The nervous system: anatomy and physiology

Part II: from individual neurons to neural systems

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI CESENA

Cognition and Neuroscience

Academic year 2024/2025

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Learning objectives

- Define a synapse and differentiate between the pre- and post-synaptic cells.
- Describe the three types of synapses and their characteristics.
- Compare and contrast electrical and chemical synapses in terms of structure and function.
- Describe the process of chemical synaptic transmission, including the role of neurotransmitters and the process of neurotransmitter inactivation.

Learning objectives

- Explain the concepts of neural circuits and neural systems.
- Describe the three components of the neural control of behavior.
- Define parallel processing and explain its evolutionary advantage.
- Describe the knee-jerk reflex as an example of a simple neural circuit.
- Differentiate between divergence and convergence in neural circuits.
- Distinguish between feed-forward and feedback inhibition and explain their functional utility.

- Describe the organization and functions of the peripheral nervous system (PNS) and of the central nervous system (CNS).
- Identify the six subdivisions of the brain and their key functions.
- Describe the role of the basal ganglia, amygdala and hippocampus.
- Describe the structure of the cerebral cortex.
- Identify the key functions of the four lobes of the cerebral cortex.

Information transfer between two neurons

Signaling within and between neurons is handled differently

Within a neuron:

- transferring information involves changes in the **electrical state** of the neuron

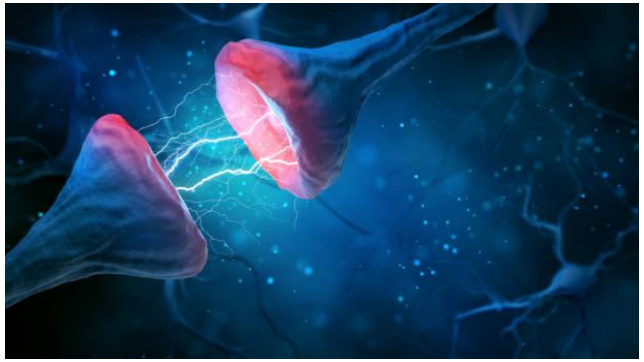
- electrical currents flow through the volume of the neuron --> neuronal spikes

Between neurons:

- information transfer occurs at **synapses**

Chemical synapse

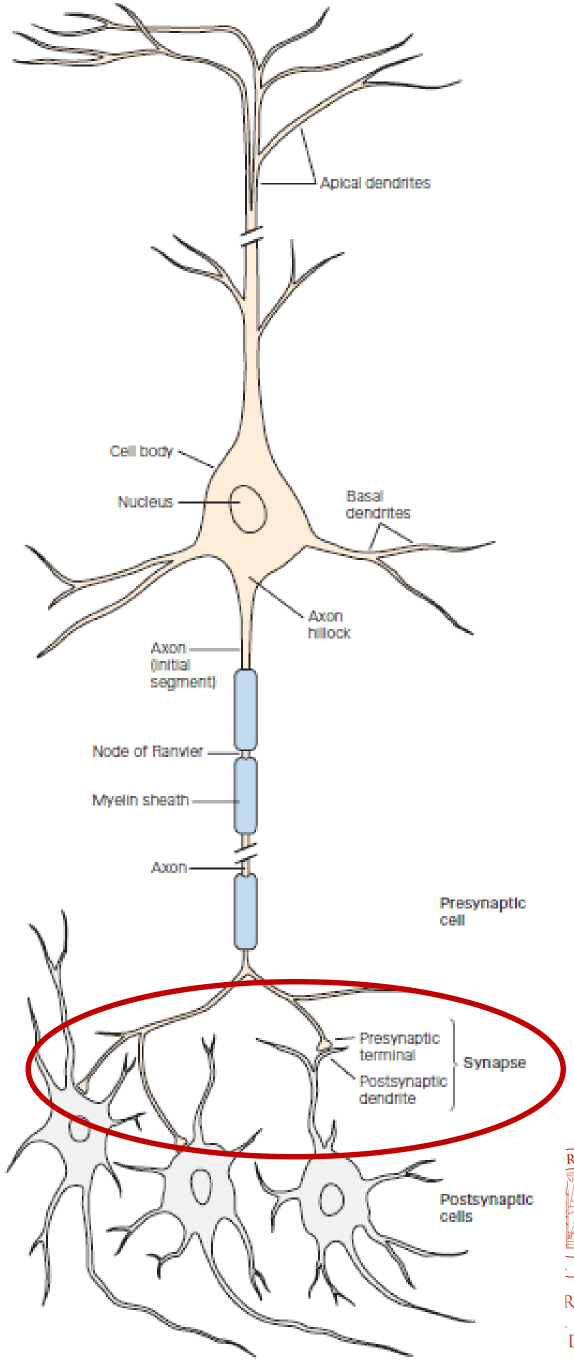
Electrical synapse



Synapses enable communication between neurons

Synapse:

- **multiple processes**
- represents the **output zone** of the neuron
- specialized structure at the end of the axon, where two neurons come into close contact so that chemical or electrical **signals can be passed from one cell to the next**
- enable communication between neurons



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Synapses enable communication between neurons

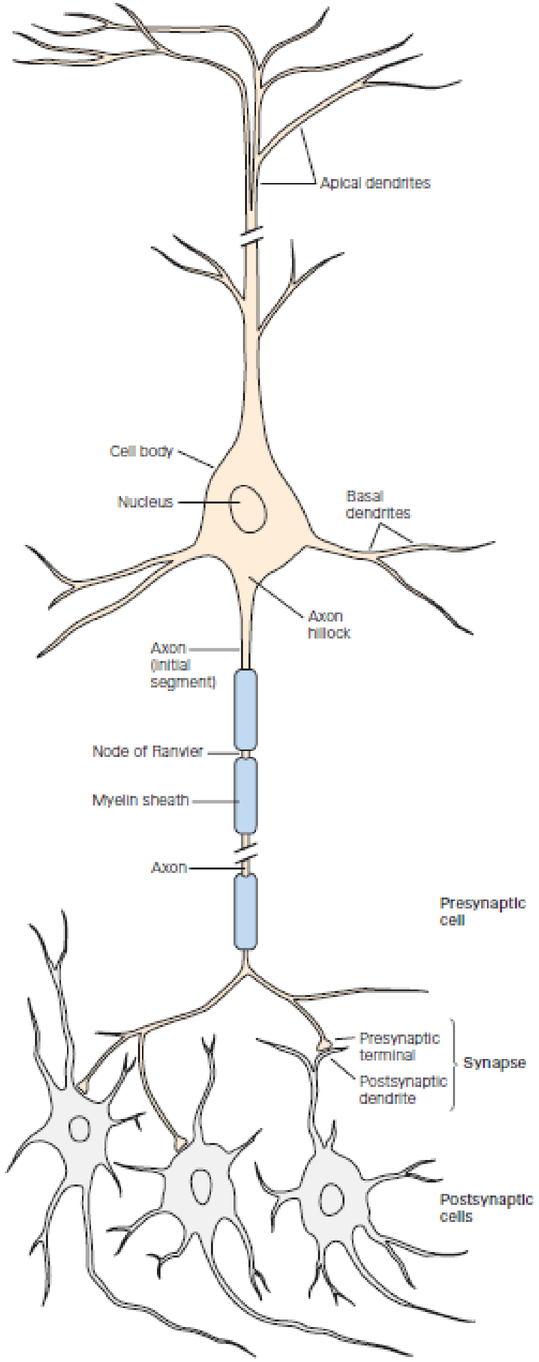
Presynaptic cell

- The nerve cell transmitting a signal
- From presynaptic terminals or nerve terminals, i.e. specialized enlarged regions of its axon's branches

Postsynaptic cell

- The cell receiving the signal

Synaptic cleft: the narrow space separating the presynaptic and postsynaptic cell



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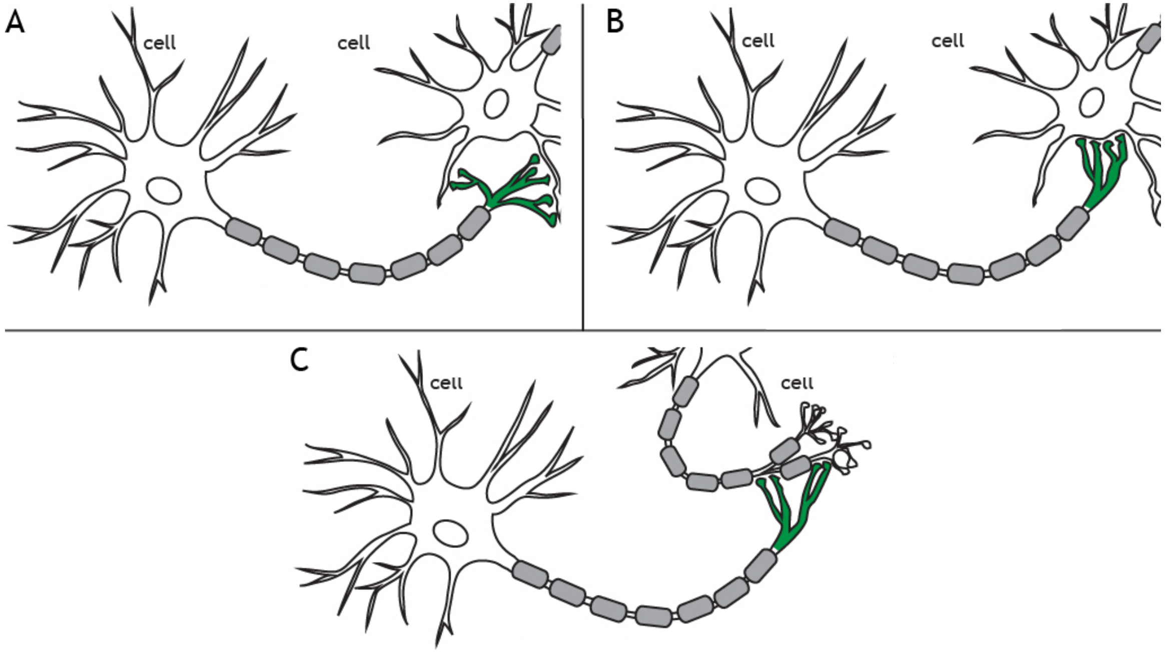
Which one is the pre-synaptic and which one the post-synaptic cell?



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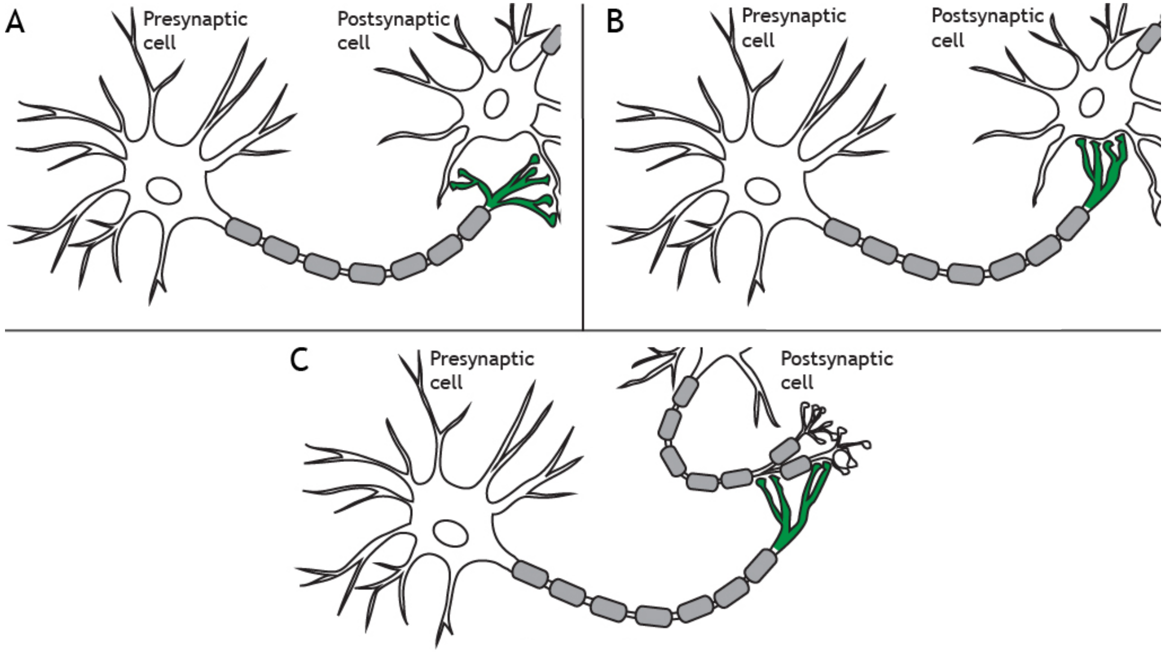
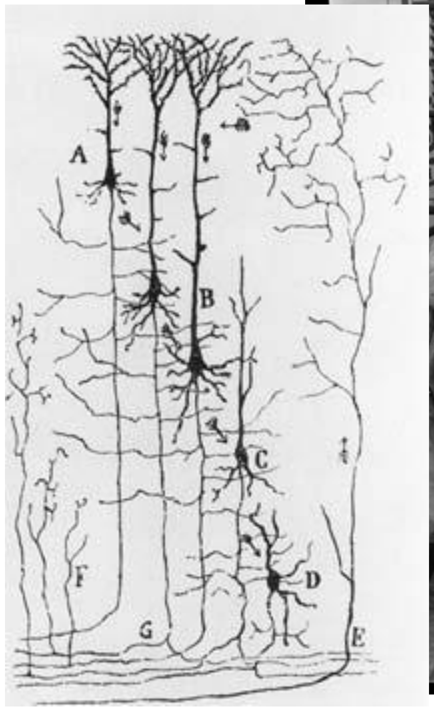
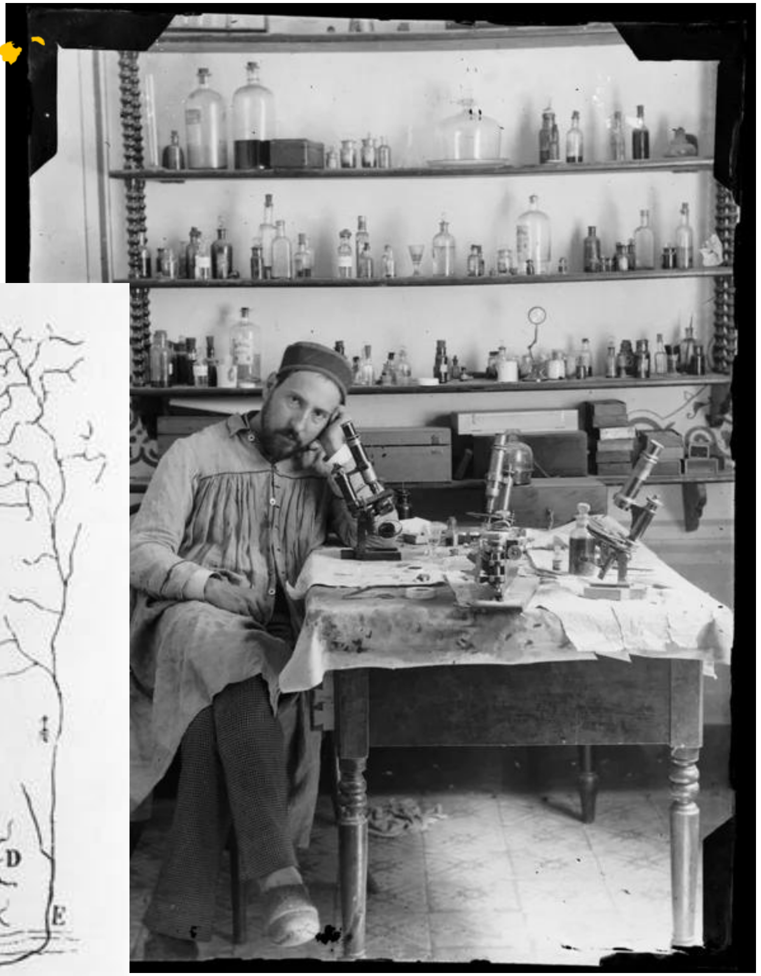


Principle of connectional specificity

Nerve cells do not connect randomly with one another in the formation of networks. Rather, each cell makes **specific connections - at particular contact points -** with certain postsynaptic target cells but not with others.



Ramón y Cajal’s drawing of the afferent inflow to the mammalian cortex



Santiago Ramón y Cajal (1852–1934)

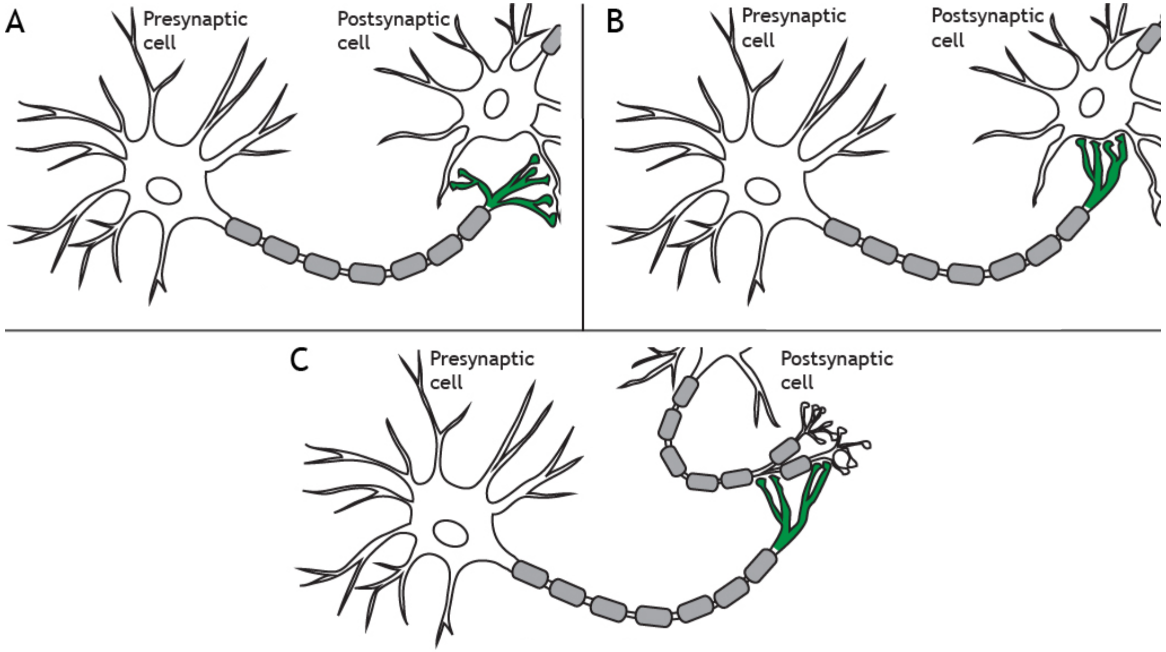
Three types of synapses

Axosomatic: synapses that are made onto the soma or cell body of a neuron.

Axodendritic: synapses that one neuron makes onto the dendrite of another neuron. The most common type.

Axoaxonic: synapses made by one neuron onto the synapse of another neuron. Axoaxonic synapses mediate presynaptic inhibition and presynaptic facilitation.

What kind of synapses are these?



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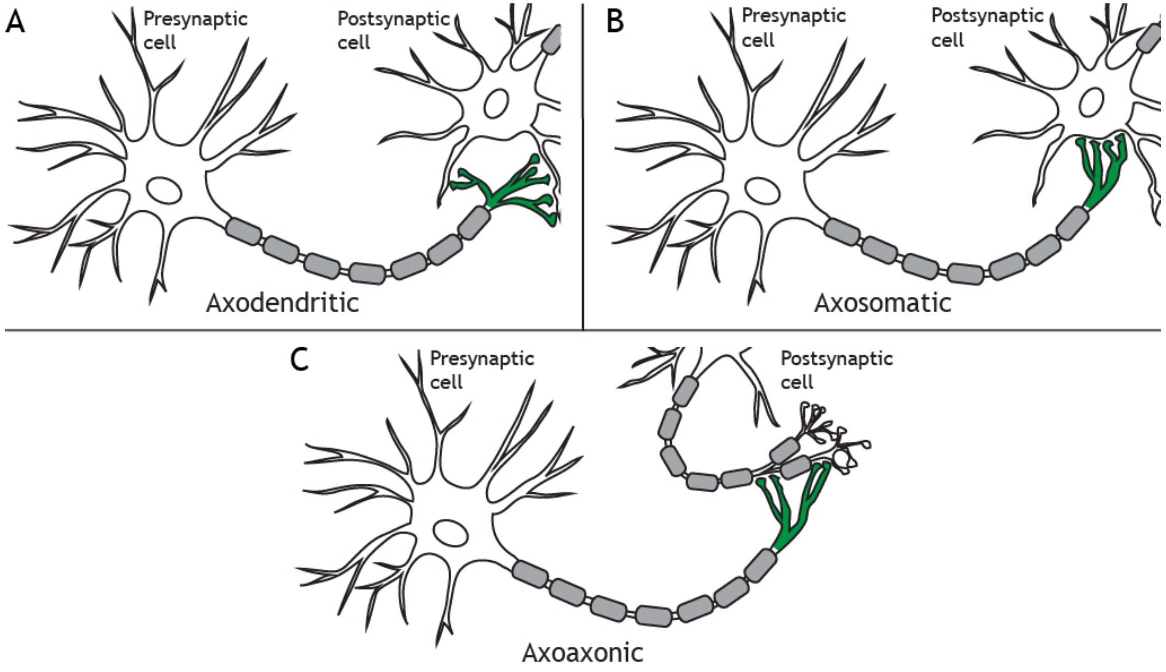

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Axoaxonic synapses

- Axo-axonic synapses selectively control individual terminals of the axon, by increasing or decreasing Ca^{2+} influx into the presynaptic terminals of the postsynaptic cell, thereby enhancing or depressing transmitter release, respectively.
- For reasons that are not well understood, presynaptic modulation usually occurs early in sensory pathways.

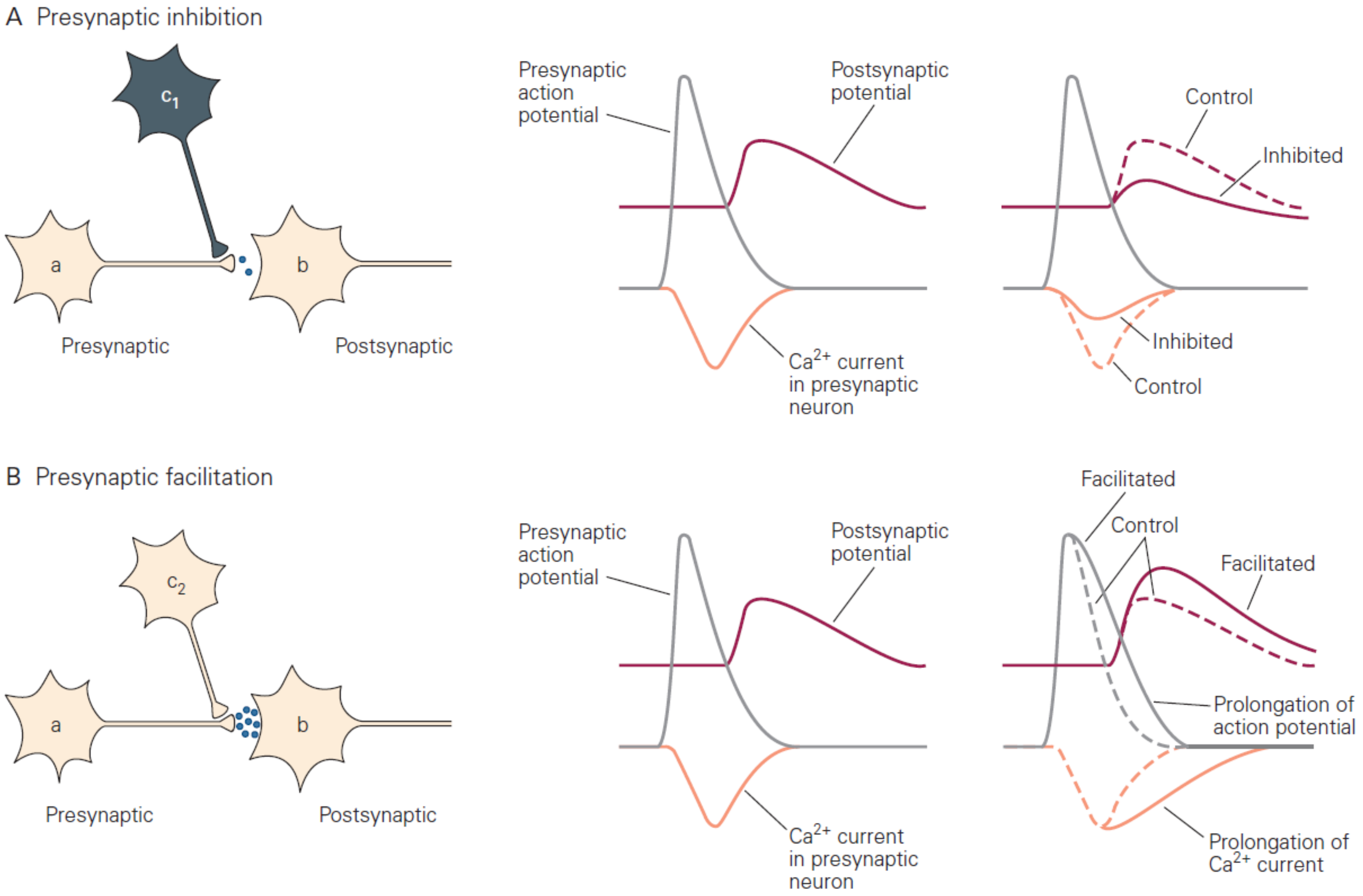


Figure 12–16 Axoaxonic synapses can inhibit or facilitate transmitter release by the presynaptic cell.

A. An inhibitory neuron (c_1) forms a synapse on the axon terminal of neuron a. Release of transmitter by cell c_1 activates a metabotropic receptor on the terminals of cell a, which inhibits the Ca^{2+} current in these terminals, thereby reducing the amount of transmitter released by cell a onto cell b. The reduction of transmitter release from cell a in turn reduces the amplitude of the excitatory postsynaptic potential in cell b, a process termed presynaptic inhibition.

B. A facilitating neuron (c_2) forms a synapse on the axon terminal of neuron a. Release of transmitter by cell c_2 activates a metabotropic receptor on the terminals of cell a, which decreases a K^+ current in the terminals, thereby prolonging the action potential and increasing Ca^{2+} influx into cell a. This increases transmitter release from cell a onto cell b, thereby increasing the size of the EPSP in cell b, a process termed presynaptic facilitation.

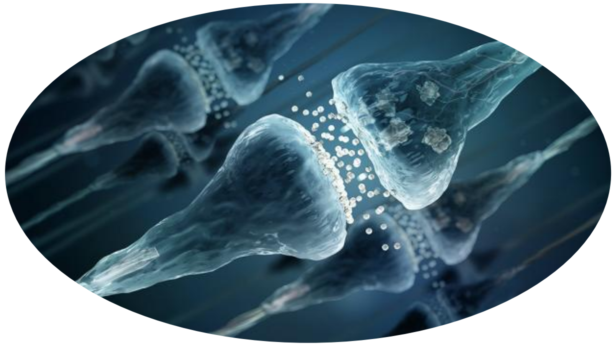
The synapse enables neuronal communication

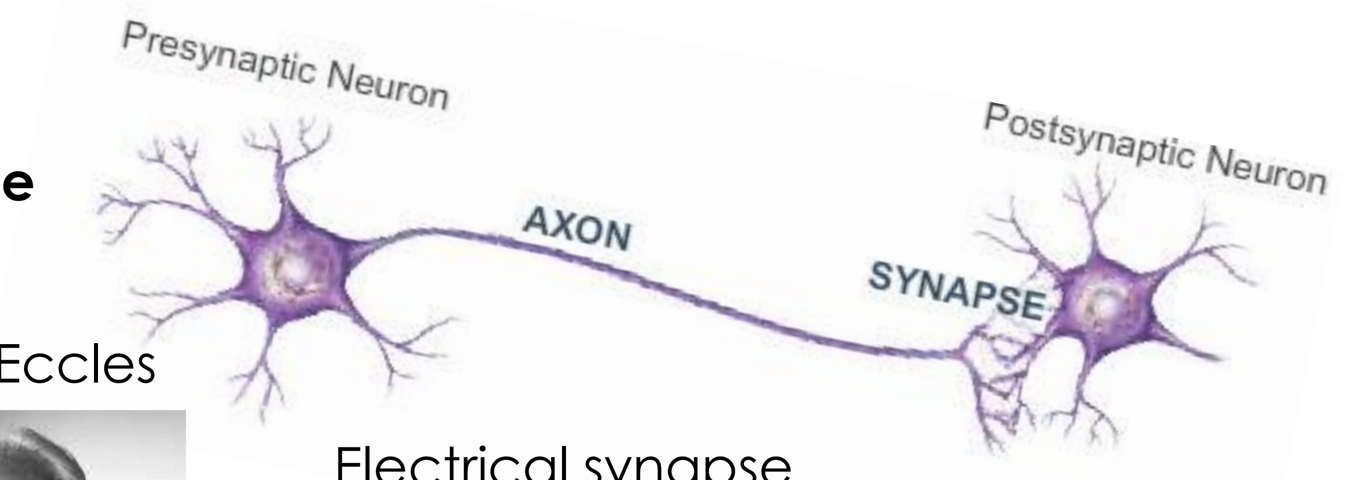
1930s synaptic transmission "fight"

Charles Sherrington realized that reflexes were not as fast as they should be if the nervous system was a continuous mass of tissue (syncytium)

Coined the term **synapse**

Chemical synapse

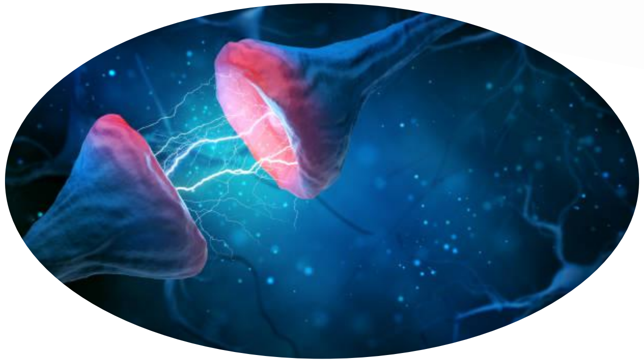




Henry Dale

Jhon Eccles

Electrical synapse



Charles Sherrington

Electrical and chemical synapses are structured differently

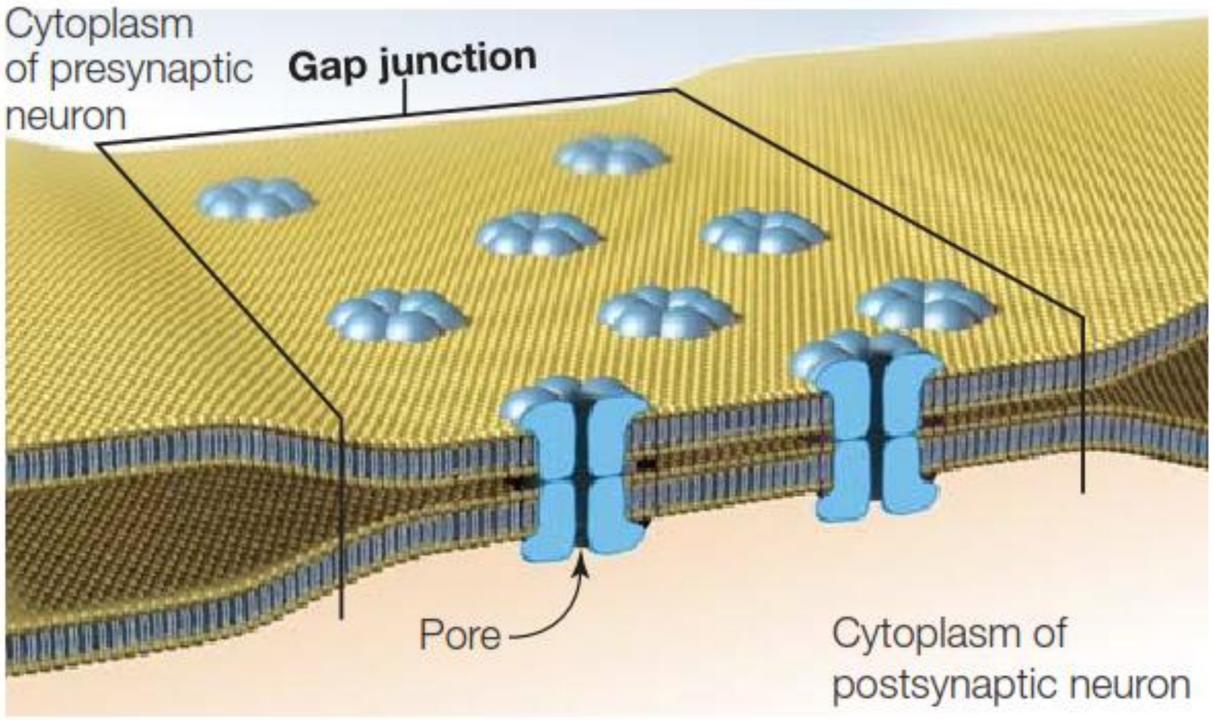


FIGURE 2.14 Electrical synapse between two neurons.

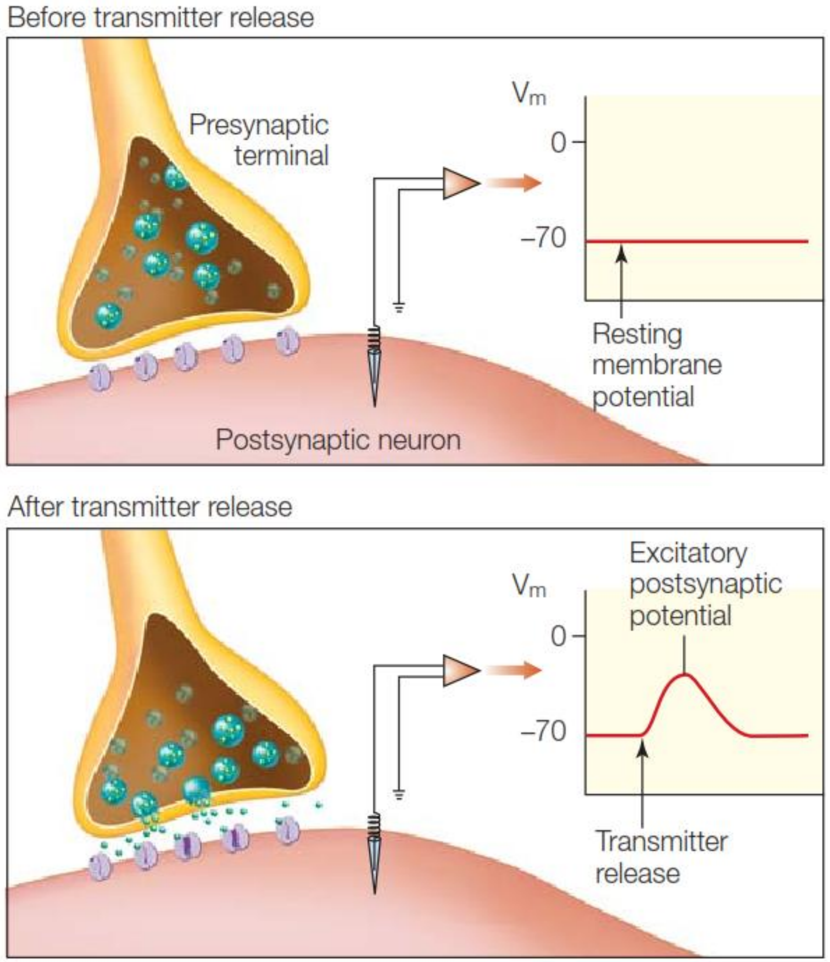


FIGURE 2.13 Neurotransmitter leading to postsynaptic potential.

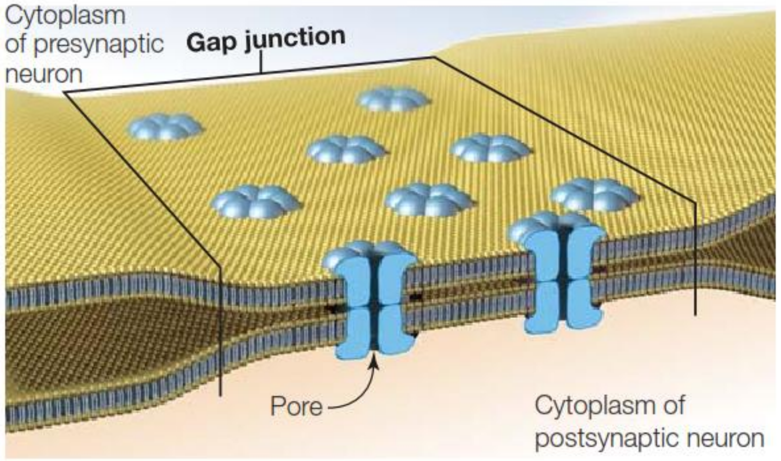
Electrical and chemical synapses are structured differently

Electrical synapses:

- neuronal membranes are touching at gap junctions, and the cytoplasm of the two neurons are essentially continuous

Chemical synapses:

- no structural continuity between pre- and postsynaptic neurons, synaptic cleft separates the neurons



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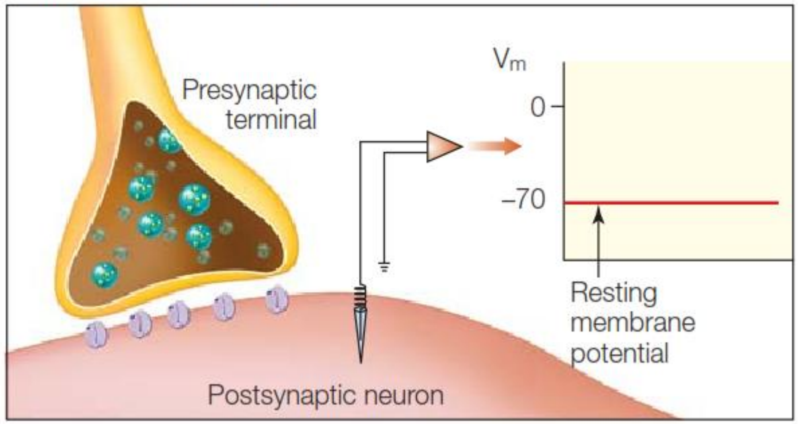
Before transmitter release



What are the functional implications of this difference in structure?

