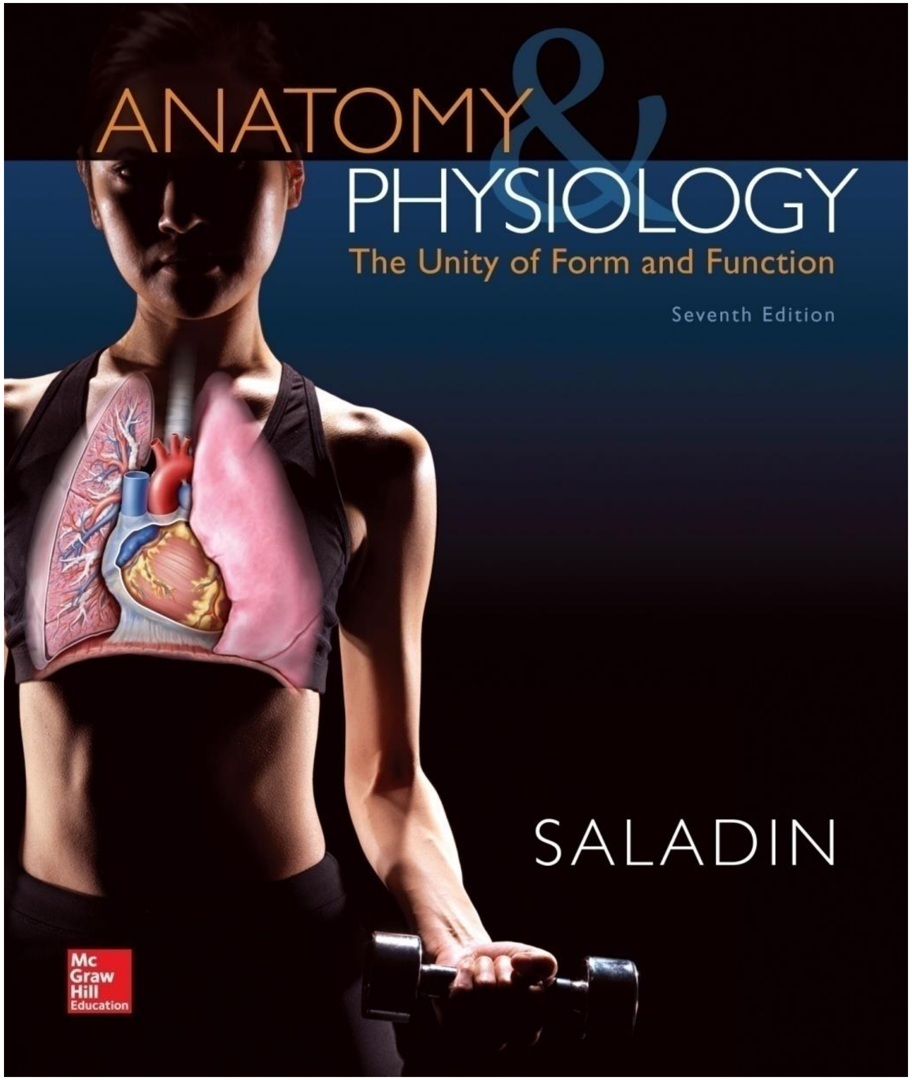
Chapter 14
Lecture Outline

See separate PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.



Introduction

- **The human brain is extremely complex**
- **Brain function is associated clinically with what it means to be alive or dead**
- **Importance of the brain hasn’t always been well understood**
  - Aristotle thought brain just cooled blood
  - But Hippocrates (earlier) had more accurate view of brain’s importance
- **This chapter is a study of the brain and cranial nerves directly connected to it**
  - Functions to be considered include: motor control, sensation, emotion, and thought

Introduction

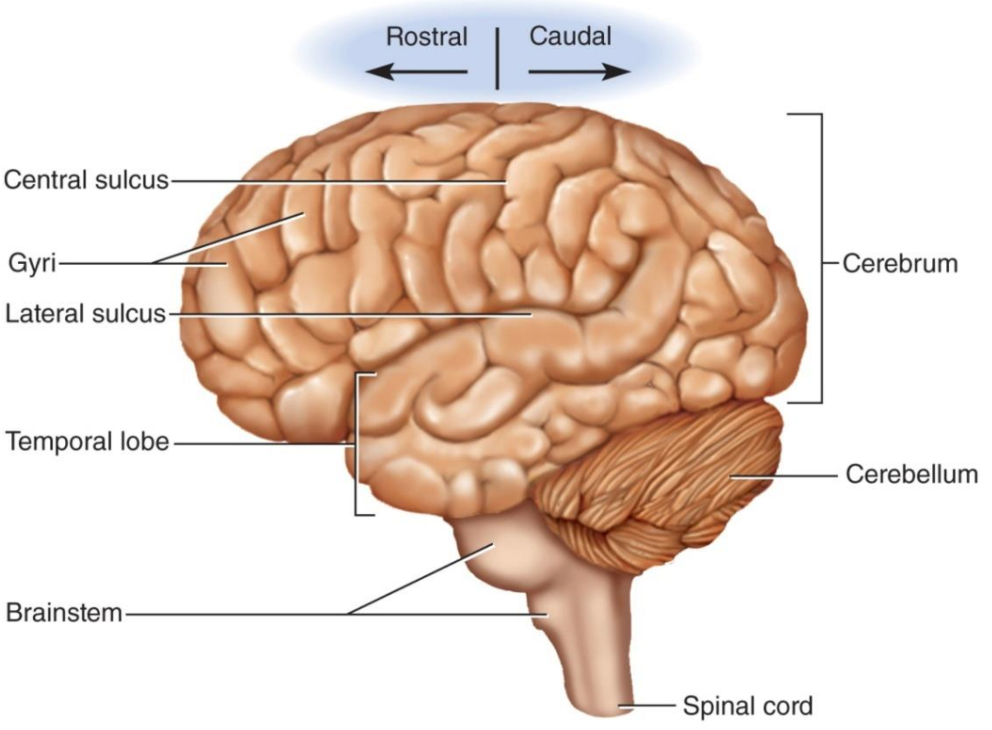
- **Evolution of human central nervous system shows that spinal cord has changed very little, while brain has changed a great deal**
  - Greatest growth in areas of vision, memory, and motor control of the prehensile hand

Overview of the Brain

- **Expected Learning Outcomes**
  - Describe the major subdivisions and anatomical landmarks of the brain.
  - Describe the locations of its gray and white matter.
  - Describe the embryonic development of the CNS and relate this to adult brain anatomy.

Major Landmarks

- **Rostral**—toward the forehead
- **Caudal**—toward the spinal cord
- **Brain weighs about 1,600 g (3.5 lb) in men, and 1,450 g in women**

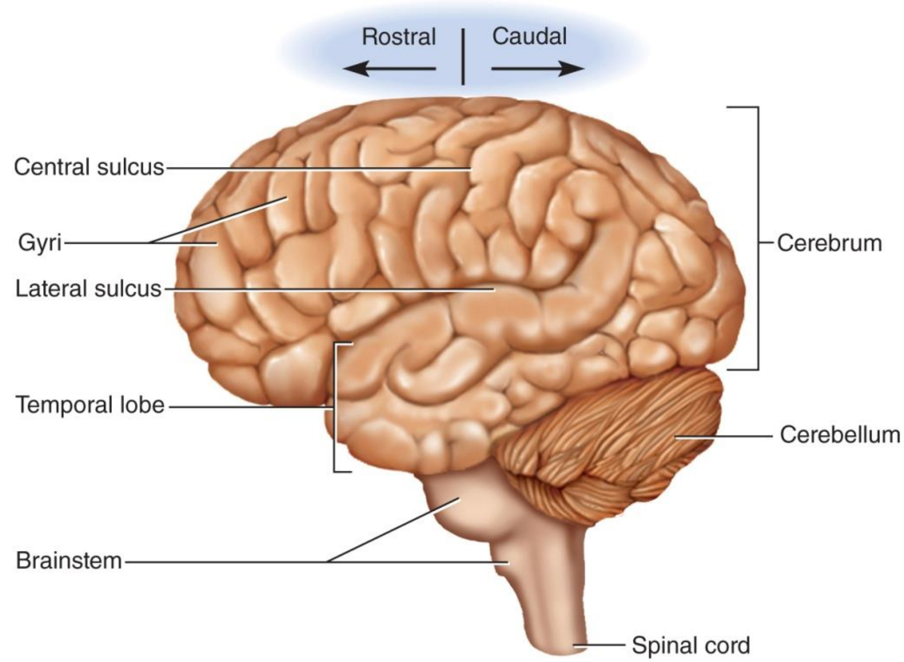


(b) Lateral view

Figure 14.1b

Major Landmarks

- **Three major portions of the brain**
  - **Cerebrum** is 83% of brain volume; cerebral hemispheres, gyri and sulci, longitudinal fissure, corpus callosum
  - **Cerebellum** contains 50% of the neurons; second largest brain region, located in posterior cranial fossa
  - **Brainstem** is the portion of the brain that remains if the cerebrum and cerebellum are removed; diencephalon, midbrain, pons, and medulla oblongata

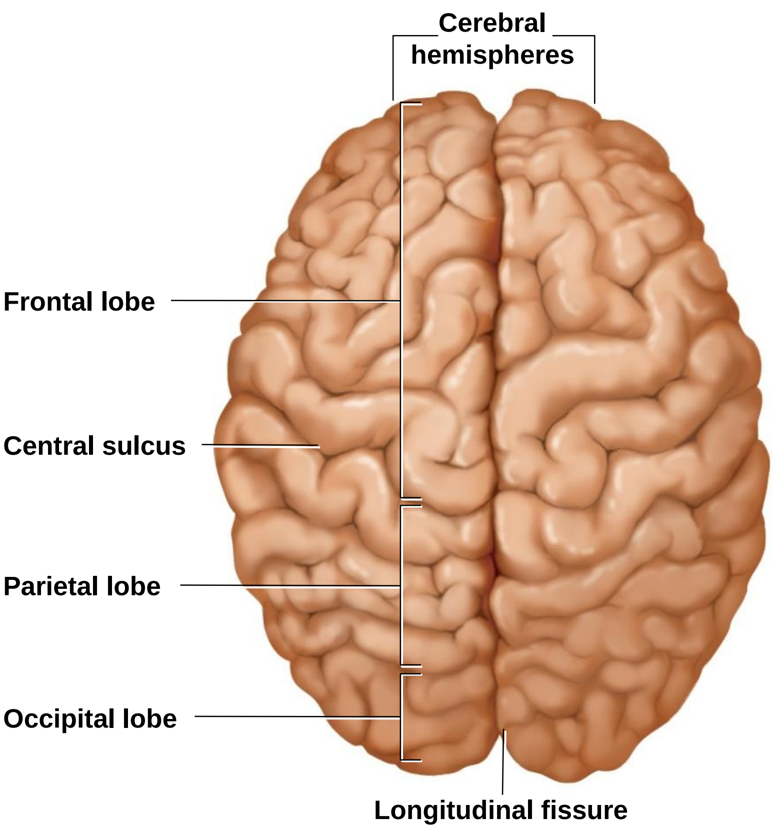


(b) Lateral view

Figure 14.1b

Major Landmarks

- **Longitudinal fissure**—deep groove that separates cerebral hemispheres
- **Gyri**—thick folds
- **Sulci**—shallow grooves
- **Corpus callosum**—thick nerve bundle at bottom of longitudinal fissure that connects hemispheres

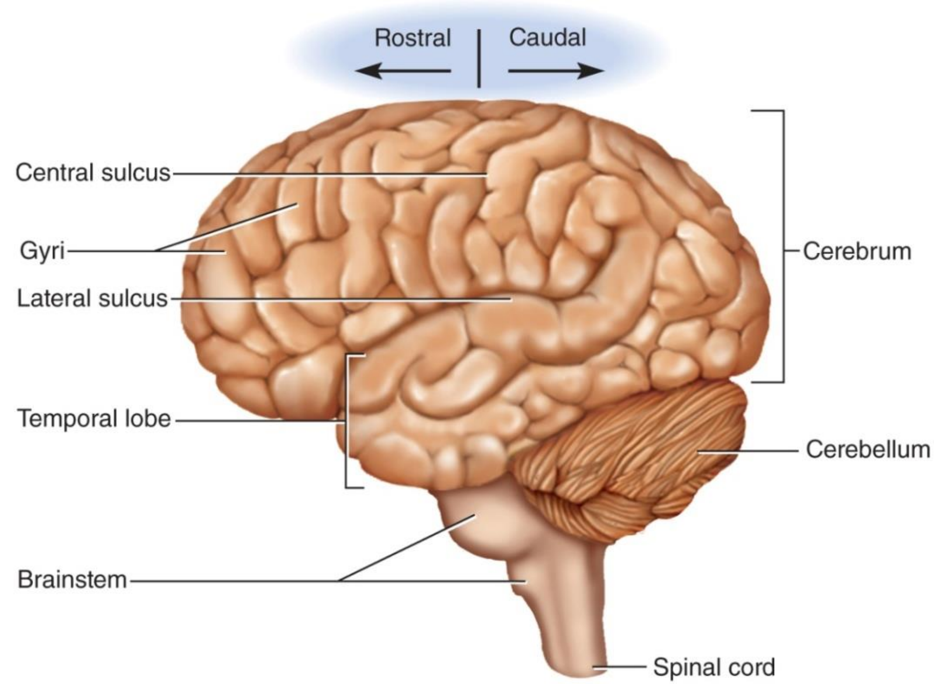


(a) Superior view

Figure 14.1a

Major Landmarks

- **Cerebellum** occupies **posterior cranial fossa**
- **Also has gyri, sulci, and fissures**
  - Separated from cerebrum by transverse cerebral fissure
- **About 10% of brain volume**
- **Contains over 50% of brain neurons**

