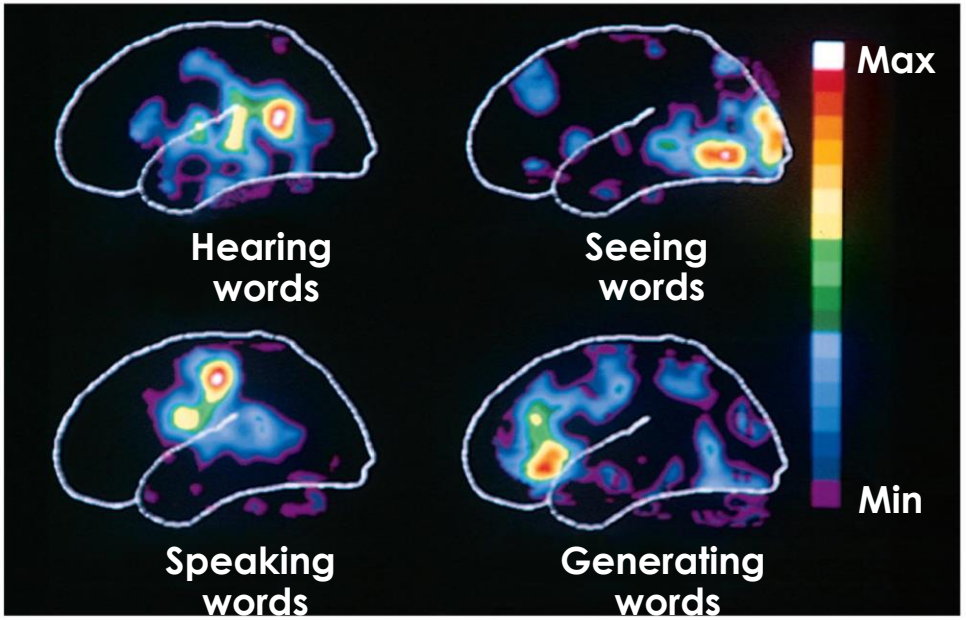
Information Processing in the Cerebral Cortex

- The cerebral cortex receives input from sensory organs and *somatosensory* receptors
- Specific types of sensory input enter the primary sensory areas of the brain lobes
- Adjacent areas process features in the sensory input and integrate information from different sensory areas
- In the somatosensory and motor cortices, neurons are distributed according to the body part that generates sensory input or receives motor input



Language and Speech

- Studies of brain activity have mapped areas responsible for language and speech
- Broca's area in the frontal lobe is active when speech is generated
- Wernicke's area in the temporal lobe is active when speech is heard