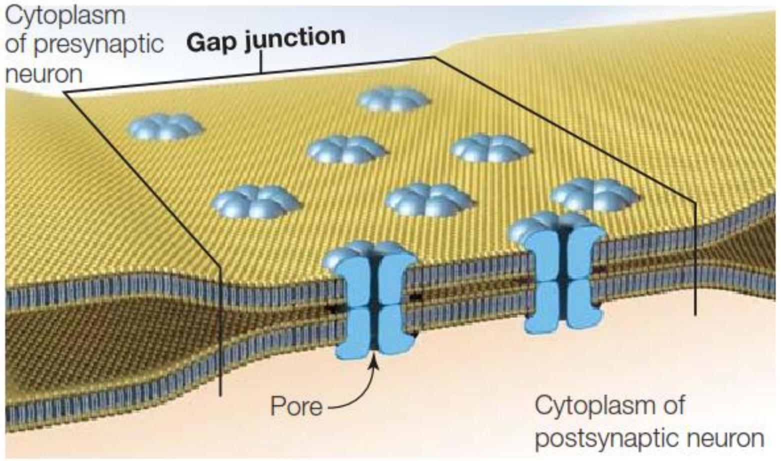
Electrical and chemical synapses function differently

Electrical synapses:

- Electrical synaptic transmission depends on the <u>instantaneous transmission of the flow of ions</u> from the pre- to the post-synaptic neuron

Chemical synapses:

- Chemical synaptic transmission depends on the <u>diffusion of a neurotransmitter</u> across the synaptic cleft



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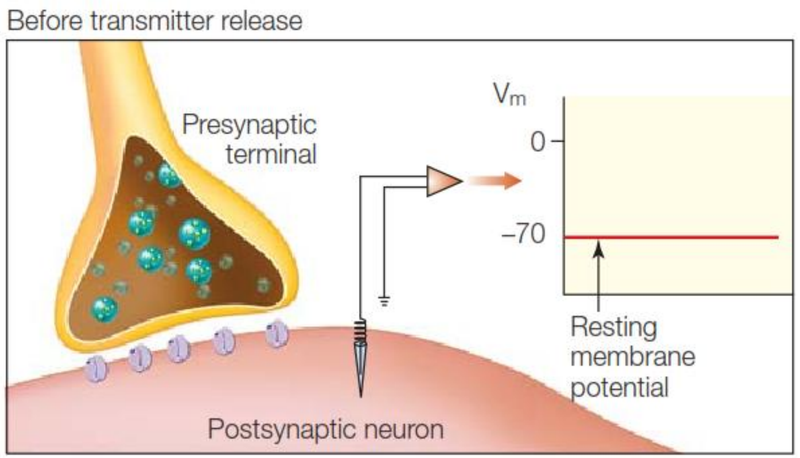
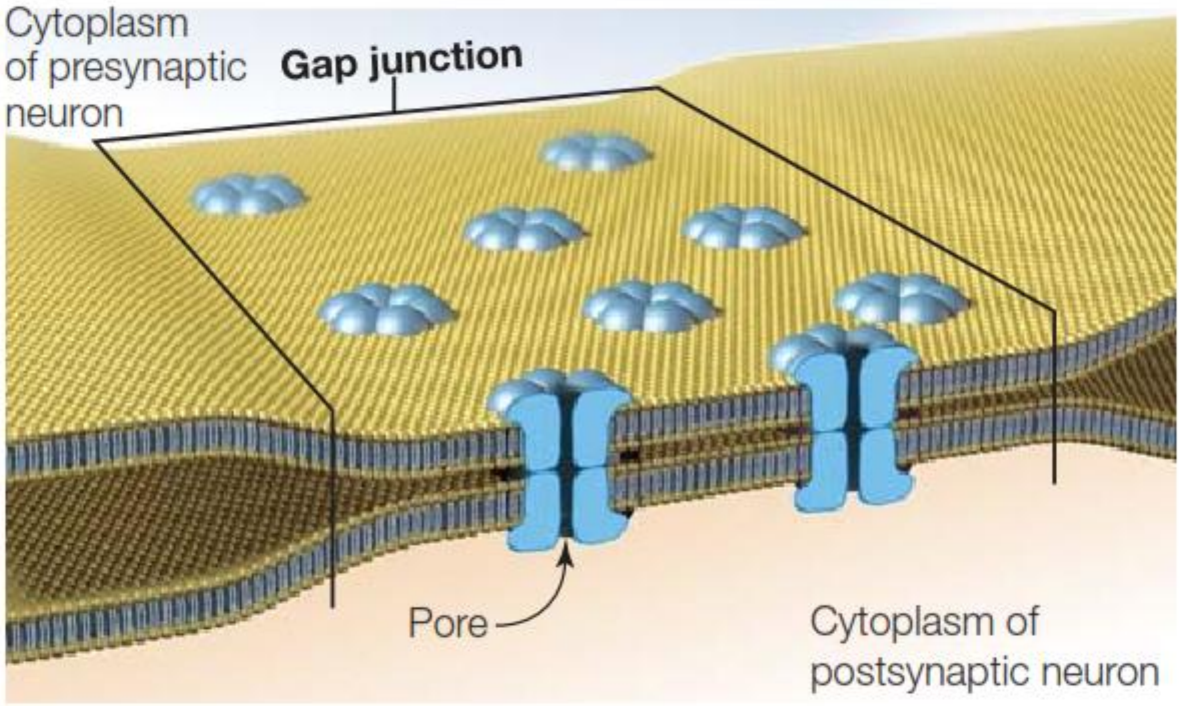


Electrical synapses provide instantaneous signal transmission

- Gap junction channels create pores connecting the cytoplasm of the two neurons
- The two neurons are **isopotential**
- Electrical changes in one neuron are reflected instantaneously in the other



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Electrical synapses: functional implications

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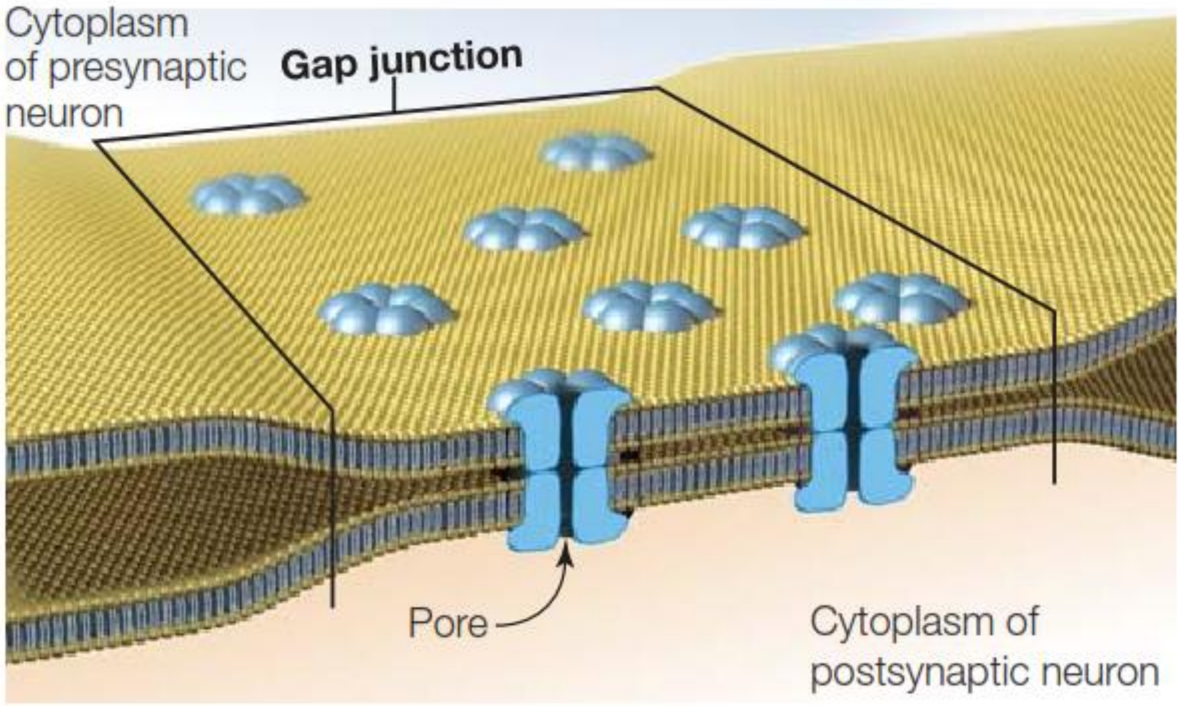

FIGURE 2.14 Electrical synapse between two neurons.

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Electrical synapses: functional implications

- Fast transmission (e.g. Invertebrate escape reflex)
- Synchronous operation of groups of neurons (e.g. hypothalamus)

- Less plastic than chemical synapses
- Cannot modulated signal from one neuron to the next
- Less specific

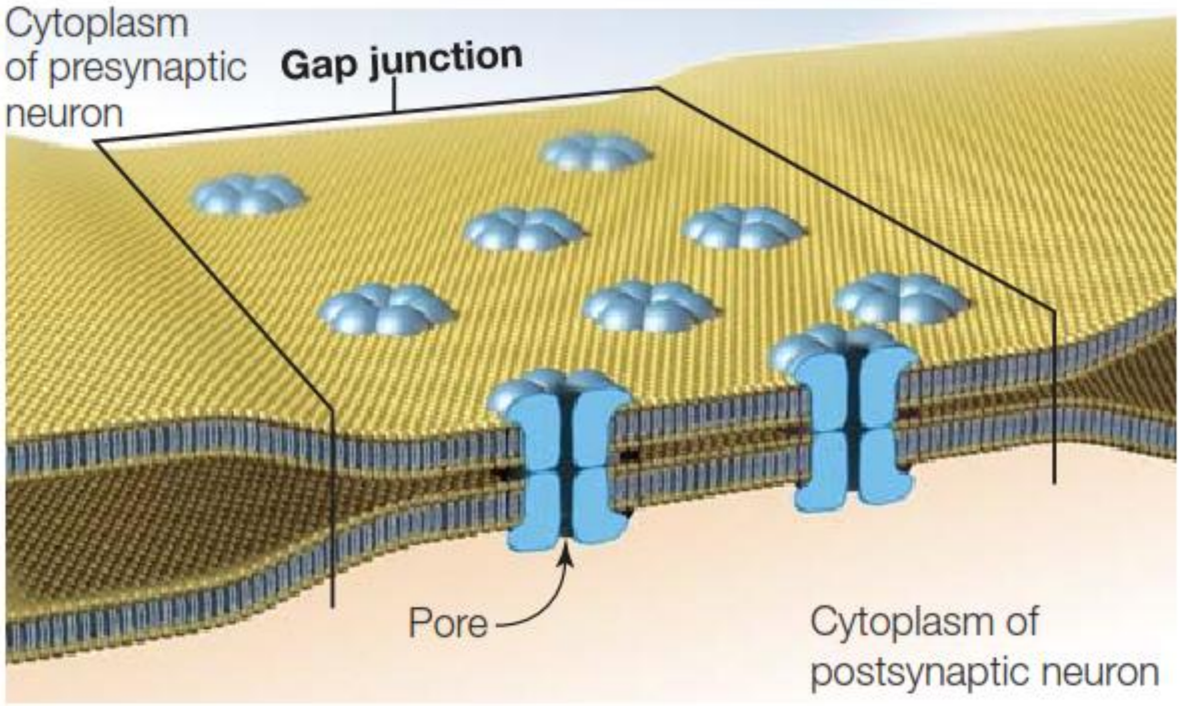

FIGURE 2.14 Electrical synapse between two neurons.

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Chemical synapses

Chemical synaptic transmission depends on the diffusion of a neurotransmitter across the synaptic cleft

Neurotransmitter: a chemical substance that binds receptors in the postsynaptic membrane of the target cell

Presynaptic terminals: specialized swellings of the axon, which typically contain synaptic vesicles

Synaptic vesicles: vesicles filled with several thousand molecules of the neurotransmitter

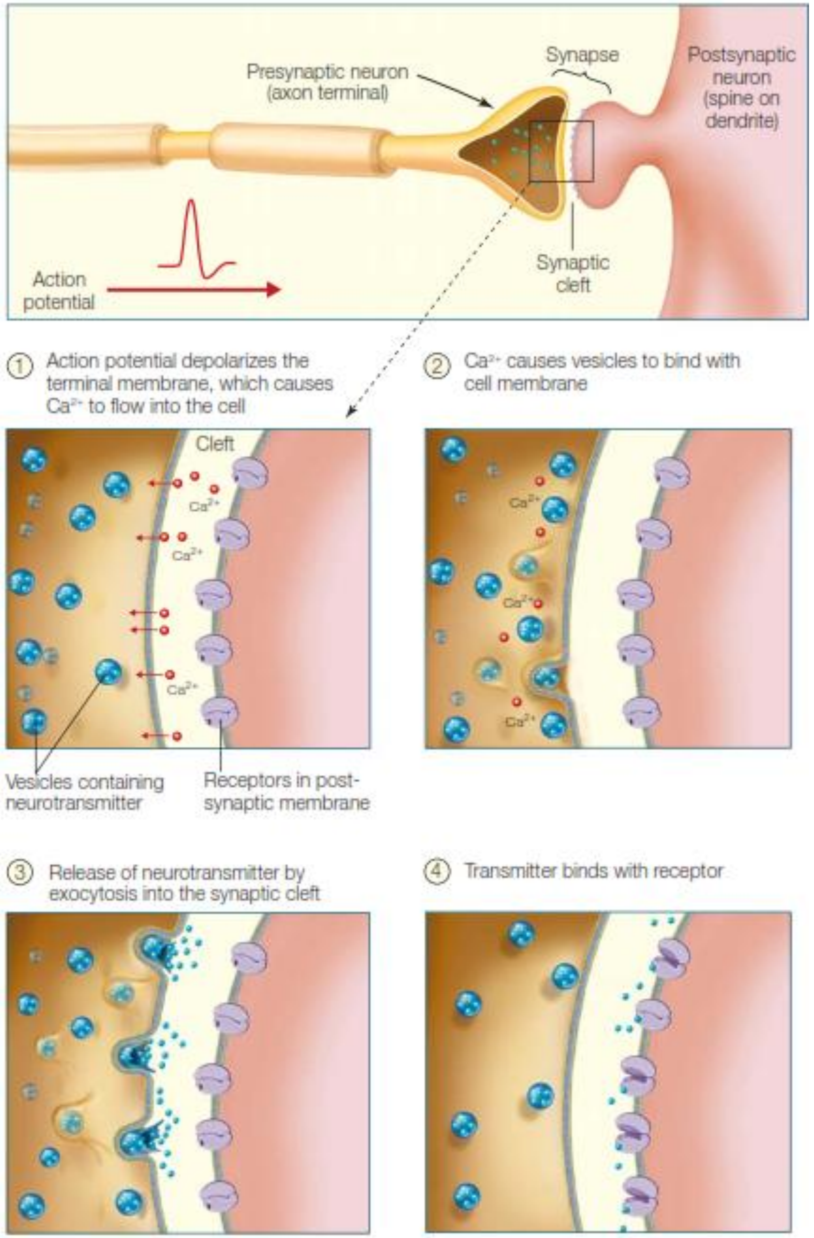


FIGURE 2.12 Neurotransmitter release at the synapse, into synaptic cleft. The synapse consists of various specializations where the presynaptic and postsynaptic membranes are in close apposition. When the action potential invades the axon terminals, it causes voltage-gated Ca^{2+} channels to open (1), which triggers vesicles to bind to the presynaptic membrane (2). Neurotransmitter is released into the synaptic cleft by exocytosis and diffuses across the cleft (3). Binding of the neurotransmitter to receptor molecules in the postsynaptic

Chemical synapses

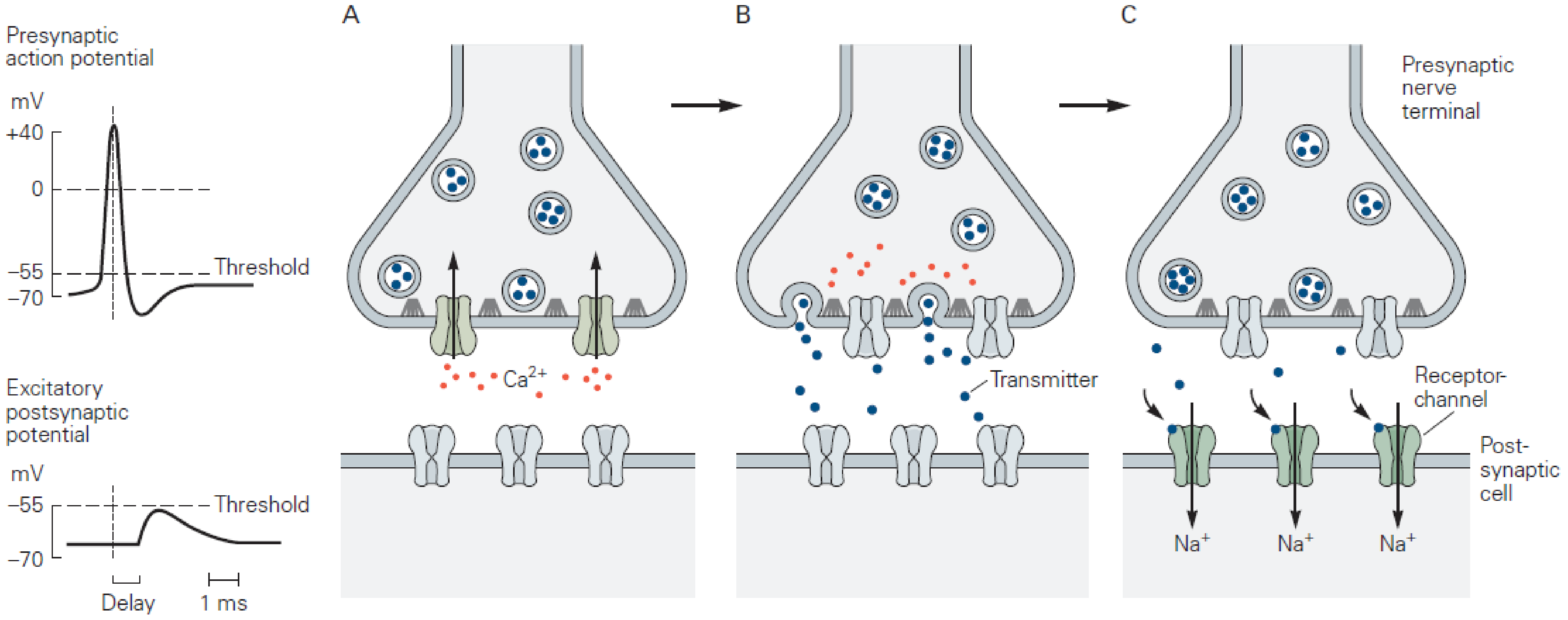
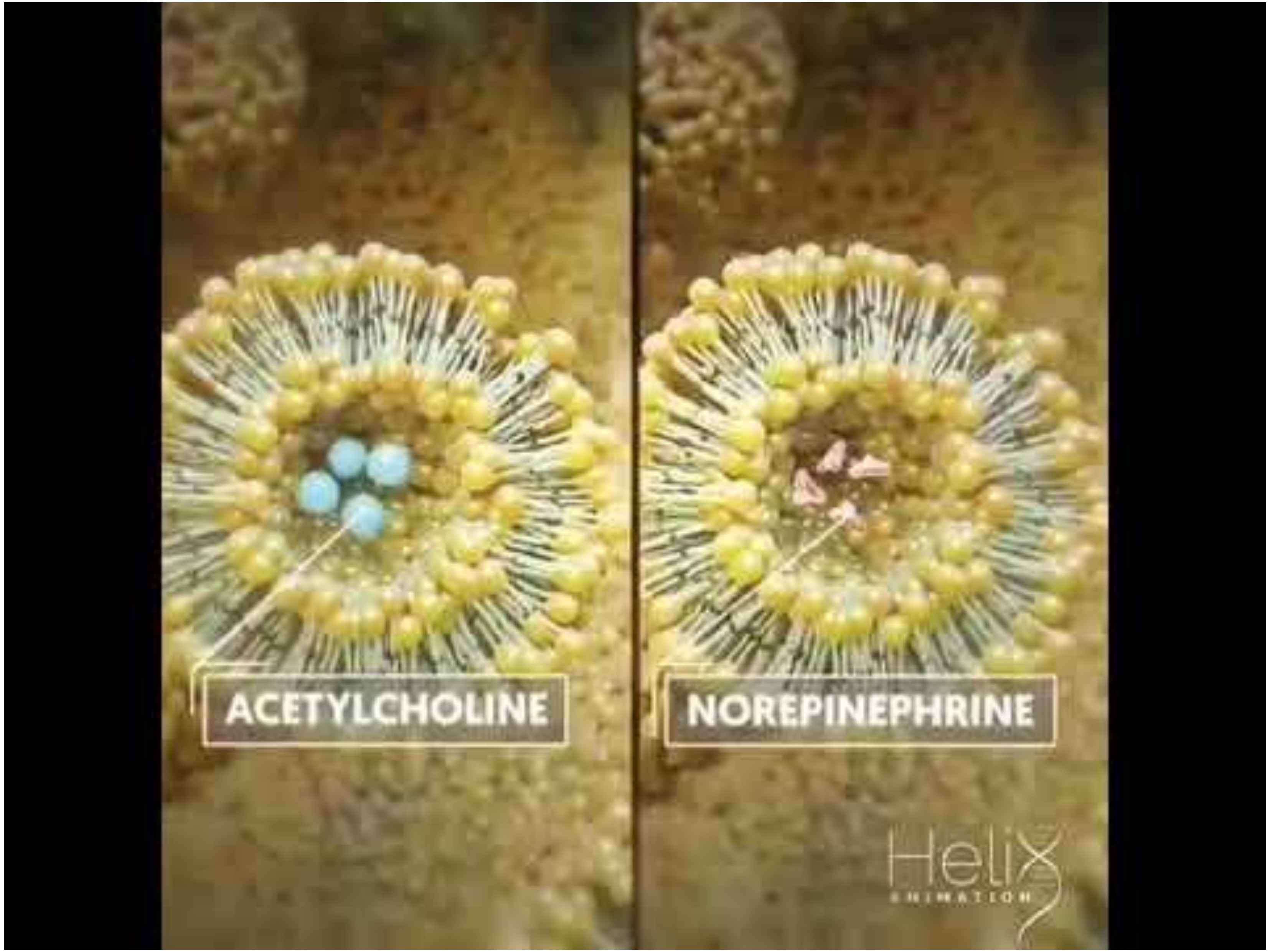


Figure 8–8 Synaptic transmission at chemical synapses involves several steps. The complex process of chemical synaptic transmission accounts for the delay between an action potential in the presynaptic cell and the synaptic potential in the postsynaptic cell compared with the virtually instantaneous transmission of signals at electrical synapses (see Figure 8–2B).

A. An action potential arriving at the terminal of a presynaptic axon causes voltage-gated Ca^{2+} channels at the active zone to open. The **gray filaments** represent the docking and release sites of the active zone.

B. The Ca^{2+} channel opening produces a high concentration of intracellular Ca^{2+} near the active zone, causing vesicles containing neurotransmitter to fuse with the presynaptic cell membrane and release their contents into the synaptic cleft (a process termed *exocytosis*).

C. The released neurotransmitter molecules then diffuse across the synaptic cleft and bind specific receptors on the postsynaptic membrane. These receptors cause ion channels to open (or close), thereby changing the membrane conductance and membrane potential of the postsynaptic cell.

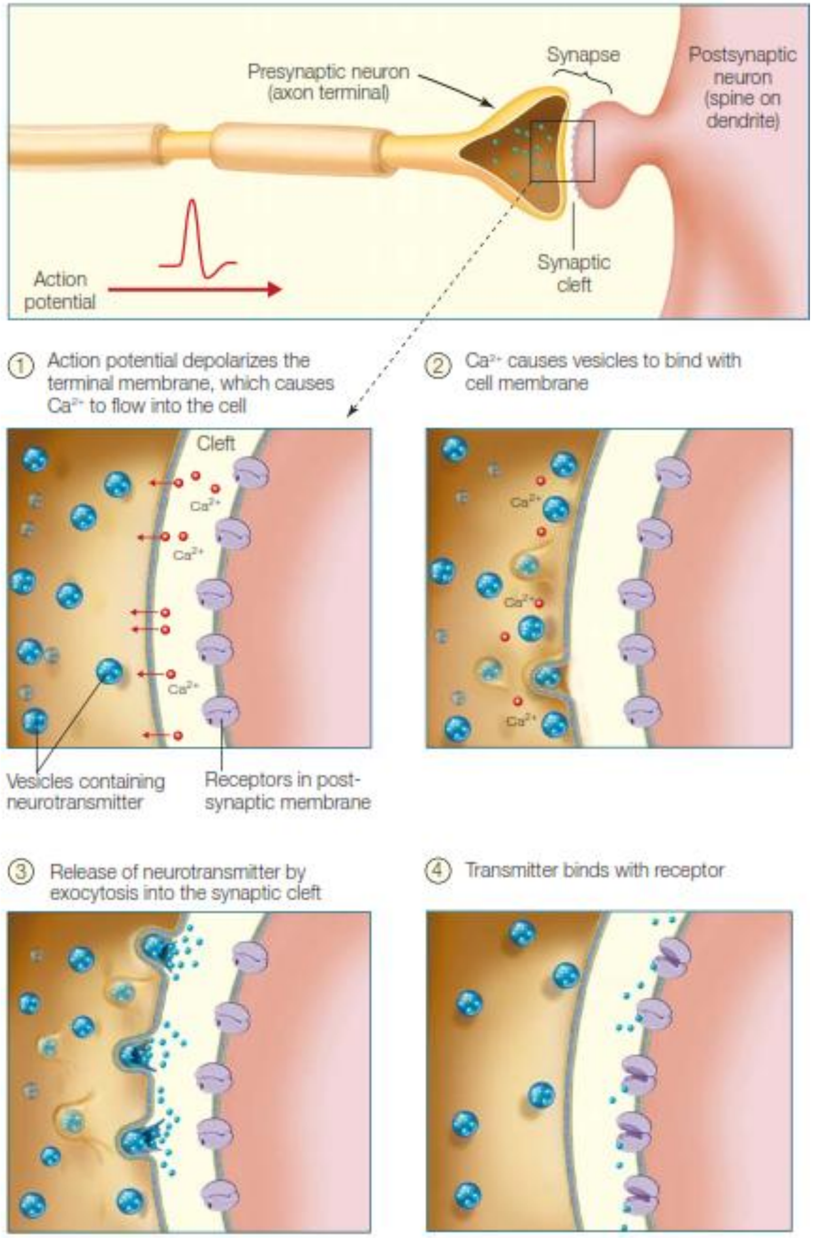


https://www.youtube.com/watch?v=vicGtfC_yq0

Chemical synapses

Inactivation of Neurotransmitters can be accomplished by

1. Active reuptake of the substance back into the presynaptic terminal
2. Enzymatic breakdown or degradation of the transmitter in the synaptic cleft
3. Diffusion of the neurotransmitter away from the site of action (e.g., in the case of hormones that act on target cells distant from the synaptic terminals)



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Neurotransmitter

- **the effect of a neurotransmitter on the postsynaptic neuron is determined by the postsynaptic receptor** rather than by the transmitter itself

- the same neurotransmitter released from the same presynaptic neuron onto two different postsynaptic cells might cause one to depolarize (excitation) and the other to hyperpolarize (inhibition)

- Although most of the time neurotransmitters have a typical effect, either inhibitory or excitatory

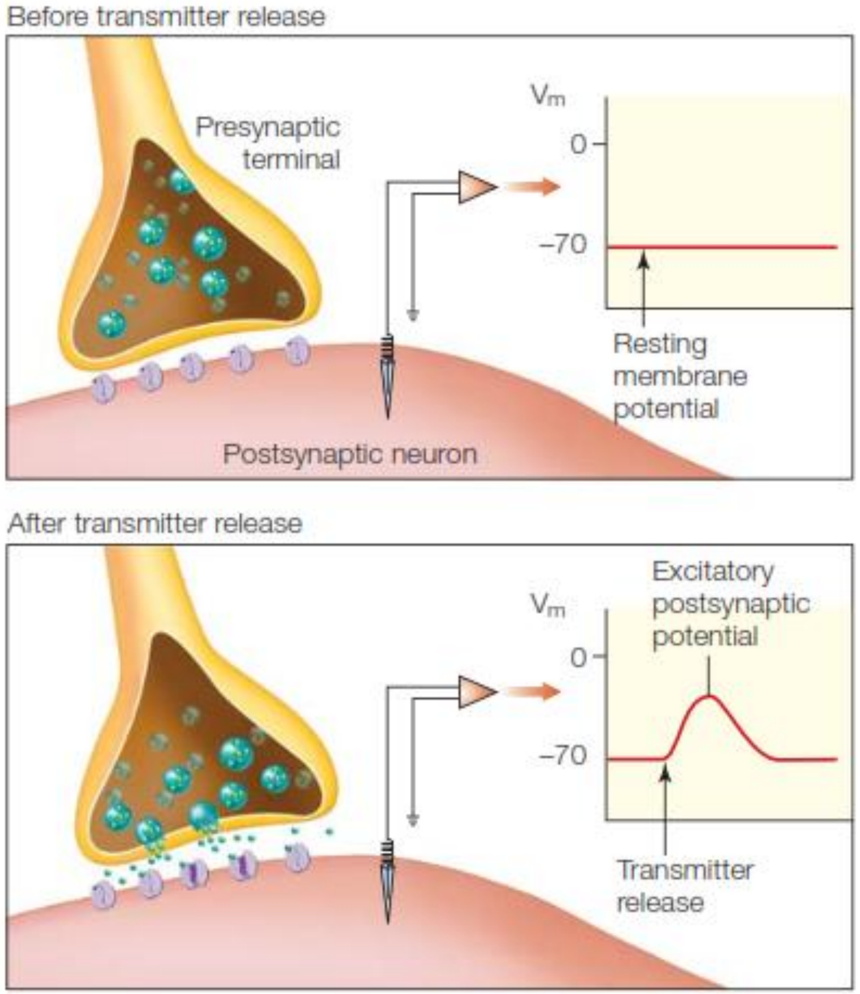

FIGURE 2.13 Neurotransmitter leading to postsynaptic potential. The binding of neurotransmitter to the postsynaptic membrane receptors changes the membrane potential (V_m). These postsynaptic potentials can be either excitatory (depolarizing the membrane), as shown here, or inhibitory (hyperpolarizing the membrane).

Chemical Synapses: functional implications

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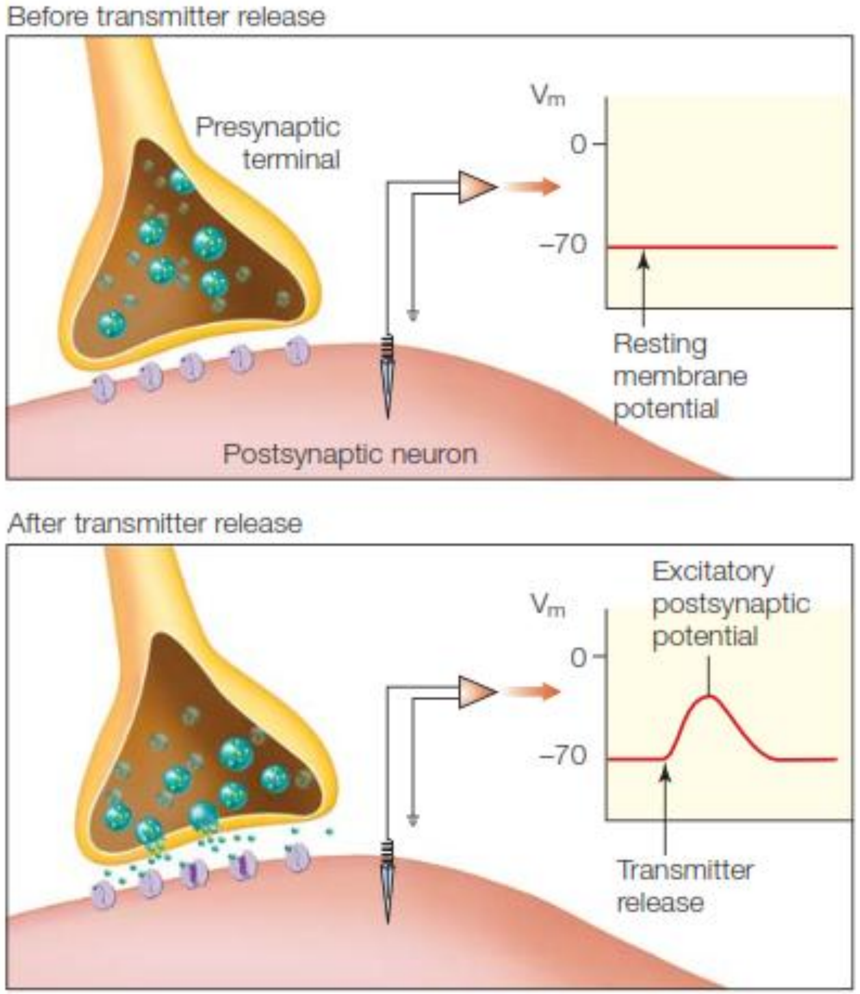

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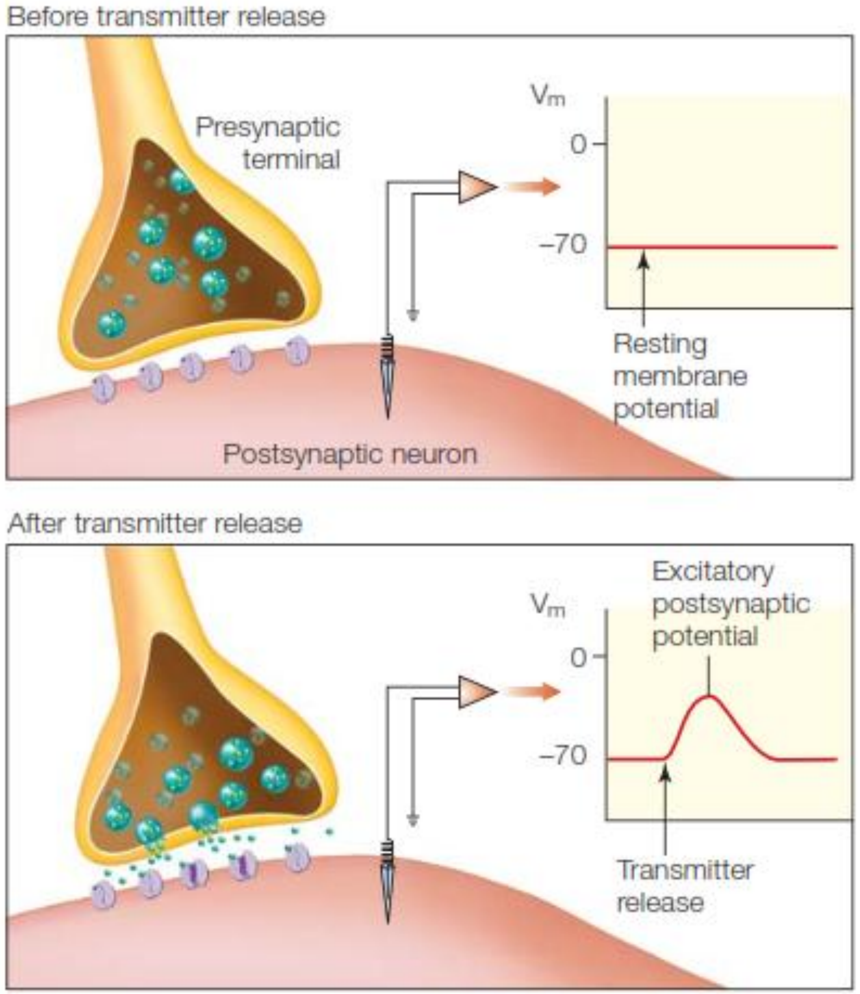
Chemical Synapses: functional implications

- More plastic than electrical synapses (functional and structural)
- Signal can be modulated from one neuron to the next: e.g. amplified, inhibited
- Highly specific depending on the presynaptic neurotransmitter and postsynaptic receptors

- Slower transmission



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https://youtu.be/VitFvNvRIIY

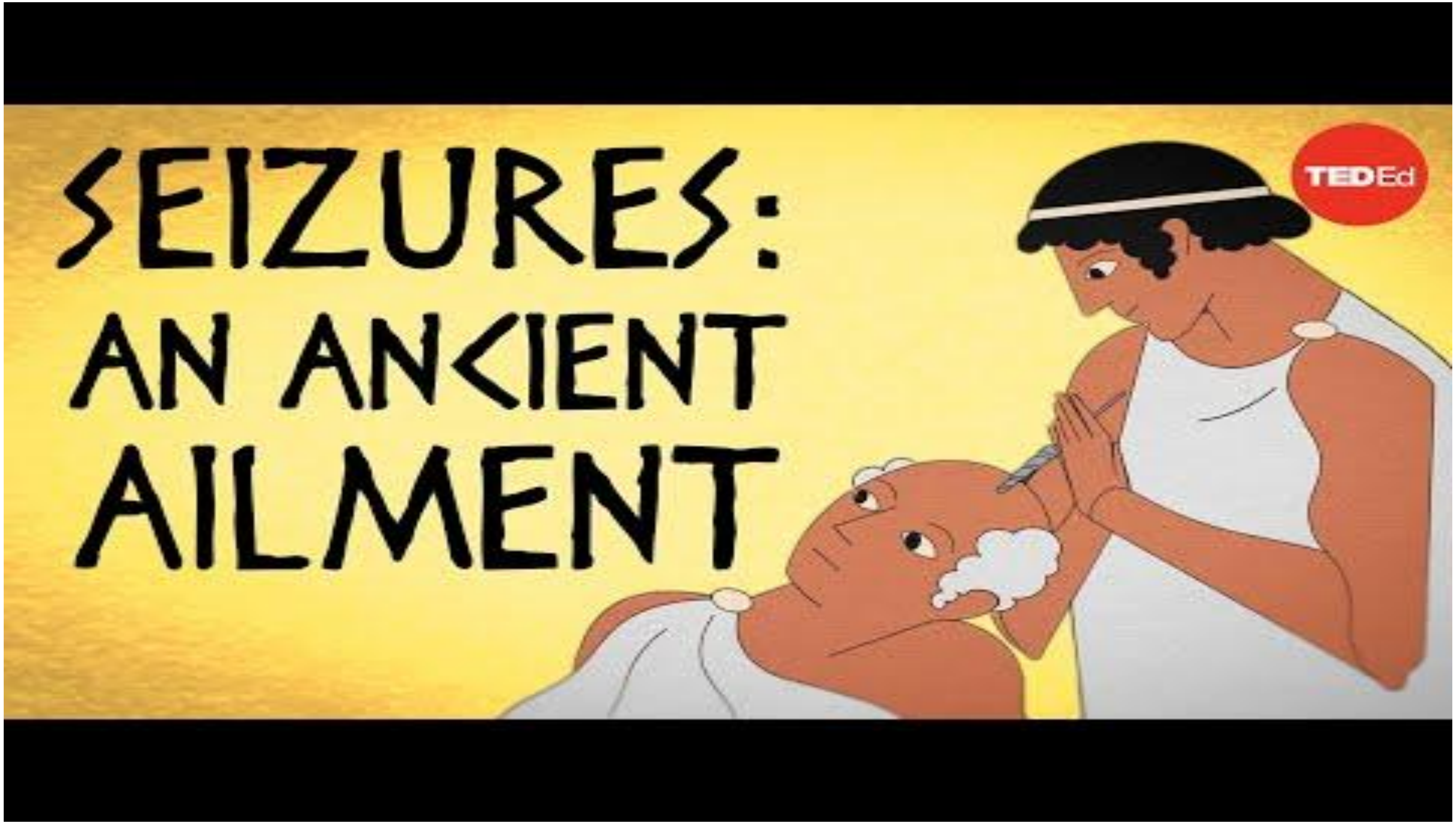
wooclap

Questions 1-4

Correct firing is crucial for correct functioning...