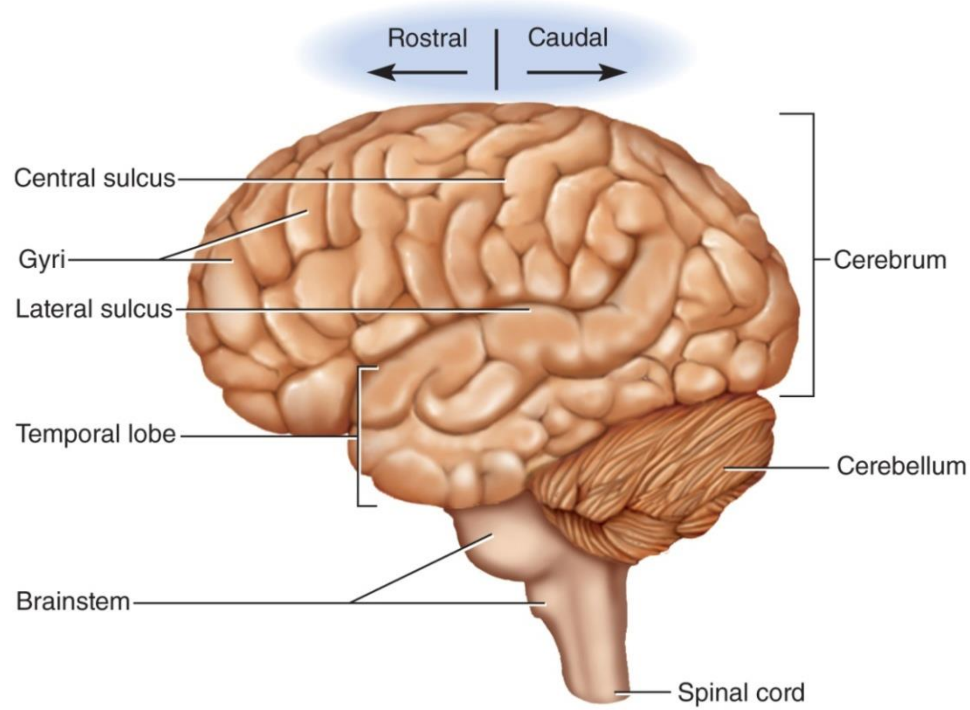


(b) Lateral view

Figure 14.1b

Major Landmarks

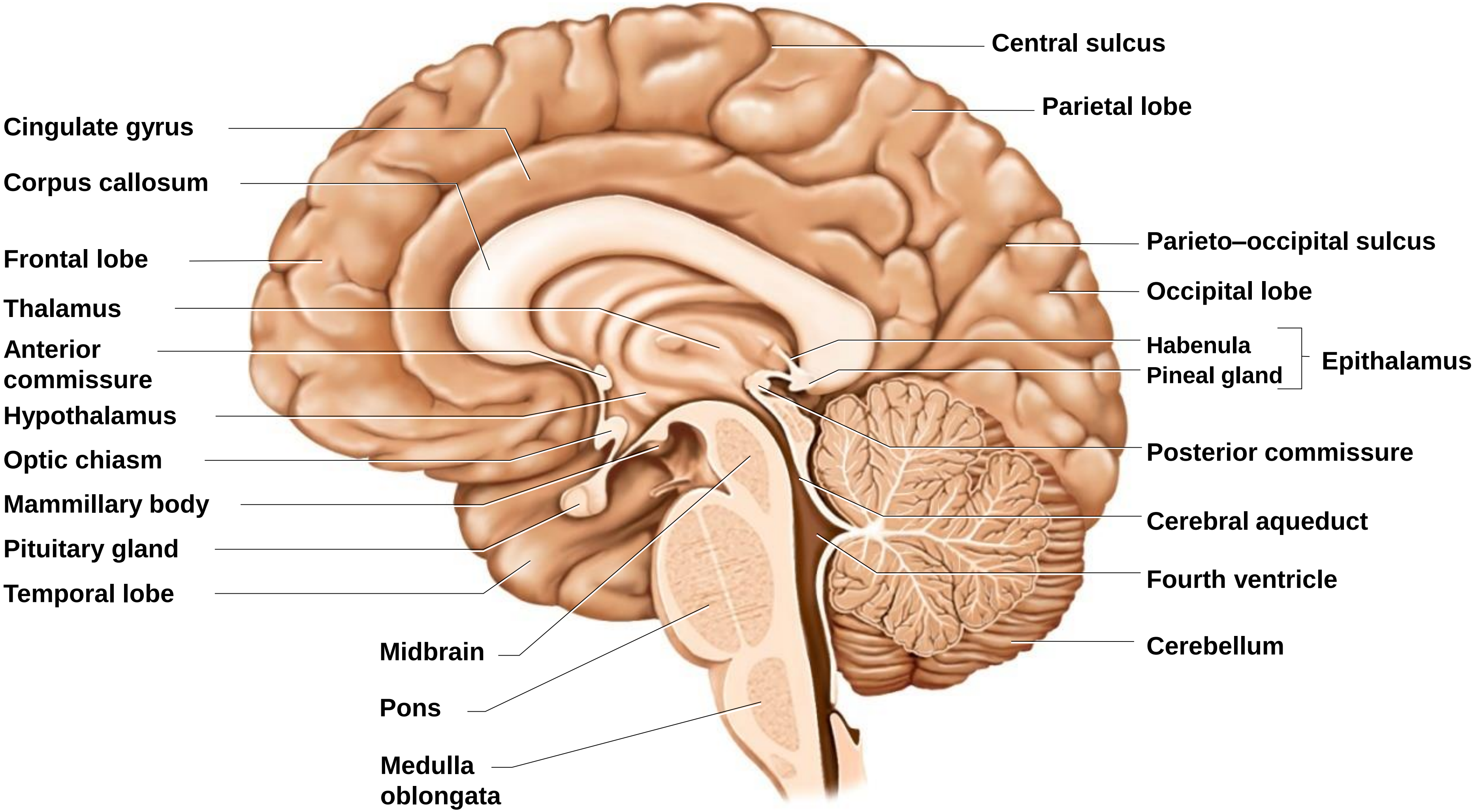
- **Brainstem**—what remains of the brain if the cerebrum and cerebellum are removed
- **Major components**
  - **Diencephalon**
  - **Midbrain**
  - **Pons**
  - **Medulla oblongata**



(b) Lateral view

Figure 14.1b

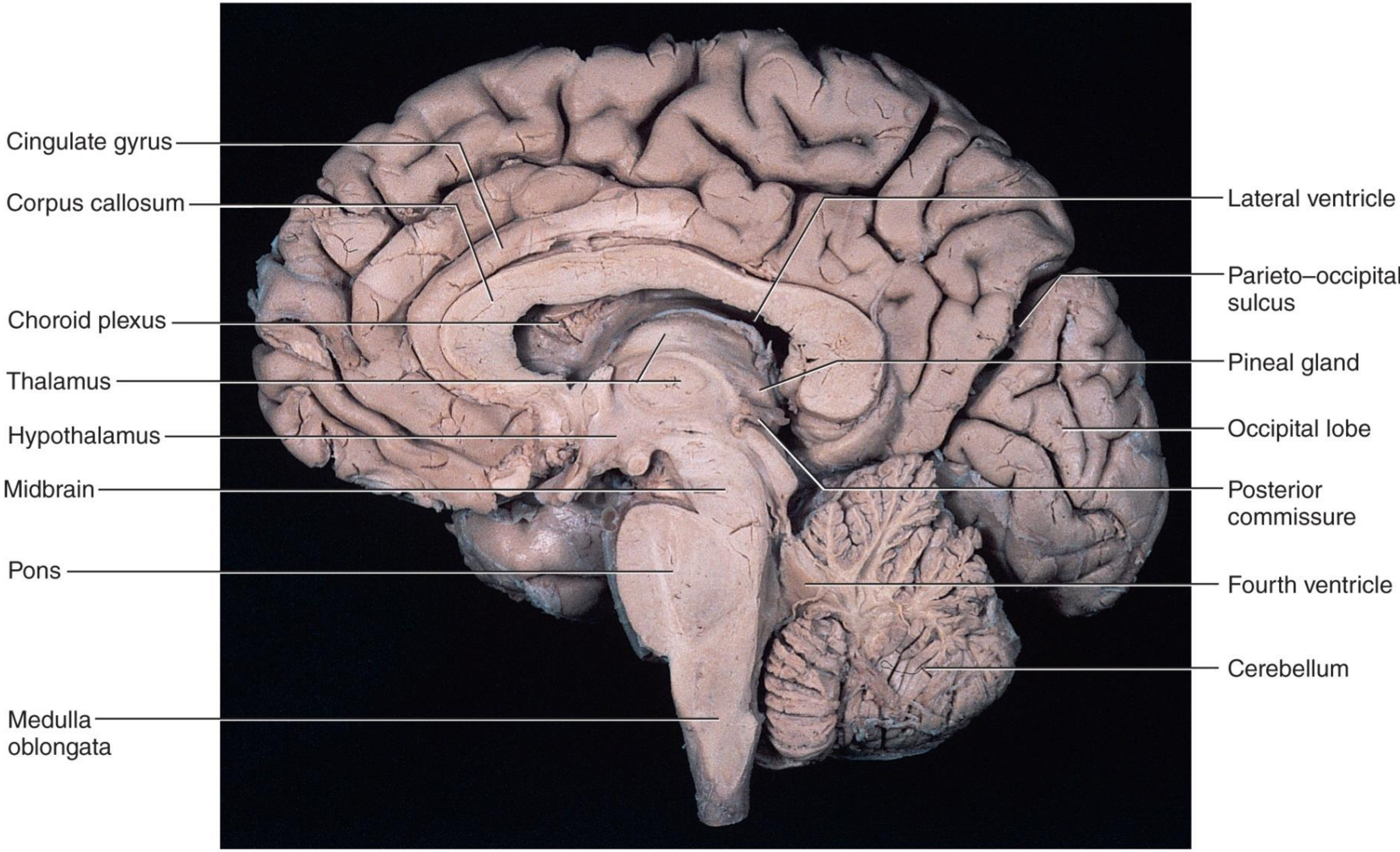
Major Landmarks



(a)

Figure 14.2a

Major Landmarks



(b)

Figure 14.2b

Gray and White Matter

- **Gray matter**—the seat of neurosomas, dendrites, and synapses
  – Dull color due to little myelin
  – Forms surface layer **(cortex)** over cerebrum and cerebellum
  – Forms **nuclei** deep within brain

- **White matter**—bundles of axons
  – Lies **deep to cortical gray matter,** opposite relationship in the spinal cord
  – Pearly white color from **myelin** around nerve fibers
  – Composed of **tracts,** or bundles of axons, that connect one part of the brain to another, and to the spinal cord

Embryonic Development

- Nervous system develops from **ectoderm**
  - Outermost tissue layer of the embryo
- **Early in third week of development**
  - Dorsal midline of embryo thickens to form **neural plate**
- **As thickening progresses, neural plate sinks and its edges thicken**
  - Forms a **neural groove** with a raised **neural fold** on each side
  - Neural folds fuse, creating a hollow **neural tube** by day 26
    - Lumen of neural tube becomes fluid-filled space that will later be ventricles of brain and central canal of spinal cord

Embryonic Development

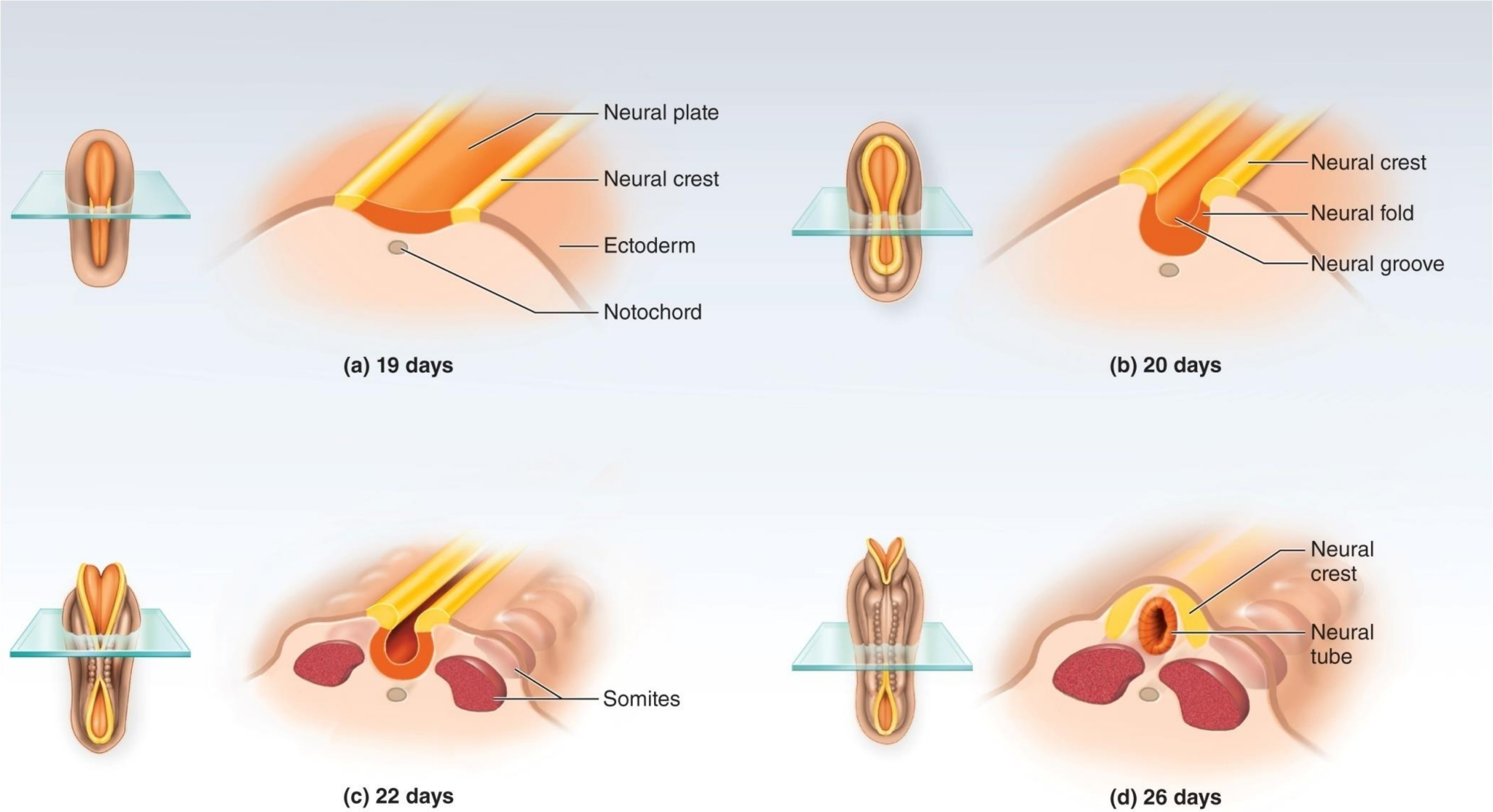


Figure 14.3

Embryonic Development

- **Neural crest**—longitudinal column on each side of neural tube formed from ectodermal
  - Gives rise to the two inner meninges, most of peripheral nervous system, and other structures of skeletal, integumentary, and endocrine systems

- By fourth week, the neural tube exhibits three **primary vesicles** at its anterior end
  - **Forebrain** (prosencephalon)
  - **Midbrain** (mesencephalon)
  - **Hindbrain** (rhombencephalon)

Embryonic Development

- **By fifth week, it subdivides into five secondary vesicles**
  - **Forebrain** divides into two of them
    - **Telencephalon**—becomes cerebral hemispheres
    - **Diencephalon**—has optic vesicles that become retina of the eye
  - **Midbrain** remains undivided
    - **Mesencephalon**
  - **Hindbrain** divides into two vesicles
    - **Metencephalon**
    - **Myelencephalon**

Embryonic Development

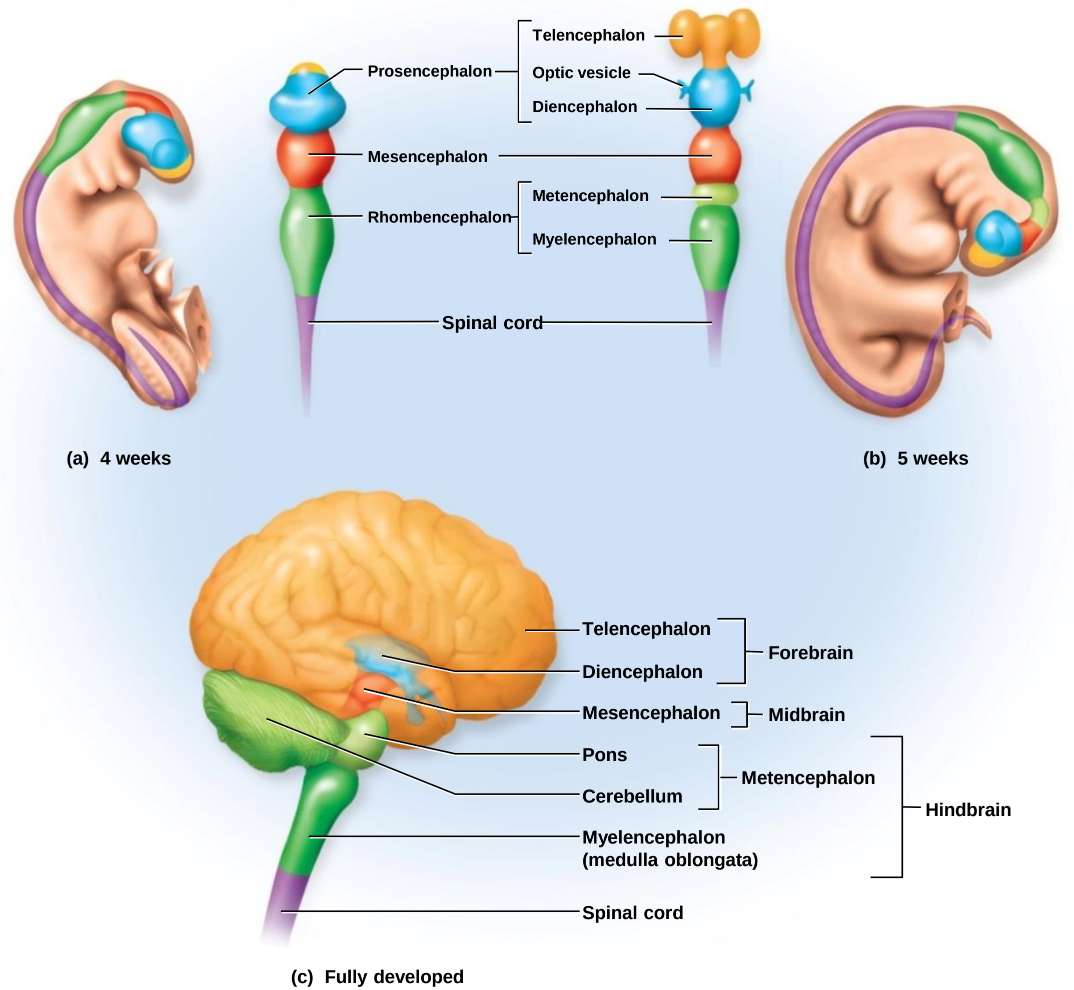


Figure 14.4

Meninges, Ventricles, Cerebrospinal Fluid, and Blood Supply

- **Expected Learning Outcomes**
  - Describe the meninges of the brain.
  - Describe the fluid-filled chambers within the brain.
  - Discuss the production, circulation, and function of the cerebrospinal fluid that fills these chambers.
  - Explain the significance of the brain barrier system.