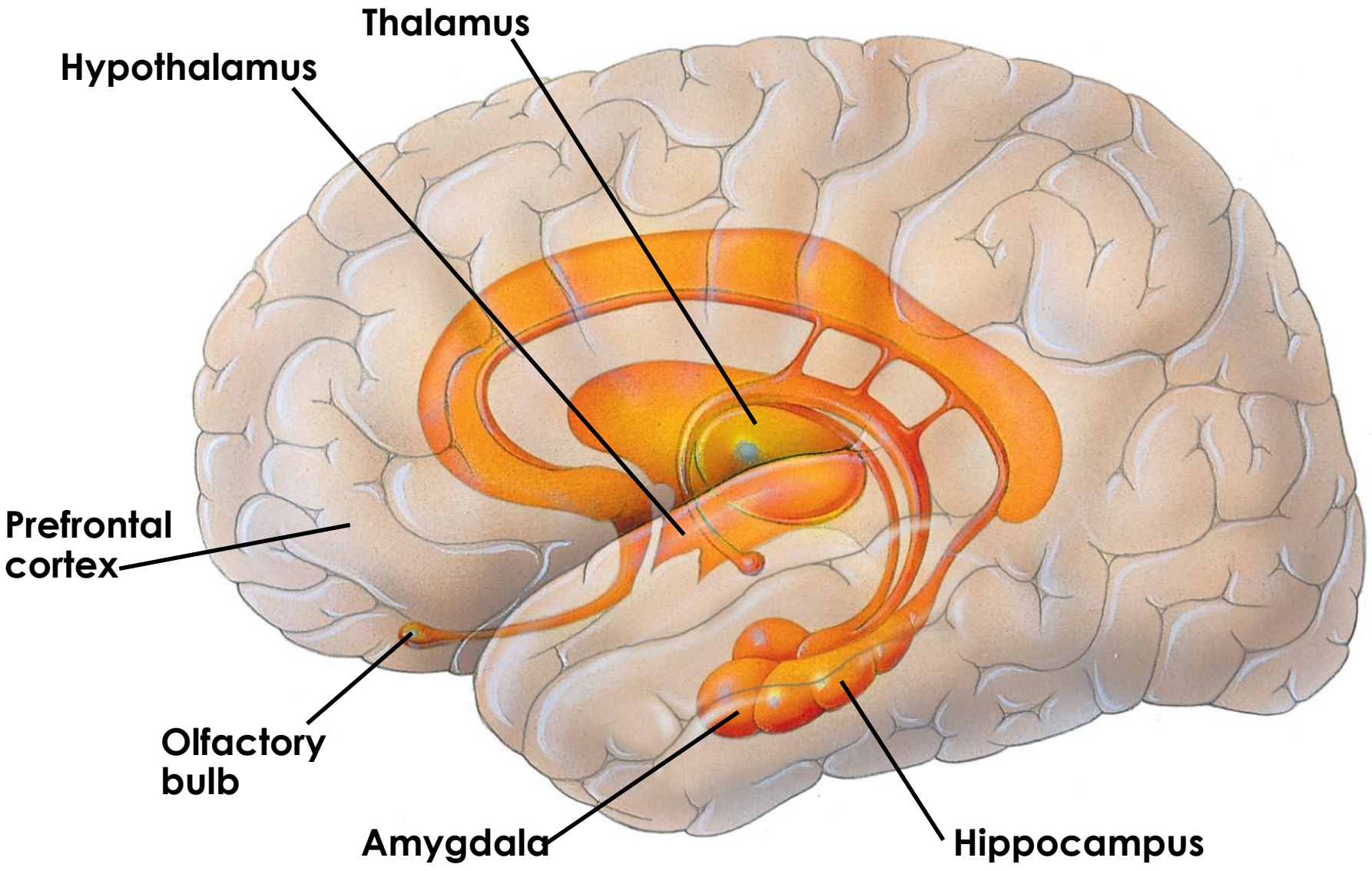


Lateralization of Cortical Function

- The corpus callosum transmits information between the two cerebral hemispheres
- The left hemisphere is more adept at language, math, logic, and processing of serial sequences
- The right hemisphere is stronger at pattern recognition, nonverbal thinking, and emotional processing
- The differences in hemisphere function are called **lateralization**
- Lateralization is linked to handedness

Emotions

- Emotions are generated and experienced by the limbic system and other parts of the brain including the sensory areas
- The *limbic system* is a ring of structures around the brainstem that includes the amygdala, hippocampus, and parts of the thalamus
- The **amygdala** is located in the temporal lobe and helps store an emotional experience as an emotional memory
- Modern brain-imaging techniques suggest that consciousness is an emergent property of the brain based on activity in many areas of the cortex