https://youtu.be/LcO9YU-Pdws

Correct firing is crucial for correct functioning...
Seizures: the misfiring of neurons



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Combination of neurons create a neural circuit

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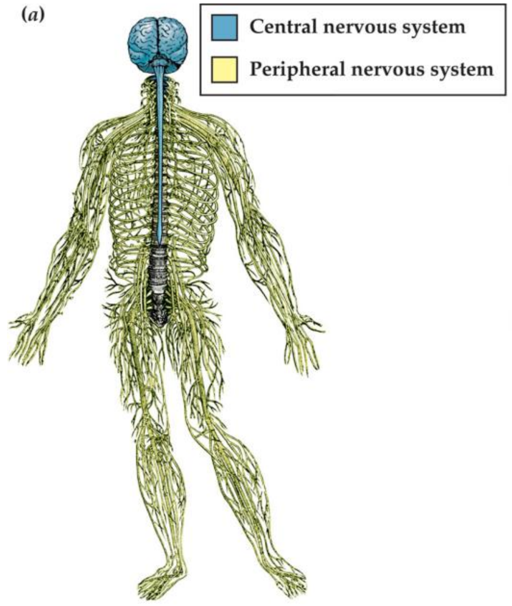
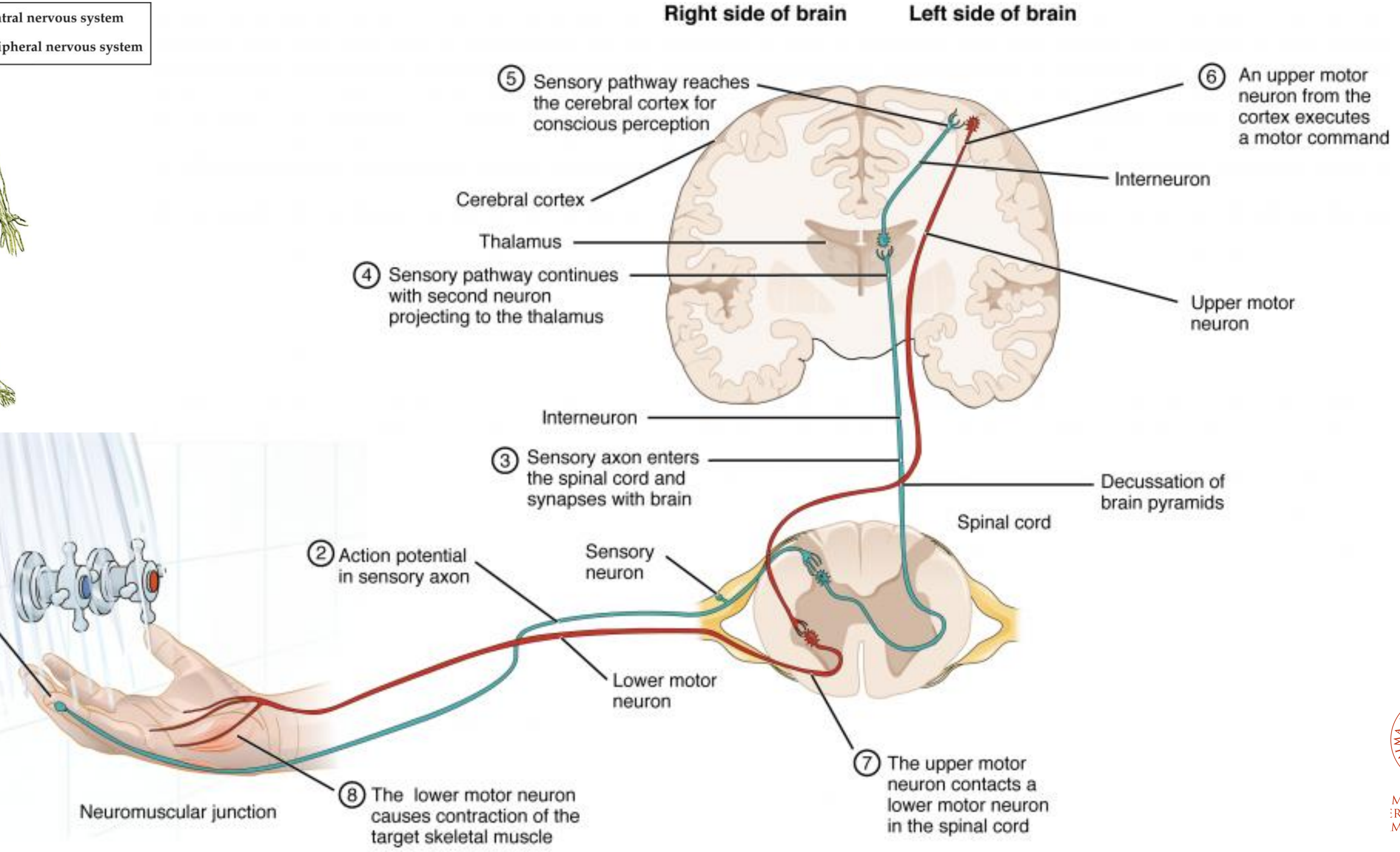
No complex human behavior is initiated by a single neuron

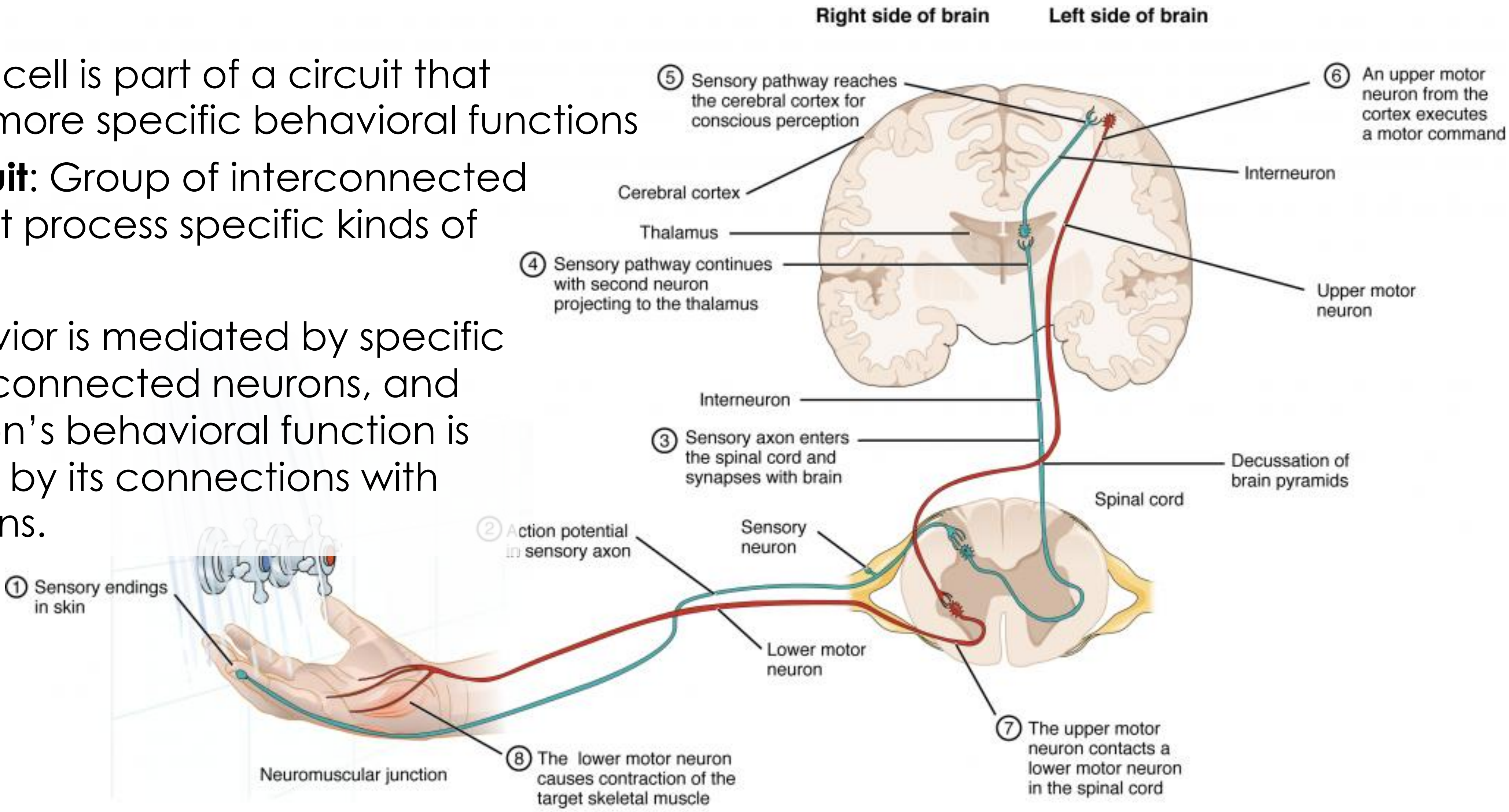


THE MIND'S MACHINE, Figure 2.6



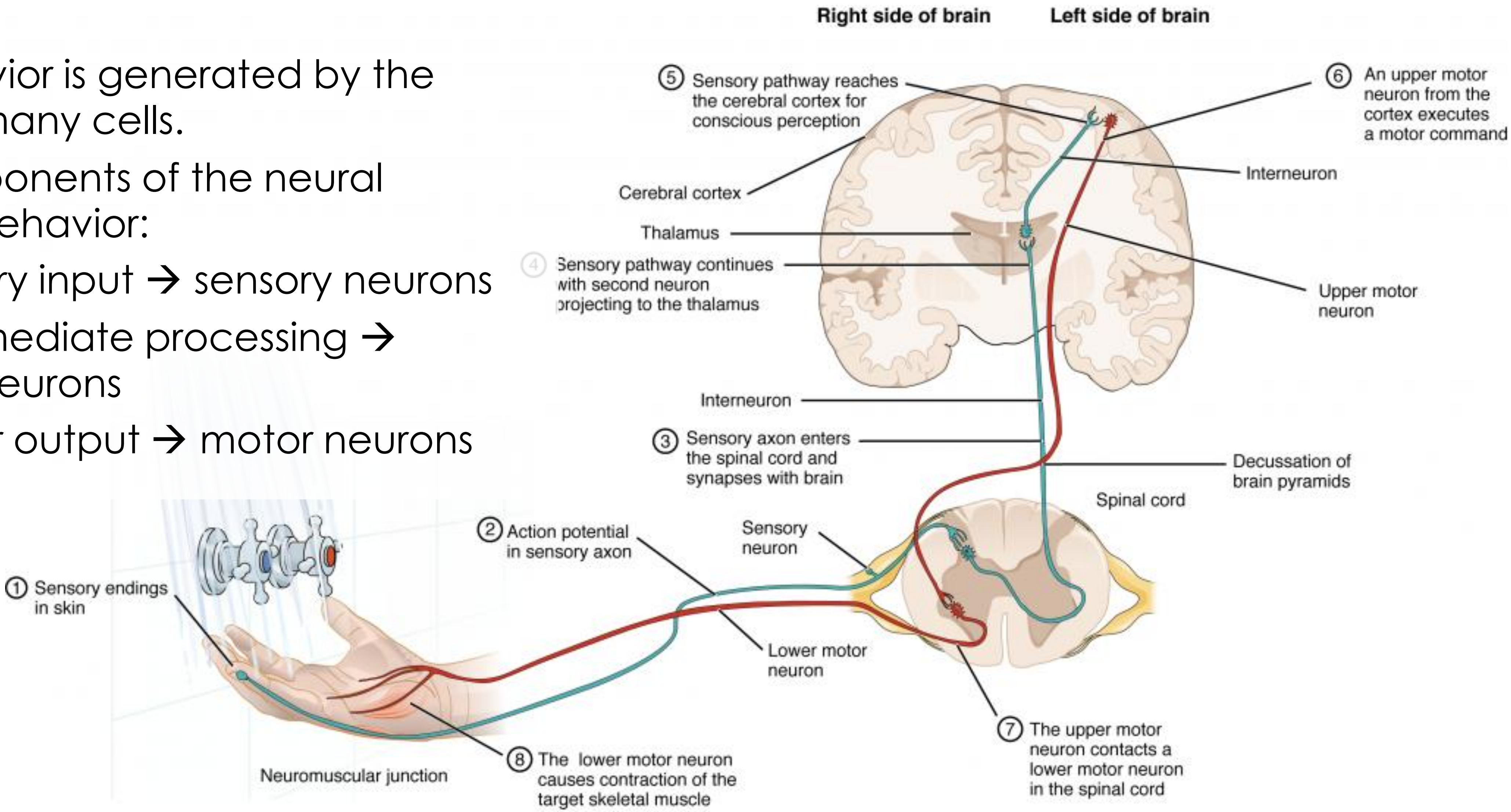
No complex human behavior is initiated by a single neuron

- Each nerve cell is part of a circuit that has one or more specific behavioral functions
- **Neural circuit**: Group of interconnected neurons that process specific kinds of information.
- Every behavior is mediated by specific sets of interconnected neurons, and every neuron's behavioral function is determined by its connections with other neurons.



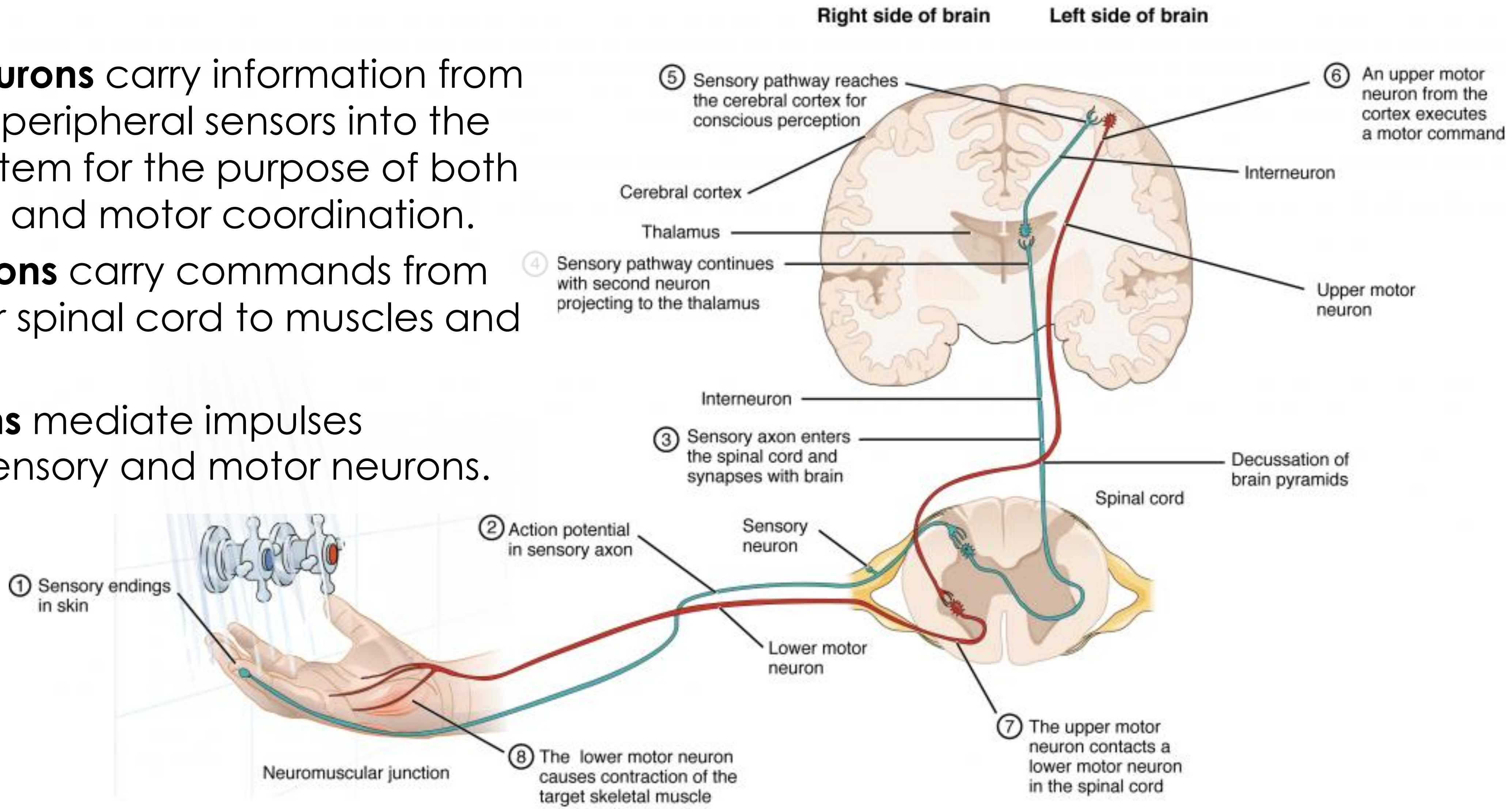
No complex human behavior is initiated by a single neuron

- Each behavior is generated by the actions of many cells.
- Three components of the neural control of behavior:
    - sensory input → sensory neurons
    - intermediate processing → interneurons
    - motor output → motor neurons



No complex human behavior is initiated by a single neuron

1. **Sensory neurons** carry information from the body's peripheral sensors into the nervous system for the purpose of both perception and motor coordination.
2. **Motor neurons** carry commands from the brain or spinal cord to muscles and glands.
3. **Interneurons** mediate impulses between sensory and motor neurons.



Sensory neurons carry information from the body's peripheral sensors

- Sensory information can be defined as neural activity originating from stimulation of receptor cells in specific parts of the body.
- These senses include the classic five senses plus a variety of modalities not recognized by the ancients but essential to bodily function: the somatic sensations of proprioception (posture and movement of our own body), pain, itch, and temperature; visceral sensations (both conscious and unconscious) necessary for homeostasis; and the vestibular senses of balance (the position of the body in the gravitational field) and head movement.

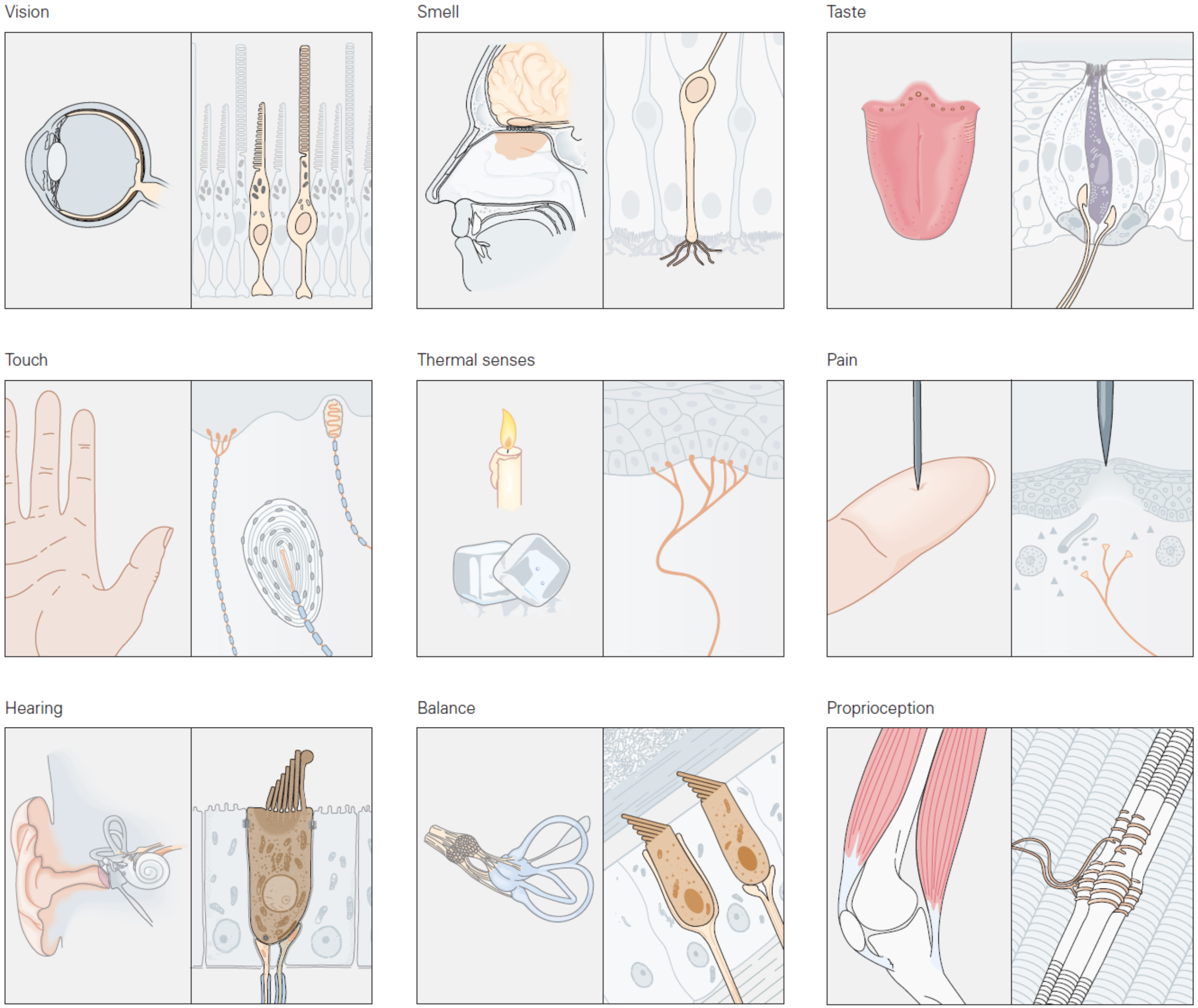
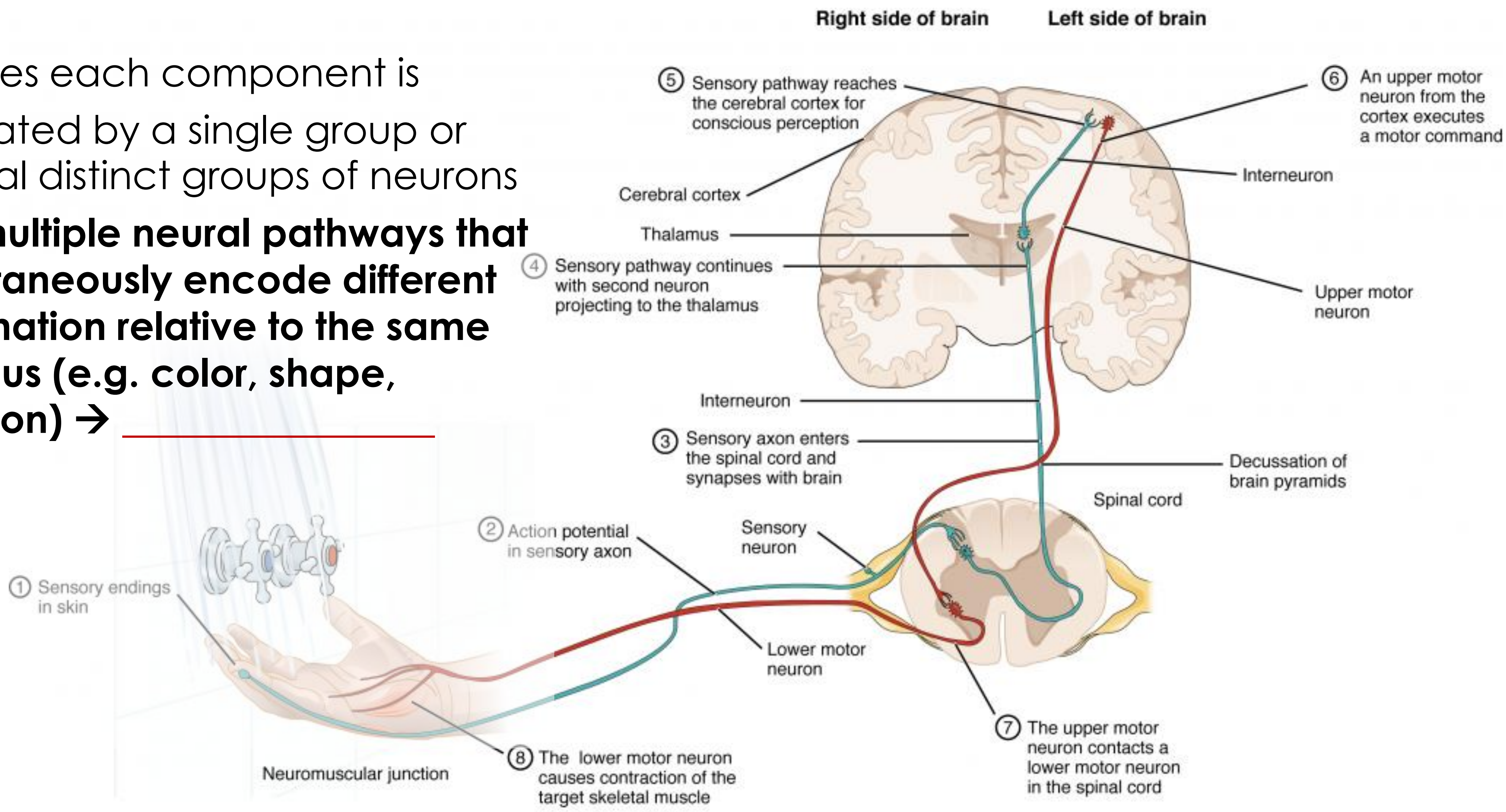


Figure 21–1 The major sensory modalities in humans are mediated by distinct classes of receptor neurons located in specific sense organs. Each class of receptor cell transforms one type of stimulus energy into electrical signals that are encoded as trains of action potentials. The principal receptor cells include photoreceptors (vision), chemoreceptors (smell, taste, and pain), thermal receptors, and mechanoreceptors (touch, hearing, balance, and proprioception). The classic five senses—vision, smell, taste, touch, and hearing—and the sense of balance are mediated by receptors in the eye, nose, mouth, skin, and inner ear, respectively. The other somatosensory modalities—thermal senses, pain, and proprioception—are mediated by receptors distributed throughout the body.

No complex human behavior is initiated by a single neuron

- In vertebrates each component is
  - mediated by a single group or several distinct groups of neurons
  - **has multiple neural pathways that simultaneously encode different information relative to the same stimulus (e.g. color, shape, loaction) → ______________**



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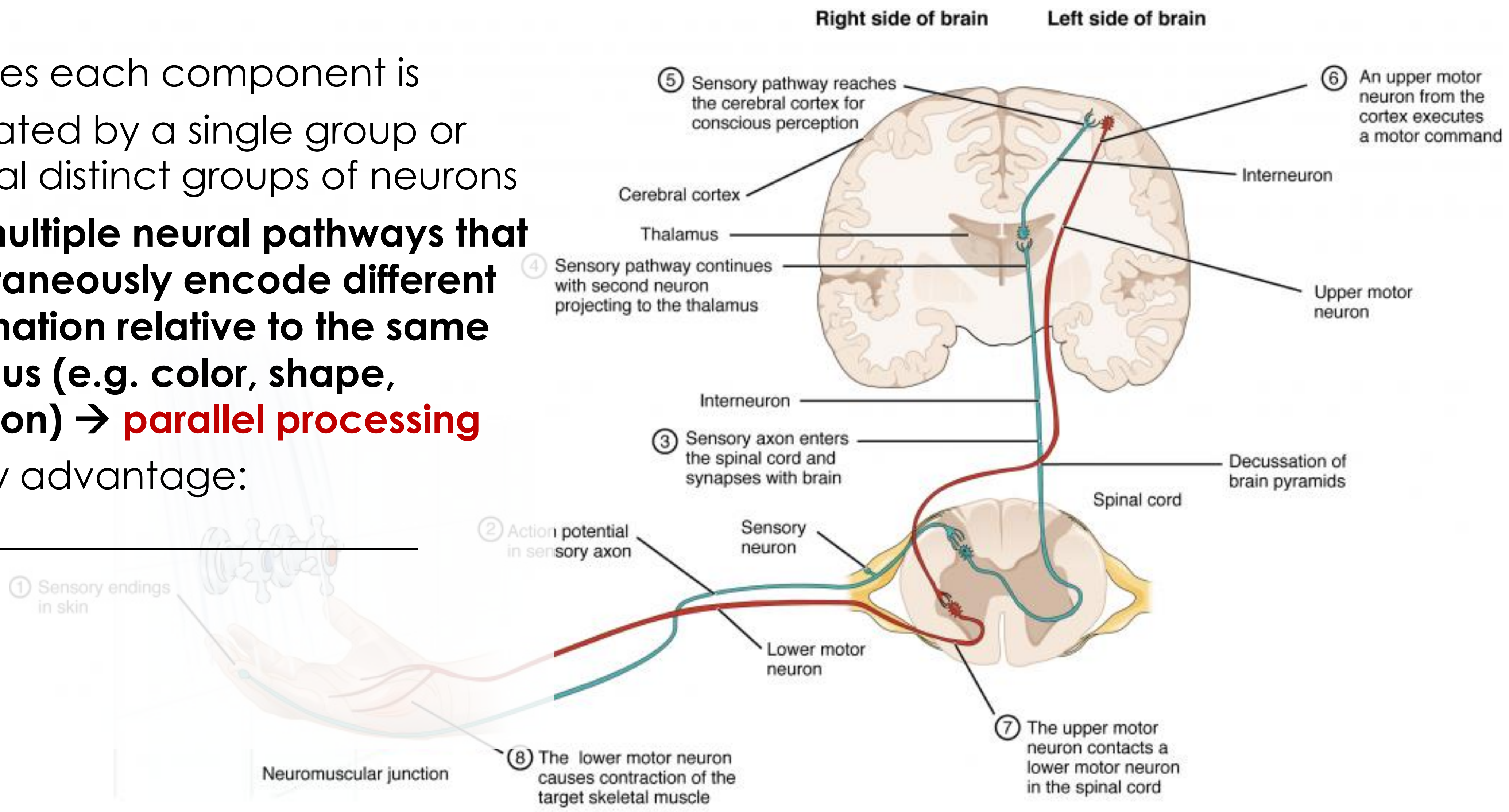
- Evolutionary advantage:

____



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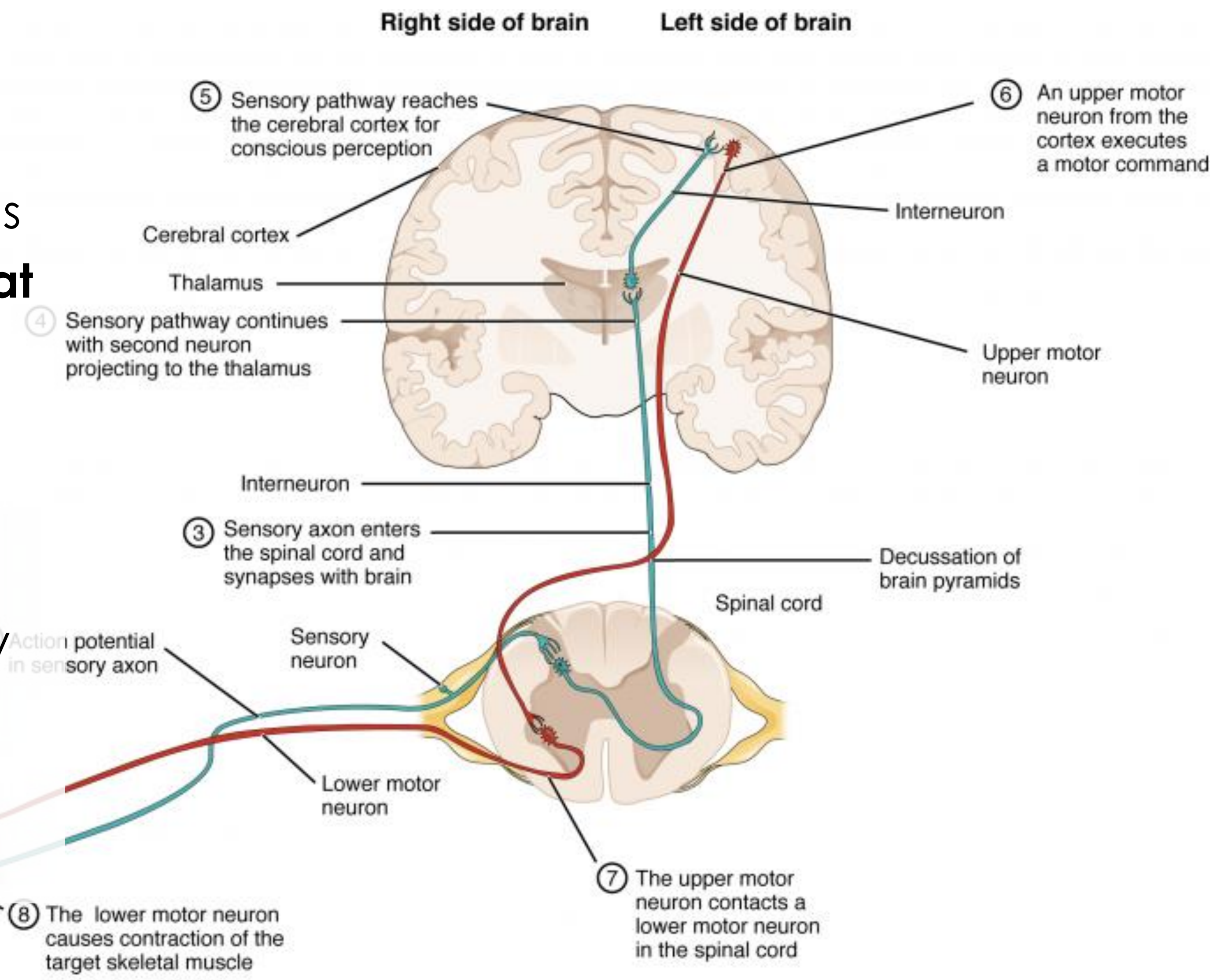
- Evolutionary advantage:

it increases both the speed and reliability of information transfer

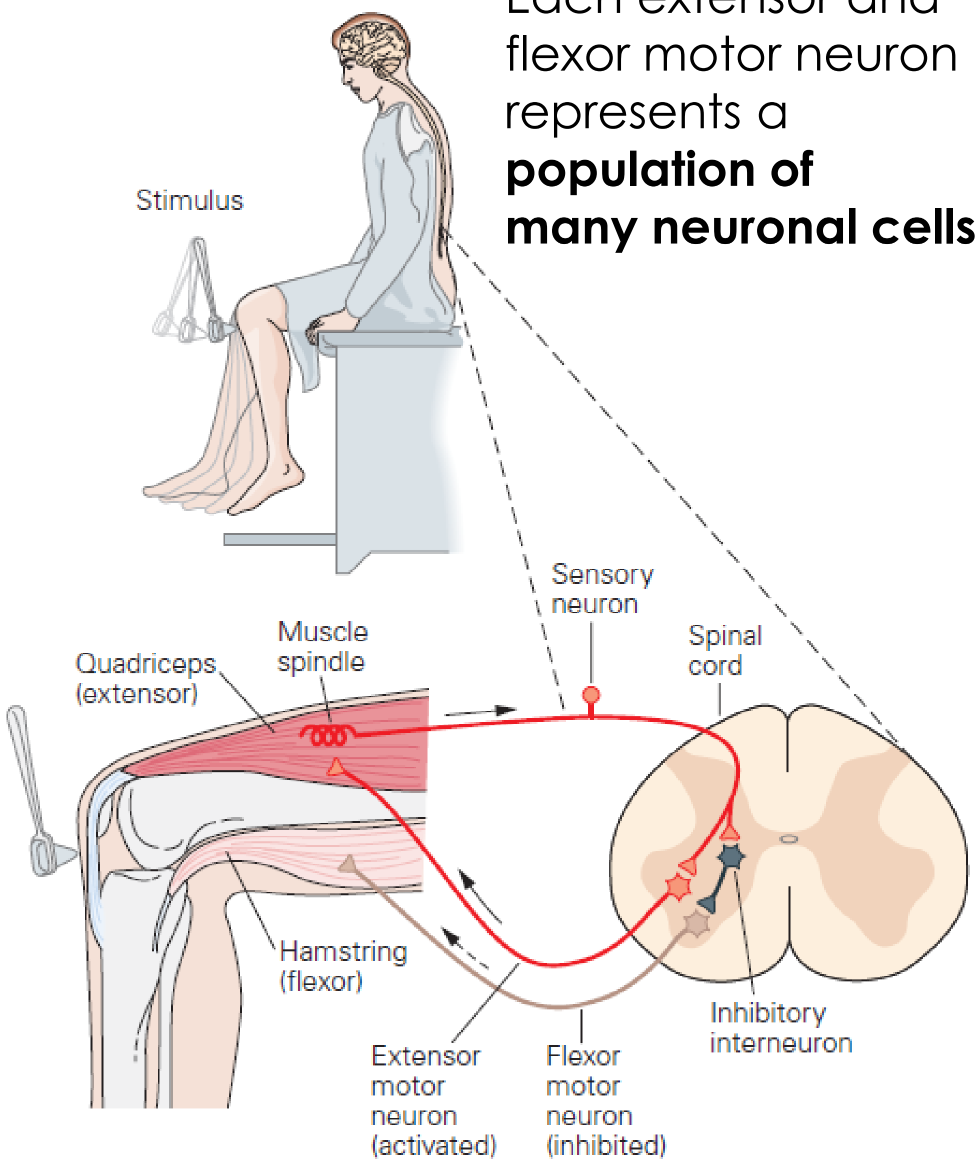


A simple neural circuit: the knee-jerk reflex

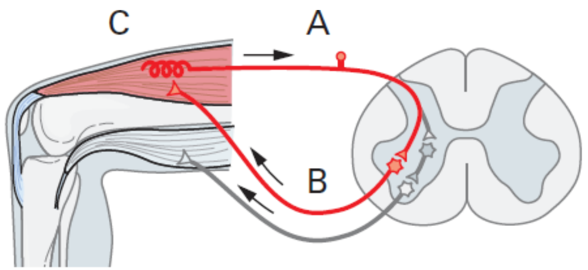
The combination of excitatory and inhibitory activity produces the reflex.