Meninges

- **Meninges**—three connective tissue membranes that envelop the brain
  - Lie between the nervous tissue and bone
  - As in spinal cord, they are the **dura mater, arachnoid mater,** and the **pia mater**
  - Protect the brain and provide structural framework for its arteries and veins

Meninges

- **Cranial dura mater**
  - Has **two layers**
    - Outer **periosteal**—equivalent to periosteum of cranial bones
    - Inner **meningeal**—continues into vertebral canal and forms dural sheath around spinal cord
    - Layers separated by **dural sinuses**—collect blood circulating through brain
  - Dura mater is pressed closely against cranial bones
    - No epidural space
    - Not directly attached to bone except: around foramen magnum, sella turcica, crista galli, and sutures of the skull
  - Folds inward to extend between parts of brain
    - **Falx cerebri** separates two cerebral hemispheres
    - **Tentorium cerebelli** separates cerebrum from cerebellum
    - **Falx cerebelli** separates right and left halves of cerebellum

Meninges

- **Arachnoid mater and pia mater are similar to those in the spinal cord**
- **Arachnoid mater**
  - Transparent membrane over brain surface
  - **Subarachnoid space** separates it from pia mater below
  - **Subdural space** separates it from dura mater above in some places
- **Pia mater**
  - Very thin membrane that follows contours of brain, even dipping into sulci
  - Not usually visible without a microscope

Meninges

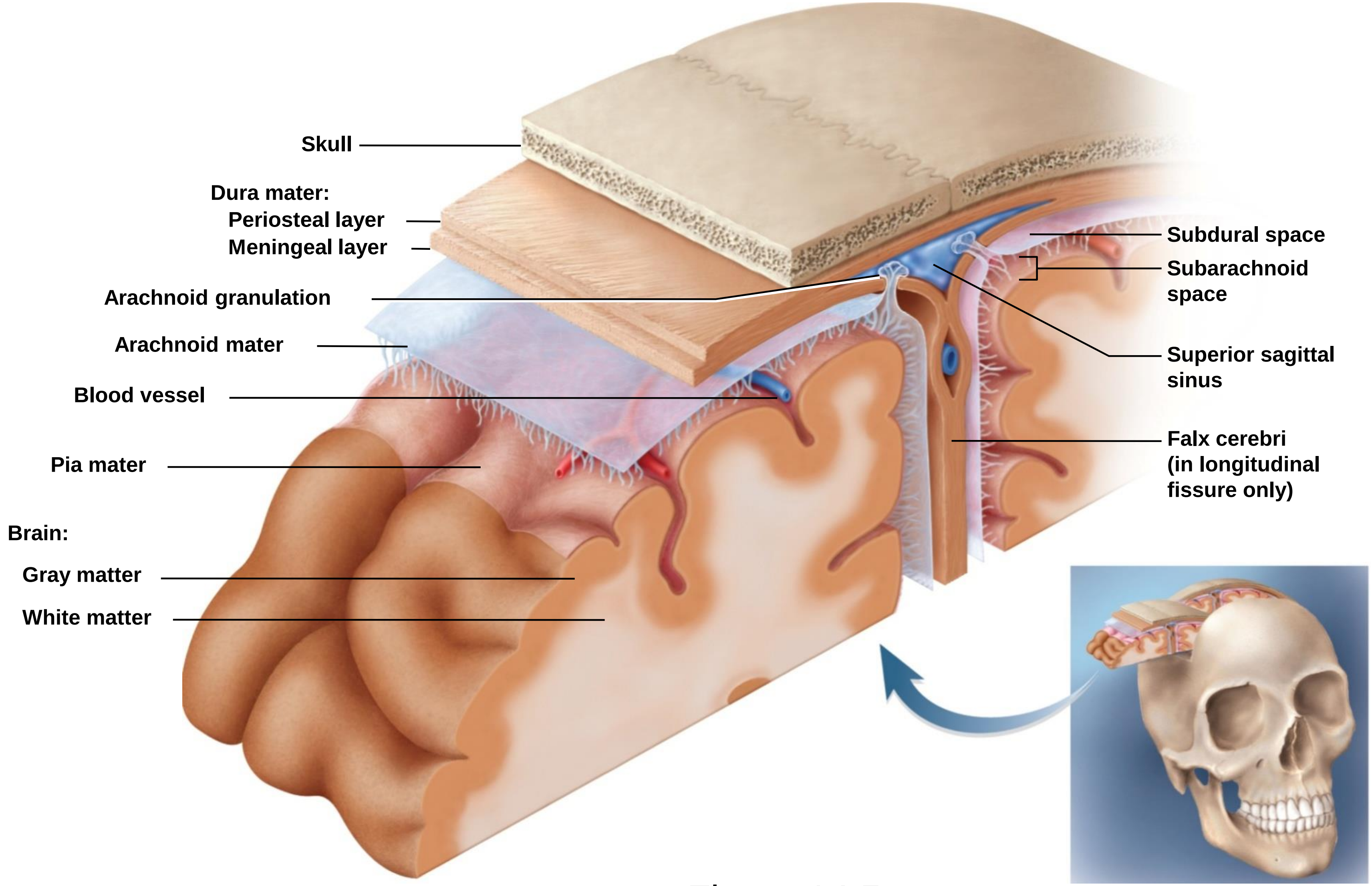
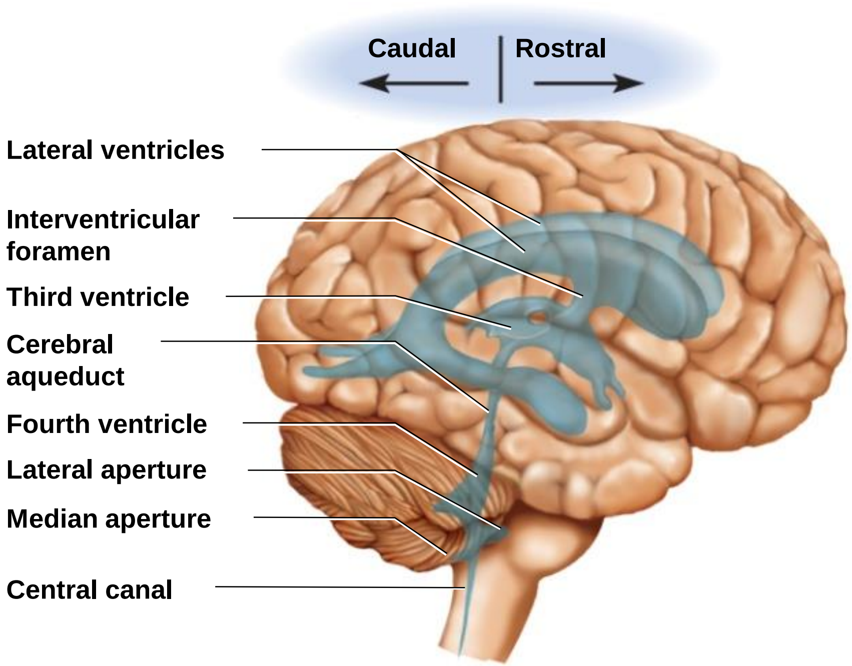


Figure 14.5

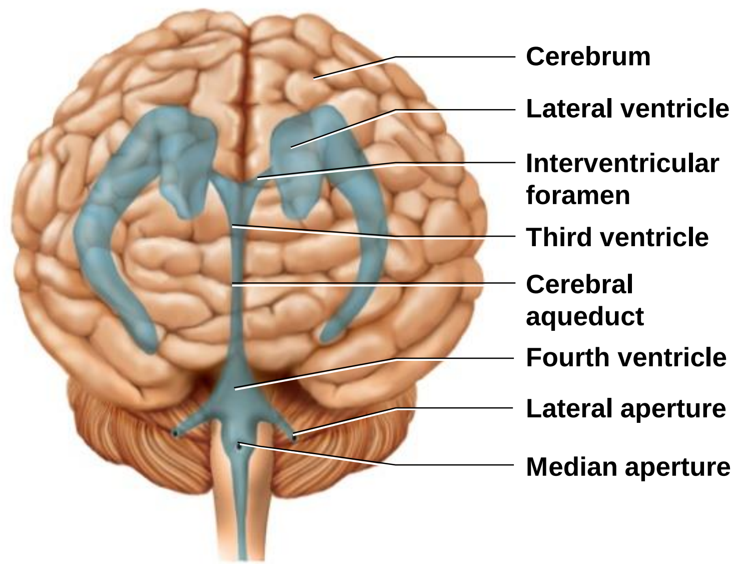
Meningitis

- **Meningitis—**inflammation of the meninges
  - Serious disease of infancy and childhood
  - Especially between 3 months and 2 years of age
- **Caused by bacterial or viral invasion of the CNS by way of the nose and throat**
- **Pia mater and arachnoid are most often affected**
- **Meningitis can cause swelling of the brain, enlargment of the ventricles, and hemorrhage**
- **Signs** include high fever, stiff neck, drowsiness, and intense headache; may progress to coma then death within hours of onset
- **Diagnosed by examining the CSF obtained by lumbar puncture (spinal tap)**

Ventricles and Cerebrospinal Fluid



(a) Lateral view



(b) Anterior view

Figure 14.6a,b

Ventricles and Cerebrospinal Fluid

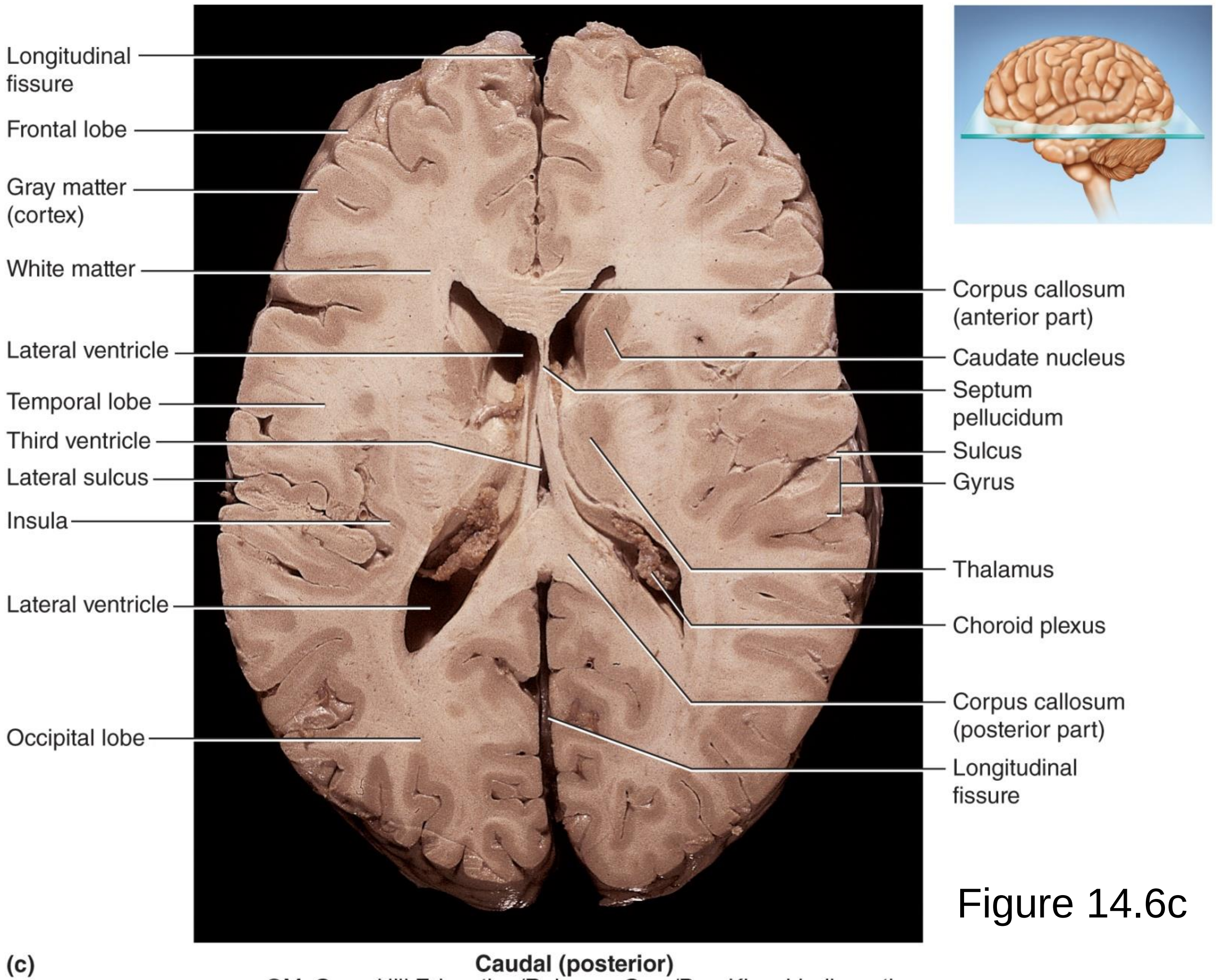


Figure 14.6c

Ventricles and Cerebrospinal Fluid

- **Ventricles**—four internal chambers within brain
  - Two **lateral ventricles:** one in each cerebral hemisphere
    - **Interventricular foramen**—tiny pore that connects to third ventricle
  - **Third ventricle:** narrow medial space beneath corpus callosum
    - **Cerebral aqueduct** runs through midbrain and connects third to fourth ventricle
  - **Fourth ventricle:** small triangular chamber between pons and cerebellum
    - Connects to **central canal** that runs through spinal cord
- **Choroid plexus**—spongy mass of blood capillaries on the floor of each ventricle
- **Ependyma**—type of neuroglia that lines ventricles and covers choroid plexus
  - Produces cerebrospinal fluid

Ventricles and Cerebrospinal Fluid

- **Cerebrospinal fluid (CSF)**—clear, colorless liquid that fills the ventricles and canals of CNS
  - Bathes its external surface
- **Brain produces and absorbs 500 mL/day**
  - 100 to 160 mL normally present at one time
  - 40% formed in subarachnoid space external to brain
  - 30% by the general ependymal lining of the brain ventricles
  - 30% by the choroid plexuses
- **Production begins with filtration of blood plasma through capillaries of the brain**
  - Ependymal cells modify the filtrate, so CSF has more sodium and chloride than plasma, but less potassium, calcium, glucose, and very little protein

Ventricles and Cerebrospinal Fluid

- **CSF continually flows through and around the CNS**
  - Driven by its own pressure, beating of ependymal cilia, and pulsations of the brain produced by each heartbeat

- CSF secreted in **lateral ventricles** flows through **intervertebral foramina** into **third ventricle**

- Then down the **cerebral aqueduct** into the **fourth ventricle**

- **Third and fourth ventricles add more CSF along the way**

Ventricles and Cerebrospinal Fluid

- Small amount of CSF fills **central canal** of spinal cord
- **All CSF ultimately escapes through three pores**
  - **Median aperture** and **two lateral apertures**
  - Leads into **subarachnoid space** of brain and spinal cord surface
- CSF is reabsorbed by **arachnoid granulations**
  - Cauliflower-shaped extension of the **arachnoid meninx**
  - Protrude through dura mater into **superior sagittal sinus**
  - CSF penetrates the walls of the villi and mixes with the blood in the sinus

Ventricles and Cerebrospinal Fluid

- **Functions of CSF**
  - **Buoyancy**
    - Allows brain to attain considerable size without being impaired by its own weight
    - If it rested heavily on floor of cranium, the pressure would kill the nervous tissue
  - **Protection**
    - Protects the brain from striking the cranium when the head is jolted
    - **Shaken child syndrome** and **concussions** do occur from severe jolting
  - **Chemical stability**
    - Flow of CSF rinses away metabolic wastes from nervous tissue and homeostatically regulates its chemical environment

Ventricles and Cerebrospinal Fluid

1. CSF is secreted by choroid plexus in each lateral ventricle.
2. CSF flows through interventricular foramina into third ventricle.
3. Choroid plexus in third ventricle adds more CSF.
4. CSF flows down cerebral aqueduct to fourth ventricle.
5. Choroid plexus in fourth ventricle adds more CSF.
6. CSF flows out two lateral apertures and one median aperture.
7. CSF fills subarachnoid space and bathes external surfaces of brain and spinal cord.
8. At arachnoid villi, CSF is reabsorbed into venous blood of dural venous sinuses.