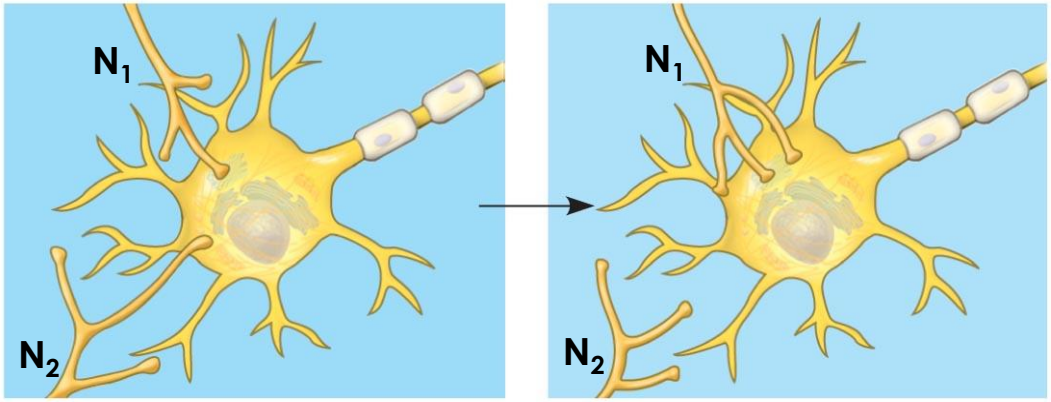


Concept 49.4
Changes in synaptic connections underlie memory and learning

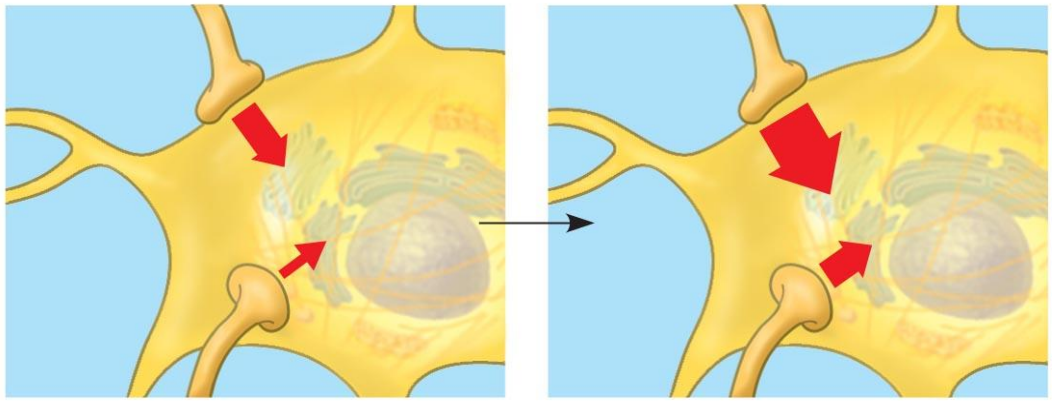
- Two processes dominate embryonic development of the nervous system
  - Neurons compete for growth-supporting factors in order to survive
  - Only half the synapses that form during embryo development survive into adulthood

Neural Plasticity

- **Neural plasticity** describes the ability of the nervous system to be modified after birth
- Changes can strengthen or weaken signaling at a synapse



(a) Synapses are strengthened or weakened in response to activity.



(b) If two synapses are often active at the same time, the strength of the postsynaptic response may increase at both synapses