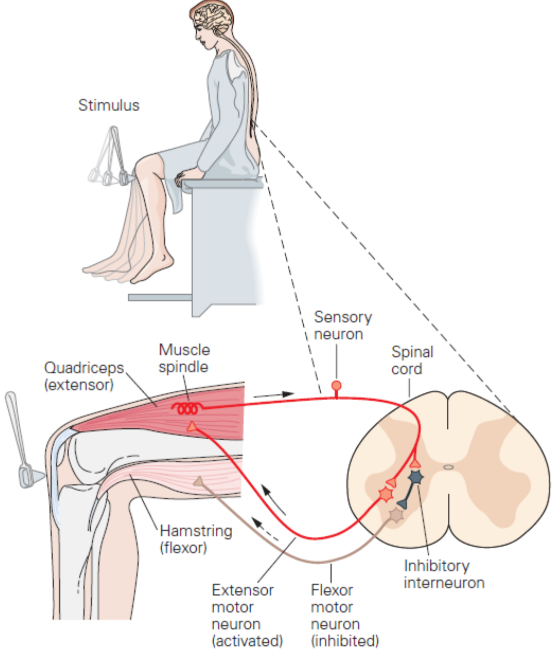
1. Sensory information is conveyed to the central nervous system (the spinal cord) from muscle.
2. Motor commands from the central nervous system are issued to the muscles that carry out the knee jerk.
3. Inhibitory commands are issued to motor neurons that innervate opposing (antagonist) muscles, providing coordination of muscle action.

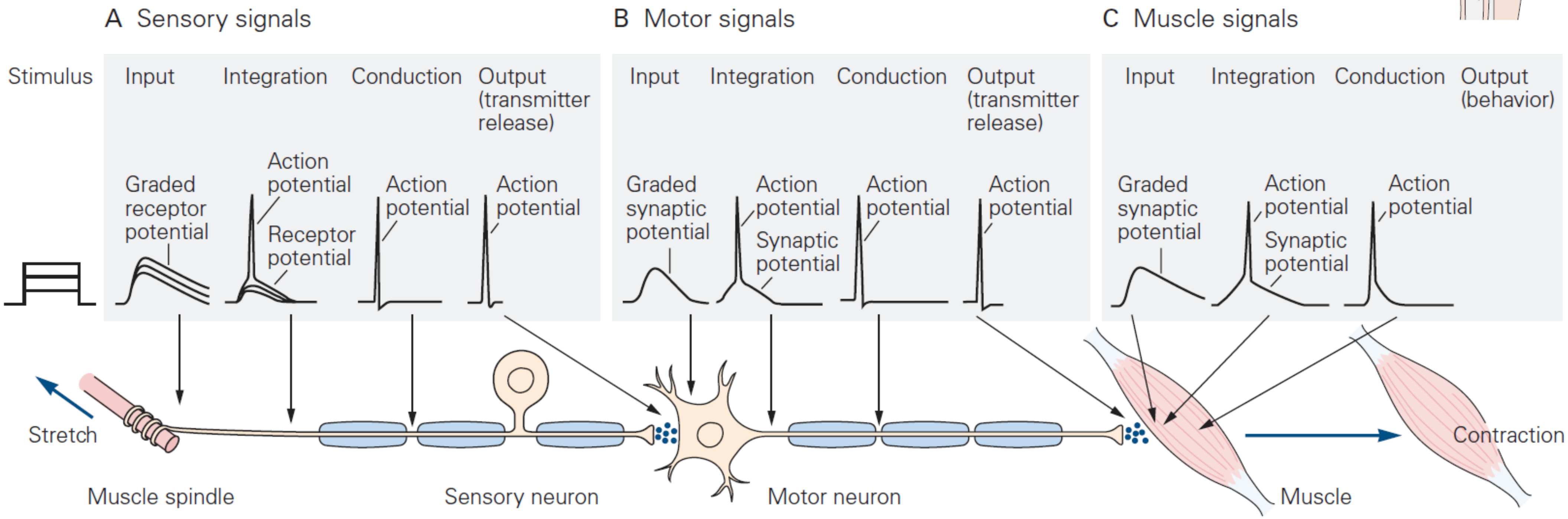
Each extensor and flexor motor neuron represents a **population of many neuronal cells.**



A simple neural circuit: the knee-jerk reflex







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https://youtu.be/c-dD0N53QRg?feature=shared

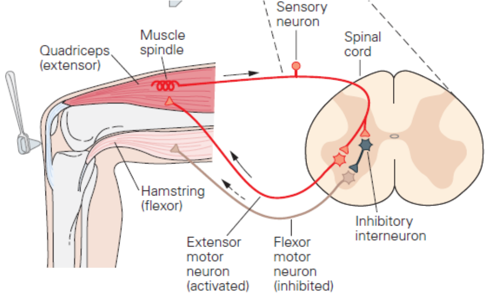
Divergence and convergence

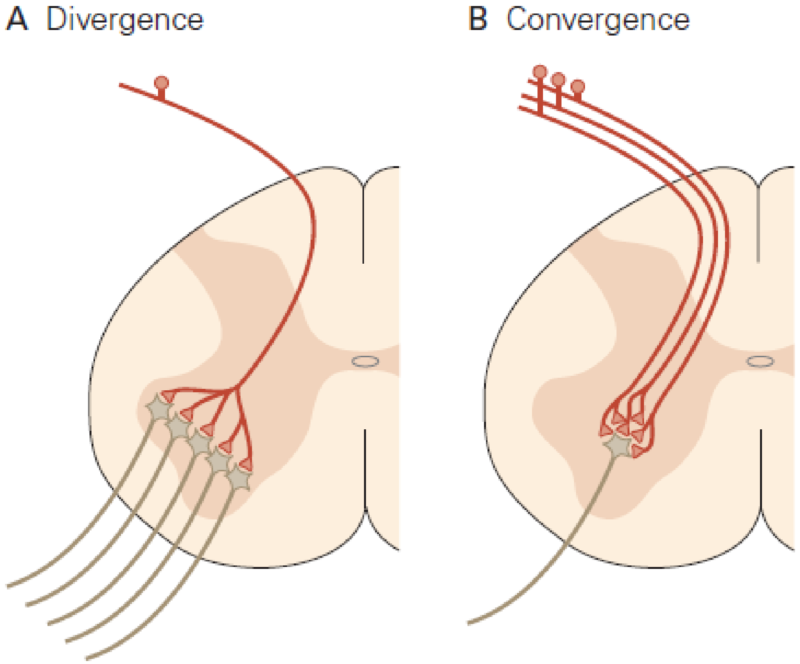
Divergence:

- The stretching of just one muscle activates several hundred **sensory neurons, each of which makes direct contact with 45 to 50 motor neurons**

Convergence:

- A **single motor neuron** in the knee jerk circuit **receives 200 to 450 input** contacts **from approximately 130 sensory neurons**





One neuron activates **many** target cells

Many neurons activate a **single** target cells

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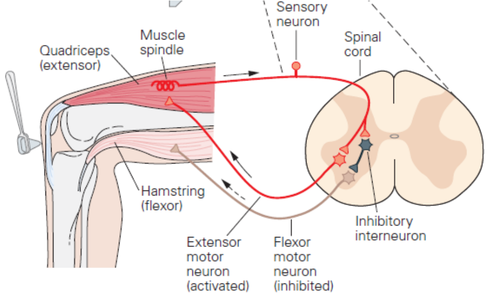
Divergence and convergence

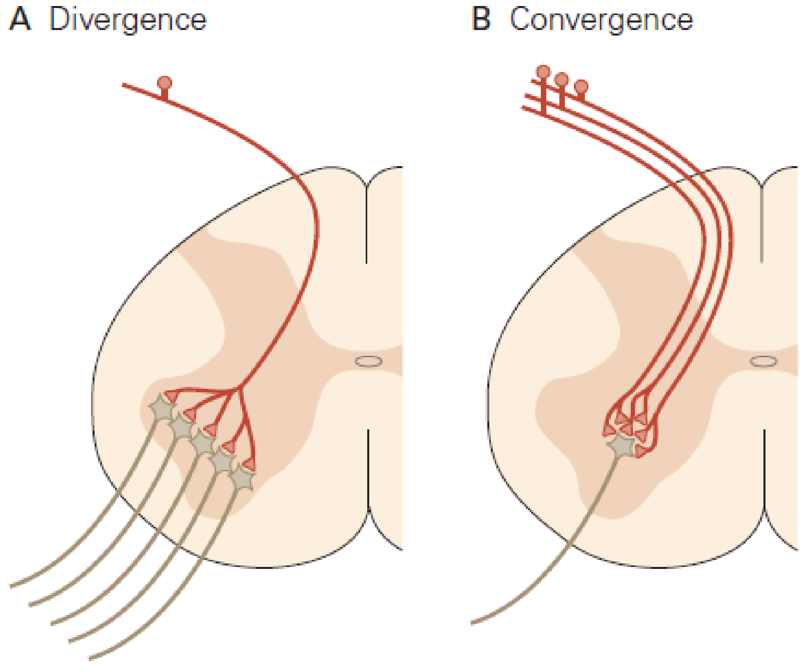


Divergence:

- Structurally: **One** neuron activates **many** target cells
- observed at the input stages of the nervous system
- Functional implication:______________

Convergence:

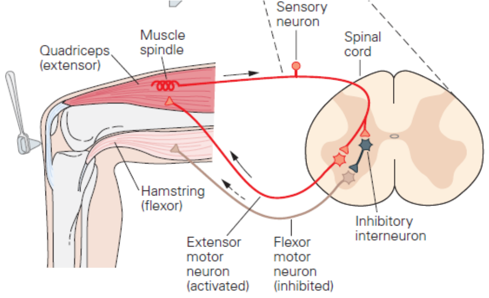
- Structurally: **Many** neurons activate a **single** target cells
- observed at the output stages of the nervous system
- Functional implication: _______________



One neuron activates **many** target cells

Many neurons activate a **single** target cells

Divergence and convergence

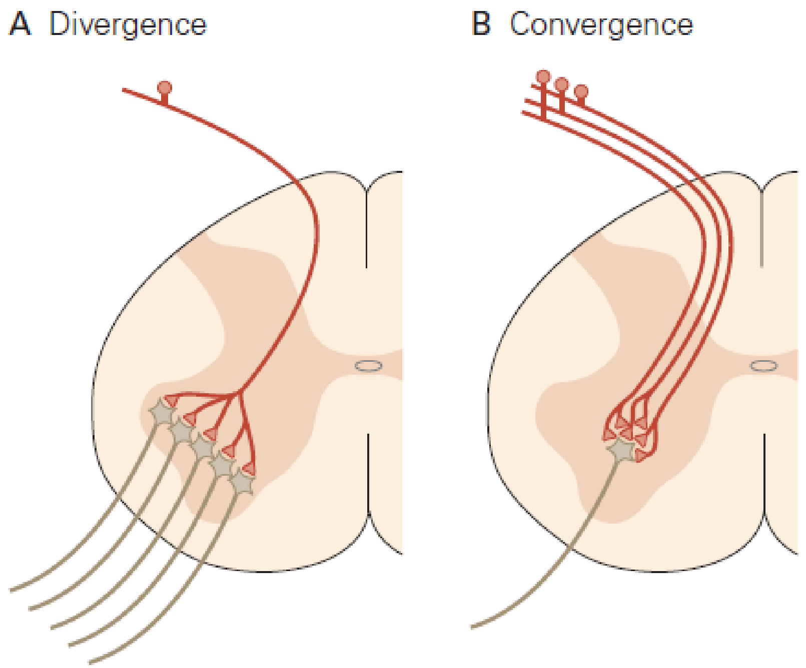


Divergence:

- Structurally: **One** neuron activates **many** target cells
- observed at the input stages of the nervous system
- Functional implication: a single neuron can exert wide and diverse influence.

Convergence:

- Structurally: **Many** neurons activate a **single** target cells
- observed at the output stages of the nervous system
- Functional implication: ensures that a motor neuron is activated only if a sufficient number of sensory neurons become activated together.



One neuron activates **many** target cells

Many neurons activate a **single** target cells

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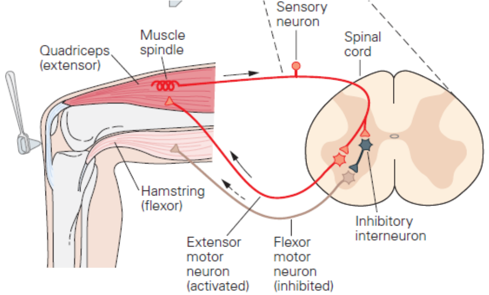
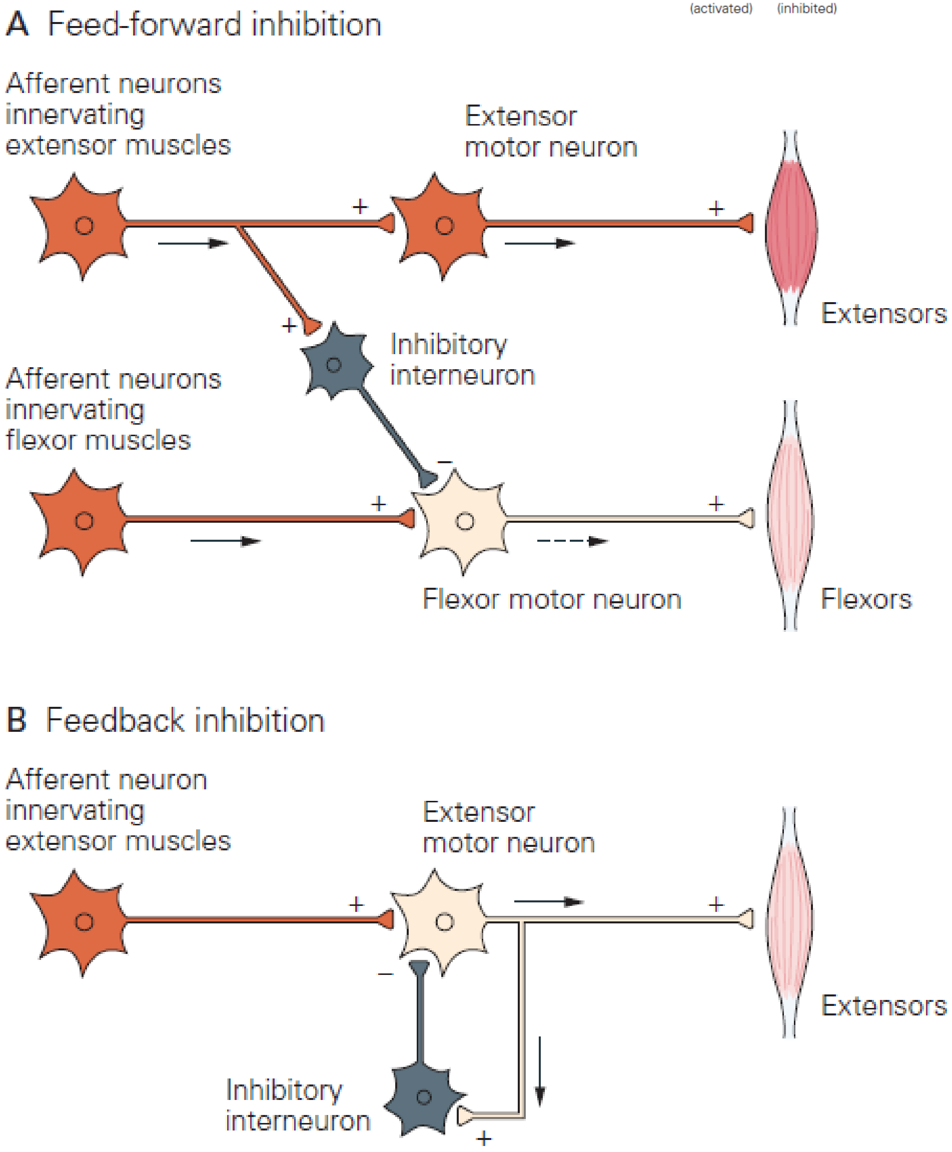
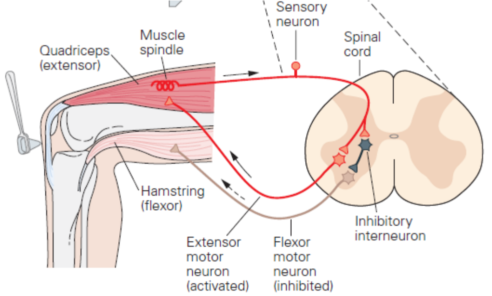
Neurons are both excitatory and inhibitory

- Excitatory neurons produce signals that increase the likelihood of firing of the postsynaptic neurons.
- Not all important signals in the brain are excitatory.
- Many neurons produce inhibitory signals that reduce the likelihood of firing.



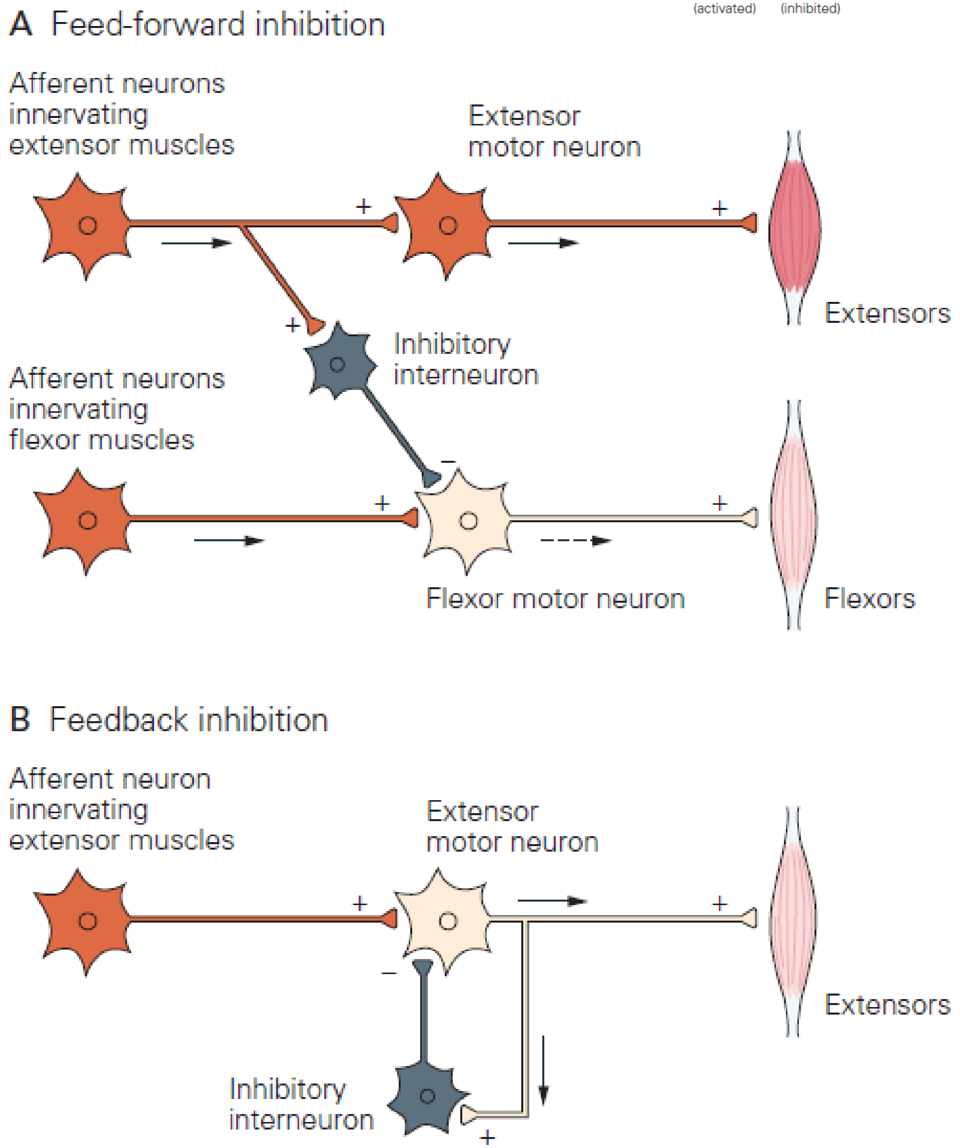


Feed-forward and feed-back inhibition



Feed-forward inhibition

- excitatory neurons synapse onto inhibitory interneurons, inhibiting other downstream neurons
- Functional utility: ______________

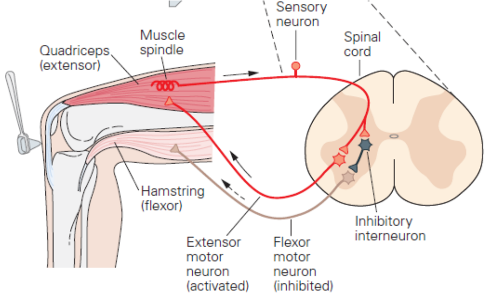


Feed-back inhibition

- excitatory neurons synapse onto inhibitory interneurons, which **project back to the same neurons** and inhibit them

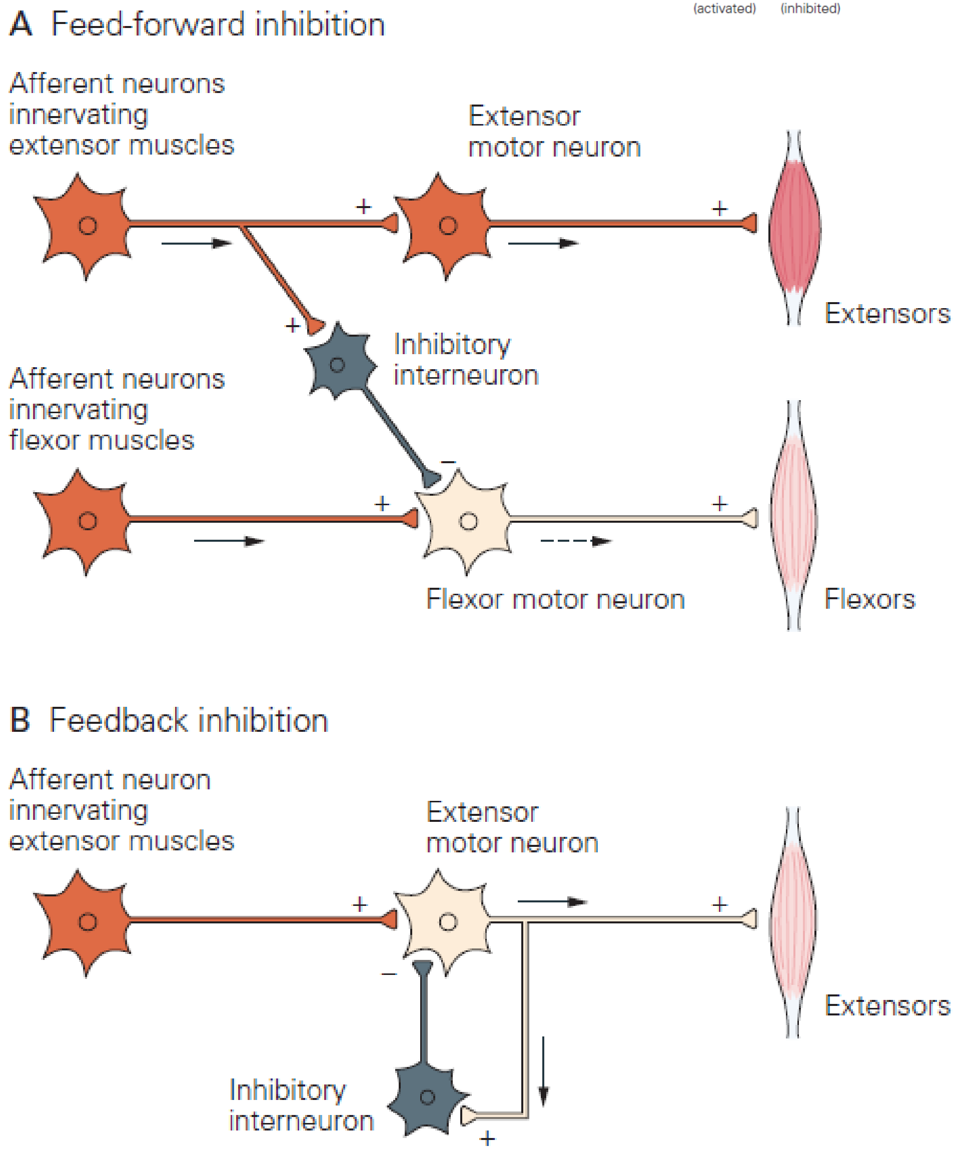
Functional utility: __________________

Feed-forward and feed-back inhibition



Feed-forward inhibition

- excitatory neurons synapse onto inhibitory interneurons, inhibiting other downstream neurons
- Functional utility: enhances the effect of the active pathway by suppressing the activity of pathways mediating opposing actions.



Feed-back inhibition

- excitatory neurons synapse onto inhibitory interneurons, which **project back to the same neurons** and inhibit them
- Functional utility: dampens activity within the stimulated pathway and prevent it from exceeding a certain critical level.

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Questions 5-6

Combination of neural circuits create a neural system

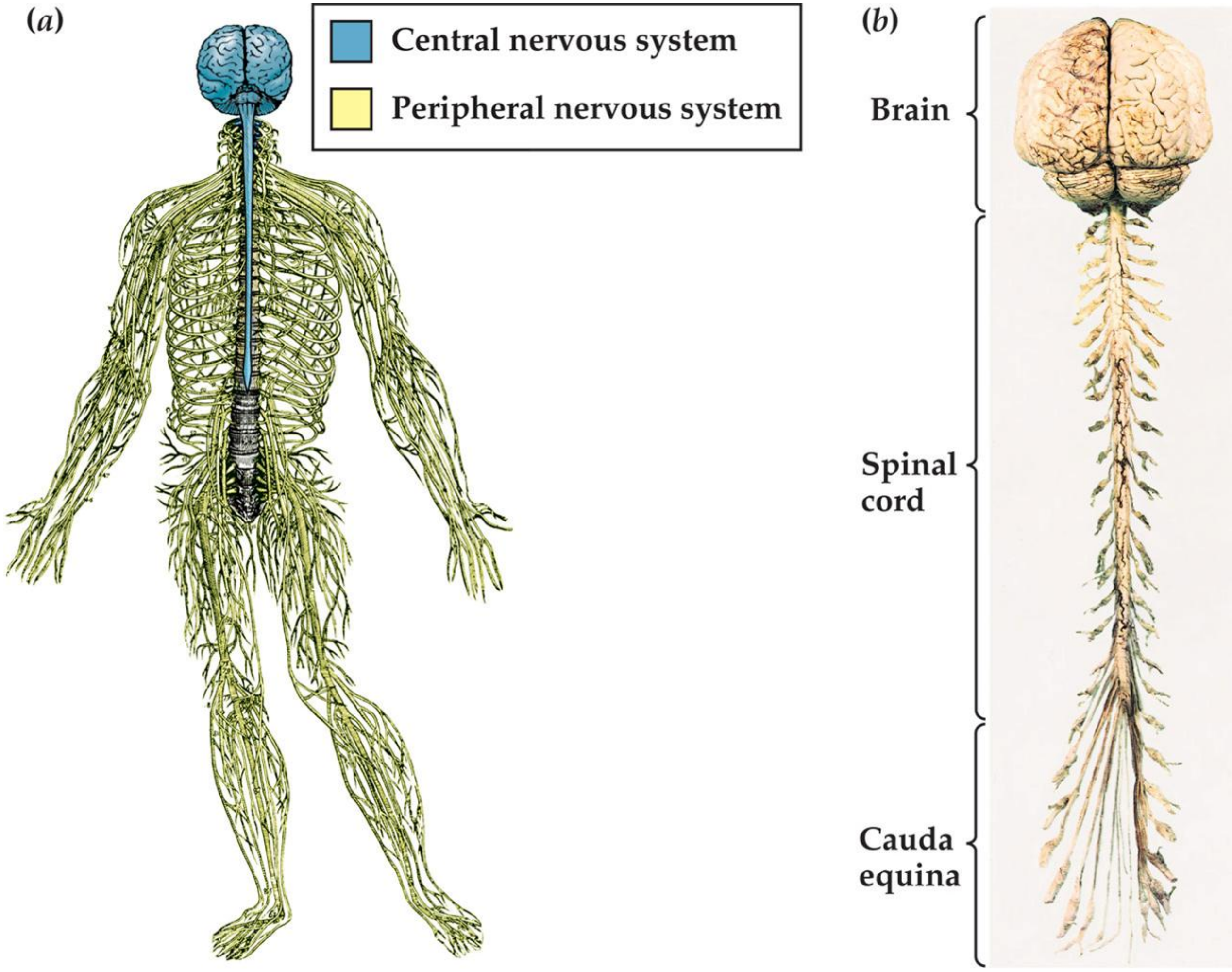
The bigger picture: neural systems

Peripheral nervous system (PNS):

- Nerves: bundles of axons and glia
- Ganglia: clumps of nerve cell bodies

outside of the CNS

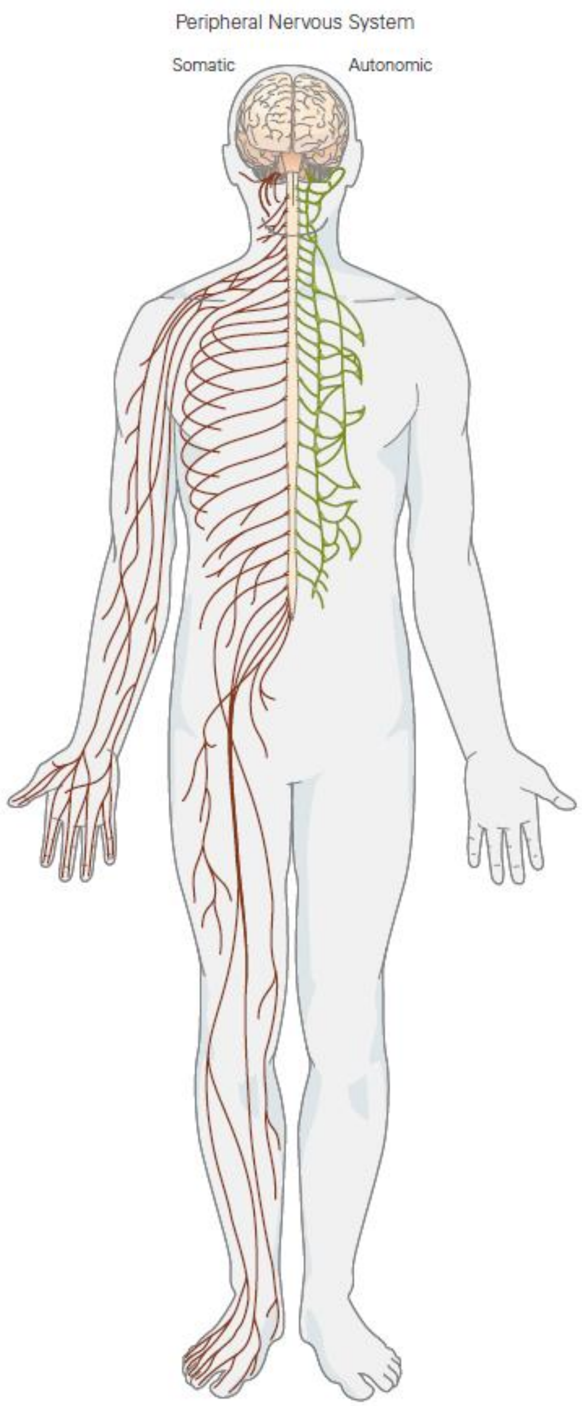
- delivers sensory information to the CNS
- carries the motor commands from the CNS to the muscles
- supplies the CNS with a continuous stream of information about both the external environment and the internal environment of the body
- has somatic and autonomic divisions



THE MIND'S MACHINE, Figure 2.6

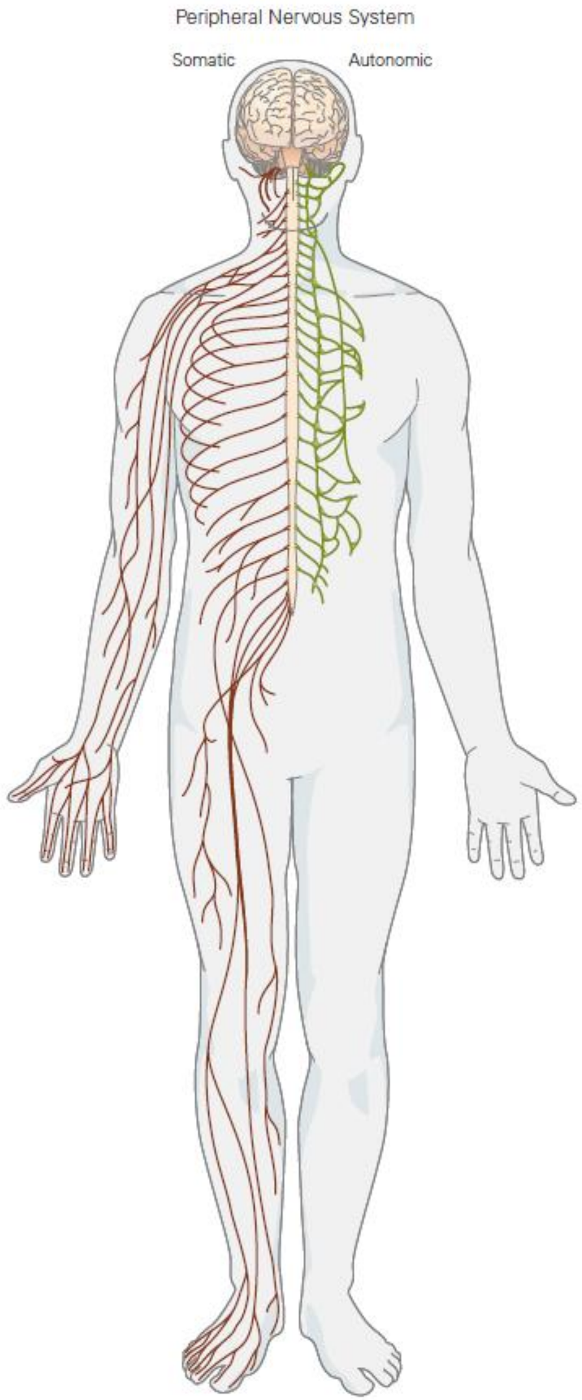
PNS: the somatic nervous system

- sensory neurons that receive information from the skin, muscles, and joints.
- Receptors associated with these cells provide information about **muscle and limb position and about touch and pressure** at the body surface.
- Receptors transduce different types of physical energy (such as deep pressure or heat) into the electrical signals used by the nervous system.