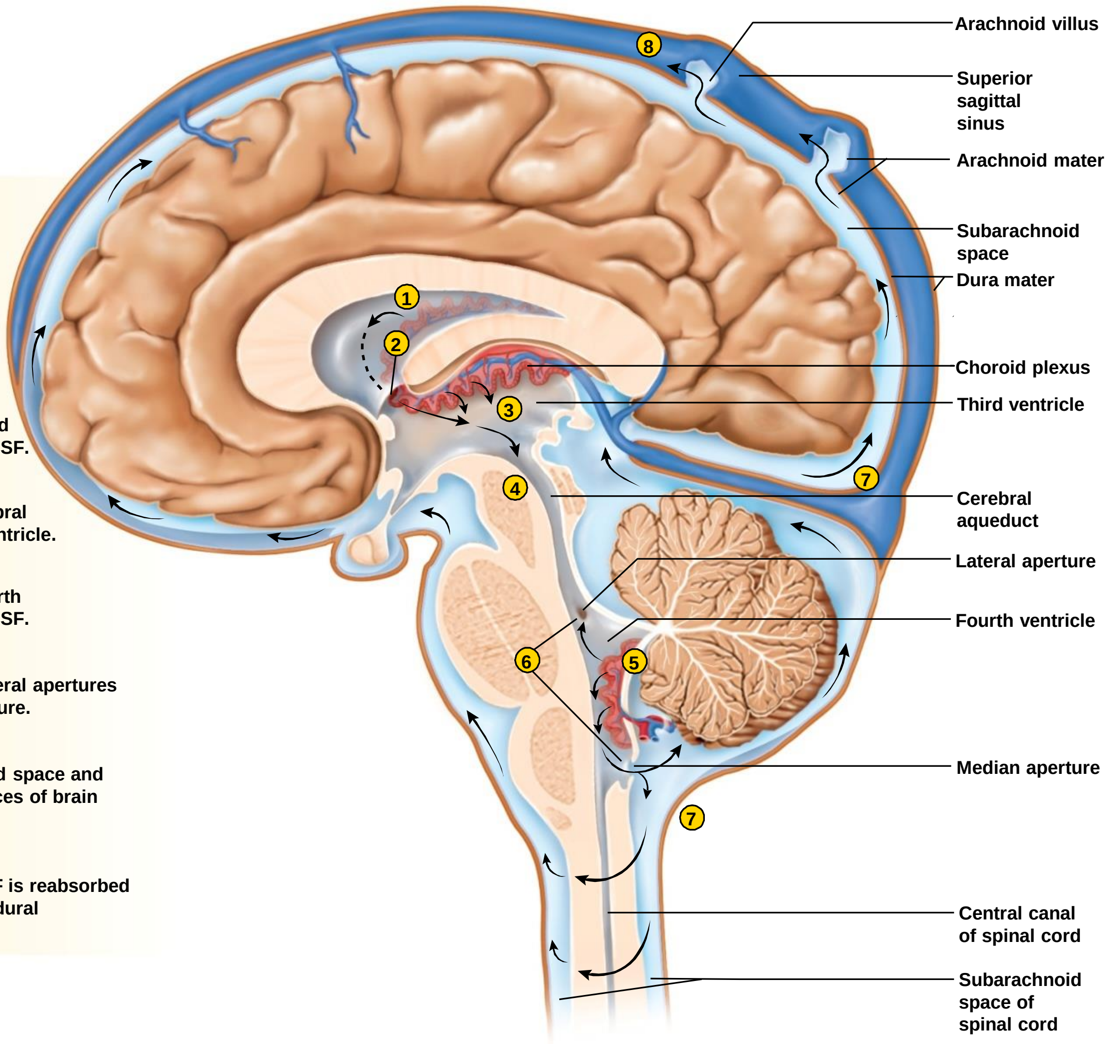


Figure 14.7

Blood Supply and the Brain Barrier System

- **Brain is only 2% of adult body weight, but receives 15% of the blood**
  - 750 mL/min.
- **Neurons have a high demand for ATP, and therefore, oxygen and glucose, so a constant supply of blood is critical**
  - A 10-second interruption of blood flow may cause loss of consciousness
  - A 1 to 2 minute interruption can cause significant impairment of neural function
  - Going 4 minutes without blood causes irreversible brain damage

Blood Supply and the Brain Barrier System

- **Brain barrier system**—regulates what substances can get from bloodstream into tissue fluid of the brain
  - Although blood is crucial, it can also contain harmful agents

- **Two points of entry must be guarded**
  - Blood capillaries throughout the brain tissue
  - Capillaries of the choroid plexus

Blood Supply and the Brain Barrier System

- **Blood–brain barrier**—protects blood capillaries throughout brain tissue
  - Consists of tight junctions between endothelial cells that form the capillary walls
  - **Astrocytes** reach out and contact capillaries with their perivascular feet
    - Induce the endothelial cells to form tight junctions that completely seal off gaps between them
  - Anything leaving the blood must pass through the cells, and not between them
  - **Endothelial cells** can exclude harmful substances from passing to the brain tissue while allowing necessary ones to pass

Blood Supply and the Brain Barrier System

- **Blood–CSF barrier**—protects brain at the choroid plexus
  - Forms tight junctions between the ependymal cells
  - Tight junctions are absent from ependymal cells elsewhere
    - Important to allow exchange between brain tissue and CSF
- **Brain barrier system** is **highly permeable** to water, glucose, and lipid-soluble substances such as oxygen, carbon dioxide, alcohol, caffeine, nicotine, and anesthetics
- **Slightly permeable** to sodium, potassium, chloride, and the waste products urea and creatinine

Blood Supply and the Brain Barrier System

- **The brain barrier system (BBS) can be an obstacle for delivering medications such as antibiotics and cancer drugs**

- **Trauma and inflammation can damage BBS and allow pathogens to enter brain tissue**
  - **Circumventricular organs (CVOs)**—places in the third and fourth ventricles where the barrier is absent
    - Blood has direct access to the brain
    - Enables the brain to monitor and respond to fluctuations in blood glucose, pH, osmolarity, and other variables
    - CVOs afford a route for invasion by the human immunodeficiency virus (HIV)

The Hindbrain and Midbrain

- **Expected Learning Outcomes**
  - List the components of the hindbrain and midbrain and their functions.
  - Describe the location and functions of the reticular formation.

The Medulla Oblongata

- **Medulla oblongata** comes from embryonic **myelencephalon**
- Begins at **foramen magnum** of skull
- **Extends about 3 cm rostrally and ends at a groove just below pons**
- **Slightly wider than spinal cord**

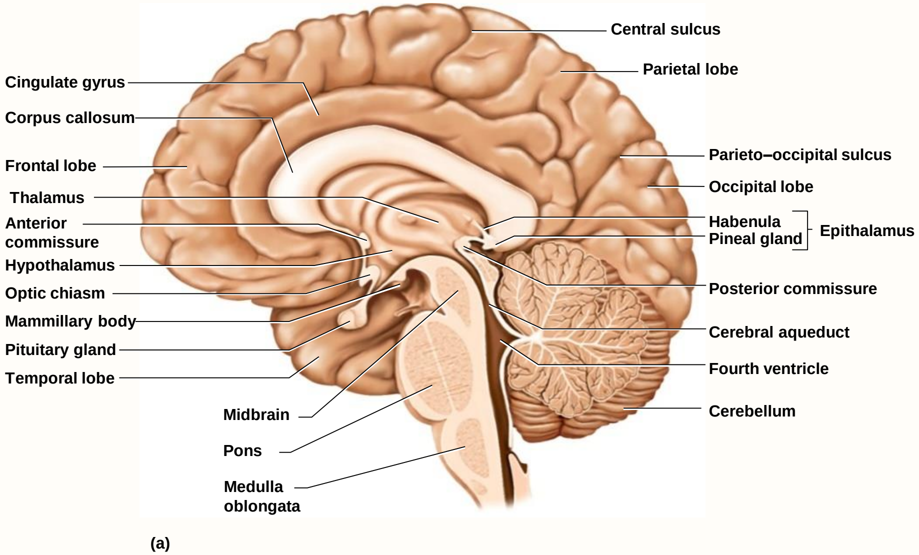
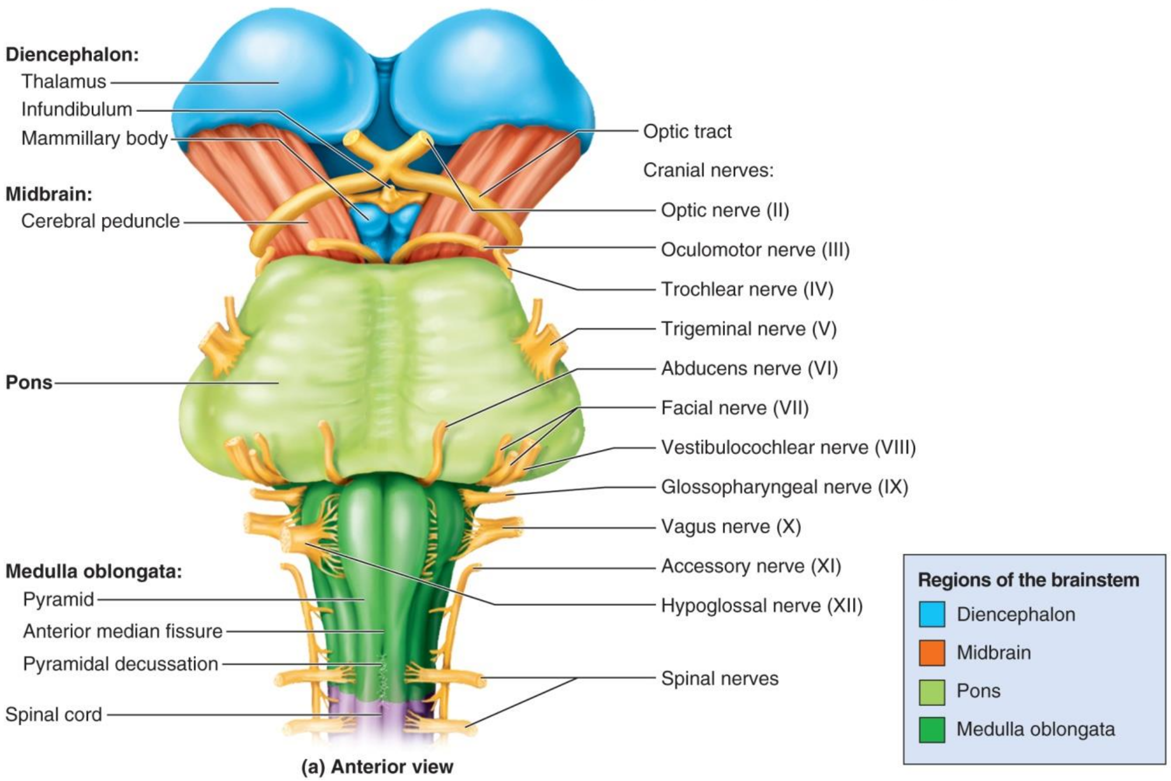


Figure 14.2a

The Medulla Oblongata



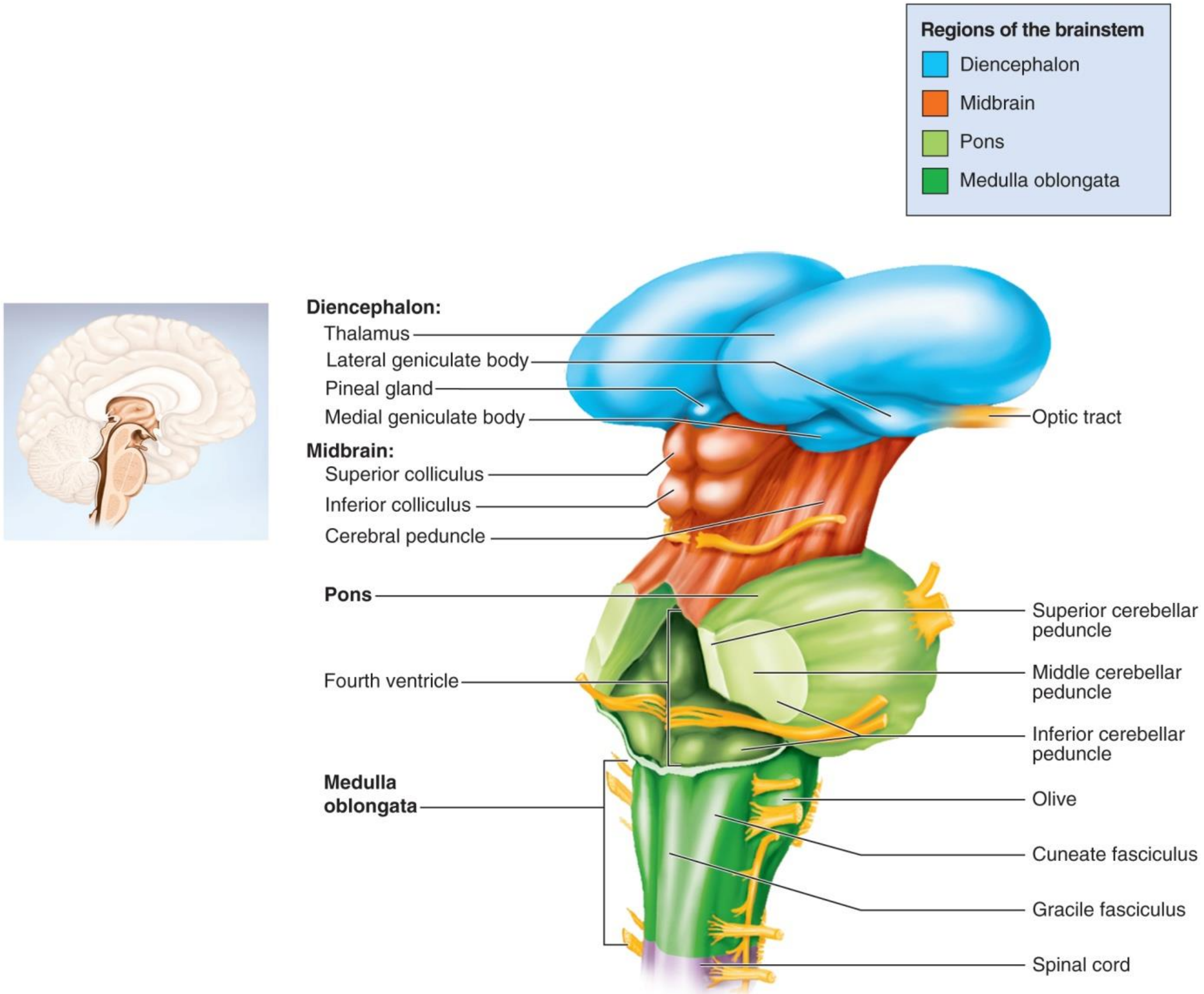
(a) Anterior view

Figure 14.8a

- **Pyramids**—pair of ridges on anterior surface resembling side-by-side baseball bats
  - Separated by anterior median fissure
- Four pairs of **cranial nerves** begin or end in medulla—VIII (in part), IX, X, and XII