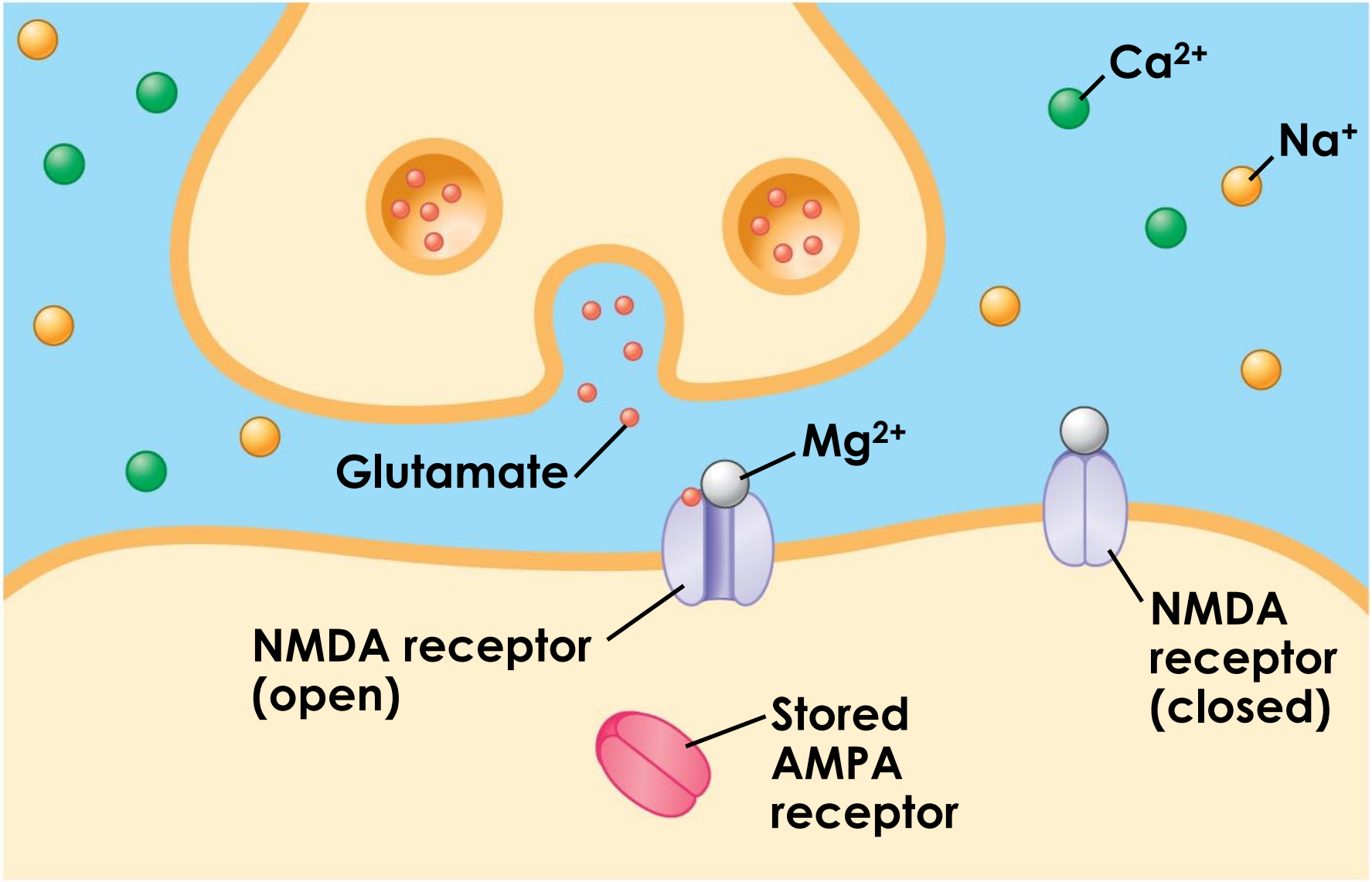
Memory and Learning

- Learning can occur when neurons make new connections or when the strength of existing neural connections changes
- **Short-term memory** is accessed via the hippocampus
- The hippocampus also plays a role in forming **long-term memory**, which is stored in the cerebral cortex

Long-Term Potentiation