PNS: the autonomic nervous system

- mediates visceral sensation as well as motor control of the viscera, vascular system, and exocrine glands.
- sympathetic system: participates in the body's response to stress
- Parasympathetic system: acts to conserve body resources and restore homeostasis
- Enteric system: controls the function of smooth muscle of the gut



The sympathetic and parasympathetic systems

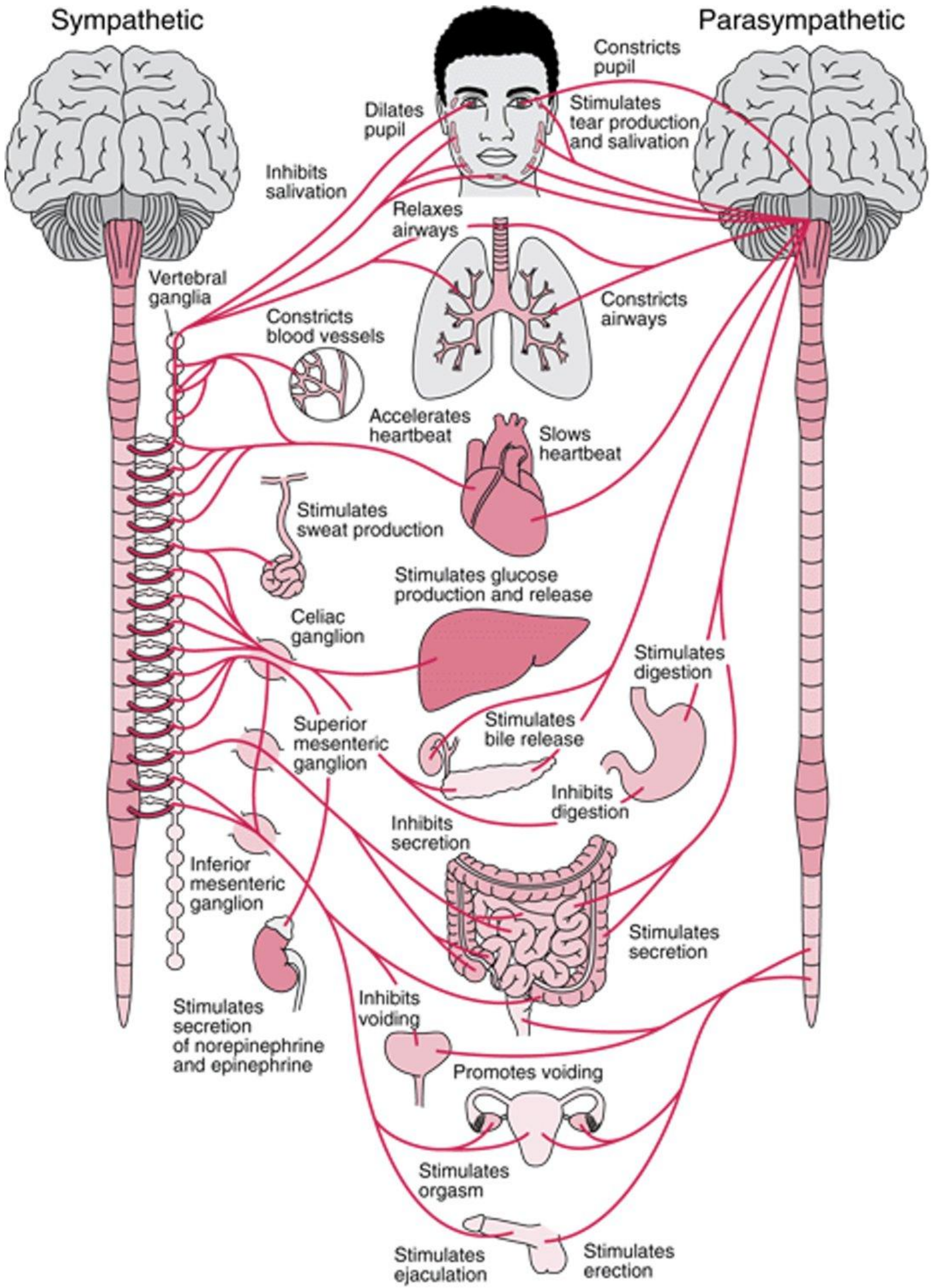
They operate antagonistically:

- sympathetic system uses norepinephrine
- parasympathetic system uses acetylcholine

Example:

Sympathetic system

- prepares the body
  for action (fight or flight) by stimulating the adrenal glands to release adrenaline
- increases heart rate
- diverts blood from the digestive tract to the somatic musculature



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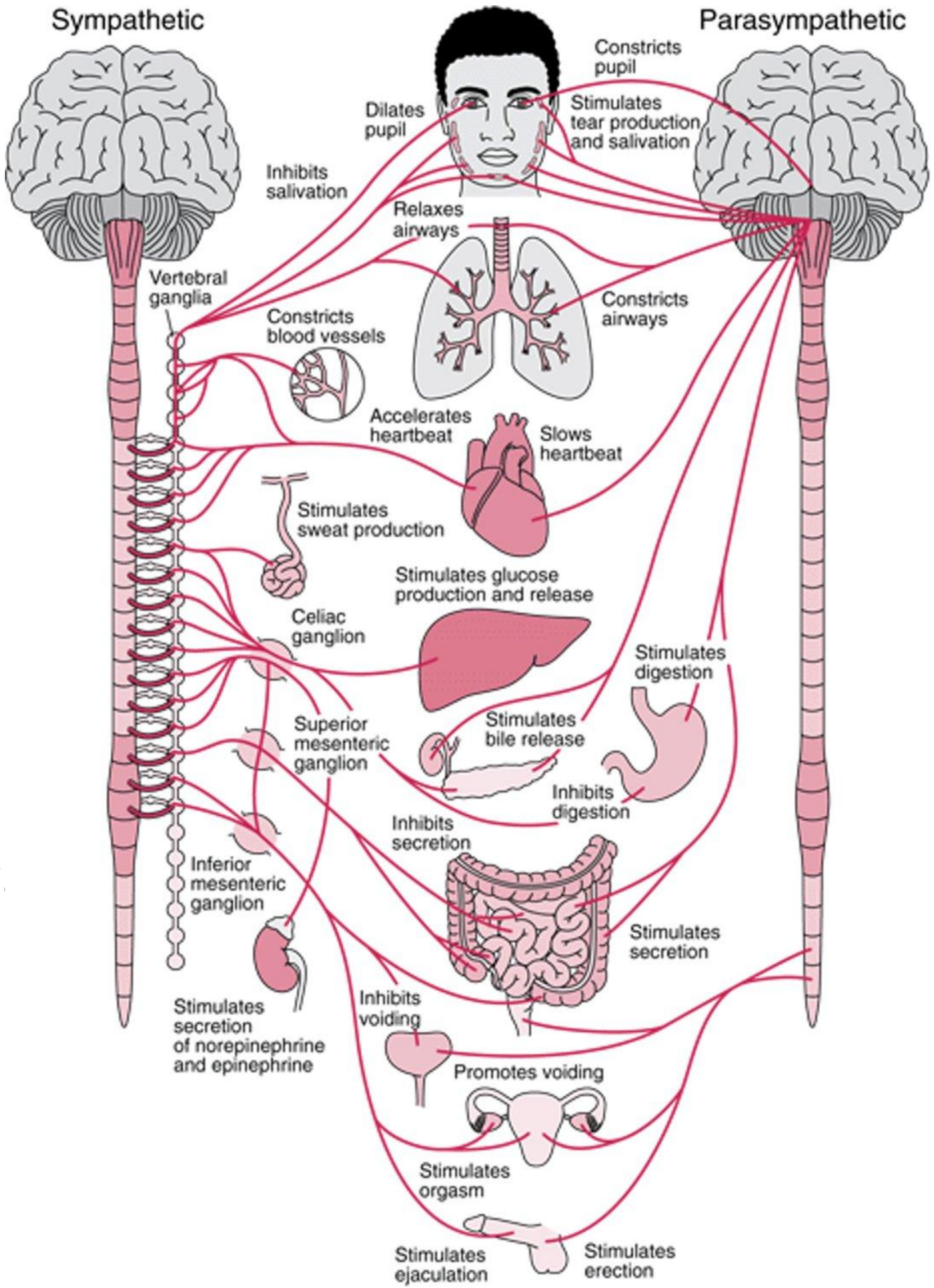
Example:

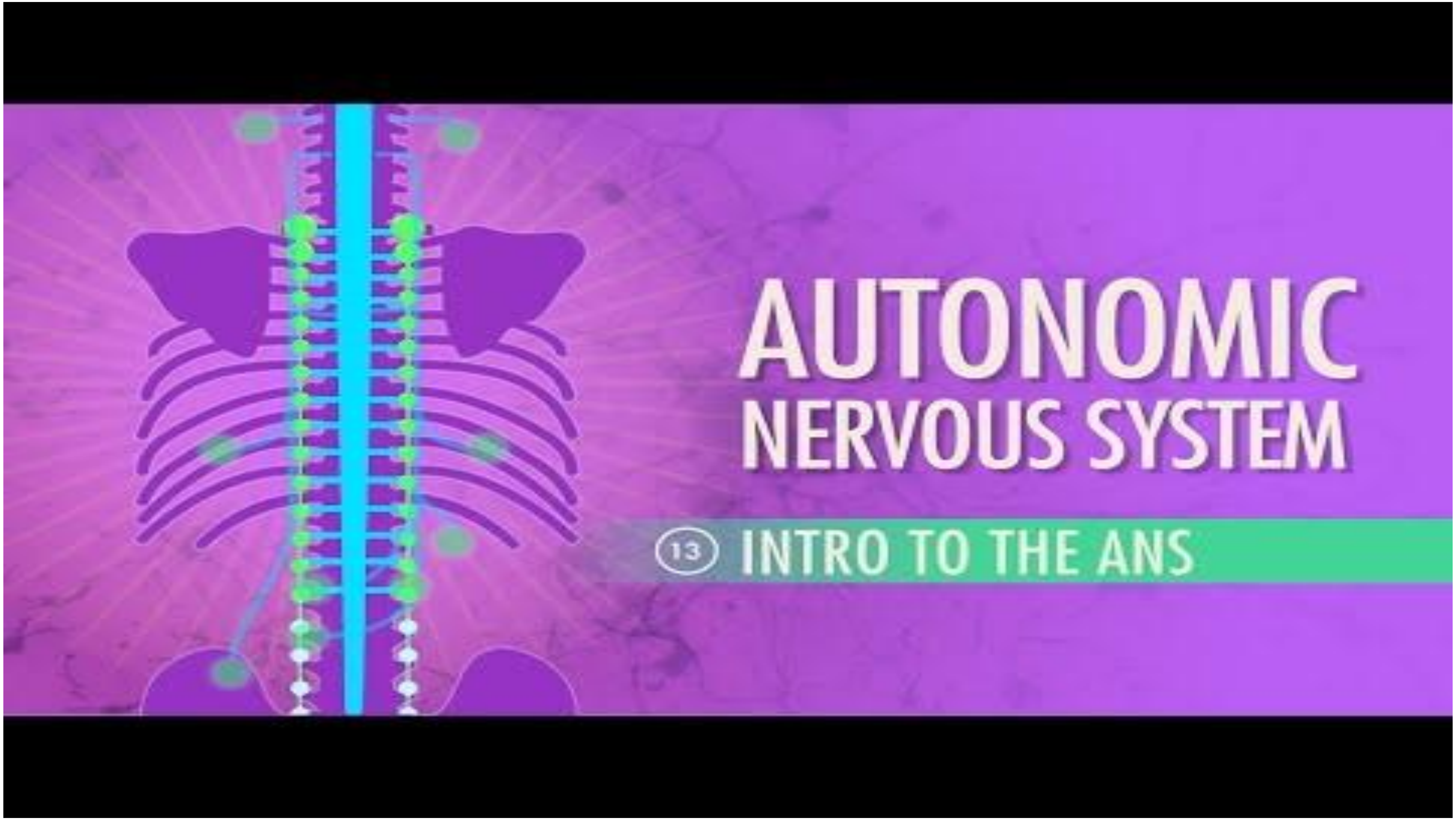
Sympathetic system

- prepares the body
  for action (fight or flight) by stimulating the adrenal glands to release adrenaline
- increases heart rate
- diverts blood from the digestive tract to the somati musculature

The parasympathetic system

- helps the body with functions
  germane to maintaining the body
- Slows heart rate
- stimulates digestion





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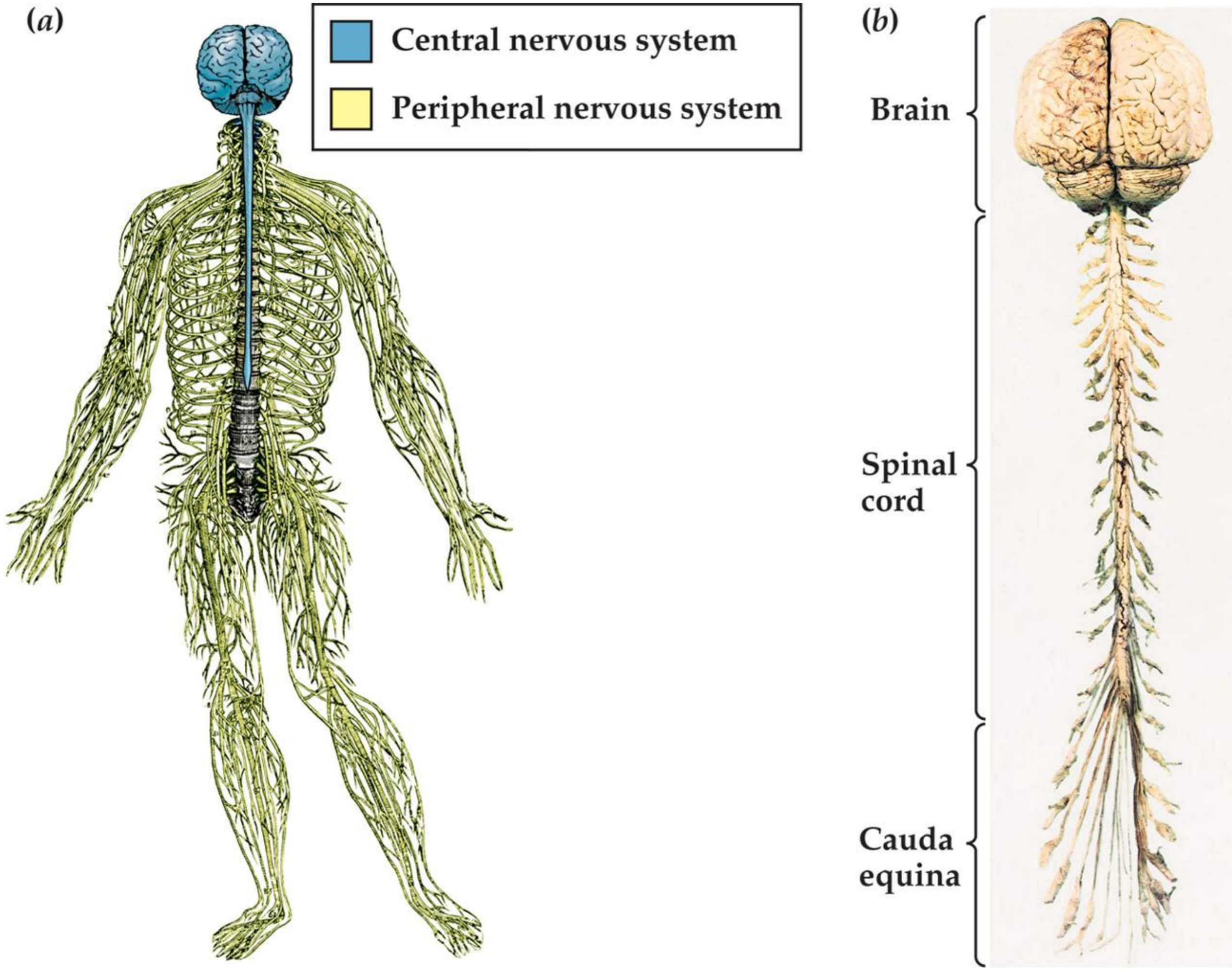
Questions 7-9

The bigger picture: neural systems

Central nervous system (CNS):

- brain
- spinal cord



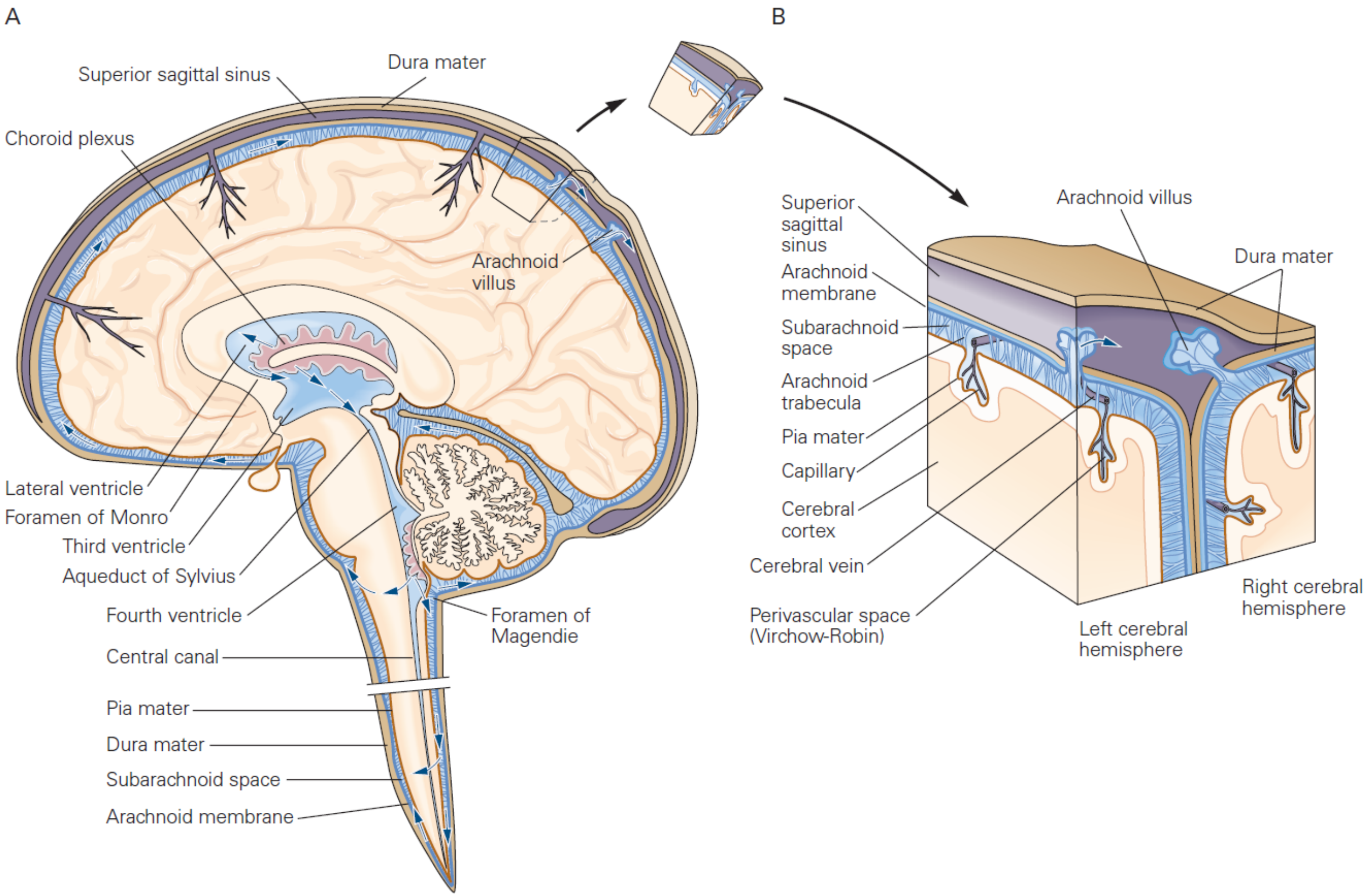
THE MIND'S MACHINE, Figure 2.6

CNS is protected by the meninges and floats in the CSF

- Meninges and cerebrospinal fluid **protect the CNS against physical damage**

Meninges

- 3 protective membranes
- Dura mater: thickest & most outer
- Arachnoid mater: middle layer
- Pia mater: inner & most delicate
    - Firmly adheres to the brain surface



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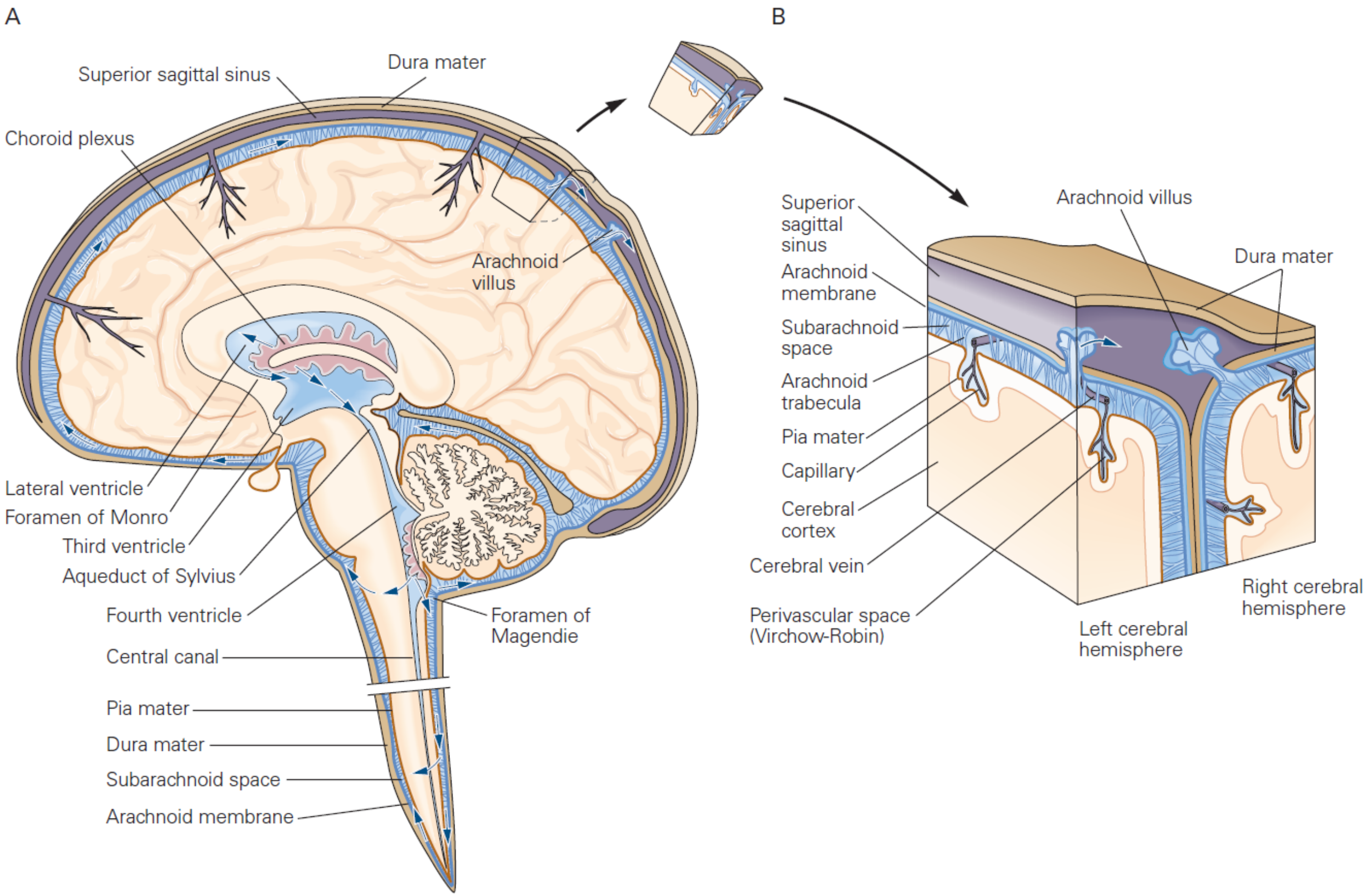
CNS is protected by the meninges and floats in the CSF

- Meninges and cerebrospinal fluid protect the CNS against physical damage

Cerebrospinal Fluid occupies:

- the space between the arachnoid membrane and the pia mater
- the brain ventricles
- cisterns and sulci
- central canal of the spinal cord



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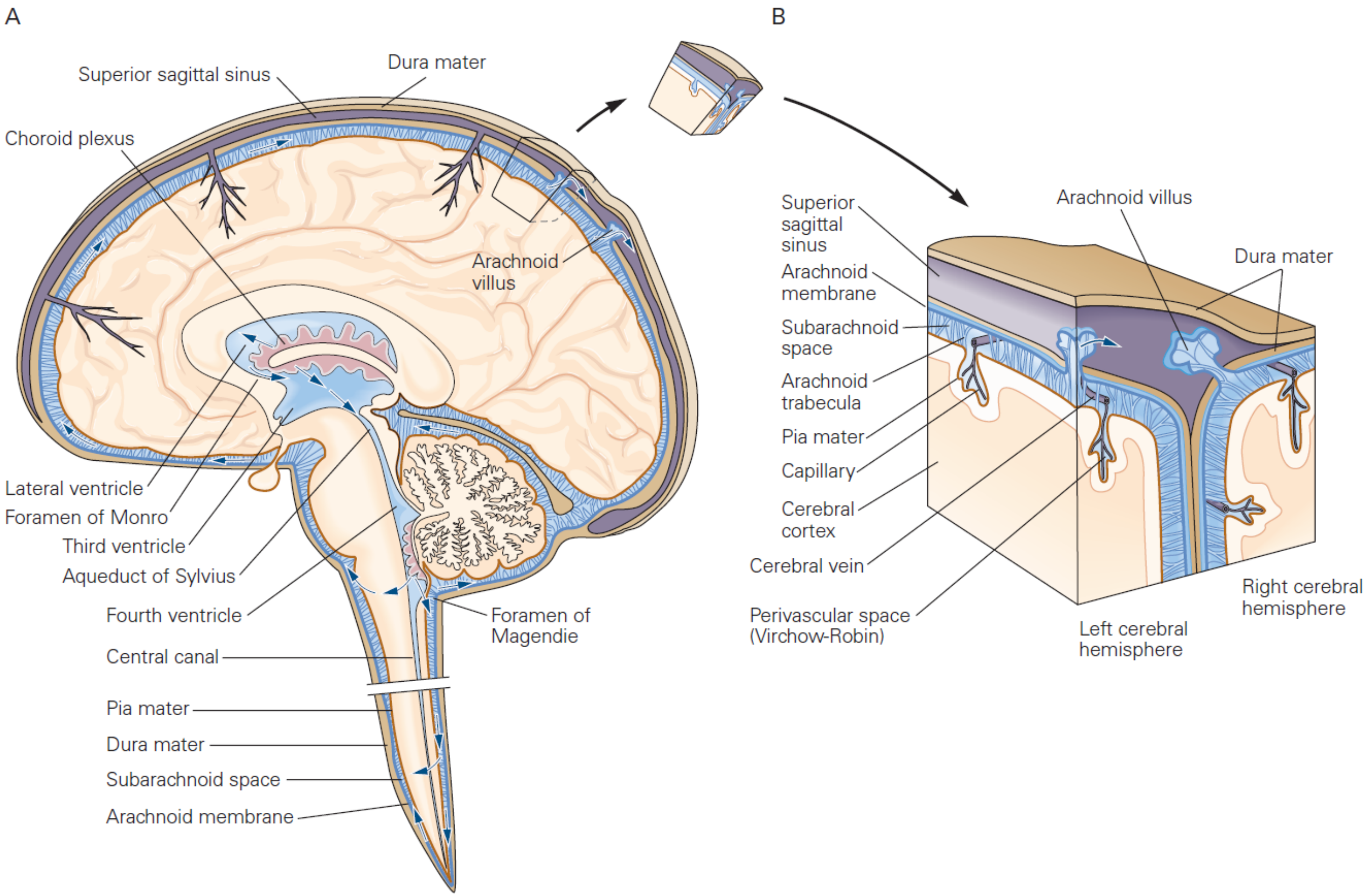
CNS is protected by the meninges and floats in the CSF

- Meninges and cerebrospinal fluid protect the CNS against physical damage

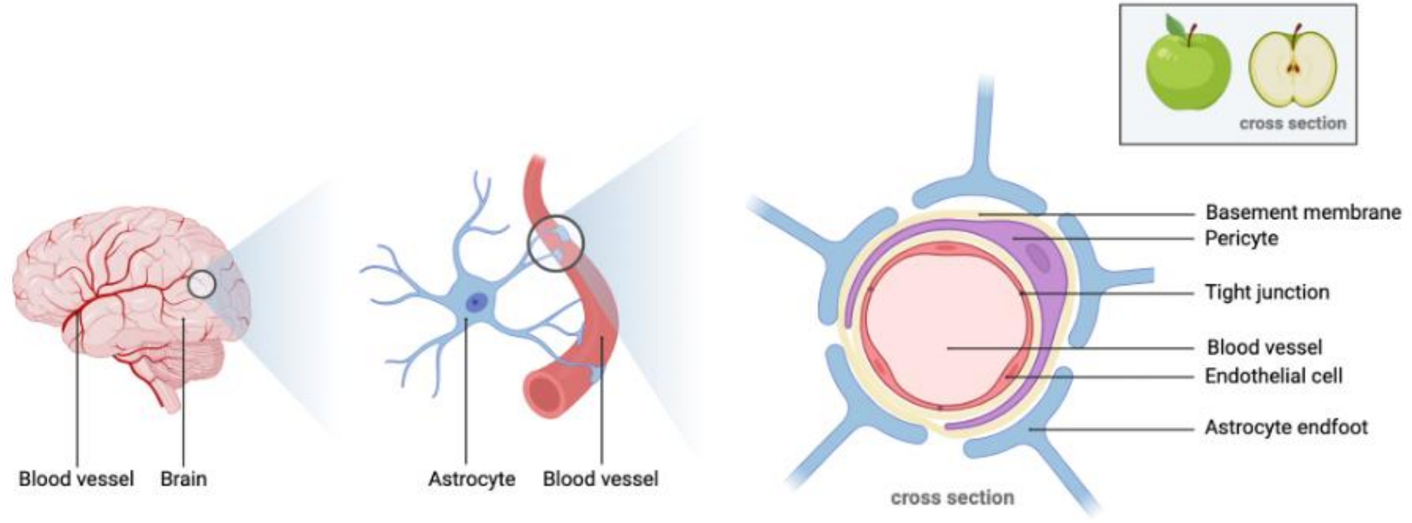
Cerebrospinal Fluid allows:

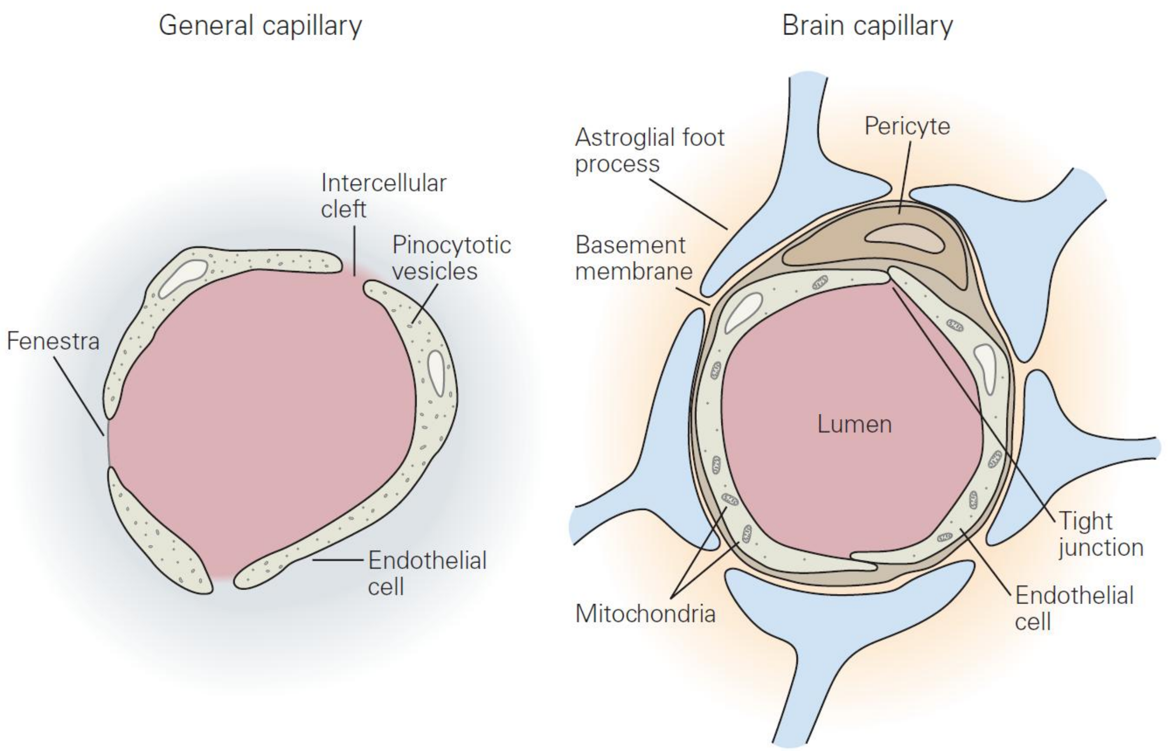
- the brain to float to help offset the pressure that would be present if the brain were merely sitting on the base of the skull
- reduces shock to the brain and spinal cord during rapid accelerations or decelerations, such as when we fall or are struck on the head



Blood-brain barrier

- Instead of being a single physical barrier, the blood-brain barrier is made up of a collection of cells with unique properties.
- Barrier between the brain's blood vessels (capillaries) and the cells and other components that make up brain tissue.
- **protect the CNS against disease-causing pathogens and toxins** that may be present in our blood.

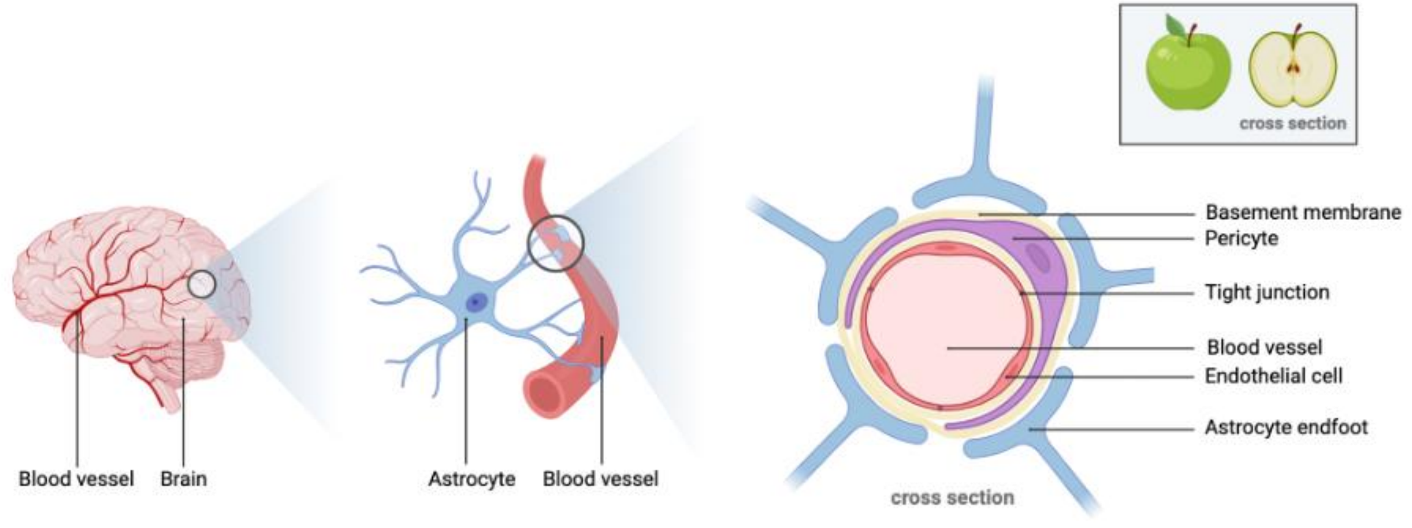


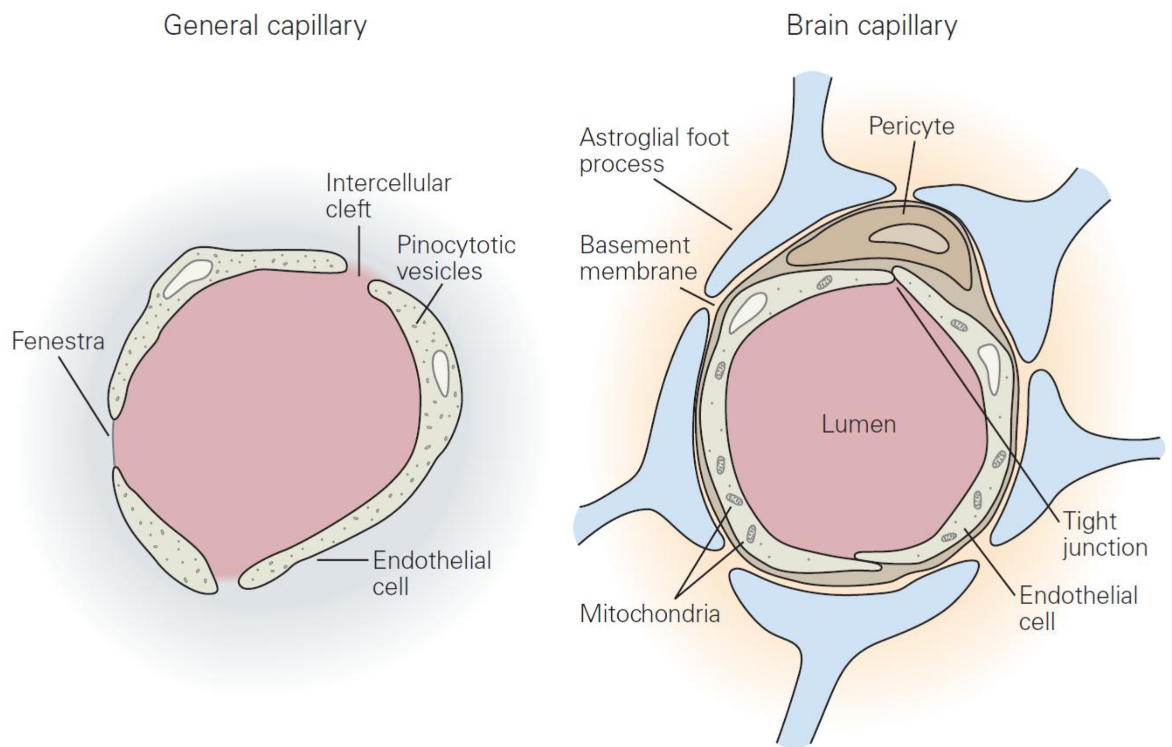


Blood-brain barrier

When do we need to get through it?

- Very effective at preventing unwanted substances from accessing the brain, which has a downside. The vast majority of potential drug treatments do not readily cross the barrier, posing a huge impediment to treating mental and neurological disorders.