The Medulla Oblongata

- **Olives**—prominent bulges lateral to each pyramid
- **Gracile** and **cuneate fasciculi** of spinal cord continue as two pair of ridges on posterior medulla

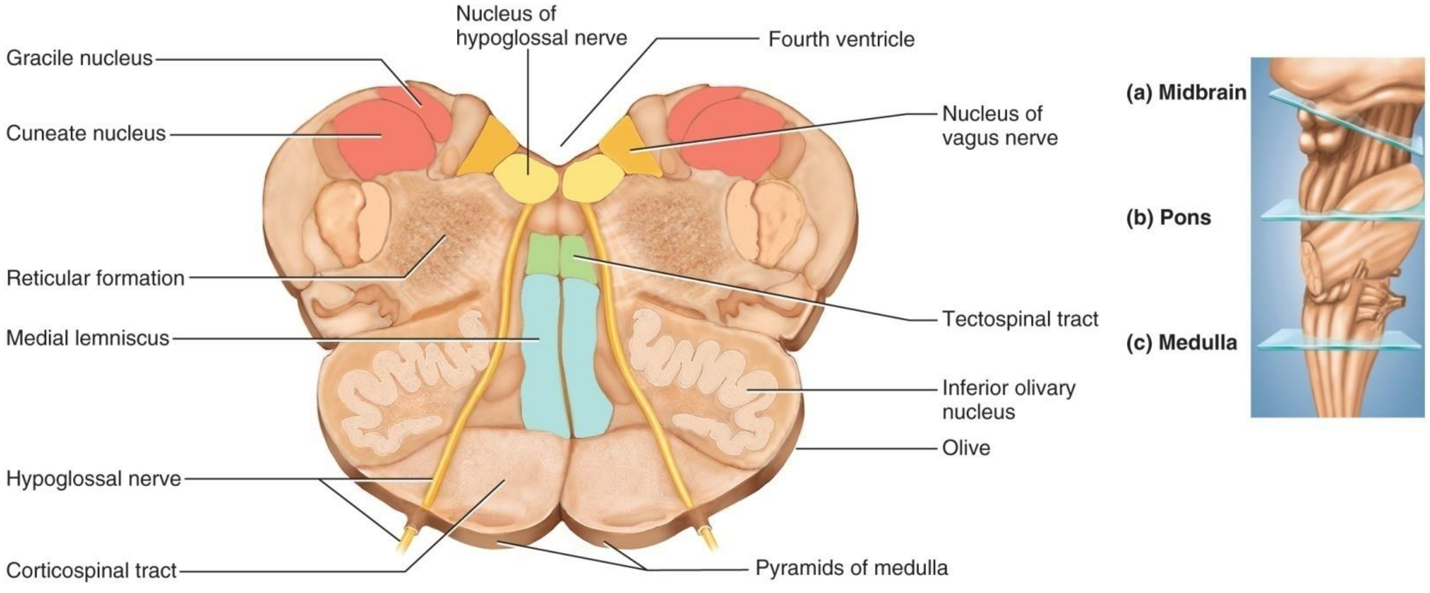


(b) Posterolateral view

Figure 14.8b

The Medulla Oblongata

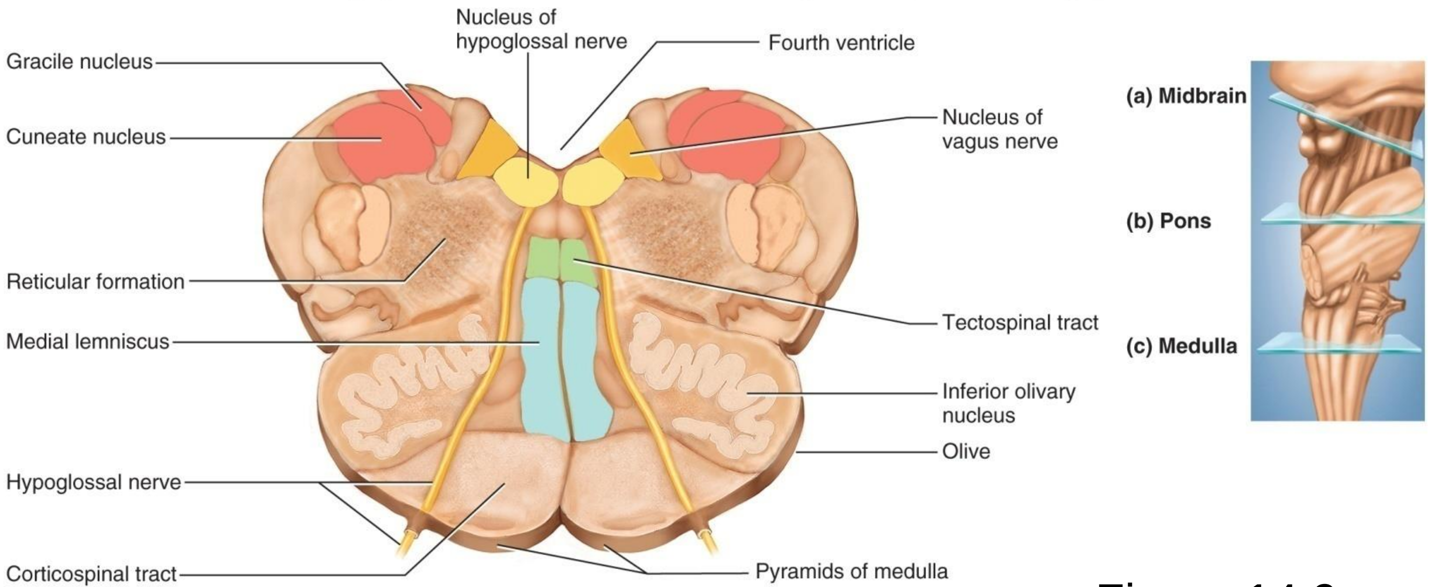
- **All ascending and descending fibers connecting brain and spinal cord pass through medulla**
- **Medulla houses somas of second order sensory neurons in gracile and cuneate nuclei**
  - Their axons decussate and form medial lemniscus



(c) Medulla oblongata

Figure 14.9c

The Medulla Oblongata



(c) Medulla oblongata

Figure 14.9c

- **Pyramids** contain descending fibers called corticospinal tracts
  - Carry motor signals to skeletal muscles
- **Inferior olivary nucleus**—relay center for signals to cerebellum
- **Reticular formation**—loose network of nuclei extending throughout the medulla, pons, and midbrain
  - Contains cardiac, vasomotor, and respiratory centers

The Pons

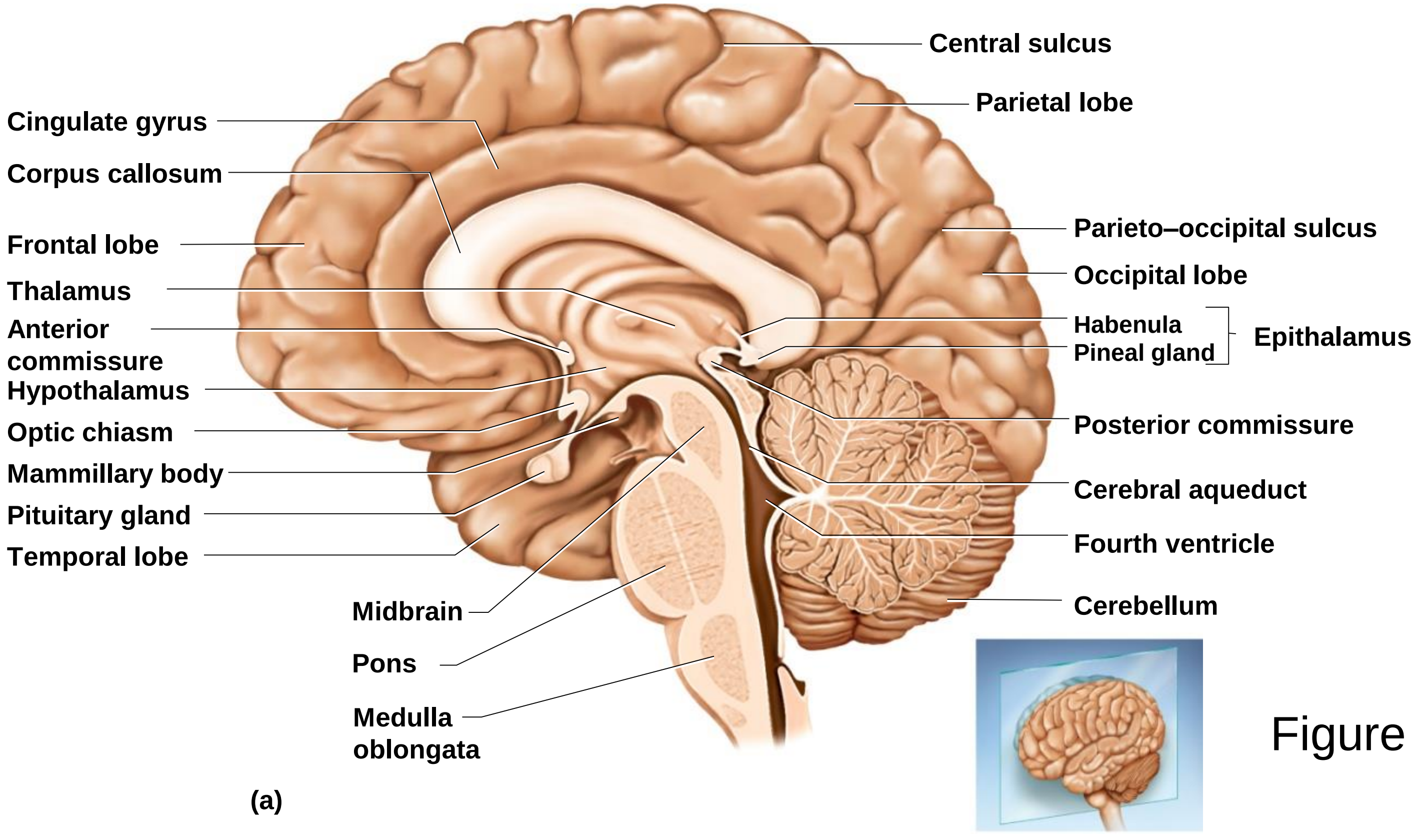


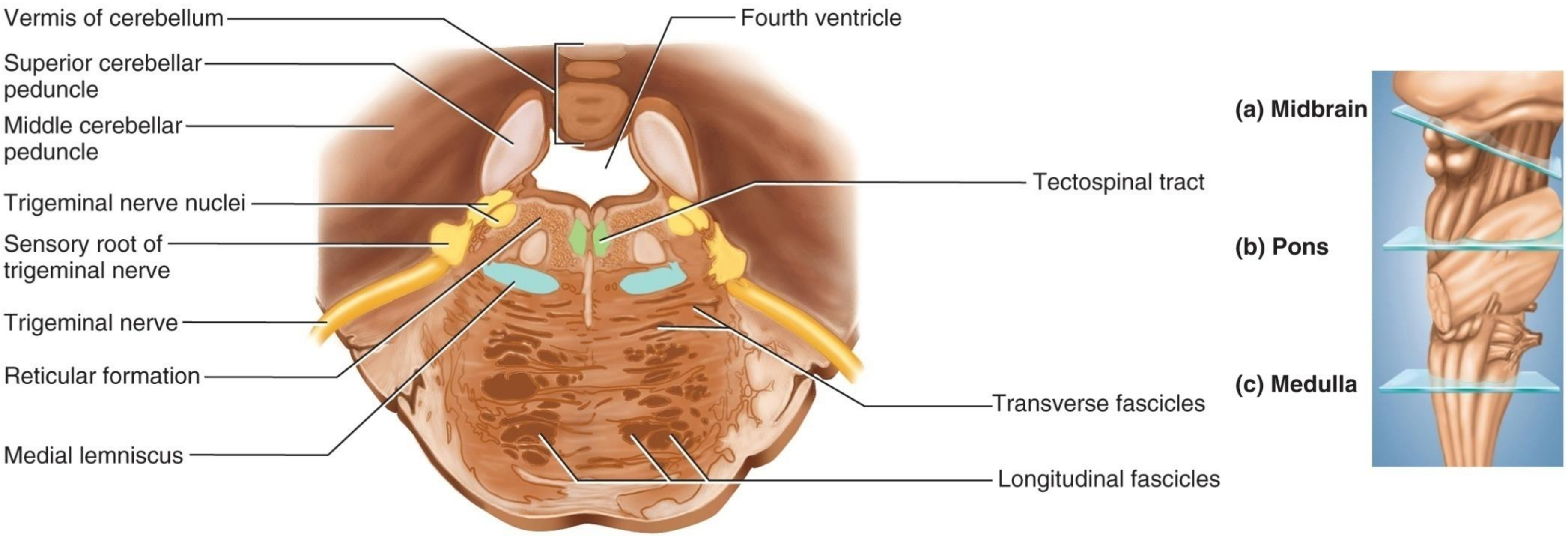
Figure 14.2a

- **Pons**—anterior bulge in brainstem, rostral to medulla
  - Develops from metencephalon
- **Cerebellar peduncles**—thick stalks on posterior pons that connect it (and the midbrain) to the cerebellum

The Pons

- **Ascending sensory tracts**
- **Descending motor tracts**
- **Pathways in and out of cerebellum**
- **Cranial nerves V, VI, VII, and VIII**
  - **Sensory roles:** hearing, equilibrium, taste, facial sensations
  - **Motor roles:** eye movement, facial expressions, chewing, swallowing, urination, and secretion of saliva and tears
- **Reticular formation** in pons contains additional nuclei concerned with sleep, respiration, posture

The Pons



(b) Pons

Figure 14.9b

The Midbrain

- **Mesencephalon** becomes one mature brain structure, the **midbrain**
  - Short segment of brainstem that connects hindbrain to forebrain
  - Contains **cerebral aqueduct**
    - Surrounded by **central gray matter** involved in controlling pain
  - Contains continuations of **medial lemniscus** and **reticular formation**
  - Contains motor nuclei of **two cranial nerves** that control eye movements: CN III (oculomotor) and CN IV (trochlear)