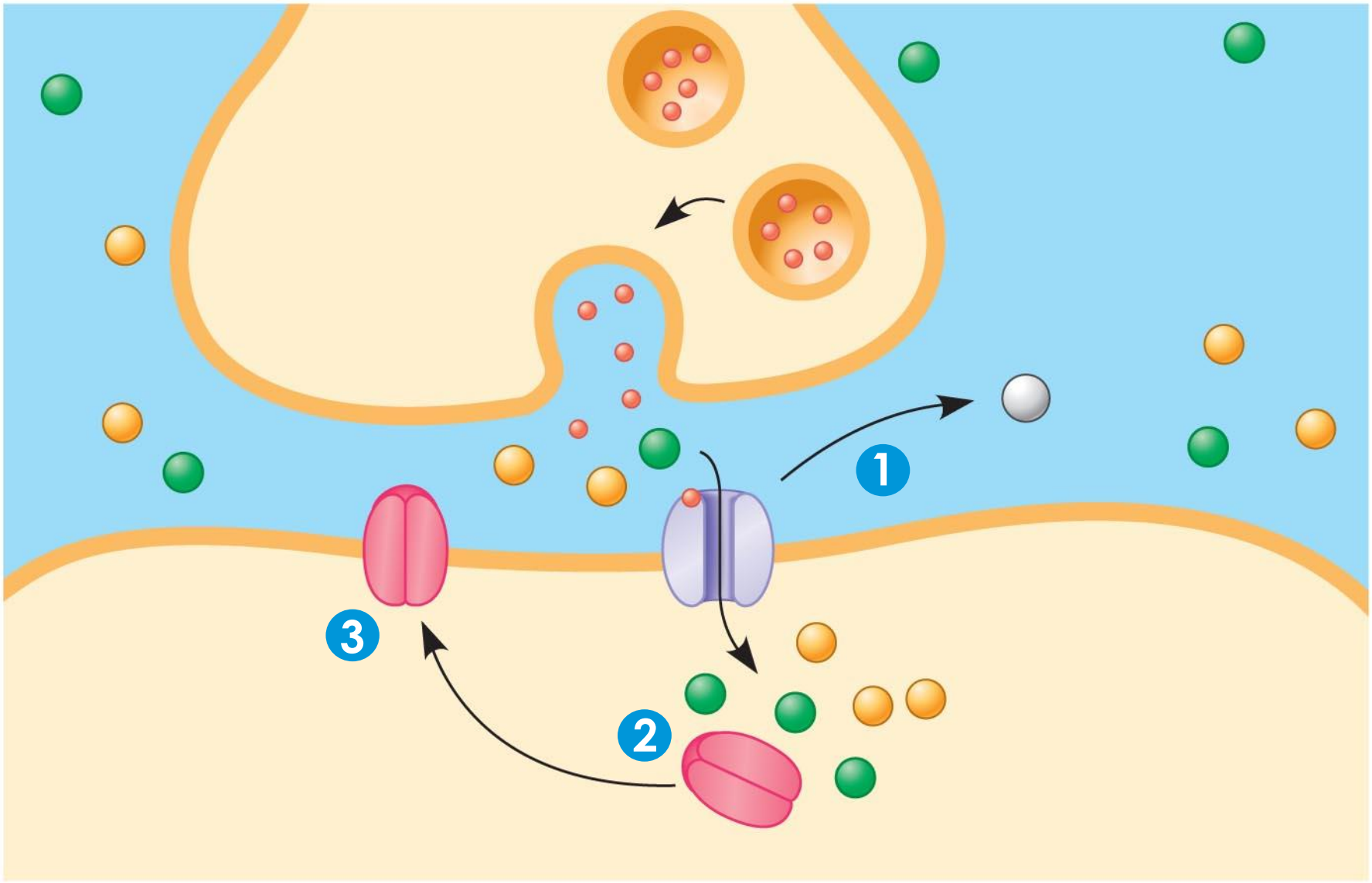
- In the vertebrate brain, a form of learning called **long-term potentiation** (**LTP**) involves an increase in the strength of synaptic transmission
- LTP involves glutamate receptors
- If the presynaptic and postsynaptic neurons are stimulated at the same time, the set of receptors present on the postsynaptic membranes changes