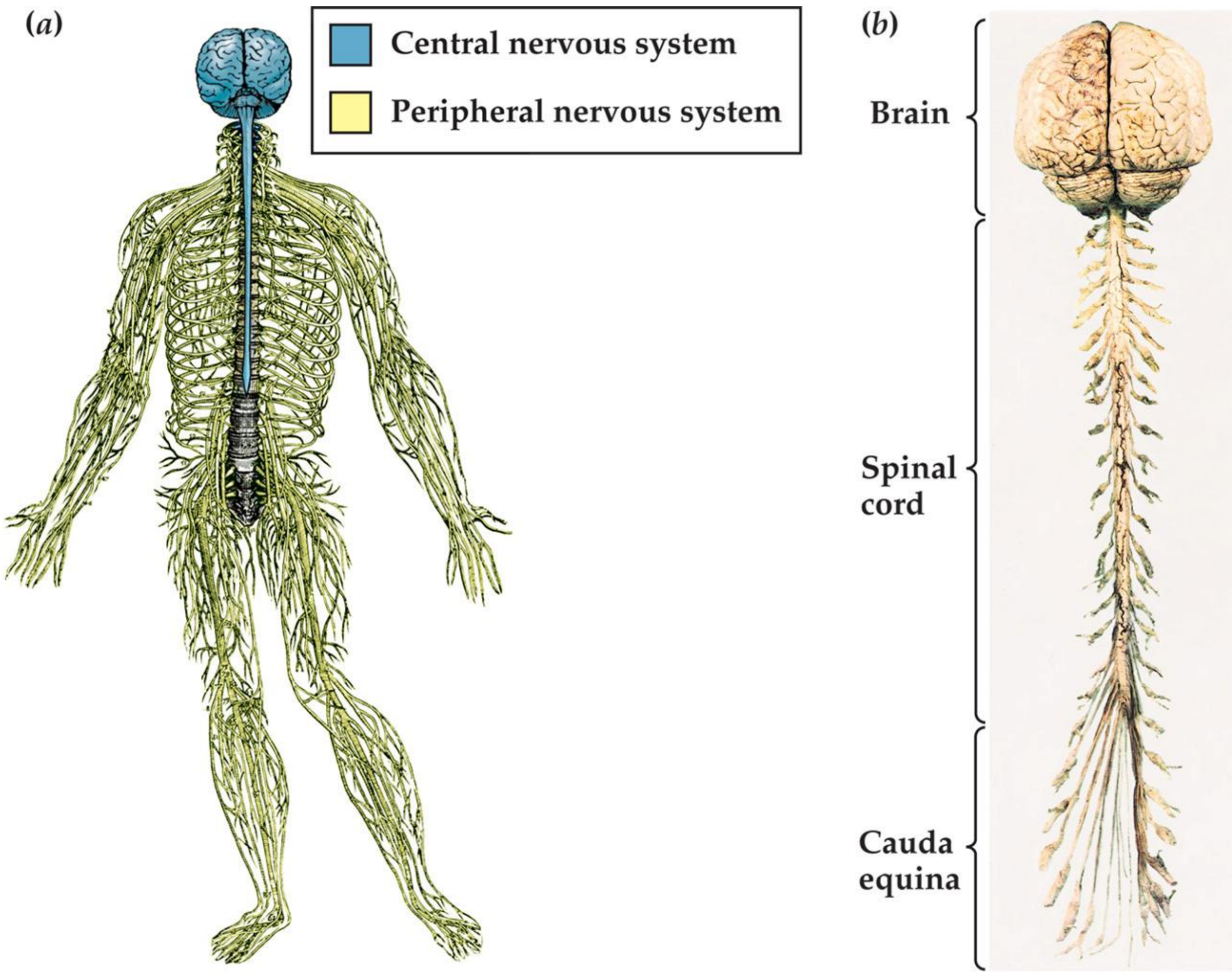




CNS: the spinal cord

- takes in sensory information from the body's peripheral sensory receptors
- relays it to the brain
- conducts the final motor signals from the brain to muscles

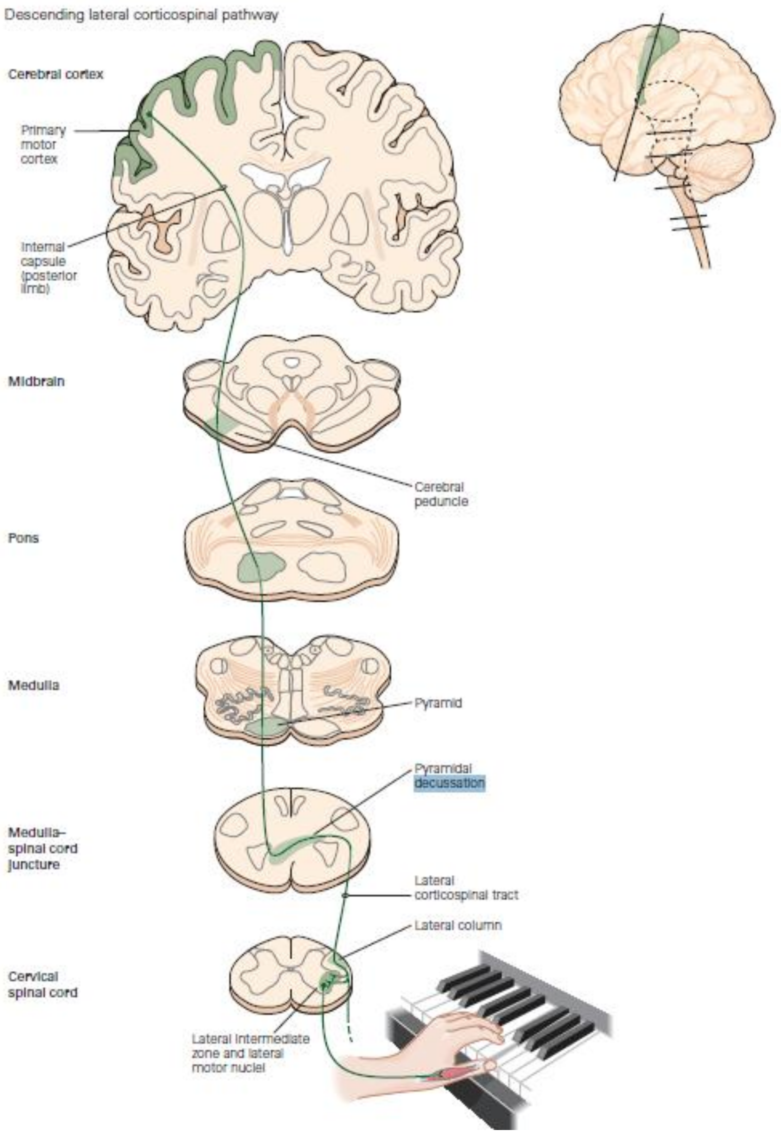
- enclosed in the **vertebral column**
    - a stack of separate bones, the vertebrae
    - extend from the base of the skull to the fused vertebrae at the coccyx (tailbone)

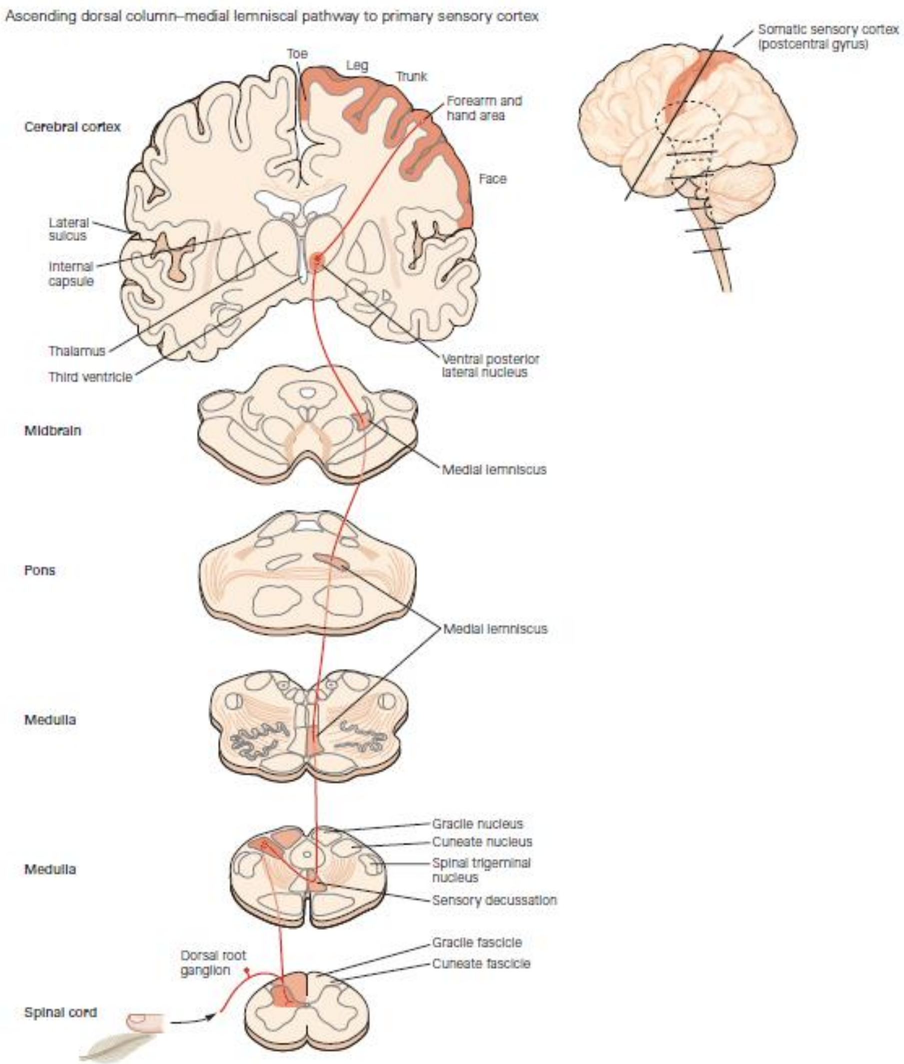


THE MIND'S MACHINE, Figure 2.6

Functional systems on one side of the brain control the other side of the body

- Most pathways in the central nervous system are **bilaterally symmetrical** and **cross over** to the opposite (contralateral) side of the brain or spinal cord
- Sensory and motor activities on one side of the body are mediated by the cerebral hemisphere on the opposite side
- The **pathways of different systems cross at different anatomical levels within the central nervous system**





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The brain

https://www.brainfacts.org/3d-brain#intro=false&focus=Brain

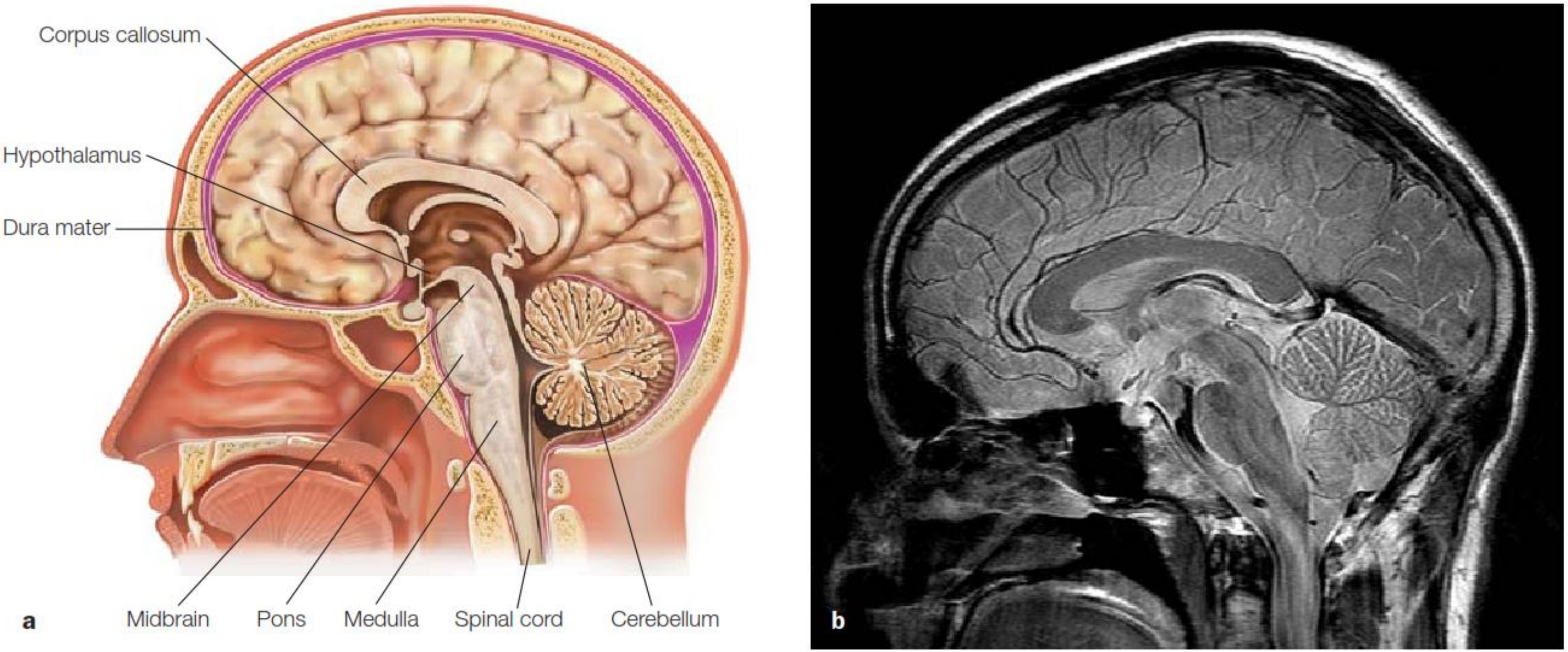


FIGURE 2.20 Gross anatomy of a brain showing brain stem.
(a) Midsagittal section through the head, showing the brainstem, cerebellum, and spinal cord. **(b)** High-resolution structural MRI obtained with a 4-tesla scanner, showing the same plane of section as in (a).

The brain

Composed of 6 subdivisions

1. Medulla
2. Pons
3. Midbrain

} Brain stem

4. Cerebellum
5. Diencephalon: thalamus & hypothalamus
6. Telencephalon: cerebral hemispheres

- It is mostly symmetrical along the midline:
    - each subdivision is found in both hemispheres of the brain with slight bilateral differences

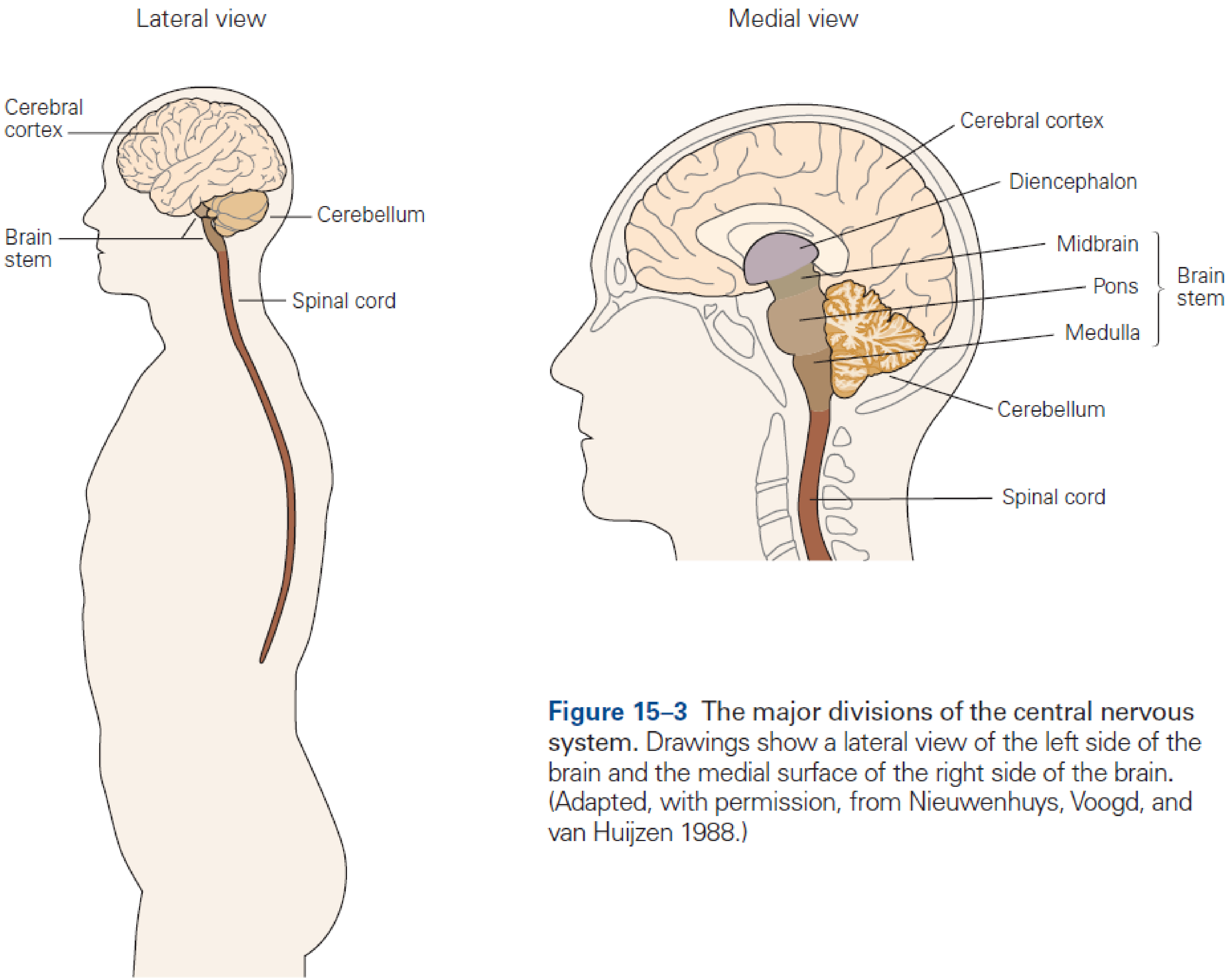


Figure 15–3 The major divisions of the central nervous system. Drawings show a lateral view of the left side of the brain and the medial surface of the right side of the brain. (Adapted, with permission, from Nieuwenhuys, Voogd, and van Huijzen 1988.)

The brain stem

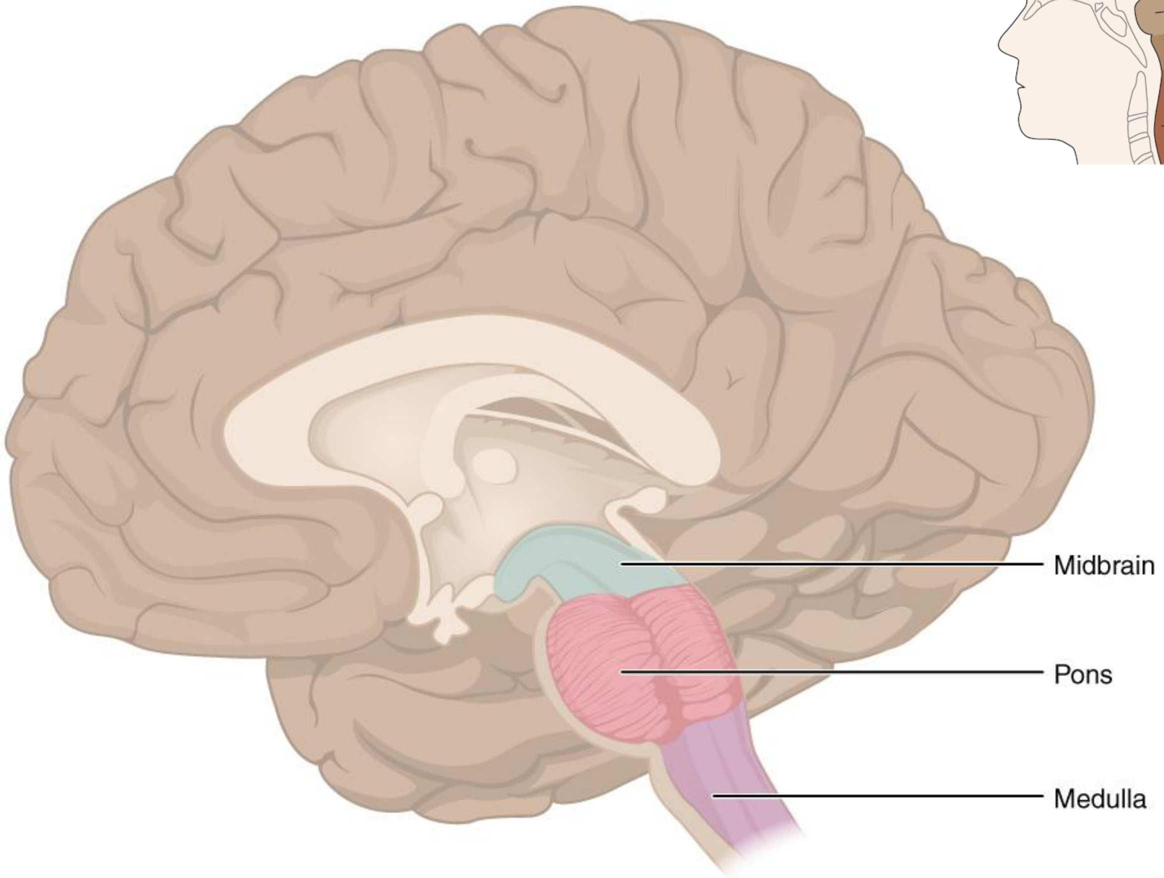
Includes

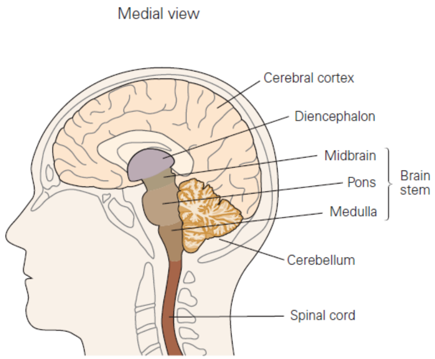
1. Medulla
2. Pons
3. Midbrain

Regulates basic life functions:

- blood pressure
- Respiration
- Sleep/wakefulness

Damage to the brainstem is life threatening





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The cerebellum

- Important for:
  - maintaining posture
  - coordinating head, eye, and arm movements
  - regulation of motor output
  - learning motor skills

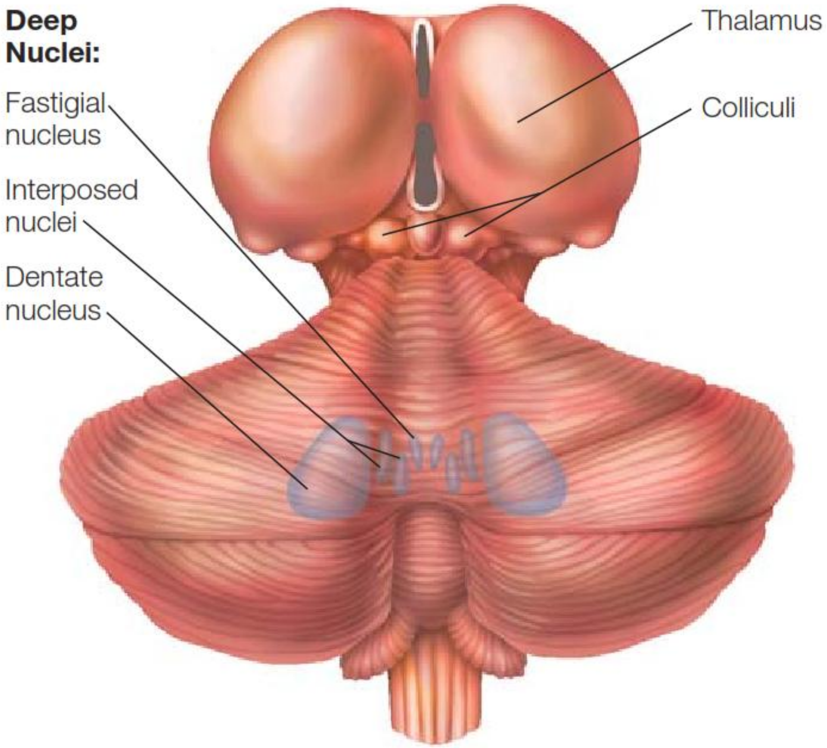
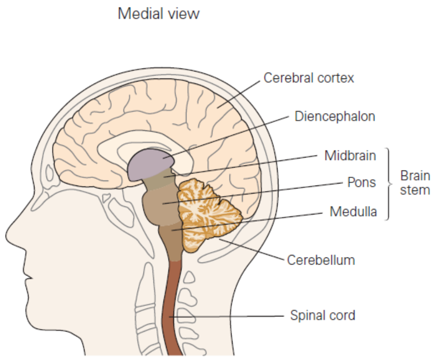


FIGURE 2.22 Gross anatomy of the cerebellum.



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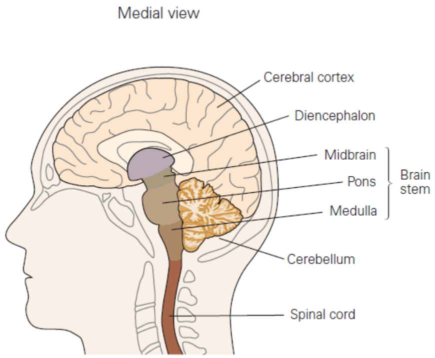
The diencephalon: thalamus & hypothalamus

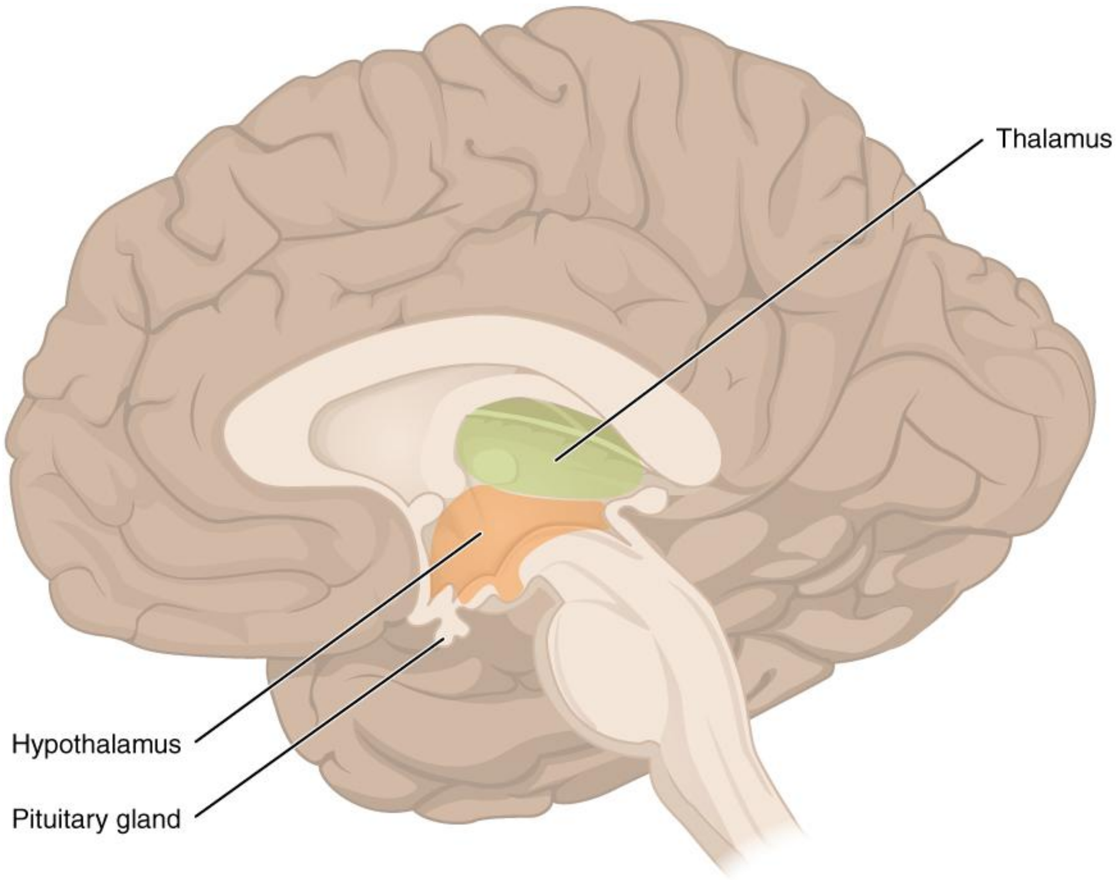
Thalamus:

- “gateway to the cortex”
- essential link in the pathway of sensory information from the periphery to sensory regions of the cerebral hemispheres
- All sensory information, except for the sense of smell, passes through the thalamus before processing by the cortex

Hypothalamus:

- Regulates homeostasis
- Regulates response of the autonomic nervous system and the endocrine system through its regulation of the pituitary gland.
- essential component of the **motivational systems** of the brain, initiating and maintaining behaviors the organism finds aversive or rewarding





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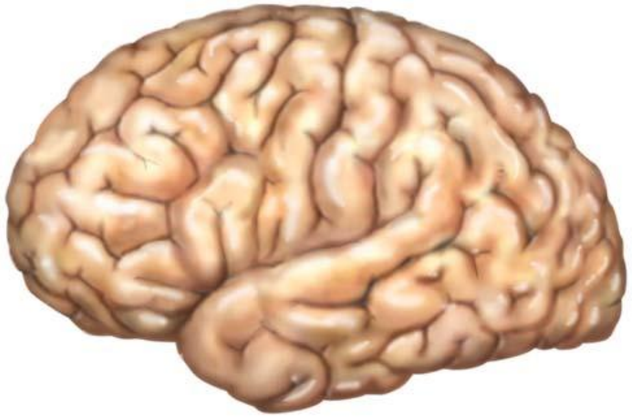
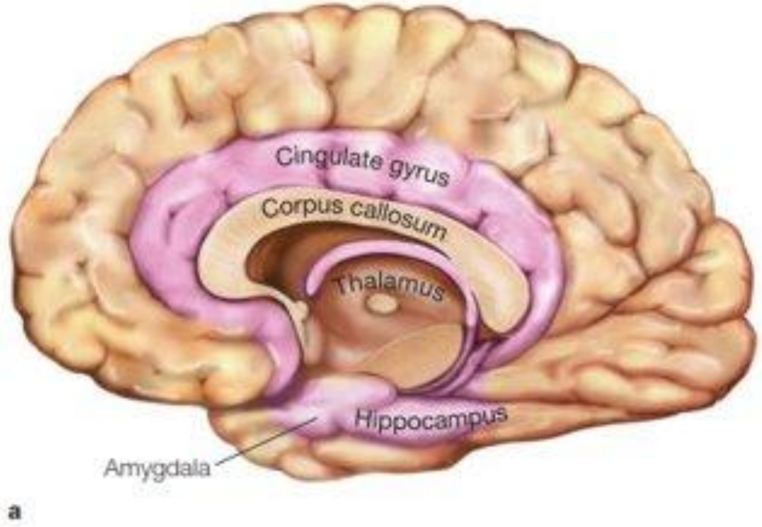
The telencephalon or cerebral hemispheres

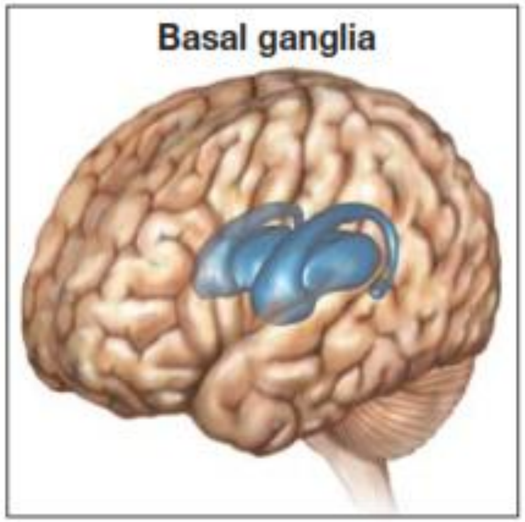
- The largest part of the human brain

Consists of:

- the cerebral cortex made of grey matter (i.e. neuronal cell bodies)
- the underlying white matter (i.e. axons and glial cells)
- three deep-lying structures that regulate cortical activity:
    - Basal ganglia
    - Amygdala
    - Hippocampus

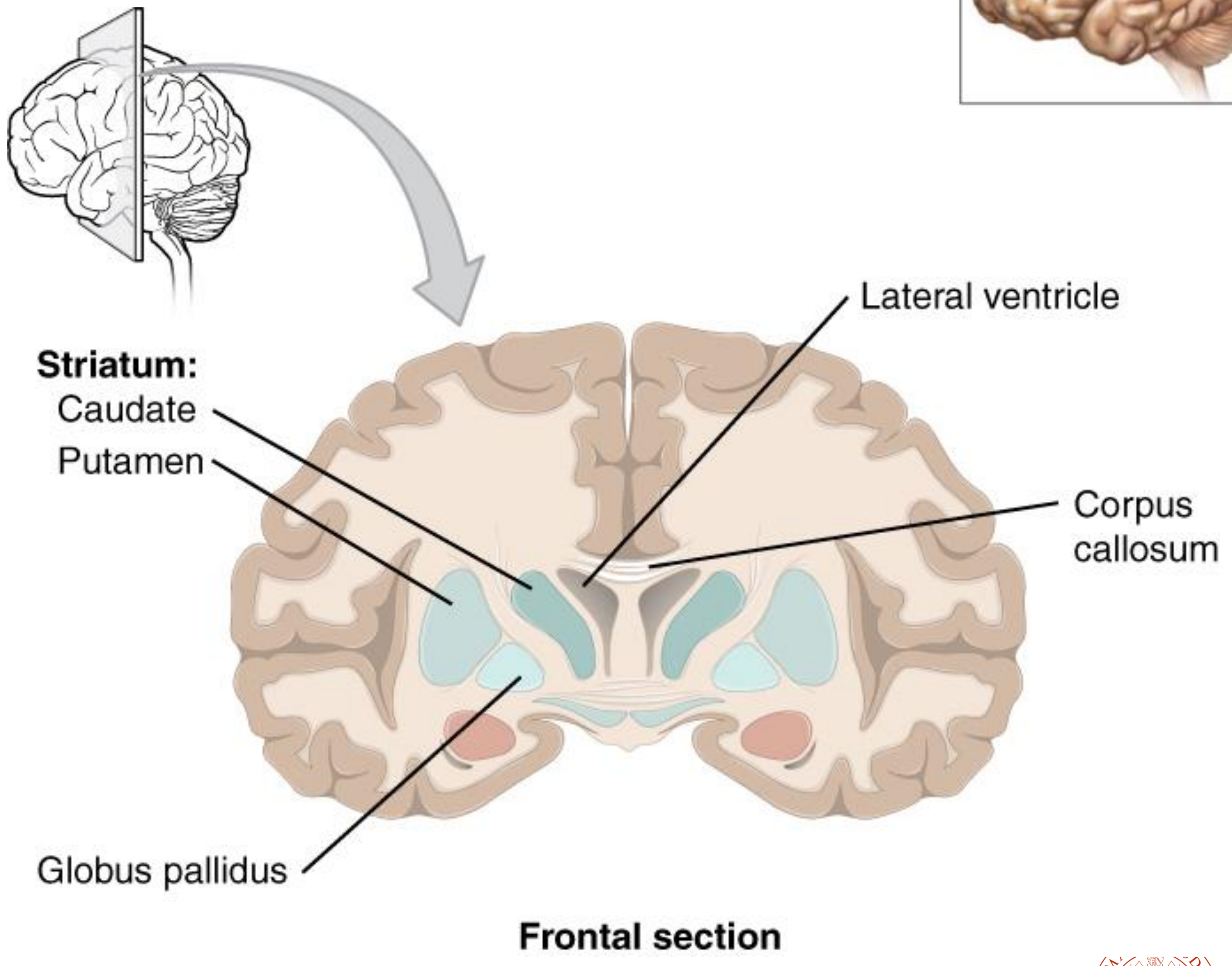


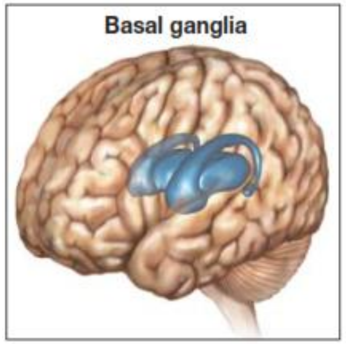




Basal Ganglia

- Collection of subcortical nuclei
- Receive inputs from sensory and motor areas
- Send output largely through the thalamus to the frontal lobe
- Extensively interconnected
- Have crucial role in
    - **motor control**
    - **reinforcement learning** and goal-oriented behavior





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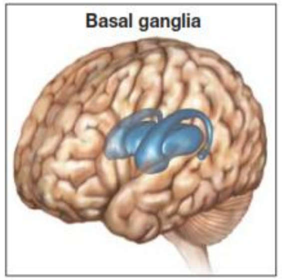
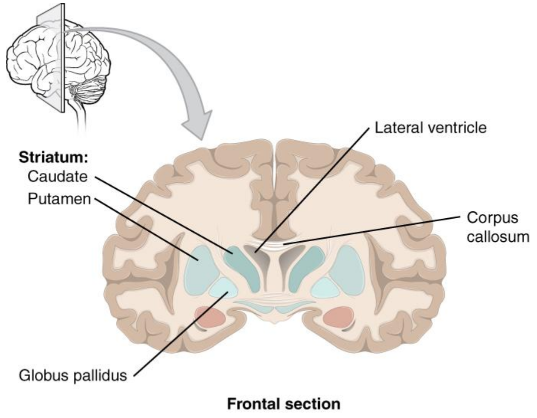
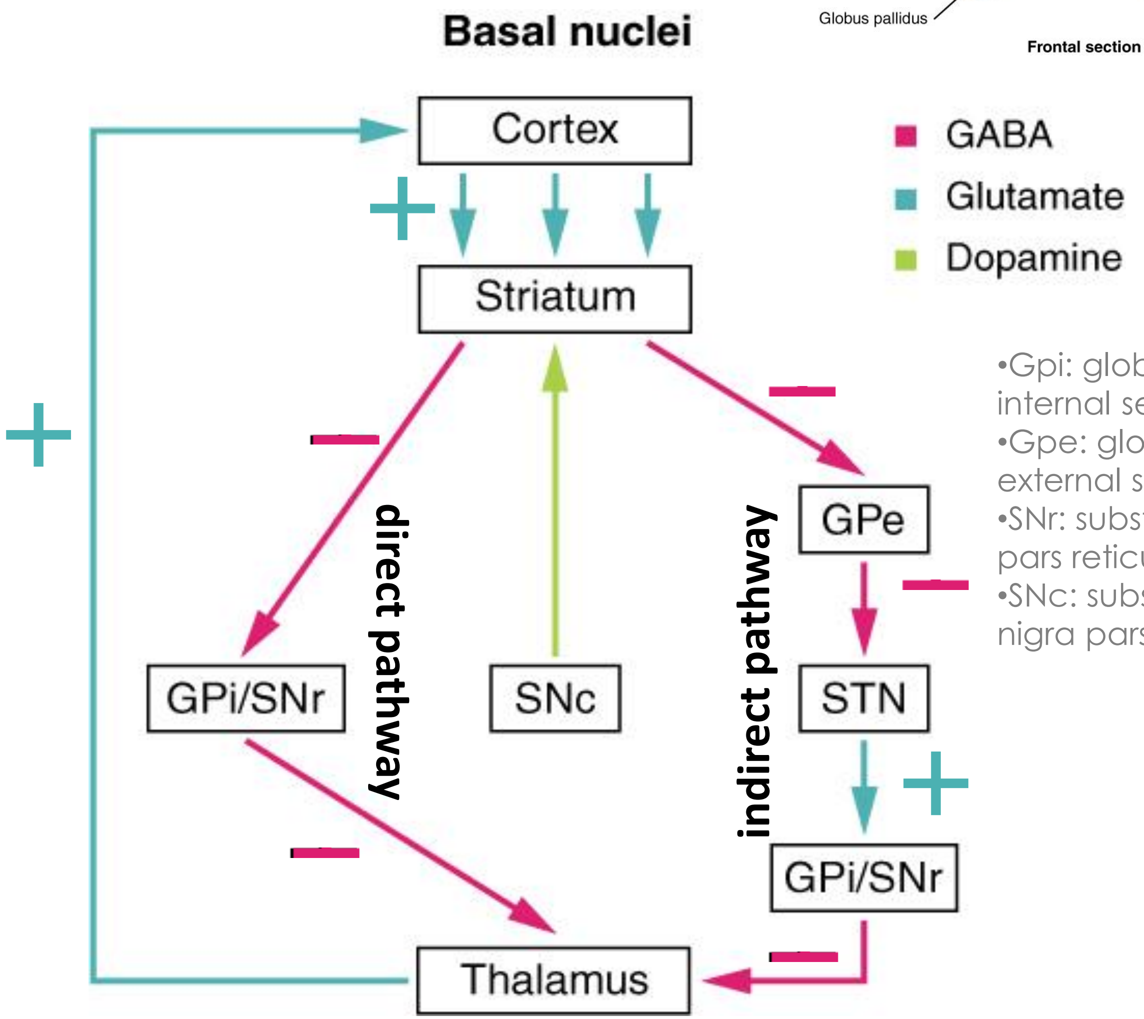
Basal Ganglia have crucial role in motor control & reinforcement learning