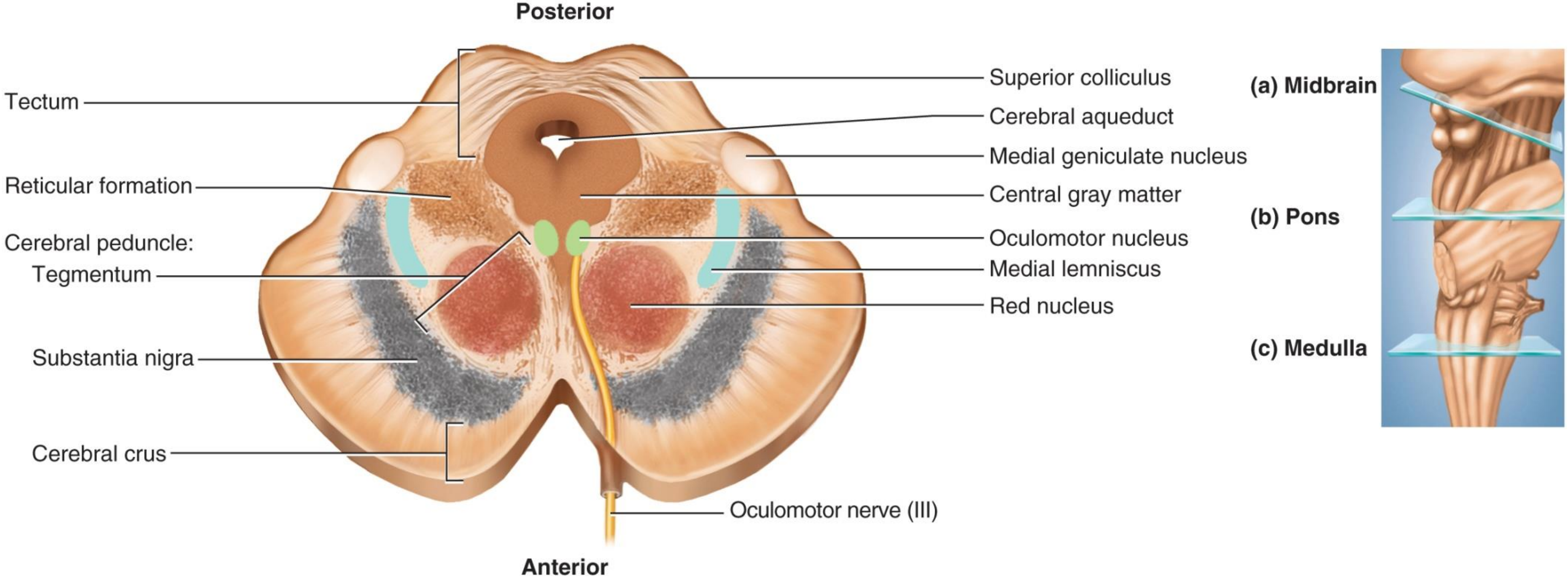
The Midbrain

- **Mesencephalon**
  - **Tectum:** roof-like part of the midbrain posterior to cerebral aqueduct
    - Exhibits four bulges, the **corpora quadrigemina**
      - Upper pair, the **superior colliculi,** function in visual attention, tracking moving objects, and some reflexes
      - Lower pair, the **inferior colliculi,** receives signals from the inner ear and relays them to other parts of the brain, especially the thalamus
  - **Cerebral peduncles:** two anterior midbrain stalks that anchor the cerebrum to the brainstem
    - Each peduncle has three parts: **tegmentum, substantia nigra,** and **cerebral crus**

Cerebral Peduncles of the Midbrain

- **Tegmentum**
  - Dominated by **red nucleus**
    - Pink color due to high density of blood vessels
    - Connections go to and from cerebellum for motor control
- **Substantia nigra**
  - Black nucleus pigmented with **melanin**
  - Motor center that relays inhibitory signals to thalamus and basal nuclei preventing unwanted body movement
  - Degeneration of neurons leads to tremors of Parkinson disease
- **Cerebral crus**
  - Bundle of nerve fibers that connect cerebrum to pons
  - Carries **corticospinal tracts**

The Midbrain



(a) Midbrain

Figure 14.9a

The Reticular Formation

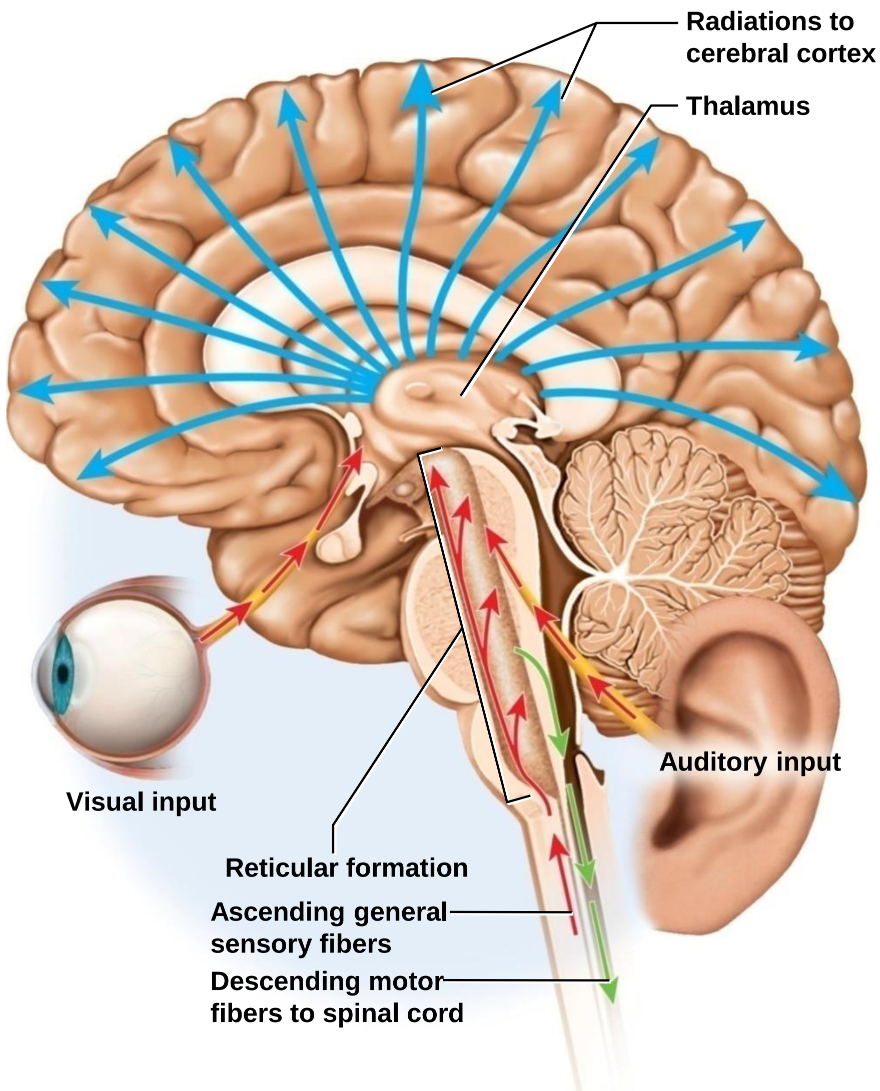


Figure 14.10

- **Loose web of gray matter that runs vertically through all levels of the brainstem**
- **Occupies space between white fiber tracts and brainstem nuclei**
- **Has connections** with many areas of cerebrum
  - More than 100 small neural networks without distinct boundaries

The Reticular Formation

- **Functions of networks**
  - **Somatic motor control**
    - Adjust muscle tension to maintain tone, balance, and posture, especially during body movements
    - Relay signals from eyes and ears to cerebellum
    - Integrate visual, auditory, balance and motion stimuli into motor coordination
    - **Gaze centers**—allow eyes to track and fixate on objects
    - **Central pattern generators**—neural pools that produce rhythmic signals to the muscles of breathing and swallowing

The Reticular Formation

Functions of networks (continued)

- **Cardiovascular control**
  - Cardiac and vasomotor centers of medulla oblongata

- **Pain modulation**
  - Some pain signals ascend through the reticular formation
  - Some descending analgesic pathways begin in the reticular formation
    - They end in the spinal cord where they block transmission of pain signals

The Reticular Formation

Functions of networks (continued)

- **Sleep and consciousness**
  - Reticular formation plays a central role in consciousness, alertness and sleep
  - Injury here can result in irreversible coma
- **Habituation**
  - **Reticular activating system** modulates activity in cerebral cortex so that it ignores repetitive, inconsequential stimuli

The Cerebellum

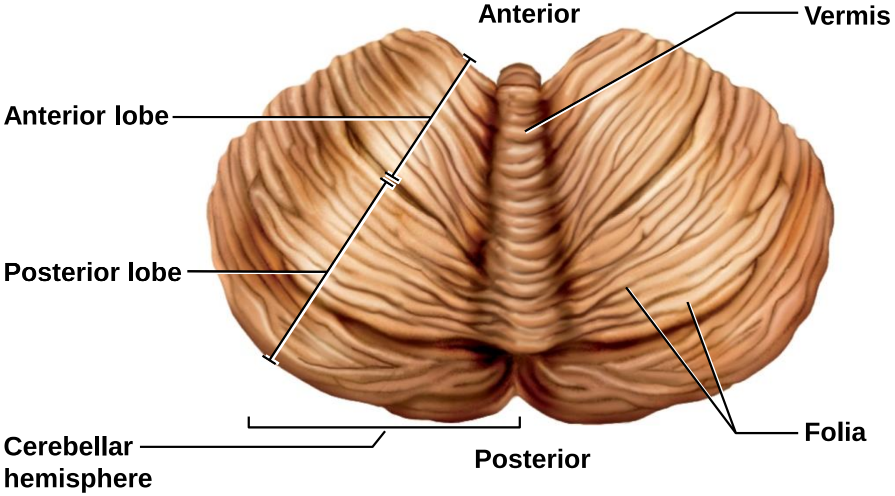


Figure 14.11b

(b) Superior view

- **Cerebellum is largest part of hindbrain and second largest part of the brain as a whole**
- Consists of right and left cerebellar hemispheres connected by **vermis**
- Superficial cortex of gray matter with folds (**folia**), branching white matter (**arbor vitae**), and **deep nuclei**
- **Contains more than half of all brain neurons—about 100 billion**
  - Many small **granule cells**
  - Large **Purkinje cells** have axons that synapse on deep nuclei

The Cerebellum

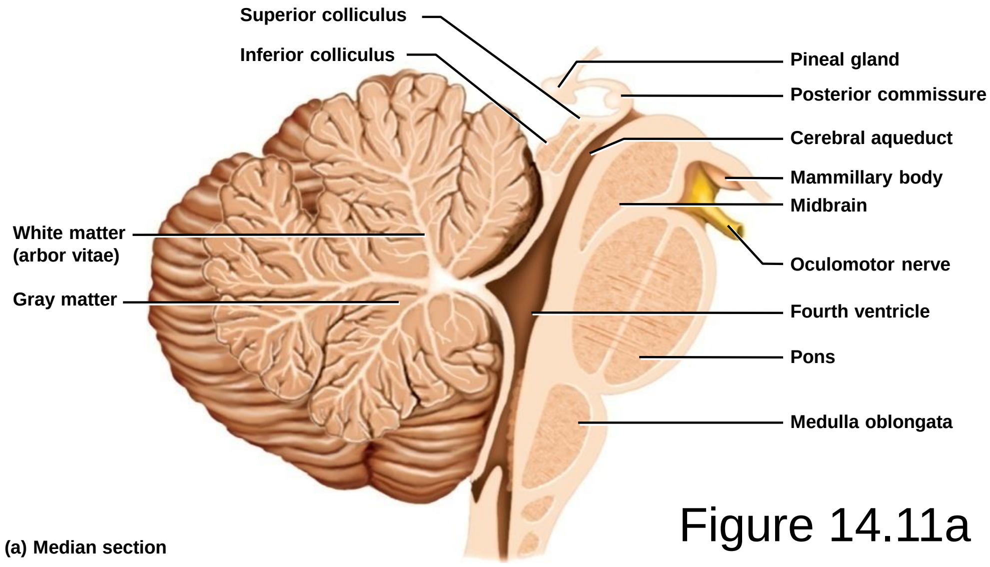


Figure 14.11a

- **Cerebellar peduncles**—three pairs of stalks that connect brainstem and cerebellum (their fibers carry signals to and from cerebellum)
  - **Inferior peduncles:** connected to medulla oblongata
    - Most spinal input enters the cerebellum through inferior peduncle
  - **Middle peduncles:** connected to pons
    - Most input from rest of the brain enters through middle peduncle
  - **Superior peduncles:** connected to the midbrain
    - Carries cerebellar output

The Cerebellum

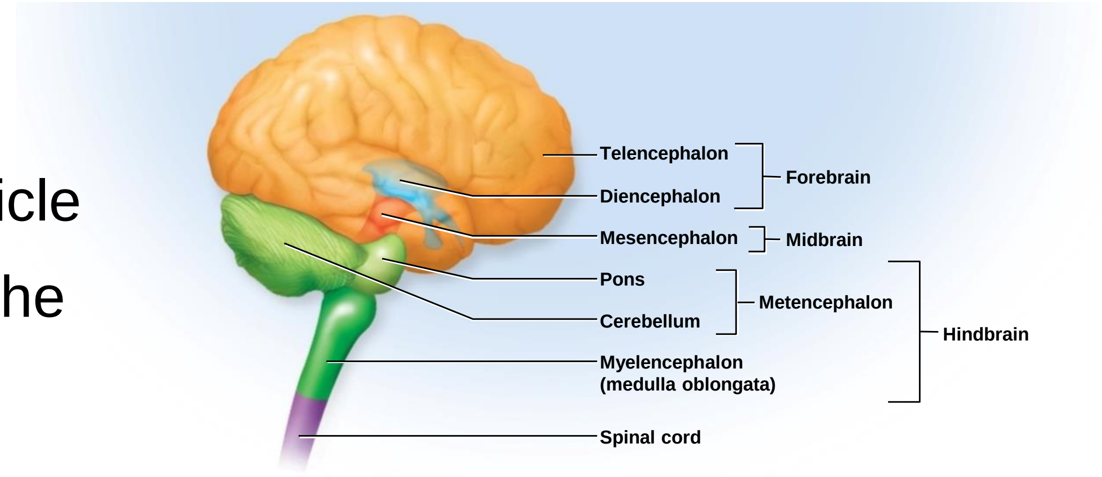
- **Cerebellum has long been known to be important for motor coordination and locomotor ability**
- **Recent studies have revealed several sensory, linguistic, emotional, and other nonmotor functions**
  - Comparing textures of objects
  - Perceiving space (as tested by pegboard puzzles)
  - Recognizing objects from different views
  - Keeping judge of elapsed time and maintaining tapping rhythm
  - Helping direct eye movements that compensate for head movements (so that gaze stays on a fixed object)
  - Judging the pitch of tones and distinguishing between similar spoken words
  - Helping in verbal association tasks
  - Planning, scheduling, and emotion control
    - Many hyperactive children have small cerebellums

The Forebrain

- **Expected Learning Outcomes**
  - Name the three major components of the diencephalon and describe their locations and functions.
  - Identify the five lobes of the cerebrum and their functions.
  - Identify the three types of tracts in the cerebral white matter.
  - Describe the distinctive cell types and histological arrangement of the cerebral cortex.
  - Describe the location and functions of the basal nuclei and limbic system.