Fig. 49-20a



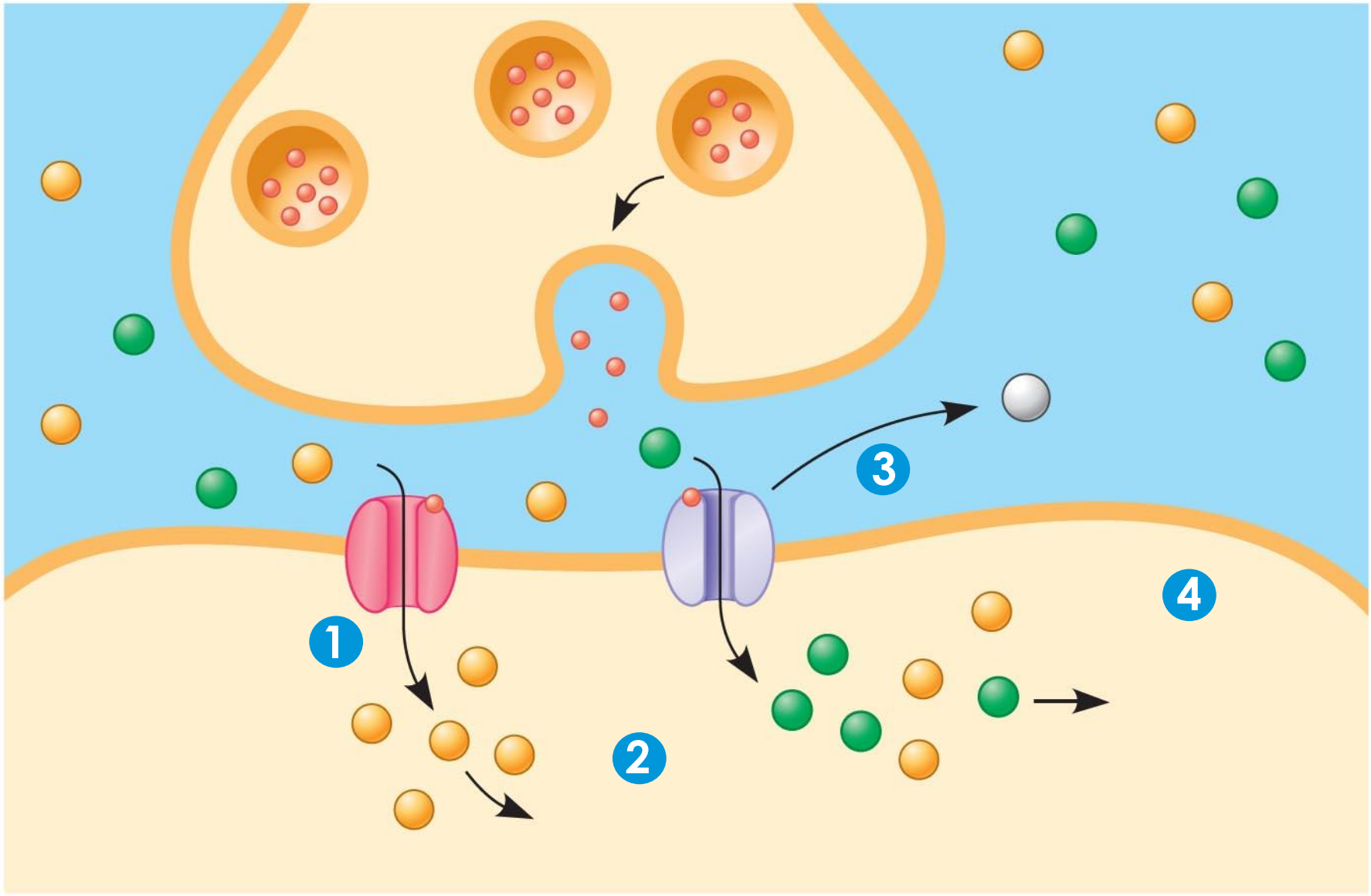
(a) Synapse prior to long-term potentiation (LTP)