- the **direct pathway** causes the disinhibition of the thalamus → **initiates movement**

- the **indirect pathway** causes, or reinforces, the normal inhibition of the thalamus → **inhibits movement**







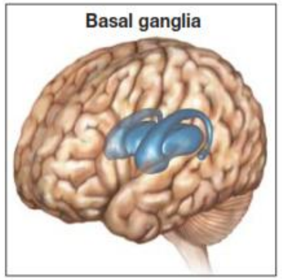
•Gpi: globus pallidus internal segment
•Gpe: globus pallidus external segment
•SNr: substantia nigra pars reticulata
•SNc: substantia nigra pars compacta

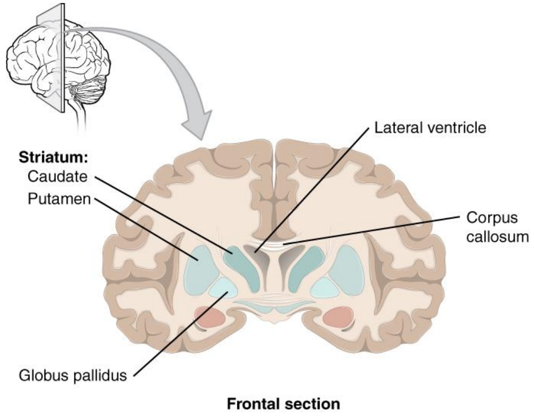
Basal Ganglia have crucial role in motor control & reinforcement learning

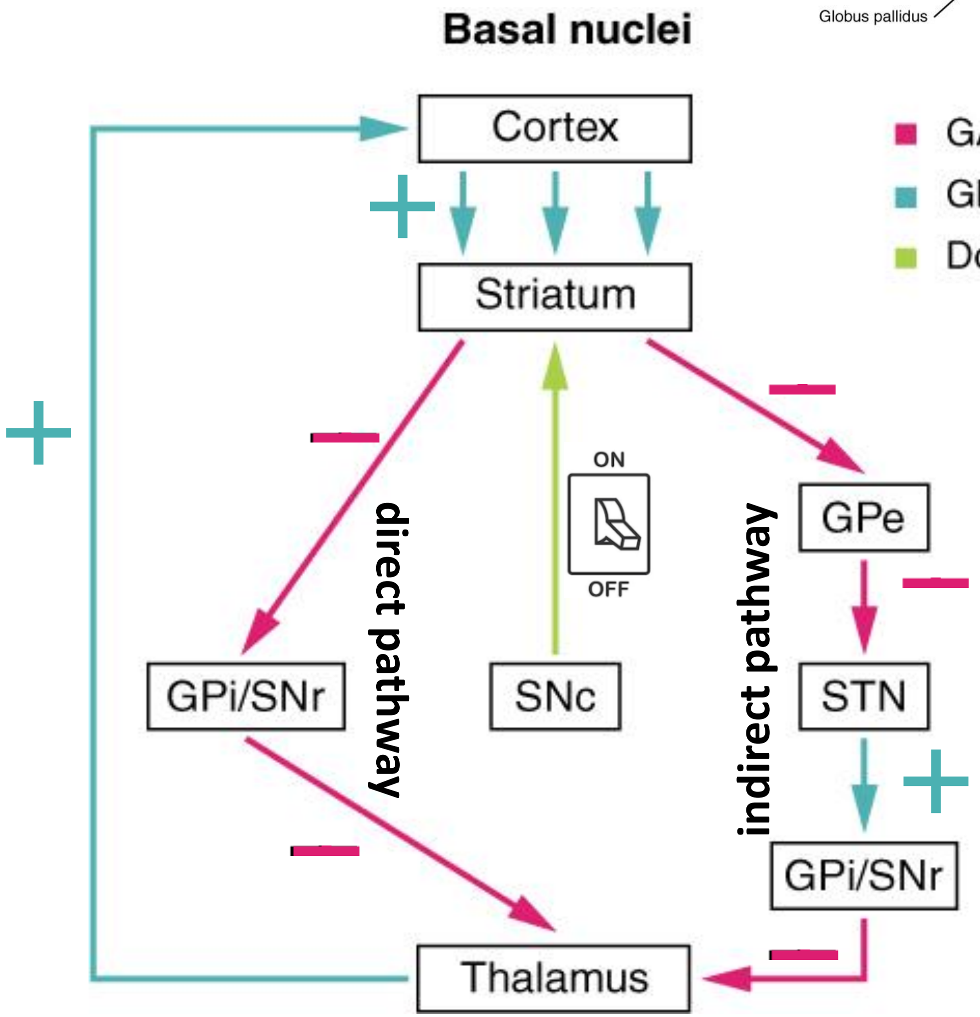
The **switch** between the two pathways is the **substantia nigra pars compacta**:

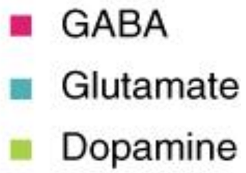
- which **projects to the striatum**
- and releases the neurotransmitter **dopamine**:

  - Activates the direct pathway
  - Inhibits the indirect pathway
  - **Dopamine release depends on the error between predicted future reward and actual reward**







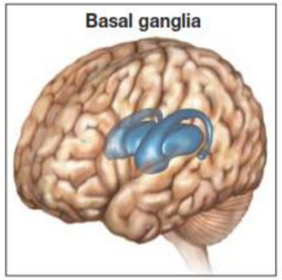


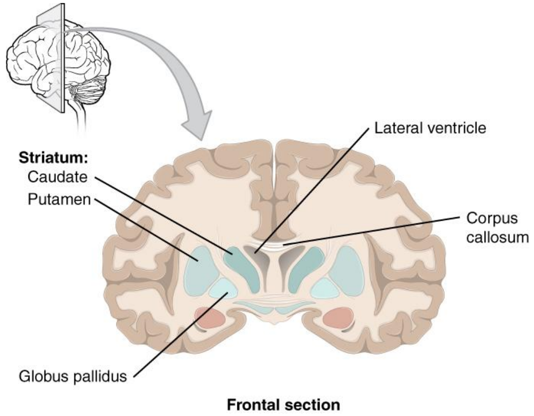
- Gpi: globus pallidus internal segment
- Gpe: globus pallidus external segment
- SNr: substantia nigra pars reticulata
- SNc: substantia nigra pars compacta

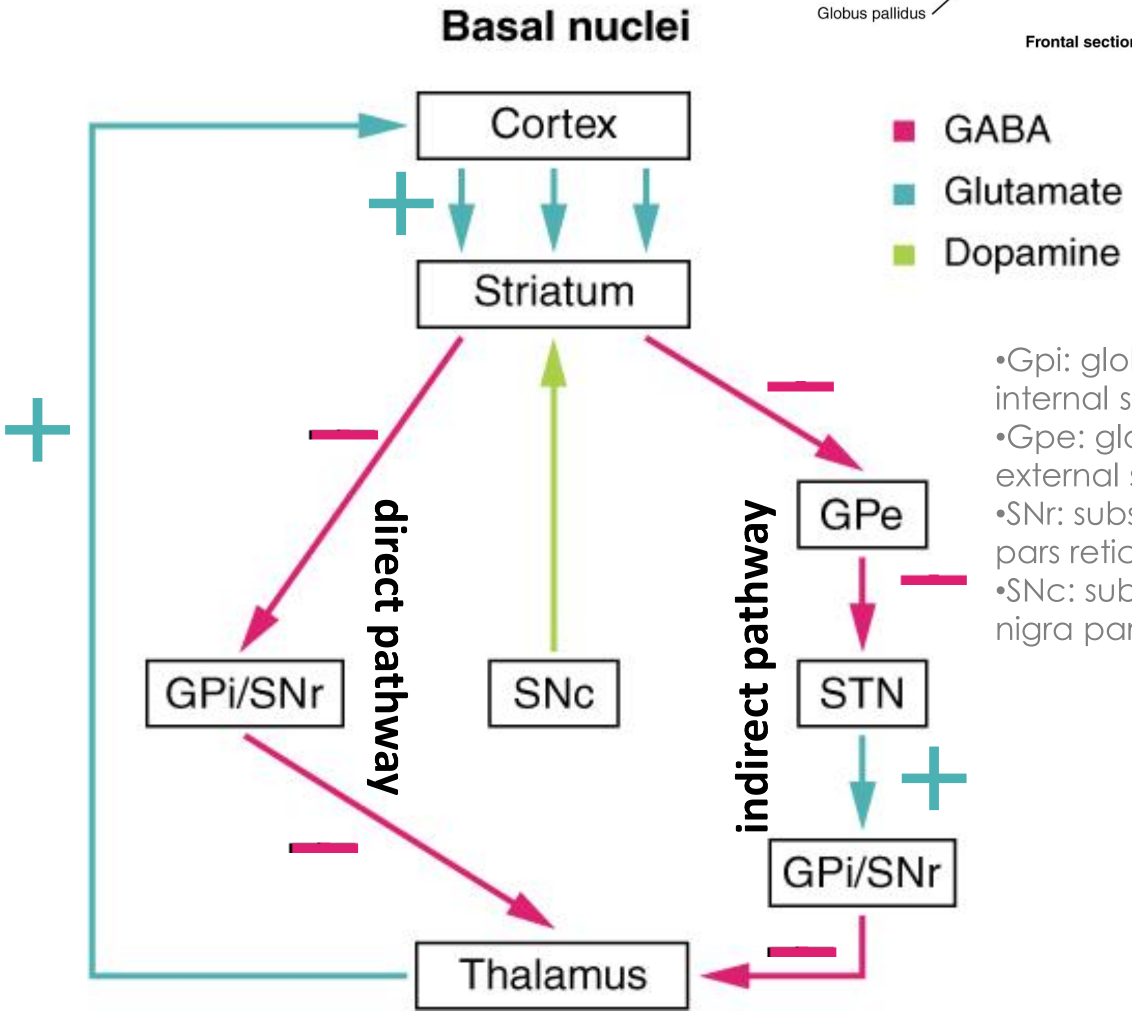
Basal Ganglia have crucial role in motor control & reinforcement learning

The **striatum** may be the **interface where reward influences action**

- The basal ganglia are involved in the selection of actions
- Rewards may influence which actions are selected
    - by affecting plasticity in the striatum, so as to reinforce rewarded actions and make them more likely to recur





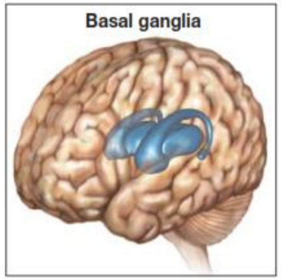


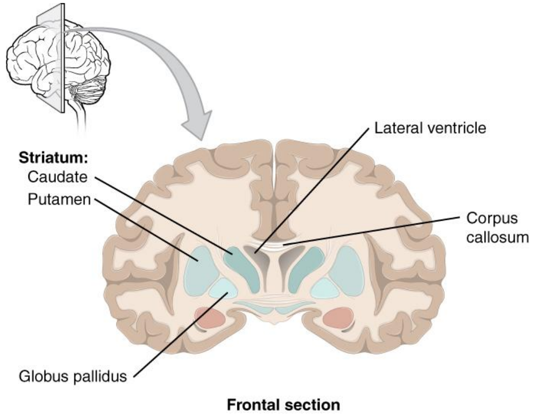
•Gpi: globus pallidus internal segment
•Gpe: globus pallidus external segment
•SNr: substantia nigra pars reticulata
•SNc: substantia nigra pars compacta

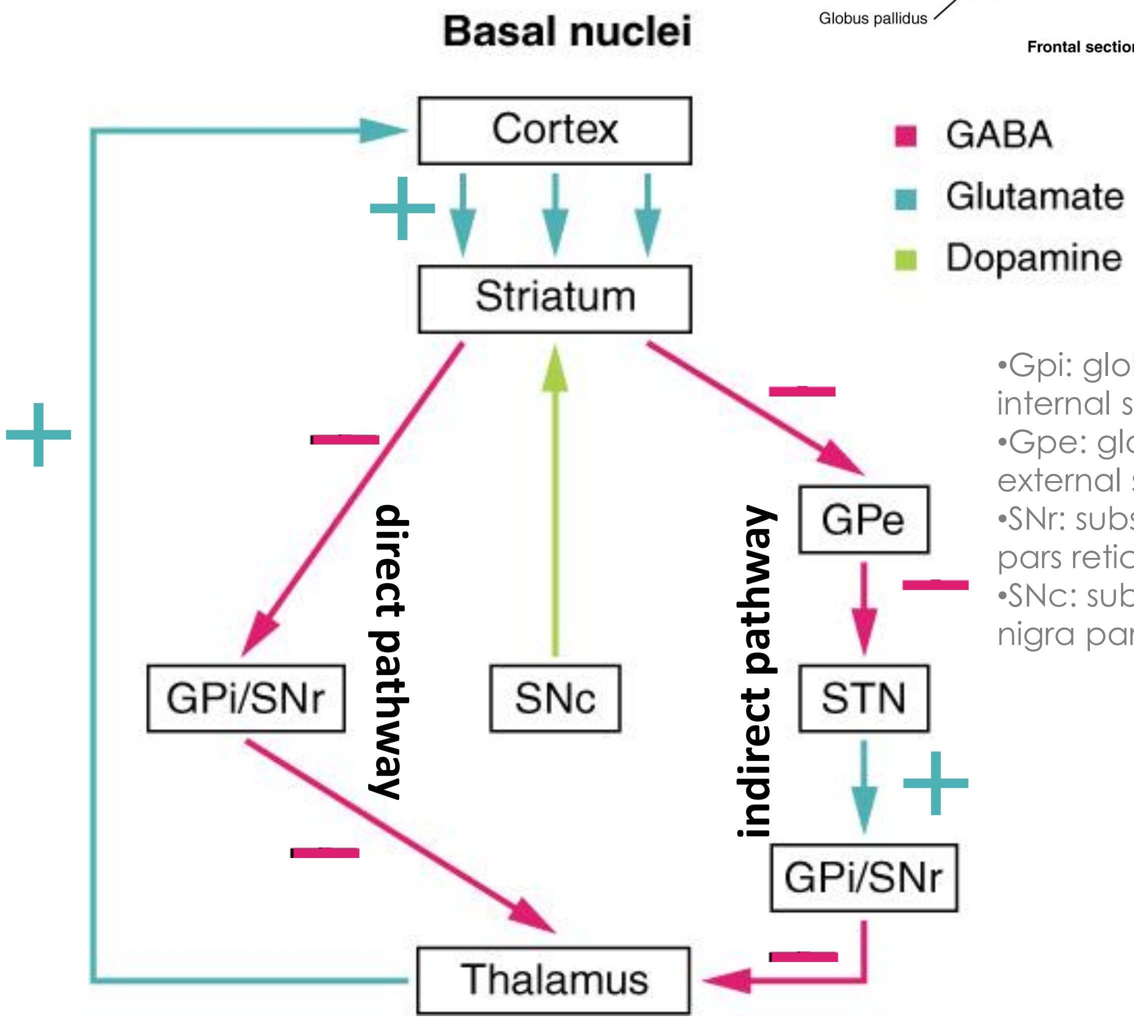
Basal Ganglia have crucial role in motor control & reinforcement learning

Parkinson's disease

- loss of dopaminergic neurons of the SNc → overactivation of the indirect pathway → decrease of movement (hypokinesia)
- But also pathological gambling or shopping



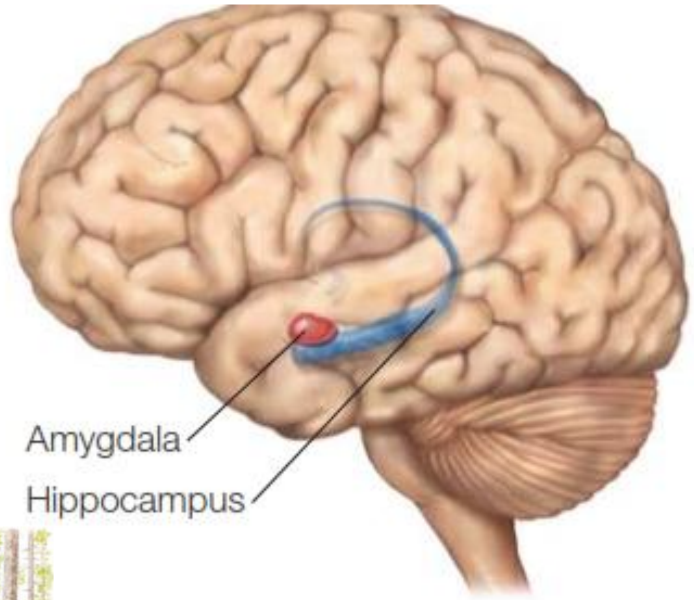




•Gpi: globus pallidus internal segment
•Gpe: globus pallidus external segment
•SNr: substantia nigra pars reticulata
•SNc: substantia nigra pars compacta

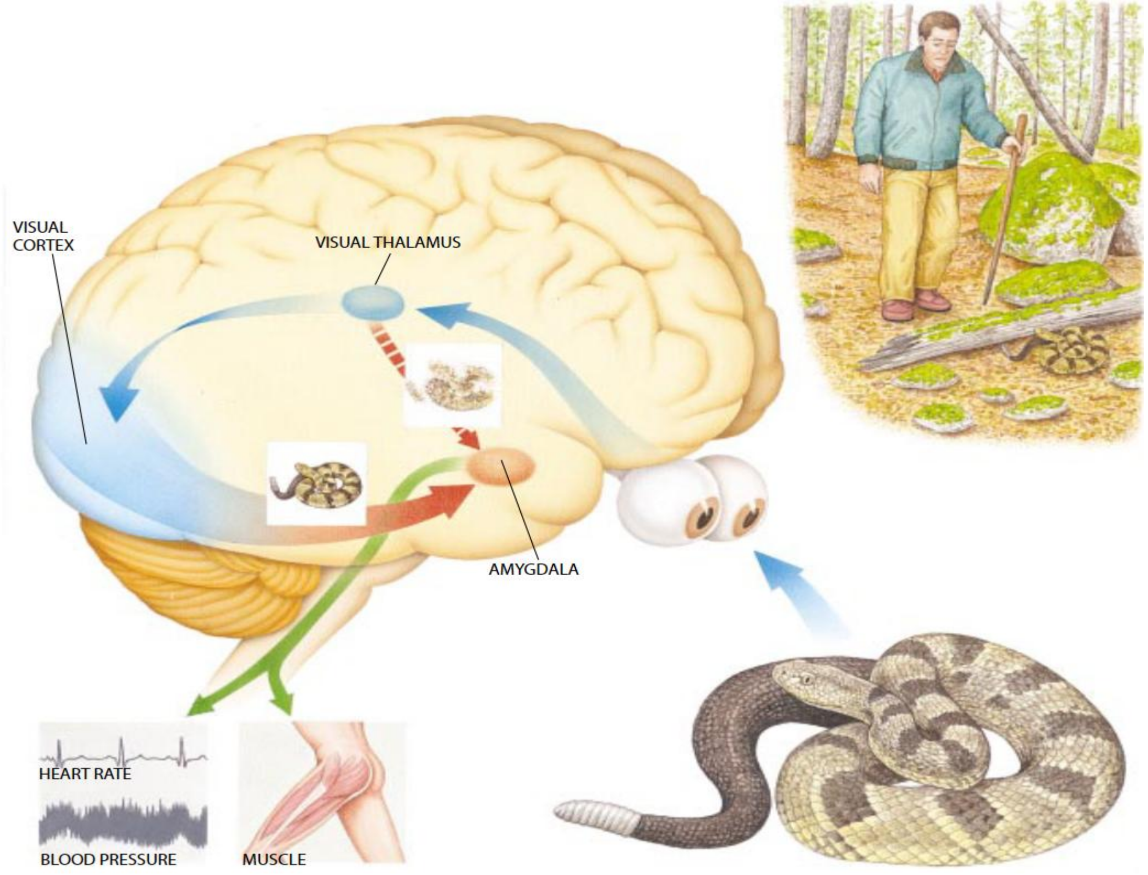
The amygdala

- Small, almond shaped structures in the medial temporal lobe
- it is involved in **determining what a stimulus is and what is to be done about it**



Involved in

- Attention
- Perception
- value representation
- decision making
- Learning
- memory

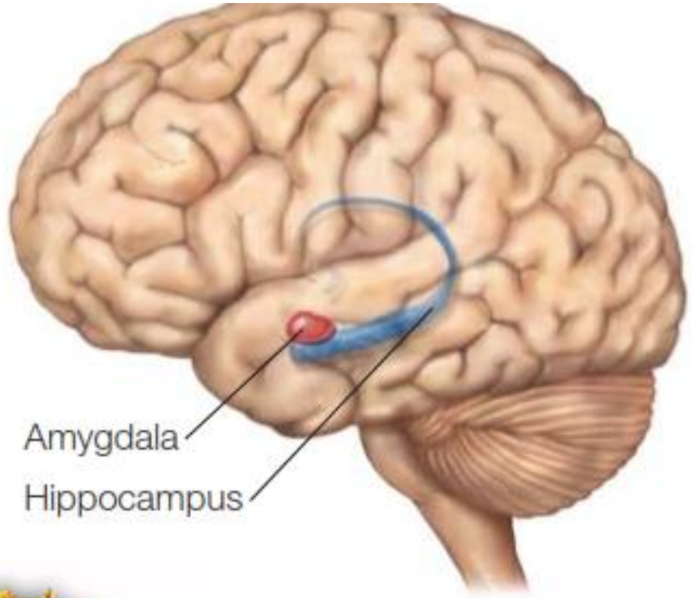


The hippocampus

- Small, curved formation

Crucial for

- ________________
- ________________

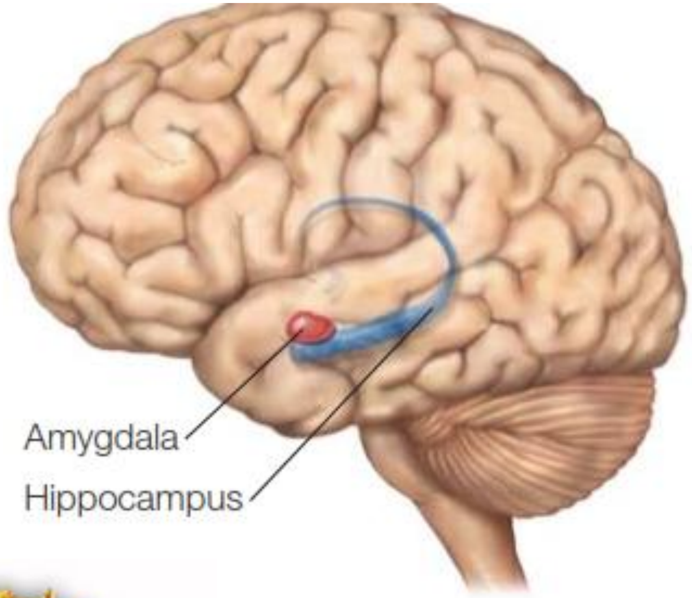


The hippocampus

- Small, curved formation

Crucial for

- Memory formation
- Declarative memory



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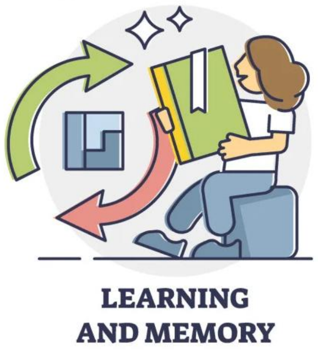
Surgically induced lesions: the hippocampus & memory

Brenda Milner
(1918–)

Penfield's patients began to complain about mild memory loss after surgery



Brenda Milner

- provided anatomical and physiological proof that there are **multiple memory systems**
- Showed that the extent of a memory deficit depended on how much of the medial temporal lobe had been removed

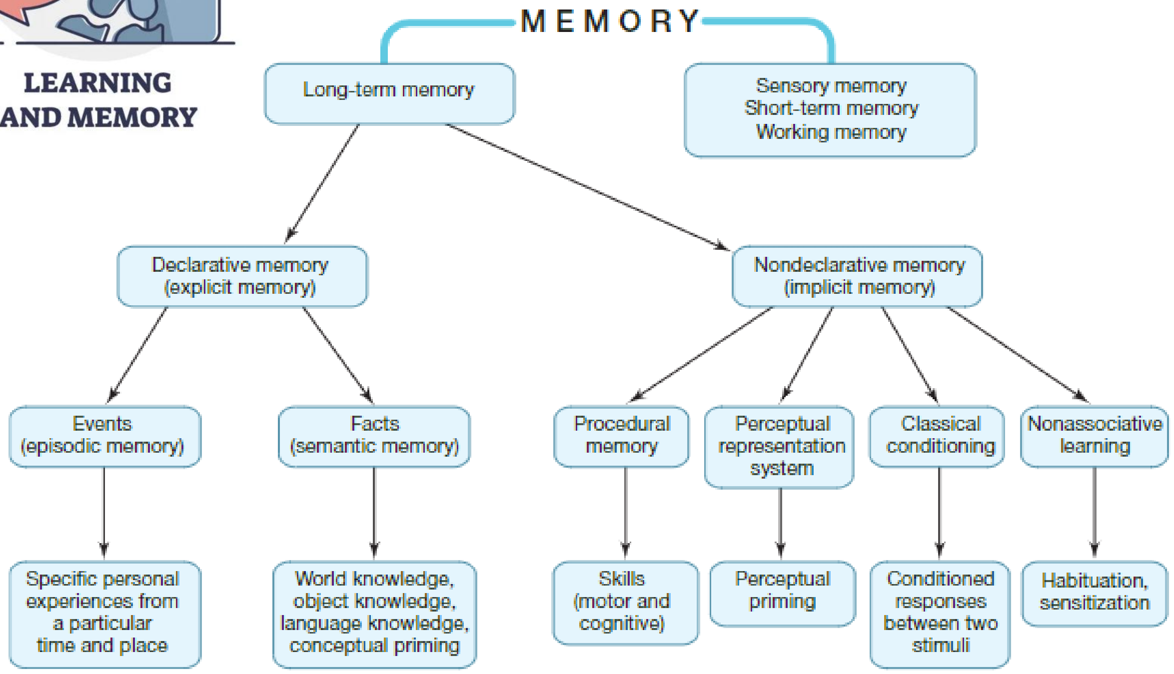
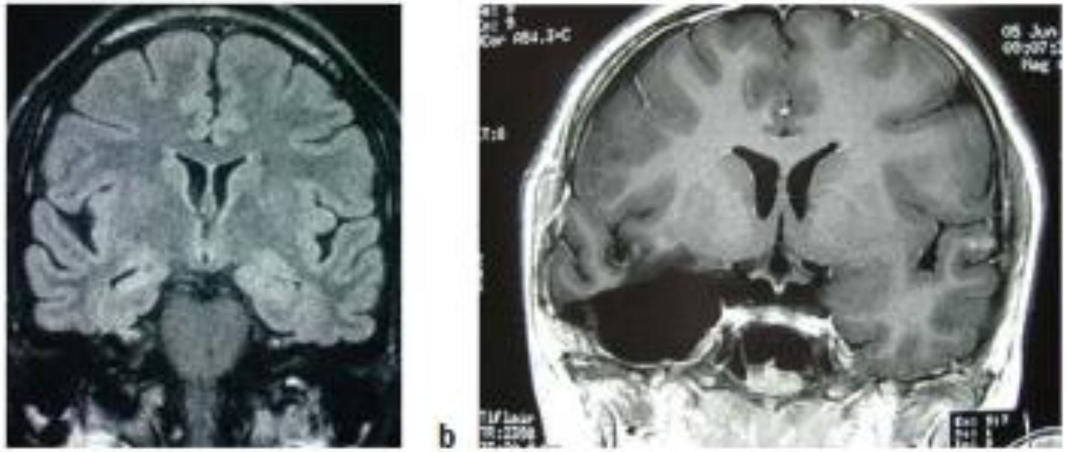


FIGURE 9.2 The hypothesized structure of human memory, diagramming the relationships among different forms of memory.

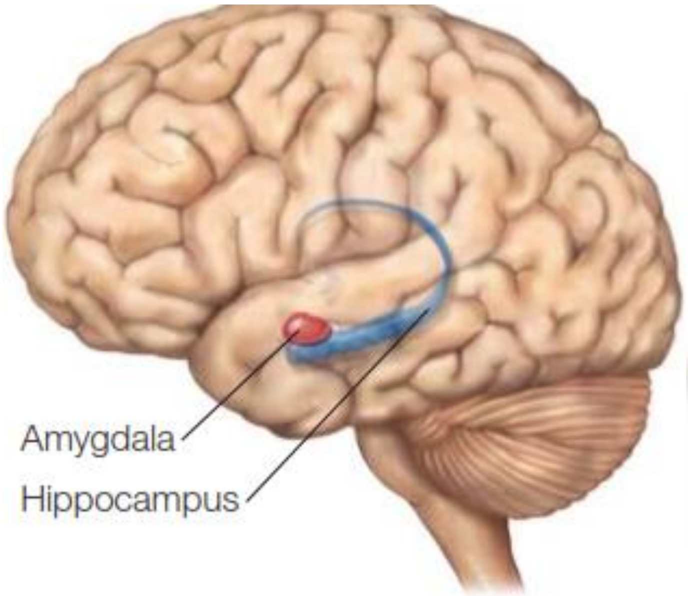


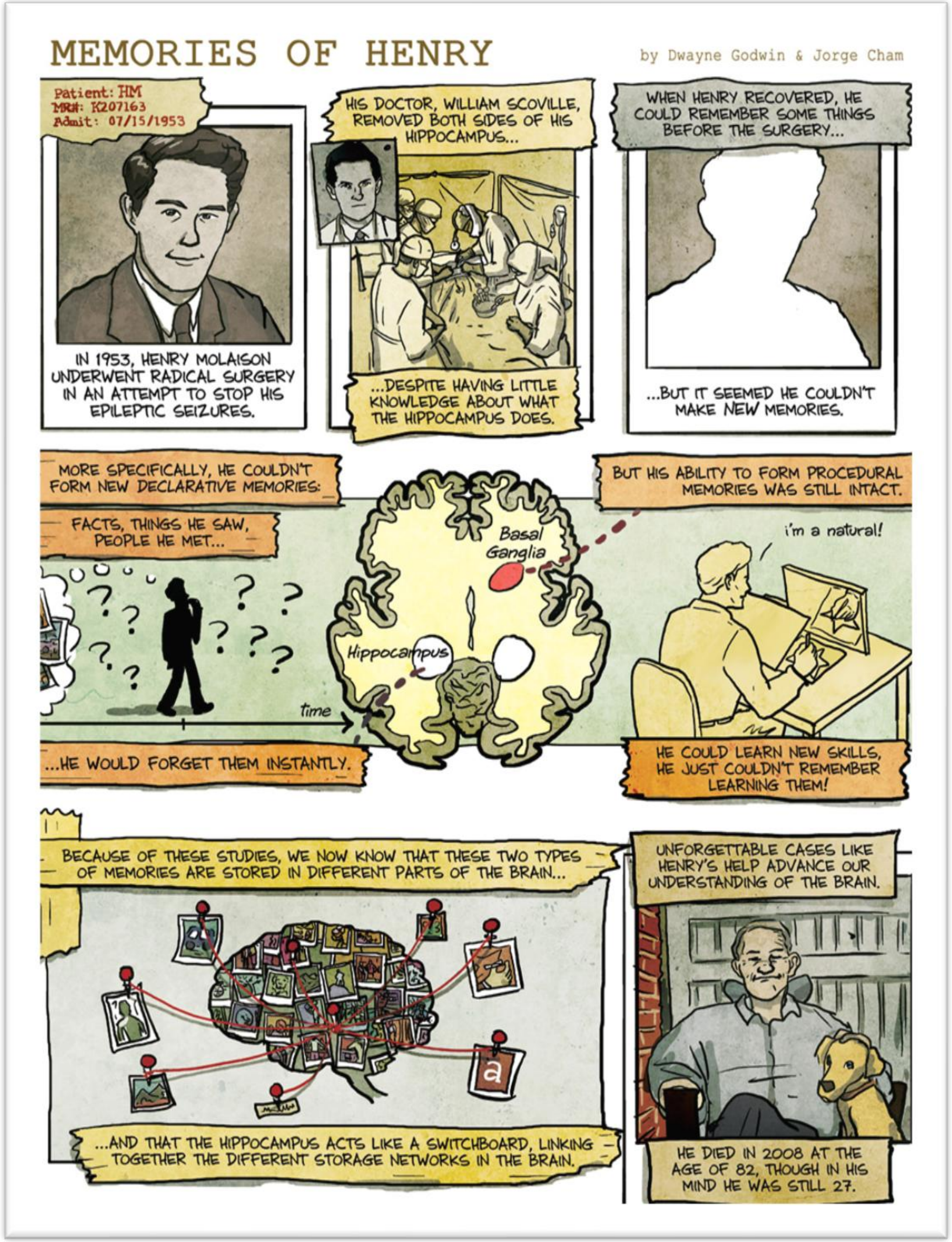
The hippocampus

- Small, curved formation

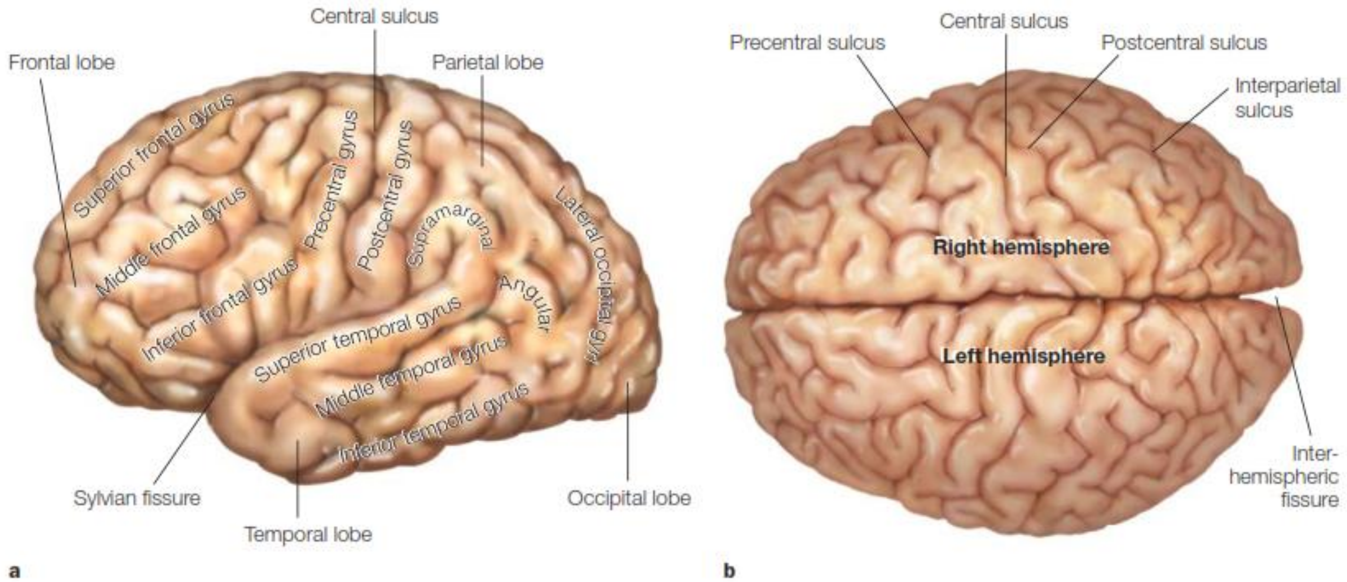
Crucial for

- Memory formation
- Declarative memory

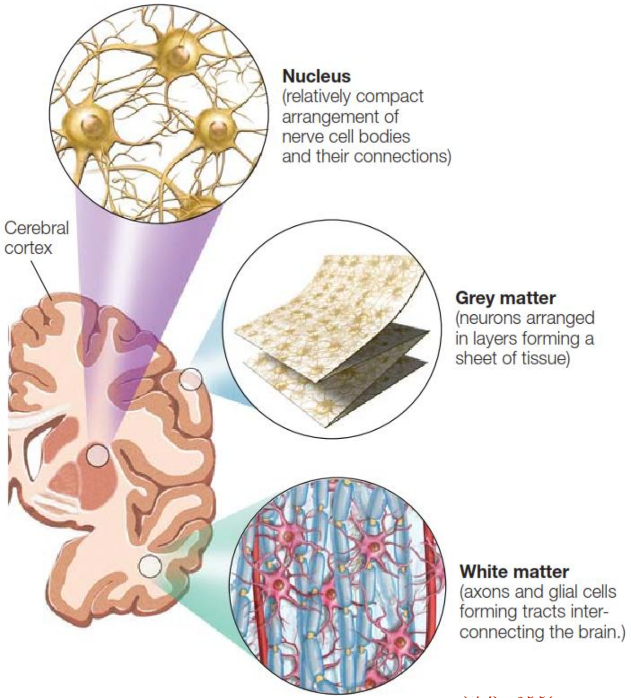




Cerebral Cortex

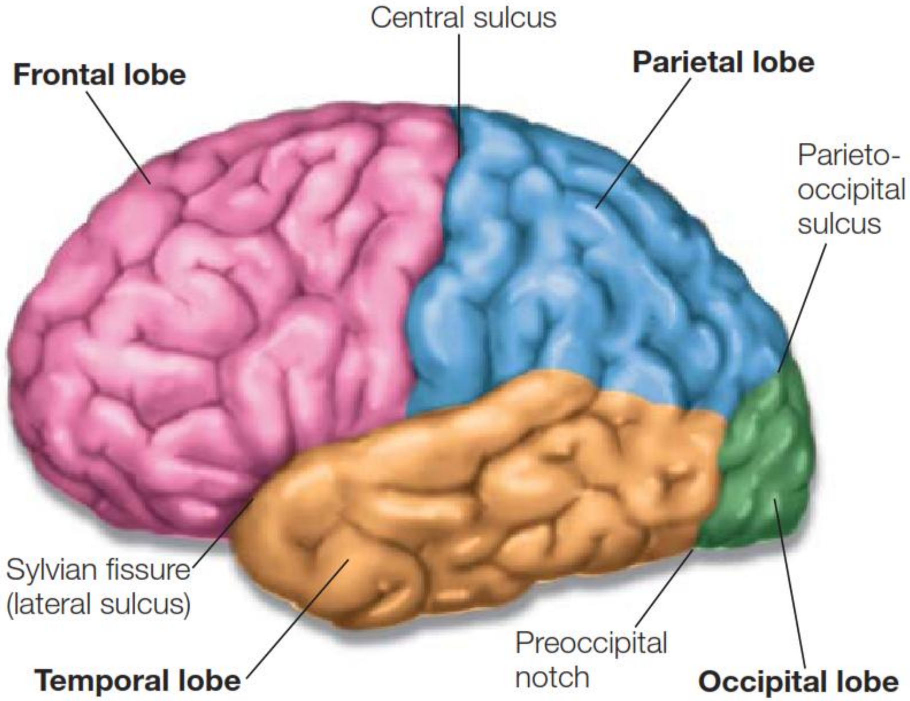


- Total surface area of the human cerebral cortex is about 2.2 to 2.4m^2
- Structurally:
  - Contains many infoldings, or convolutions
    - Sulci: crevices
    - Gyri: crowns
  - Highly folded cortex brings neurons into closer three-dimensional relationships to one another: possible because the axons run under the cortex through the white matter without following the foldings of the cortical surface
- Functional implication: Reduction of axonal length implies reduction of neuronal conduction time between different areas



Cerebral cortex: anatomical division

- Two symmetrical hemispheres connected through the corpus callosum
- Divided in **4 lobes** distinguished from one another by pronounced sulci
- The lobes of the cerebral cortex have a variety of functional roles in neural processing
- Cognitive brain systems are often composed of networks whose component parts are located in different lobes of the cortex
- Each functional system is hierarchically organized:
    - areas of the cerebral cortex are designated as primary, secondary, or tertiary areas, depending on their functional sequence within the pathway



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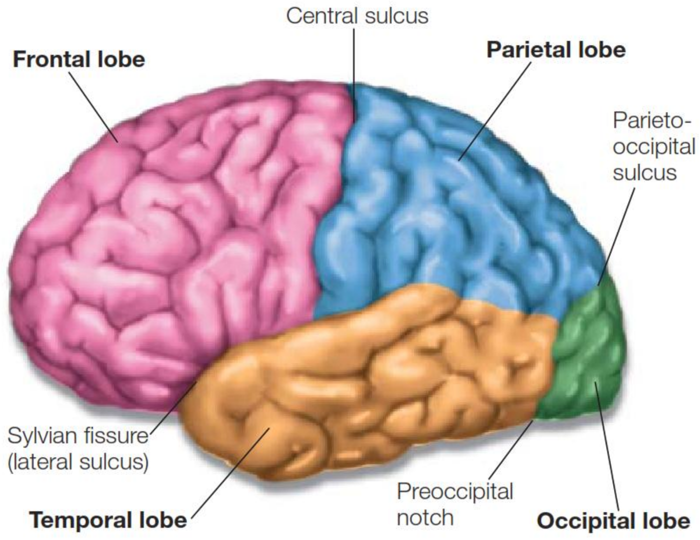
Cerebral cortex: functional division – Frontal Lobe



- **Motor cortex**
  - planning and execution of movements
  - M1: contains neurons that directly activate somatic motor neurons in the spinal cord

- **Prefrontal cortex**
  - Long-term planning & organizing
  - executive functions
  - decision making
  - Motivation and value

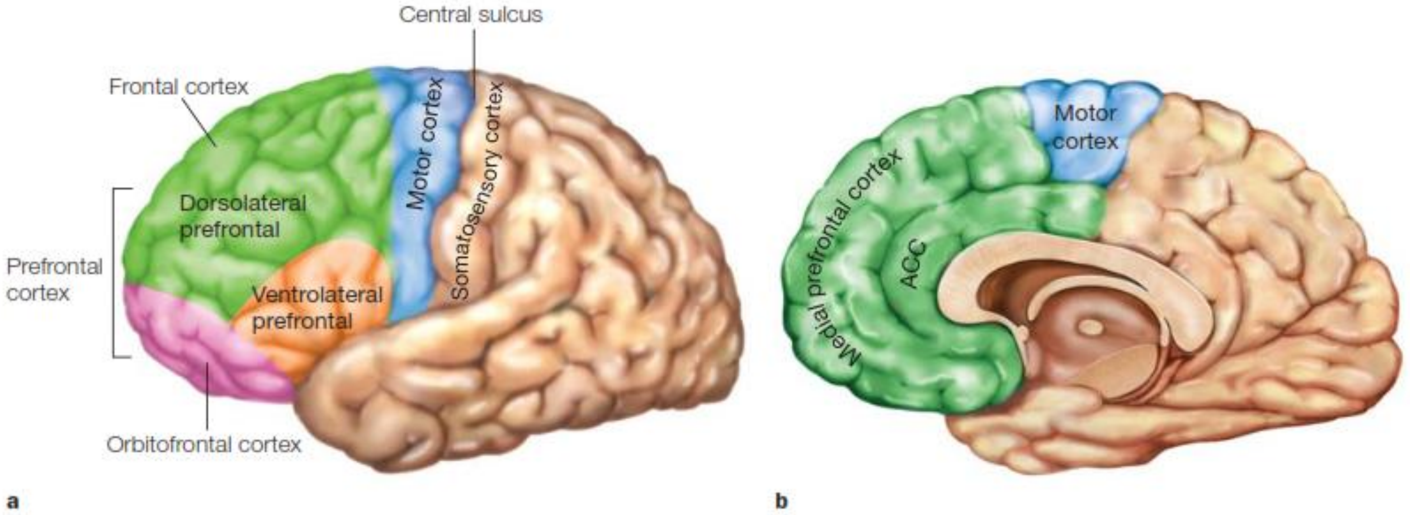


FIGURE 2.33 The human frontal cortex.
(a) Divisions of the frontal cortex. The frontal lobe contains both motor and higher order association areas. For example, the prefrontal cortex is involved in executive functions, memory, decision making, and other processes. **(b)** Midsagital section of the brain showing the medial prefrontal regions, which include the anterior cingulate cortex (ACC). Also visible is the supplementary motor area.