The Forebrain

- **Forebrain consists of two parts**
  - **Diencephalon**
    - Encloses third ventricle
    - Most rostral part of the brainstem
  - **Telencephalon**
    - Develops chiefly into the **cerebrum**

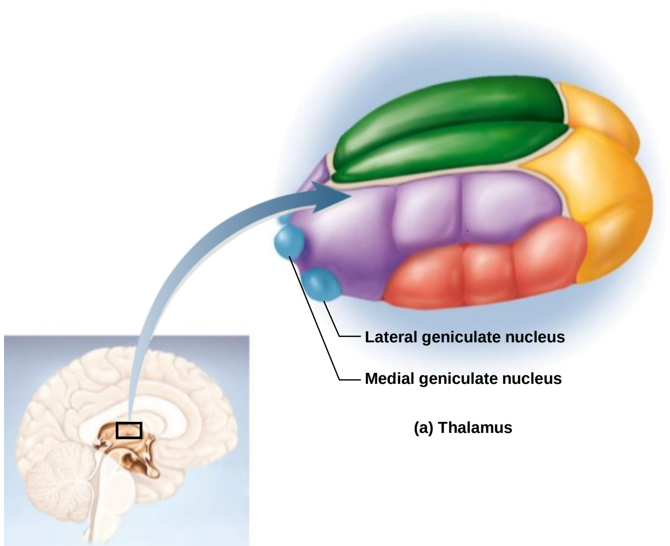


(c) Fully developed

Figure 14.4c

The Diencephalon

- **Diencephalon has three parts: thalamus, hypothalamus, epithalamus**



(a) Thalamus

Thalamic Nuclei	
Anterior group	Part of limbic system; memory and emotion
Medial group	Emotional output to prefrontal cortex; awareness of emotions
Ventral group	Somesthetic output to postcentral gyrus; signals from cerebellum and basal nuclei to motor areas of cortex
Lateral group	Somesthetic output to association areas of cortex; contributes to emotional function of limbic system
Posterior group	Relay of visual signals to occipital lobe (via lateral geniculate nucleus) and auditory signals to temporal lobe (via medial geniculate nucleus)

Figure 14.12a

- **Thalamus**—ovoid mass on each side of the brain perched at the superior end of the brainstem beneath the cerebral hemispheres
  - Constitutes about four-fifths of the diencephalon
  - **Two thalami** are joined medially by a narrow **intermediate mass**
  - Composed of at least 23 nuclei within five major functional groups

The Diencephalon: Thalamus

- **Thalamus (continued)**
  - **"Gateway to the cerebral cortex":** nearly all input to the cerebrum passes by way of synapses in the thalamic nuclei, filters information on its way to cerebral cortex
  - Plays key role in **motor control** by relaying signals from cerebellum to cerebrum and providing feedback loops between the cerebral cortex and the basal nuclei
  - Involved in the **memory** and **emotional functions** of the **limbic system:** a complex of structures that include some cerebral cortex of the temporal and frontal lobes and some of the anterior thalamic nuclei

The Diencephalon: Hypothalamus

- **Hypothalamus**—forms part of the walls and floor of the third ventricle
- Extends anteriorly to optic chiasm and posteriorly to **mammillary bodies**
- Each mammillary body contains three or four **mammillary nuclei**
  – Relay signals from the limbic system to the thalamus
- **Infundibulum—stalk attaching pituitary to hypothalamus**

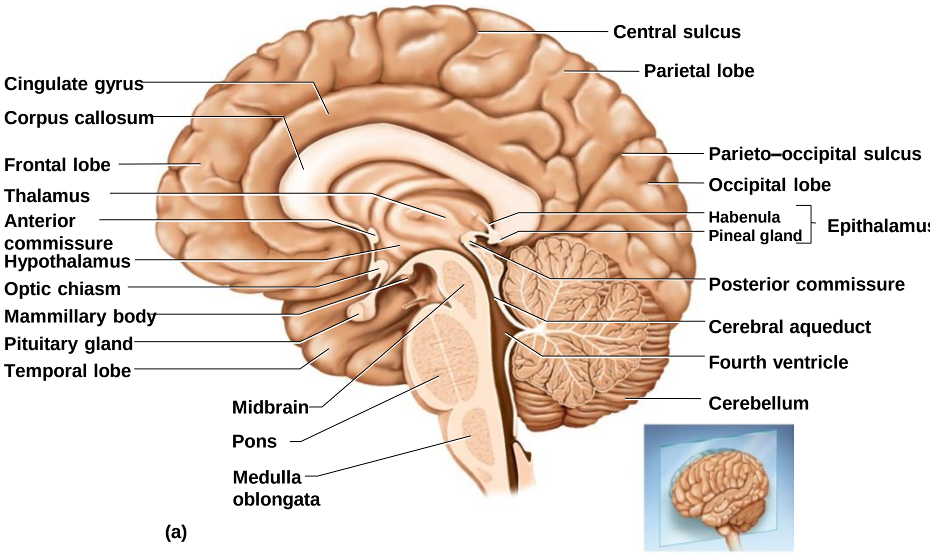


Figure 14.2a

The Diencephalon: Hypothalamus

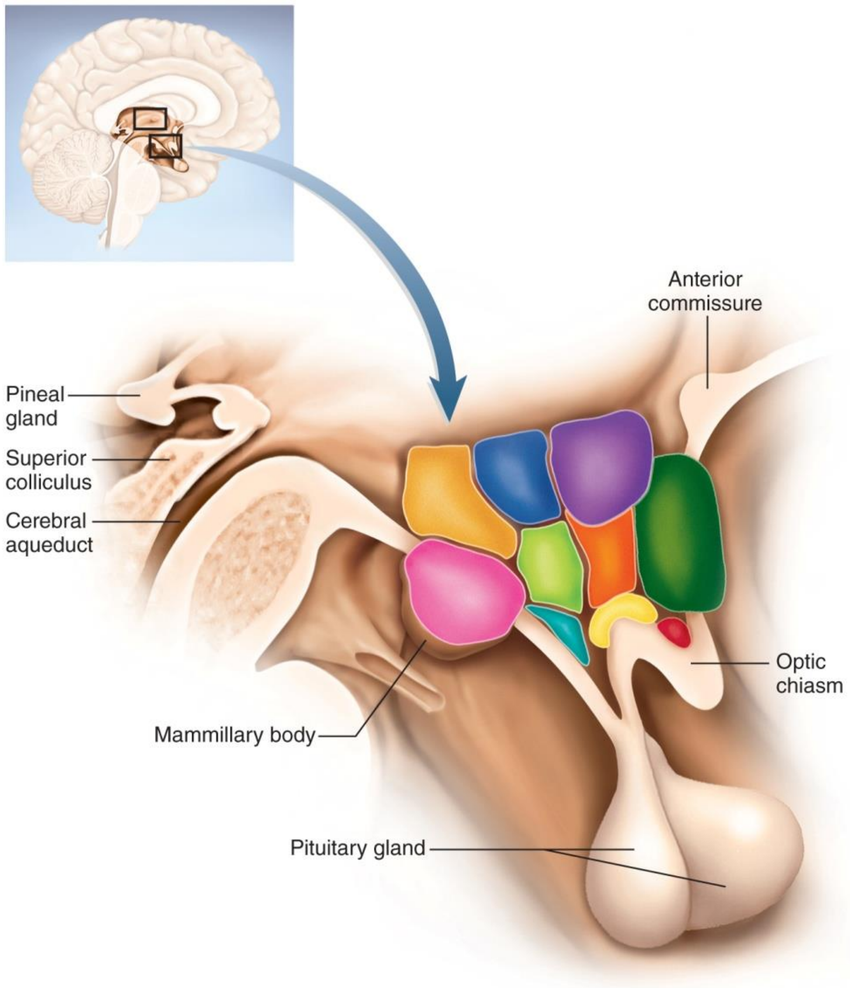
- Hypothalamus is a major control center of **autonomic** nervous system and **endocrine** system
  - Plays essential role in homeostatic regulation of all body systems

- **Functions of hypothalamic nuclei**
  - **Hormone secretion**
    - Controls anterior pituitary, thereby regulating growth, metabolism, reproduction, and stress responses
    - Produces posterior pituitary hormones for labor contractions, lactation, and water conservation
  - **Autonomic effects**
    - Major integrating center for autonomic nervous system
    - Influences heart rate, blood pressure, gastrointestinal secretions, motility, etc.

The Diencephalon: Hypothalamus

- **Hypothalamic functions include:**
  - **Thermoregulation**
    - Hypothalamic thermostat monitors body temperature
  - **Food and water intake**
    - Regulates hunger and satiety; responds to hormones influencing hunger, energy expenditure, and long-term control of body mass
    - Thirst center monitors osmolarity of blood and can stimulate production of antidiuretic hormone
  - **Sleep and circadian rhythms**
    - Suprachiasmatic nucleus sits above optic chiasm
  - **Memory**
    - **Mammillary nuclei** receive signals from hippocampus
  - **Emotional behavior and sexual response**
    - Anger, aggression, fear, pleasure, contentment, sexual drive

The Diencephalon: Hypothalamus



(b) Hypothalamus

Hypothalamic Nuclei	
Anterior nucleus	Thirst; thermoregulation
Arcuate nucleus	Regulates appetite: secretes releasing hormones that regulate anterior pituitary
Dorsomedial nucleus	Rage and other emotions
Mammillary nuclei	Relay between limbic system and thalamus; involved in long-term memory
Paraventricular nucleus	Produces oxytocin (involved in childbirth, lactation, orgasm); controls posterior pituitary
Posterior nucleus	Functions with periaqueductal gray matter of midbrain in emotional, cardiovascular, and pain control
Preoptic nucleus	Hormonal control of reproductive functions
Suprachiasmatic nucleus	Biological clock; regulates circadian rhythms and female reproductive cycle
Supraoptic nucleus	Produces antidiuretic hormone (involved in water balance); controls posterior pituitary
Ventromedial nucleus	Satiety center (suppresses hunger)

Figure 14.12b

The Diencephalon: Epithalamus

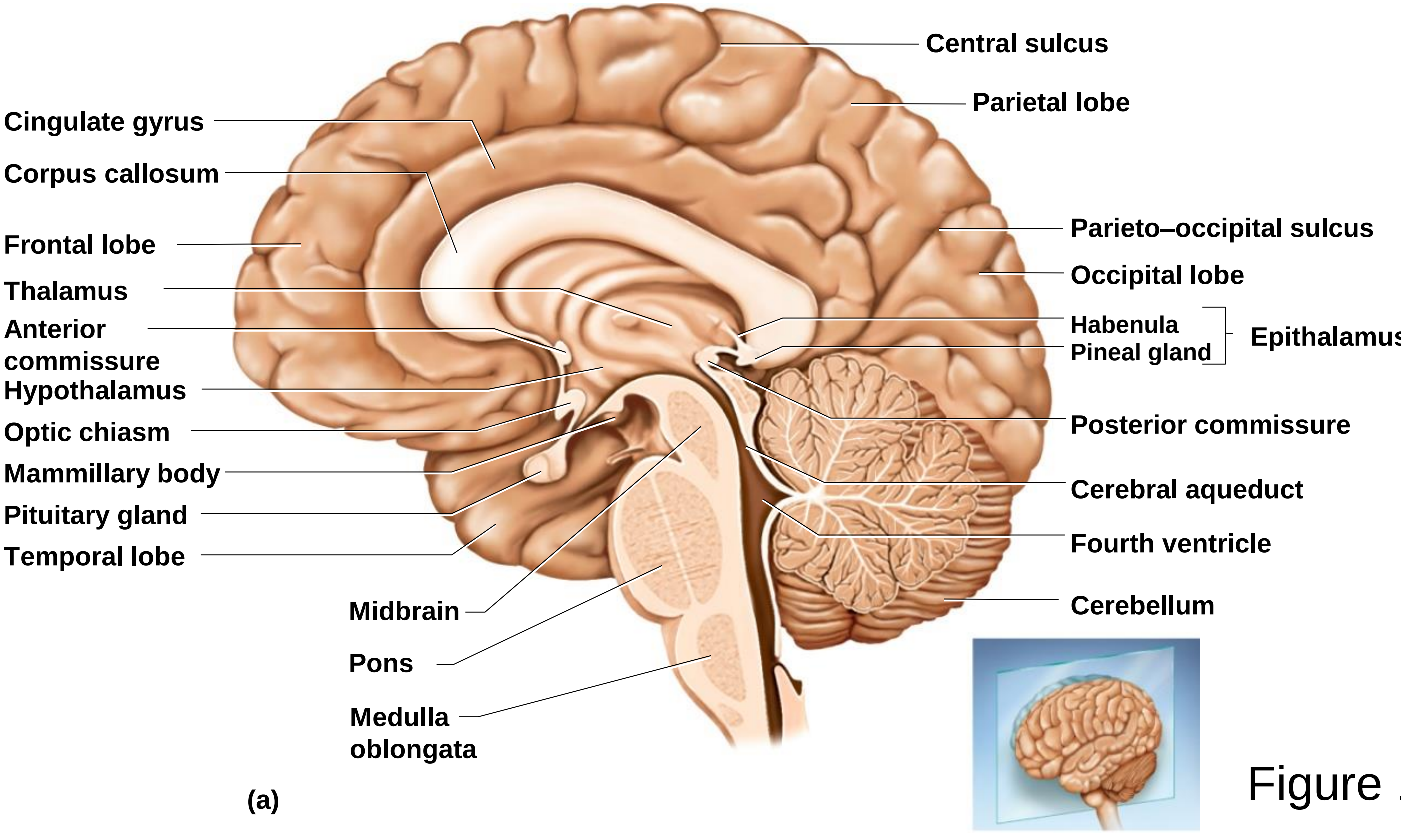


Figure 14.2a

- **Epithalamus**—very small mass of tissue composed of:
  - **Pineal gland:** endocrine gland
  - **Habenula:** relay from the limbic system to the midbrain
  - Thin roof over the third ventricle

The Cerebrum

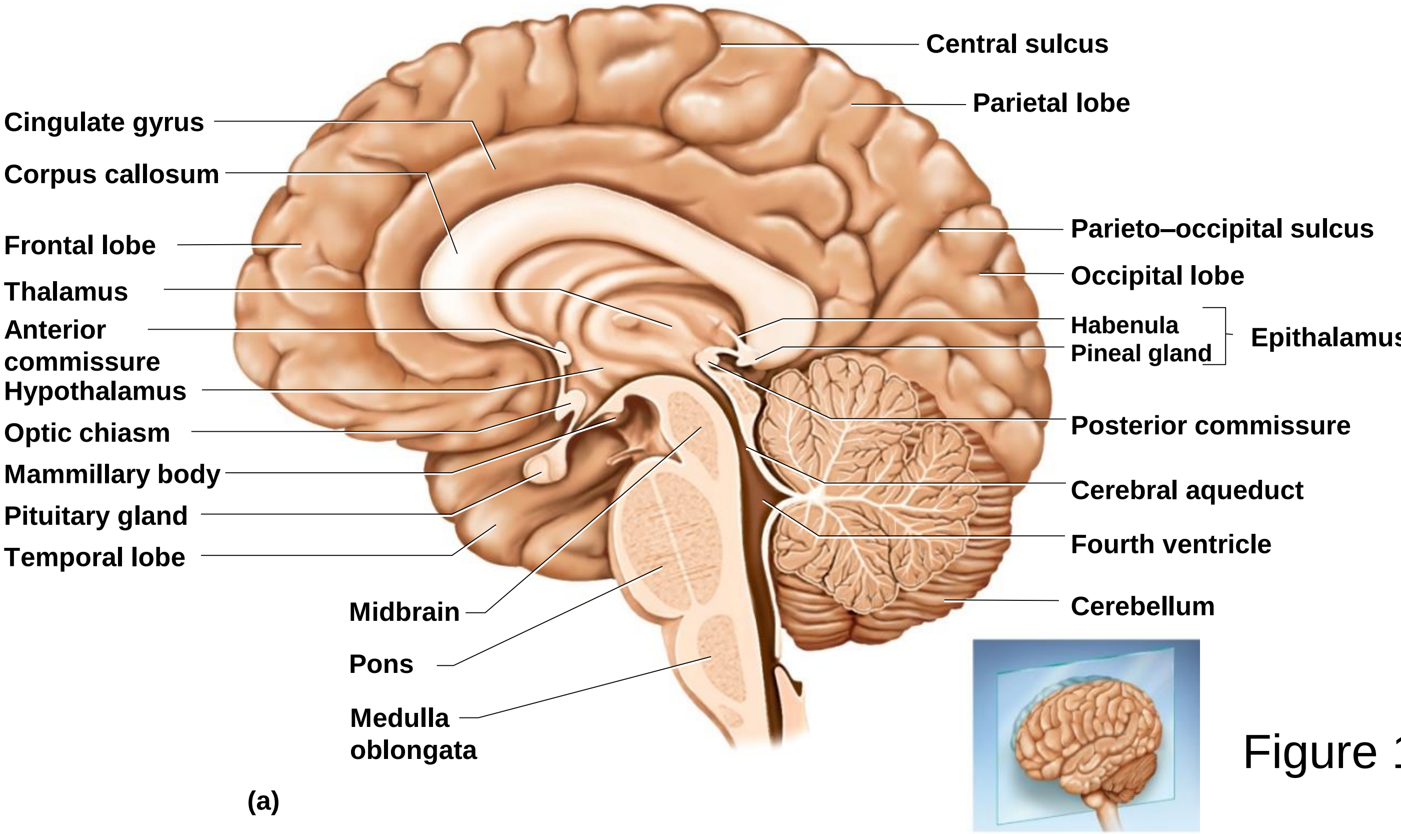


Figure 14.2a

- **Cerebrum**—largest, most conspicuous part of human brain
  - Seat of sensory perception, memory, thought, judgment, and voluntary motor actions