Fig. 49-20b



(b) Establishing LTP

Fig. 49-20c



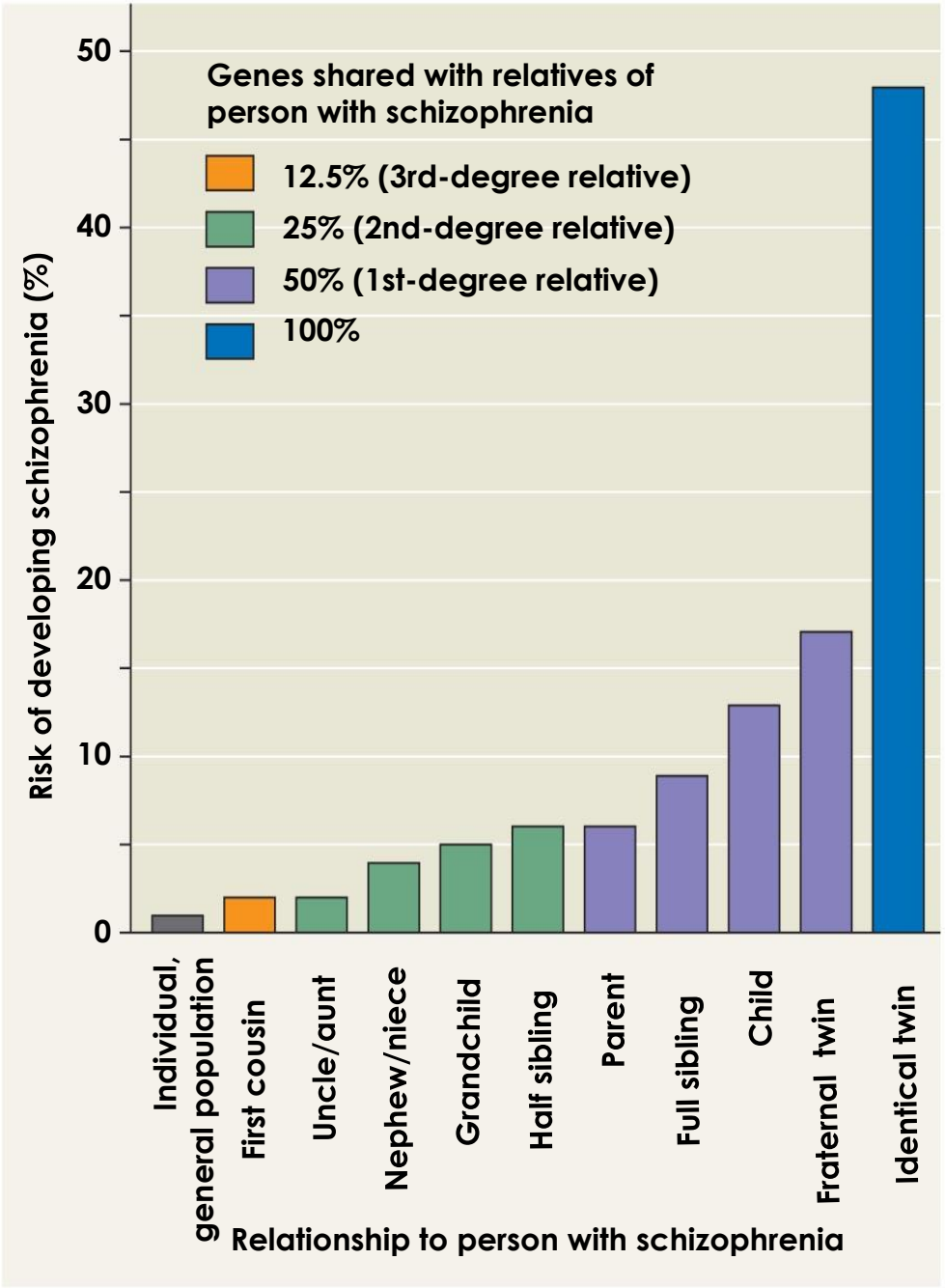
(c) Synapse exhibiting LTP

Concept 49.5
Nervous system disorders can be explained in molecular terms

- Disorders of the nervous system include schizophrenia, depression, Alzheimer's disease, and Parkinson's disease
- Genetic and environmental factors contribute to diseases of the nervous system

Schizophrenia

- About 1% of the world's population suffers from **schizophrenia**
- Schizophrenia is characterized by hallucinations, delusions, blunted emotions, and other symptoms
- Available treatments focus on brain pathways that use dopamine as a neurotransmitter