Cerebral cortex: functional division – Parietal Lobe

Receives sensory information from:

- ________________
- ________________
- ________________

and integrates it

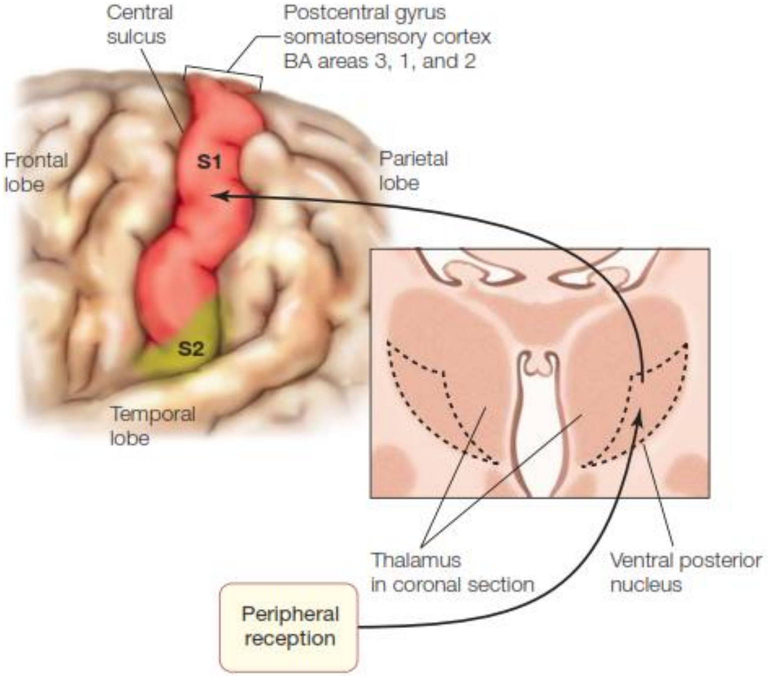
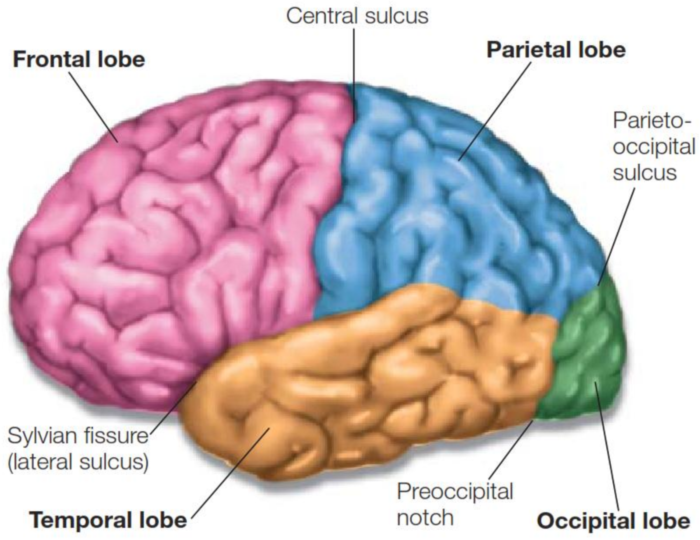


FIGURE 2.34 The somatosensory cortex, which is located in the postcentral gyrus.
Inputs from peripheral receptors project via the thalamus (shown in cross section) to the primary somatosensory cortex (S1). Secondary somatosensory cortex (S2) is also shown.

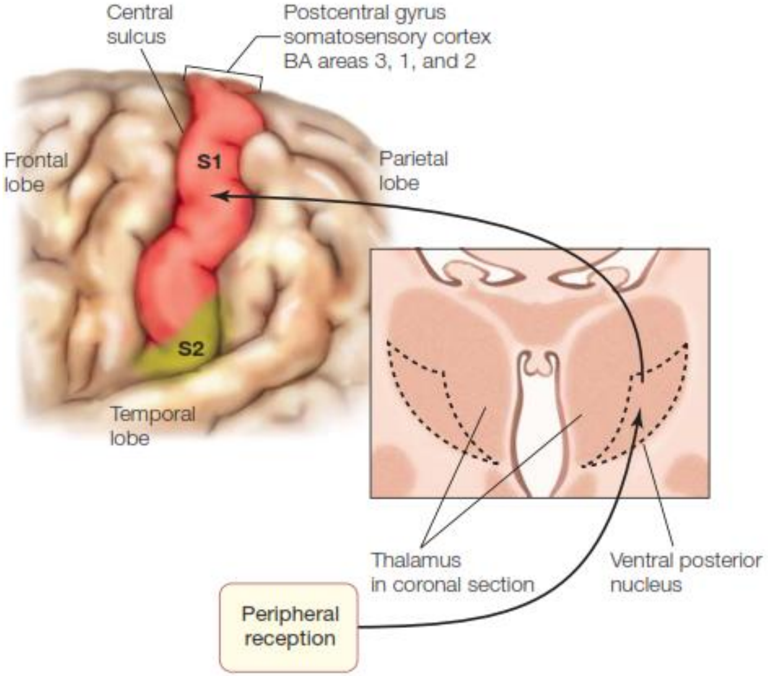


Cerebral cortex: functional division – Parietal Lobe

Receives sensory information from:

- ______________
- ______________
- ______________

and integrates it



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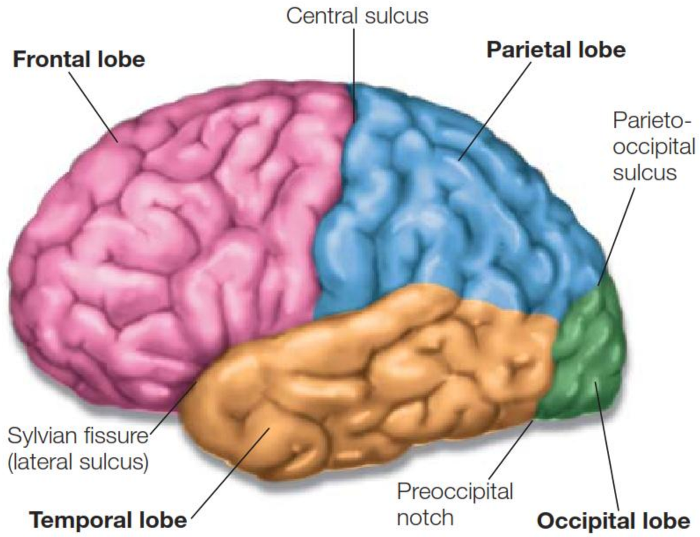


Cerebral cortex: functional division – Parietal Lobe

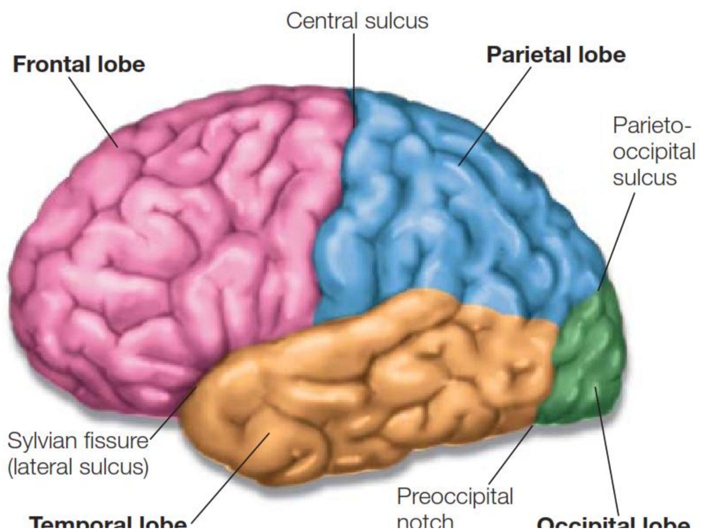
Receives sensory information from:

- the outside world
- within the body
- memory

and integrates it

Includes the somatosensory cortex:

- S1: information about touch, pain, temperature, and limb proprioception (limb position) is received via receptor cells on the skin and converted to neuronal impulses that are conducted to the spinal cord and then to the somatosensory relays of the thalamus
- Higher-order sensory area sends its outputs to multimodal association areas that integrate information from two or more sensory modalities



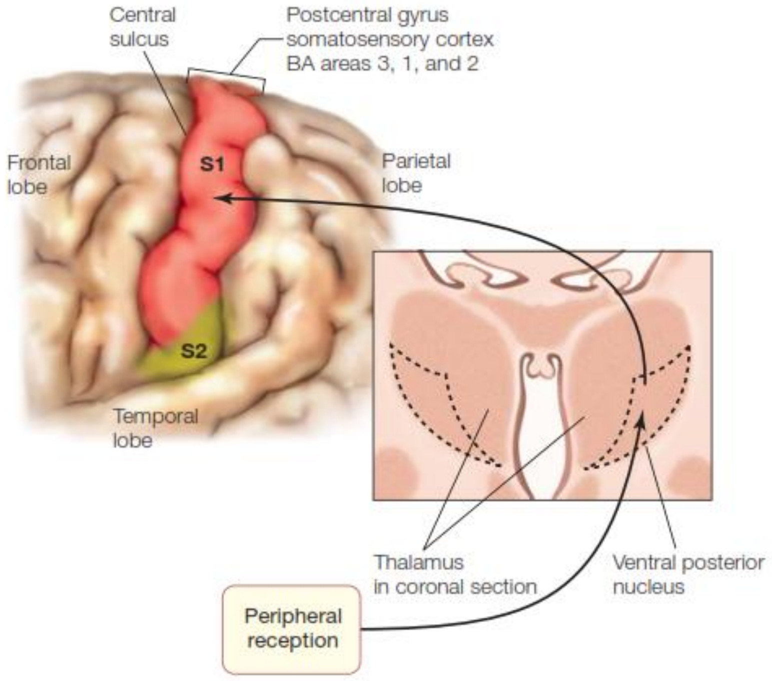
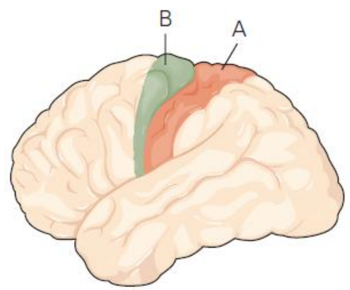
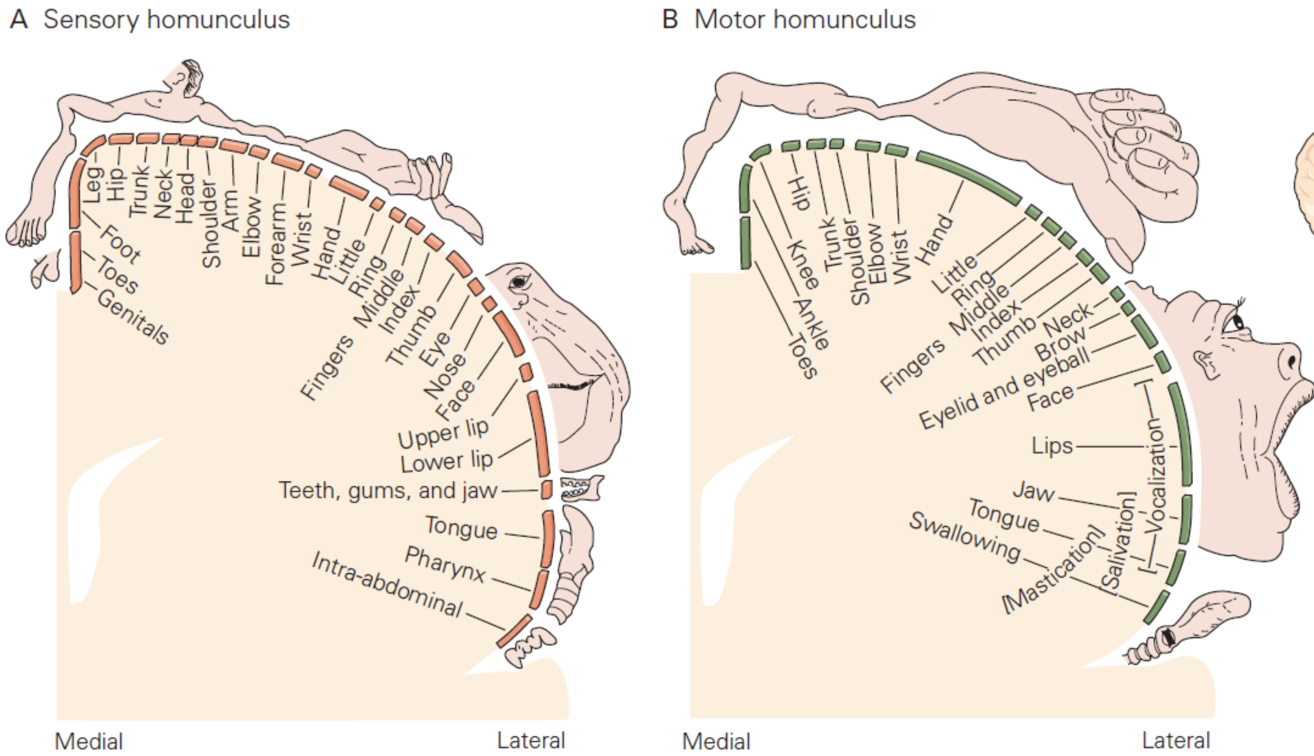


FIGURE 2.34 The somatosensory cortex, which is located in the postcentral gyrus.
Inputs from peripheral receptors project via the thalamus (shown in cross section) to the primary somatosensory cortex (S1). Secondary somatosensory cortex (S2) is also shown.

Neurons are organized into a neural map of the body



- **Topographic** correspondence between cortical regions and body surface with respect to somatosensory and motor processes
    - The neurons that regulate particular body parts are clustered together
- **Somatotopy**: mapping of specific parts of the body to areas of the cortex
- **Homunculus**: map of the body surface on the cortex
    - The extent of the representation of a body part reflects the density of innervation of that part



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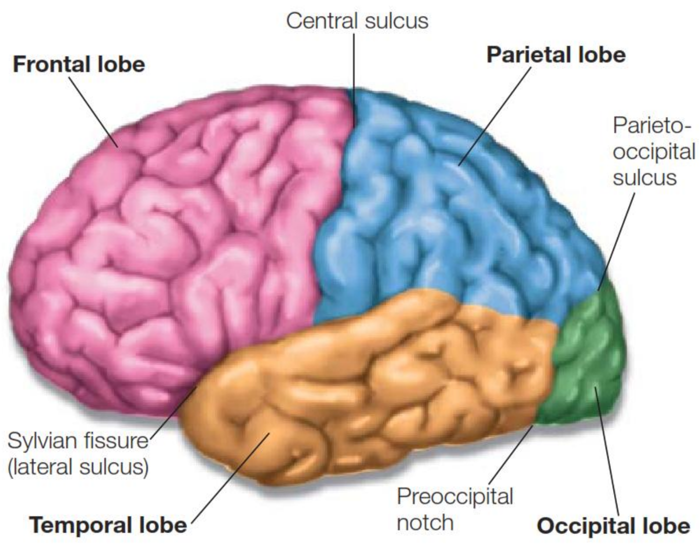
Cerebral cortex: functional division – Occipital Lobe



- Visual cortex
  - ______________________

- Primary visual cortex begins the cortical coding of visual features like
  - Luminance
  - spatial frequency
  - Orientation
  - motion
- Retinotopic maps:
  - the receptive fields of visual cells form an orderly mapping between spatial location and the neural representation of that dimension

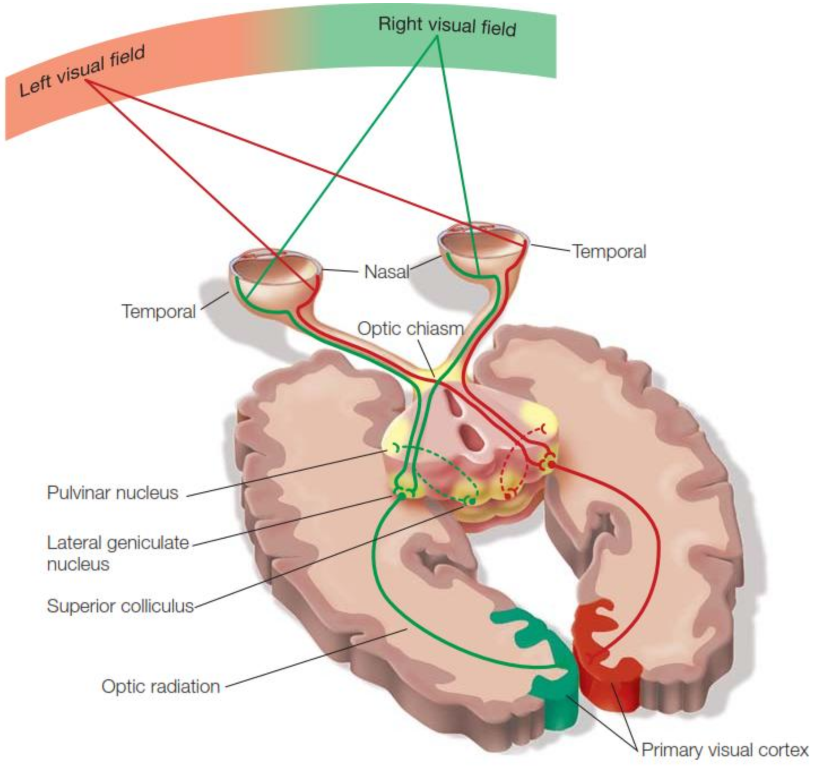


FIGURE 5.23 The primary projection pathways of the visual system.

Cerebral cortex: functional division – Temporal Lobe

Includes the auditory cortex:

- ____________________

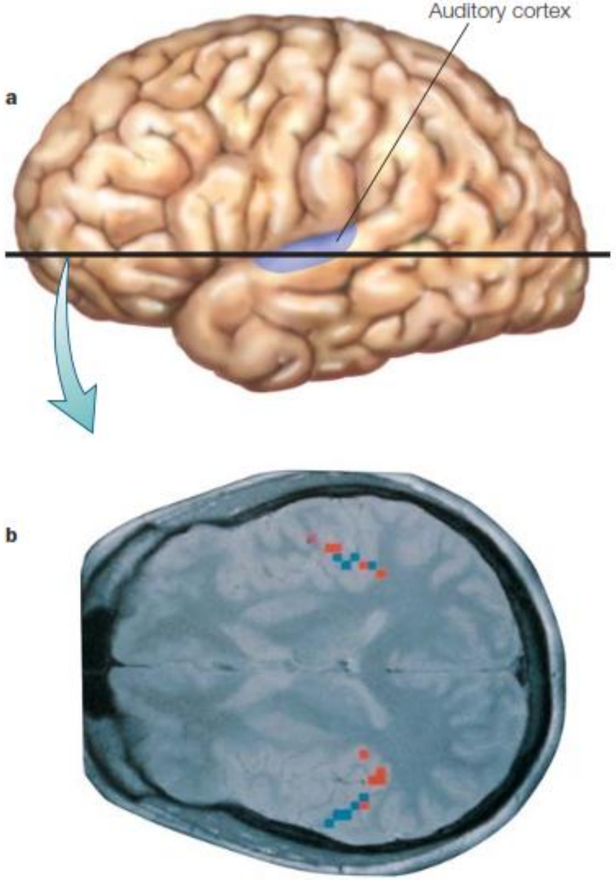
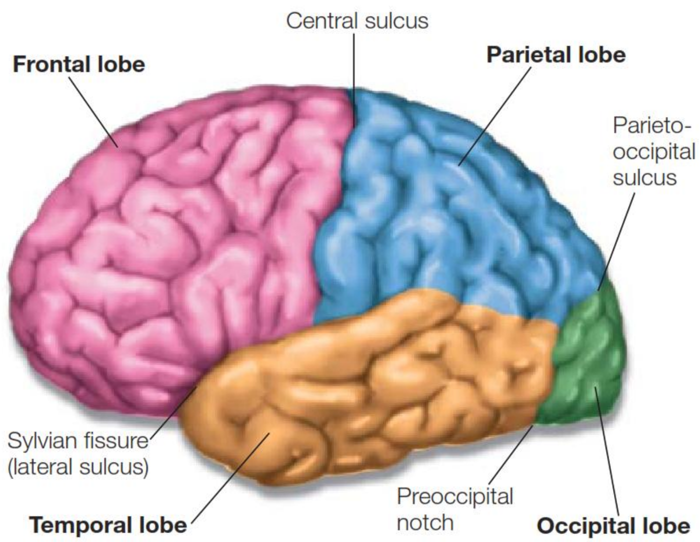


FIGURE 2.36 The human auditory cortex.
(a) Primary auditory cortex, which is located in the superior temporal lobe. The primary auditory cortex and surrounding association auditory areas contain representations of auditory stimuli and show a tonotopic organization. **(b)** This MRI shows areas of the superior temporal region in horizontal section that have been stimulated by tones of different frequencies (shown in red vs. blue) and show increased blood flow as a result of neuronal activity.



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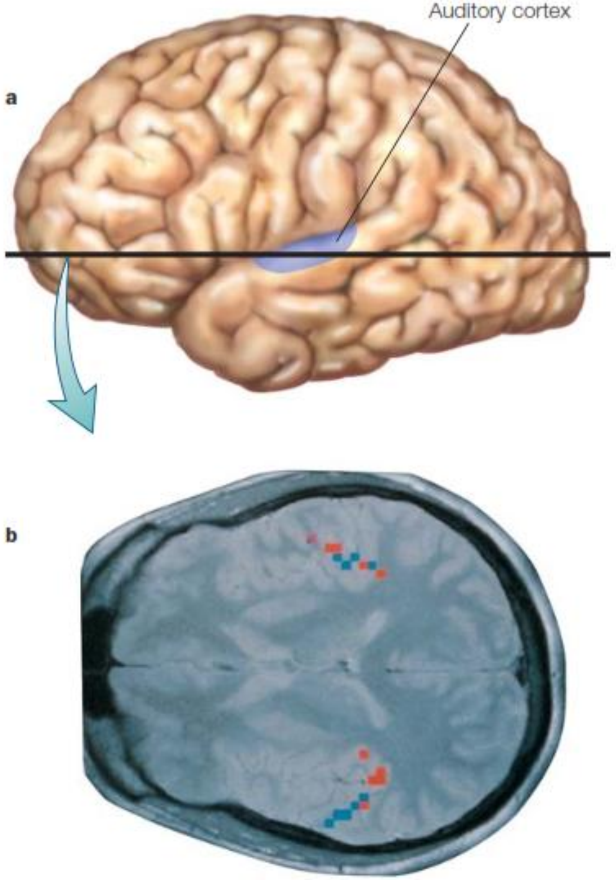
Cerebral cortex: functional division – Temporal Lobe

Includes the auditory cortex:

- Sound processing

- from the cochlea in the ear proceeds through the subcortical relays to the thalamus to reach primary auditory cortex
- Tonotopic organization:
  - layout of the neurons based on sound frequency



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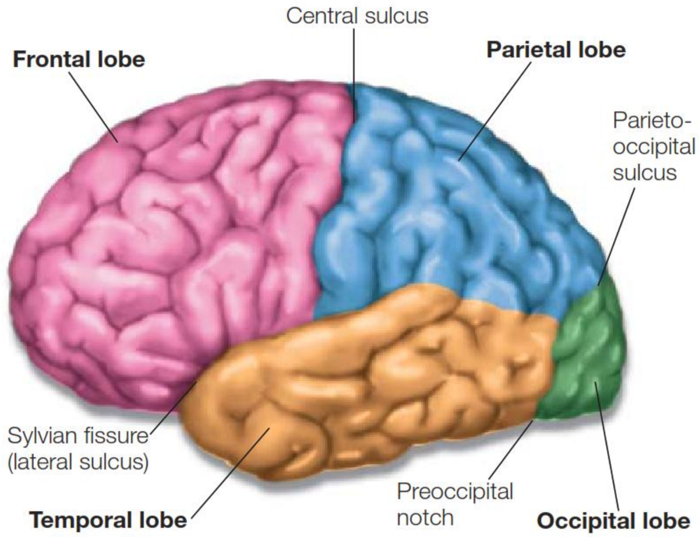

Cerebral cortex: functional division – Association cortex

- Portion of the cortex that is neither sensory nor motor
- contain cells that may be activated by more than one sensory modality
- receives and integrates inputs from many cortical areas to produce **integrated experience of the world**
- responsible for all our high-end human abilities, such as language, abstract thinking

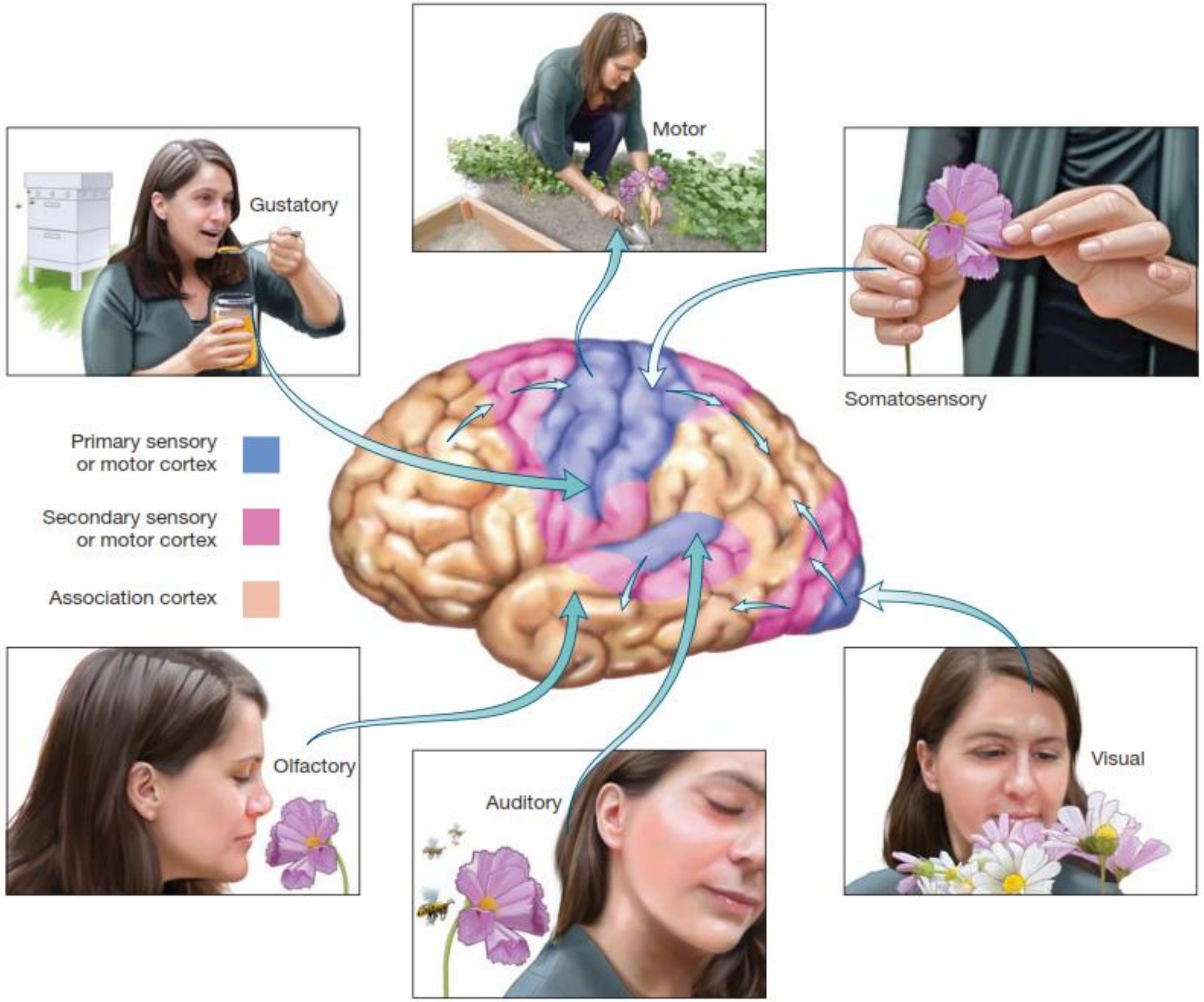

FIGURE 2.37 Primary sensory and motor cortex and surrounding association cortex. The blue regions show the primary cortical receiving areas of the ascending sensory pathways and the primary output region to the spinal cord. The secondary sensory and motor areas are colored pink. The remainder is considered association cortex.

Questions 10-16

Recommended readings

- Gazzaniga, M. S., Ivry, R. B., & Mangun, G. R. (2014). Cognitive Neuroscience, The biology of the mind.
  - Chapter 2

- Kandel, E. R., Schwartz, J. H., Jessell, T. M., Siegelbaum, S., Hudspeth, A. J., & Mack, S. (Eds.). (2000). Principles of neural science. New York: McGraw-hill.
  - Chapter 2, 4, 6, 7, 8, 15

Revision questions

- Compare and contrast electrical and chemical synapses, focusing on their structural differences, mechanisms of signal transmission, and functional implications for neural communication.
- Describe the components of a neural circuit, including sensory neurons, interneurons, and motor neurons. Provide an example of a simple neural circuit, such as the knee-jerk reflex, and explain how it functions.
- Discuss the organization and functions of the peripheral nervous system (PNS), including the somatic and autonomic divisions. Explain how the sympathetic and parasympathetic systems operate antagonistically to maintain homeostasis.
- Discuss the organization (direct and indirect pathways) and role of the basal ganglia in motor control, reinforcement learning, and goal-oriented behavior.
- Describe the organization of the cerebral cortex, including its lobes and their key functions.

Glossary of Key Terms

Axoaxonic Synapse: A synapse where one neuron connects to the axon of another neuron, mediating presynaptic inhibition or facilitation.

Axodendritic Synapse: A synapse where a neuron connects to the dendrite of another neuron; the most common type.

Axosomatic Synapse: A synapse where a neuron connects to the soma (cell body) of another neuron.

Amygdala: A structure in the medial temporal lobe involved in determining the emotional significance of stimuli, attention, perception, value representation, decision making, learning, and memory.

Basal Ganglia: A collection of subcortical nuclei involved in motor control, reinforcement learning, and goal-oriented behavior.

Blood-Brain Barrier: A protective barrier between the brain's blood vessels and brain tissue, preventing harmful substances from entering the brain.

Brain Stem: The region of the brain including the medulla, pons, and midbrain, responsible for regulating basic life functions like blood pressure, respiration, and sleep/wakefulness.

Central Nervous System (CNS): The brain and spinal cord, responsible for processing and coordinating information.

Glossary of Key Terms

Cerebellum: A brain structure important for maintaining posture, coordinating movements, regulating motor output, and learning motor skills.

Cerebral Cortex: The outer layer of the cerebral hemispheres, composed of gray matter, and responsible for higher-level cognitive functions.

Chemical Synapse: A synapse where communication occurs through the release and diffusion of neurotransmitters across the synaptic cleft.

Convergence: A neural circuit arrangement where many neurons activate a single target cell, commonly observed at the output stages of the nervous system.

Divergence: A neural circuit arrangement where one neuron activates many target cells, commonly observed at the input stages of the nervous system.

Electrical Synapse: A synapse where neuronal membranes are touching at gap junctions, allowing direct electrical transmission between neurons.

Glossary of Key Terms

Feed-back Inhibition: A neural circuit arrangement where excitatory neurons synapse onto inhibitory interneurons, which project back to the same neurons and inhibit them. Dampens activity within a pathway.

Feed-forward Inhibition: A neural circuit arrangement where excitatory neurons synapse onto inhibitory interneurons, inhibiting other downstream neurons. Enhances effect of pathway.

Hippocampus: A brain structure crucial for memory formation, particularly declarative memory.

Homunculus: A map of the body surface on the cortex, reflecting the density of innervation of different body parts.

Hypothalamus: A brain structure that regulates homeostasis, the autonomic nervous system, and the endocrine system, while also driving motivational behaviors.

Interneuron: A neuron that mediates impulses between sensory and motor neurons.

Motor Neuron: A neuron that carries commands from the brain or spinal cord to muscles and glands.

Neural Circuit: A group of interconnected neurons that process specific kinds of information.

Neurotransmitter: A chemical substance that binds to receptors in the postsynaptic membrane of a target cell, transmitting a signal.

Glossary of Key Terms

Parallel Processing: The simultaneous encoding of different information about the same stimulus by multiple neural pathways.

Peripheral Nervous System (PNS): The nerves and ganglia outside of the brain and spinal cord, responsible for delivering sensory information to the CNS and carrying motor commands to the muscles.

Postsynaptic Cell: The cell receiving a signal at a synapse.

Presynaptic Cell: The cell transmitting a signal at a synapse.

Sensory Neuron: A neuron that carries information from the body's peripheral sensors into the nervous system.

Spinal Cord: A long, cylindrical structure extending from the brainstem, responsible for relaying sensory information to the brain and conducting motor signals to the muscles.

Synapse: A specialized structure where two neurons come into close contact, enabling communication through chemical or electrical signals.

Synaptic Cleft: The narrow space separating the presynaptic and postsynaptic cells at a chemical synapse.

Thalamus: A brain structure that acts as a "gateway to the cortex," relaying sensory information to the cerebral hemispheres.