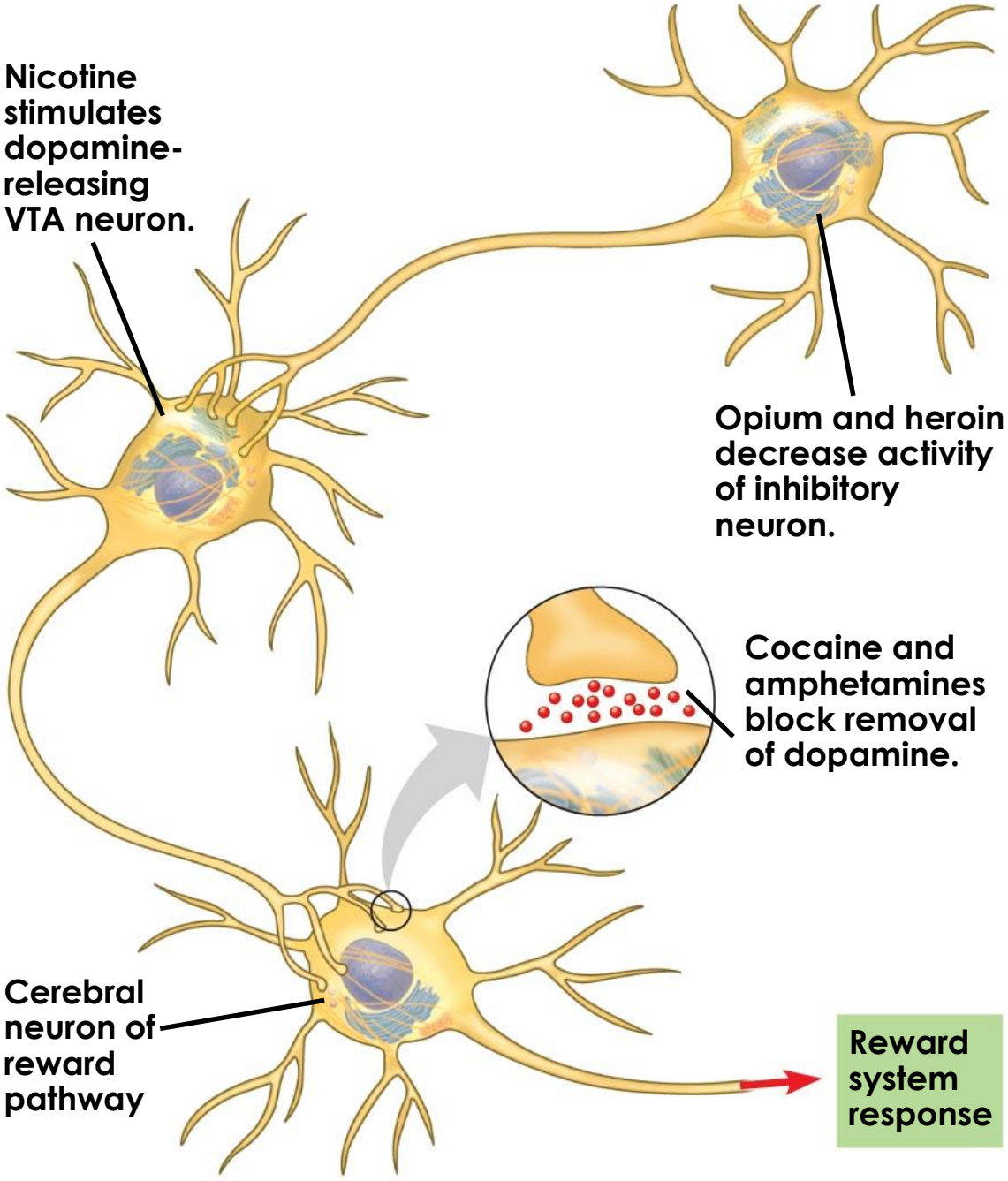


Depression

- Two broad forms of depressive illness are known: major depressive disorder and bipolar disorder
- In **major depressive disorder**, patients have a persistent lack of interest or pleasure in most activities
- **Bipolar disorder** is characterized by manic (high-mood) and depressive (low-mood) phases
- Treatments for these types of depression include drugs such as Prozac and lithium

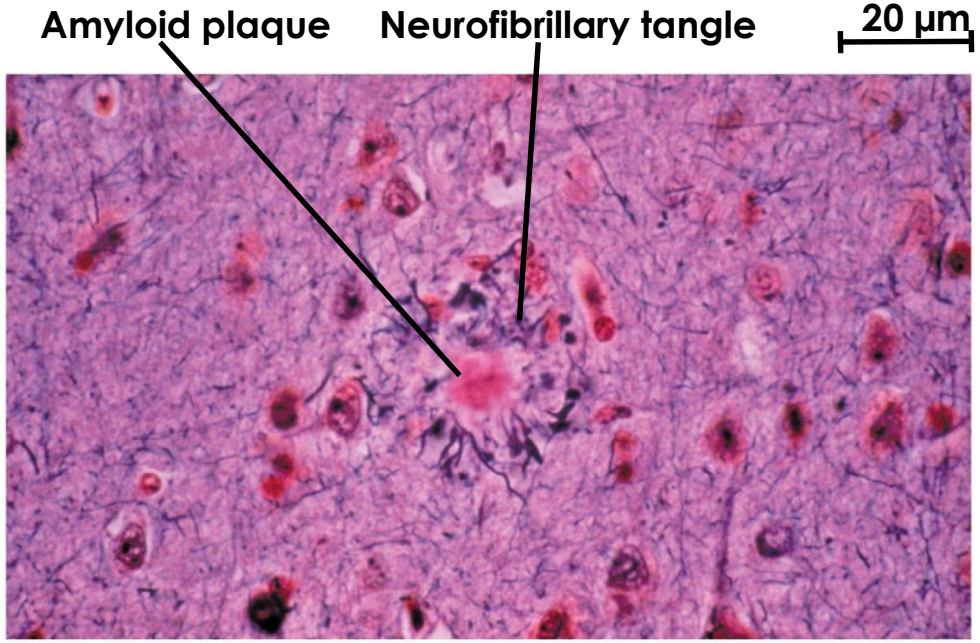
Drug Addiction and the Brain Reward System

- The brain's reward system rewards motivation with pleasure
- Some drugs are addictive because they increase activity of the brain's reward system
- These drugs include cocaine, amphetamine, heroin, alcohol, and tobacco
- Drug addiction is characterized by compulsive consumption and an inability to control intake
- Addictive drugs enhance the activity of the dopamine pathway
- Drug addiction leads to long-lasting changes in the reward circuitry that cause craving for the drug



Alzheimer's Disease

- **Alzheimer's disease** is a mental deterioration characterized by confusion, memory loss, and other symptoms
- Alzheimer's disease is caused by the formation of neurofibrillary tangles and amyloid plaques in the brain
- A successful treatment in humans may hinge on early detection of amyloid plaques
- There is no cure for this disease though some drugs are effective at relieving symptoms



Parkinson's Disease

- **Parkinson's disease** is a motor disorder caused by death of dopamine-secreting neurons in the midbrain
- It is characterized by difficulty in initiating movements, muscle tremors, slowness of movement, and rigidity
- There is no cure, although drugs and various other approaches are used to manage symptoms

Stem Cell-Based Therapy

- Unlike the PNS, the CNS cannot fully repair itself
- However, it was recently discovered that the adult human brain contains stem cells that can differentiate into mature neurons
- Induction of stem cell differentiation and transplantation of cultured stem cells are potential methods for replacing neurons lost to trauma or disease