The Cerebrum

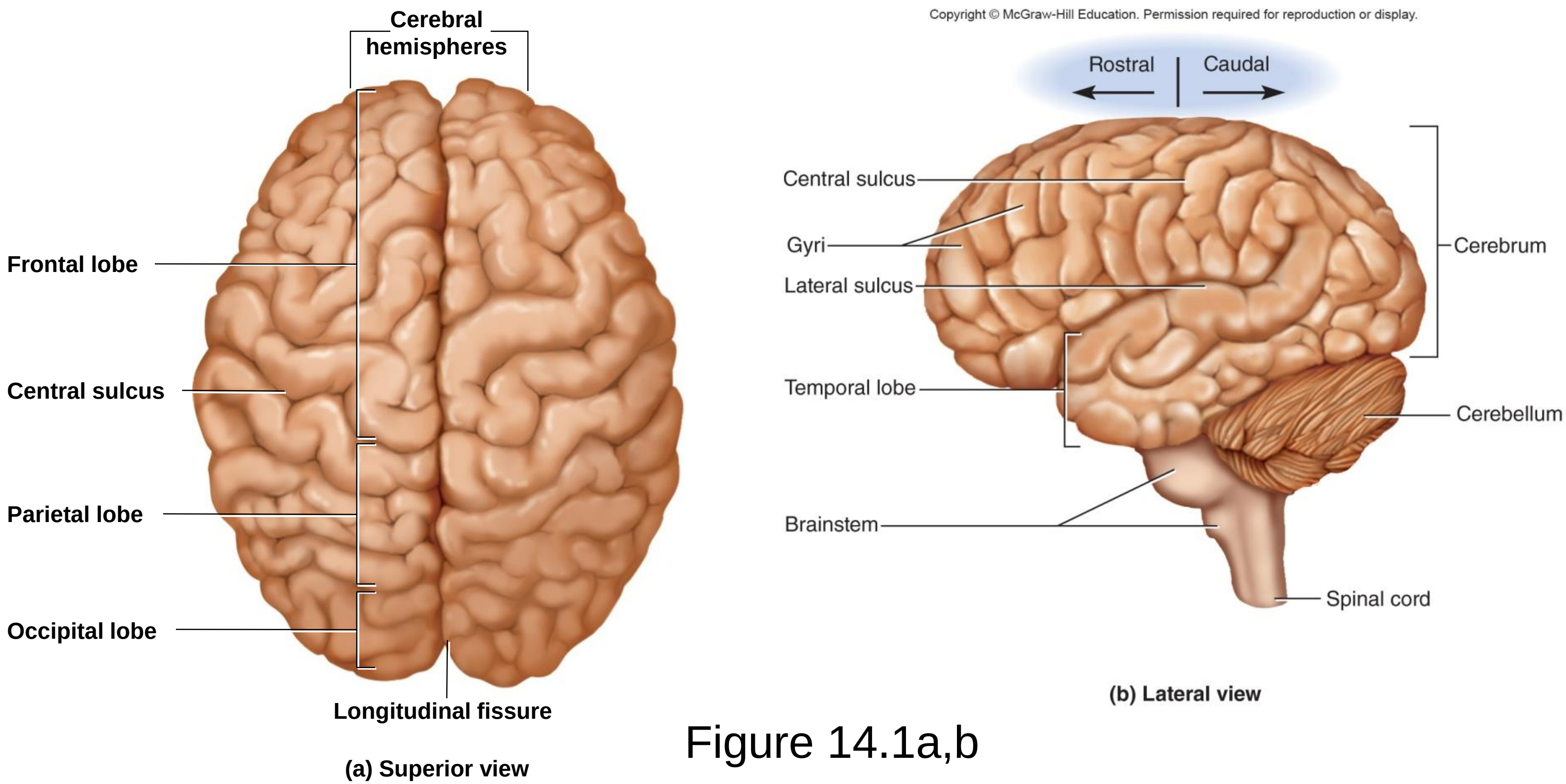


Figure 14.1a,b

- Two **cerebral hemispheres** divided by **longitudinal fissure**
  - Connected by white fibrous tract, the **corpus callosum**
  - **Gyri** and **sulci:** increase amount of cortex in the cranial cavity, allowing for more information-processing capability
  - Each hemisphere has **five lobes** named for the cranial bones overlying them

The Cerebrum

- **Frontal lobe**
  - Rostral to central sulcus
  - Voluntary motor functions, motivation, foresight, planning, memory, mood, emotion, social judgment, and aggression
- **Parietal lobe**
  - Between central sulcus and parieto-occipital sulcus
  - Integrates general senses, taste, and some visual information
- **Occipital lobe**
  - Caudal to parieto-occipital sulcus
  - Primary visual center of brain
- **Temporal lobe**
  - Lateral and horizontal; below lateral sulcus
  - Functions in hearing, smell, learning, memory, and some aspects of vision and emotion
- **Insula** (hidden by other regions)
  - Deep to lateral sulcus
  - Helps in understanding spoken language, taste and integrating information from visceral receptors

The Cerebrum

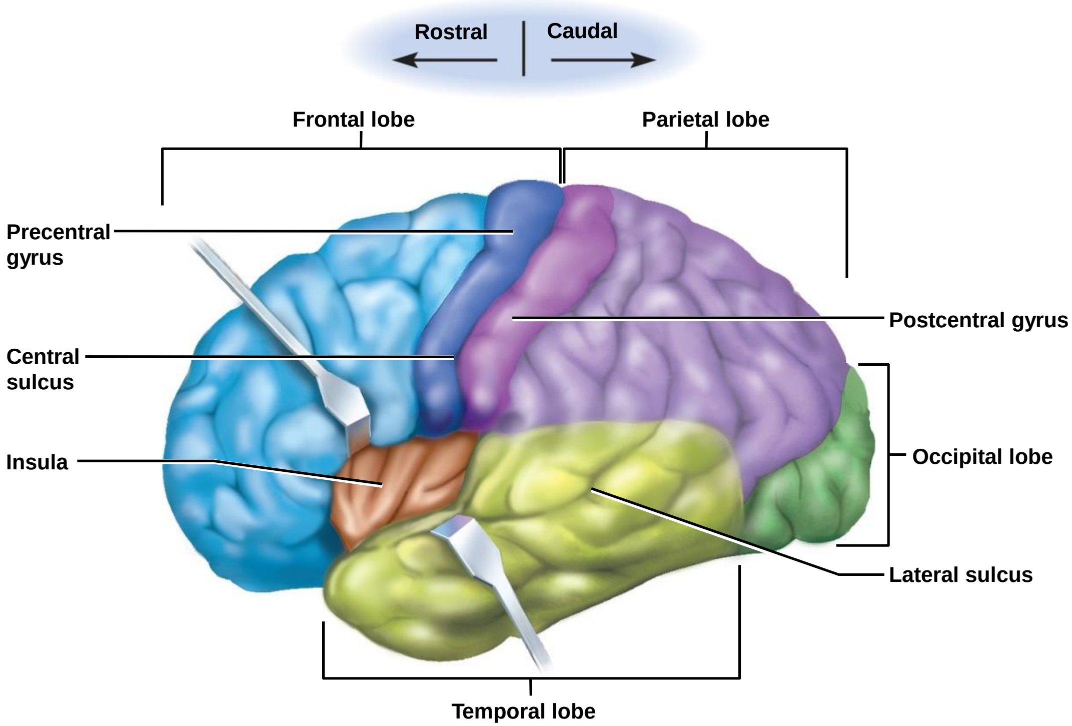
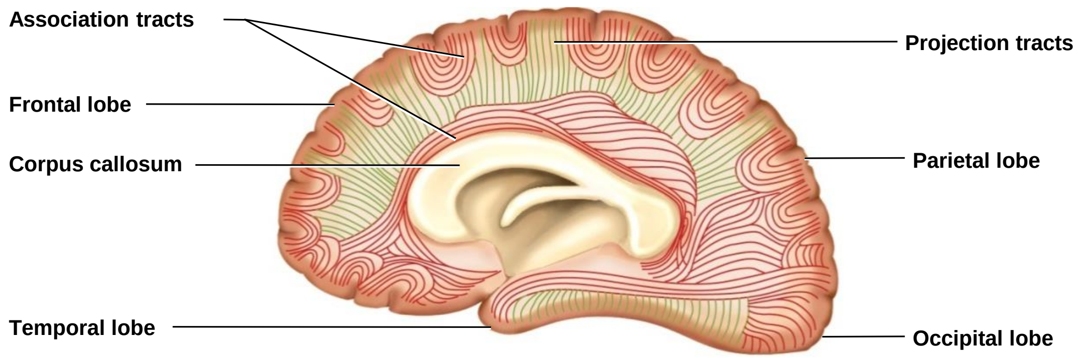
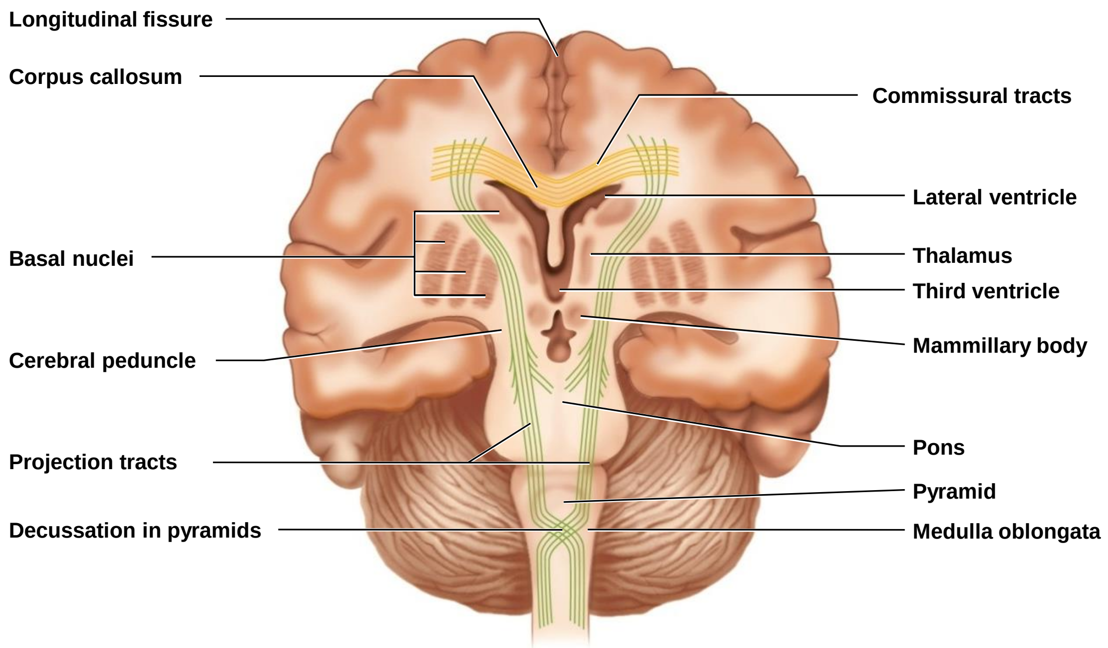


Figure 14.13

Tracts of Cerebral White Matter



(a) Sagittal section



(b) Frontal section

Figure 14.14

The Cerebral White Matter

- **Most of the volume of cerebrum is white matter**
  - Glia and **myelinated nerve fibers** that transmit signals
- **Tracts are bundles of nerve fibers in the central nervous system**
- **Three types of tracts: projection tracts, commissural tracts, and association tracts**

The Cerebral White Matter

- **Projection tracts**
  - Extend vertically between higher and lower brain and spinal cord centers
    - Example: corticospinal tracts
- **Commissural tracts**
  - Cross from one cerebral hemisphere to the other allowing communication between two sides of cerebrum
    - Largest example: **corpus callusum**
    - Other crossing tracts: **anterior** and **posterior commissures**
- **Association tracts**
  - Connect different regions within the same cerebral hemisphere
    - Long fibers connect different lobes; short fibers connect gyri within a lobe

The Cerebral Cortex

- **Neural integration** is carried out in the gray matter of the cerebrum
- **Cerebral gray matter found in three places**
  - Cerebral cortex
  - Basal nuclei
  - Limbic system

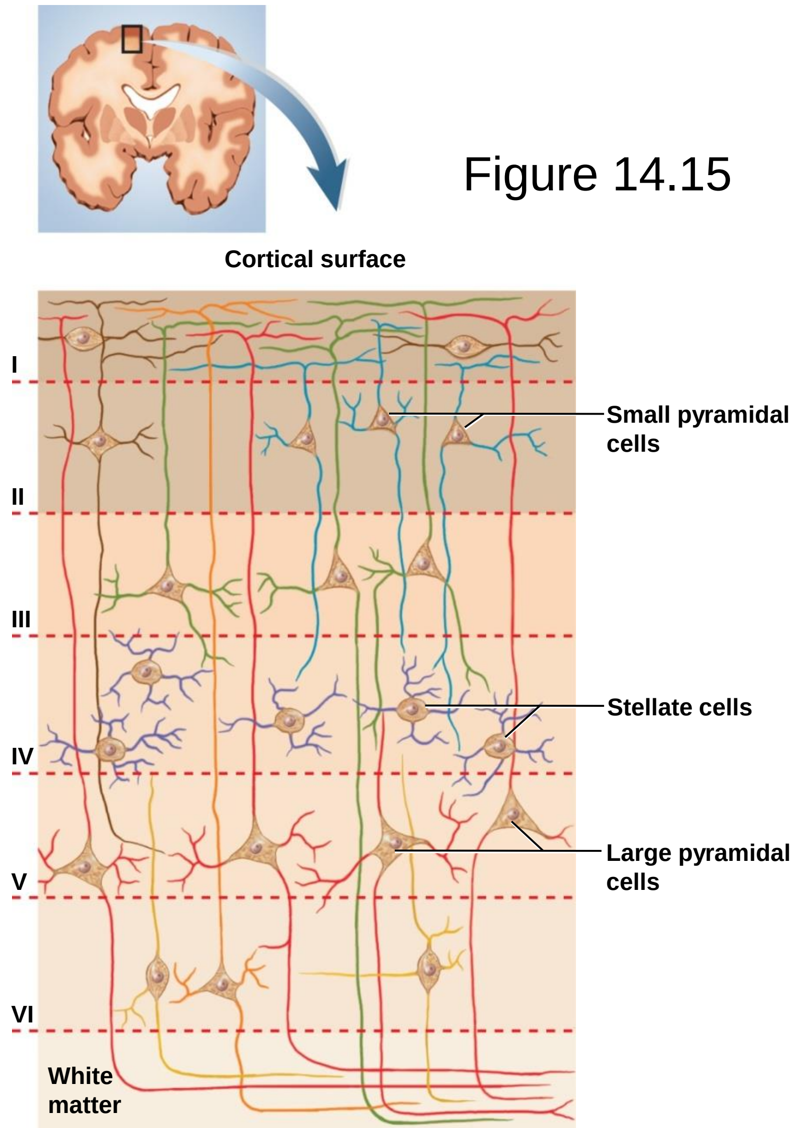


Figure 14.15

The Cerebral Cortex

- **Cerebral cortex**—covers surface of the hemispheres
  - Only 2 to 3 mm thick
  - Cortex constitutes about 40% of brain mass
  - Contains 14 to 16 billion neurons
  - 90% of human cerebral cortex is **neocortex**—six-layered tissue that has relatively recent evolutionary origin

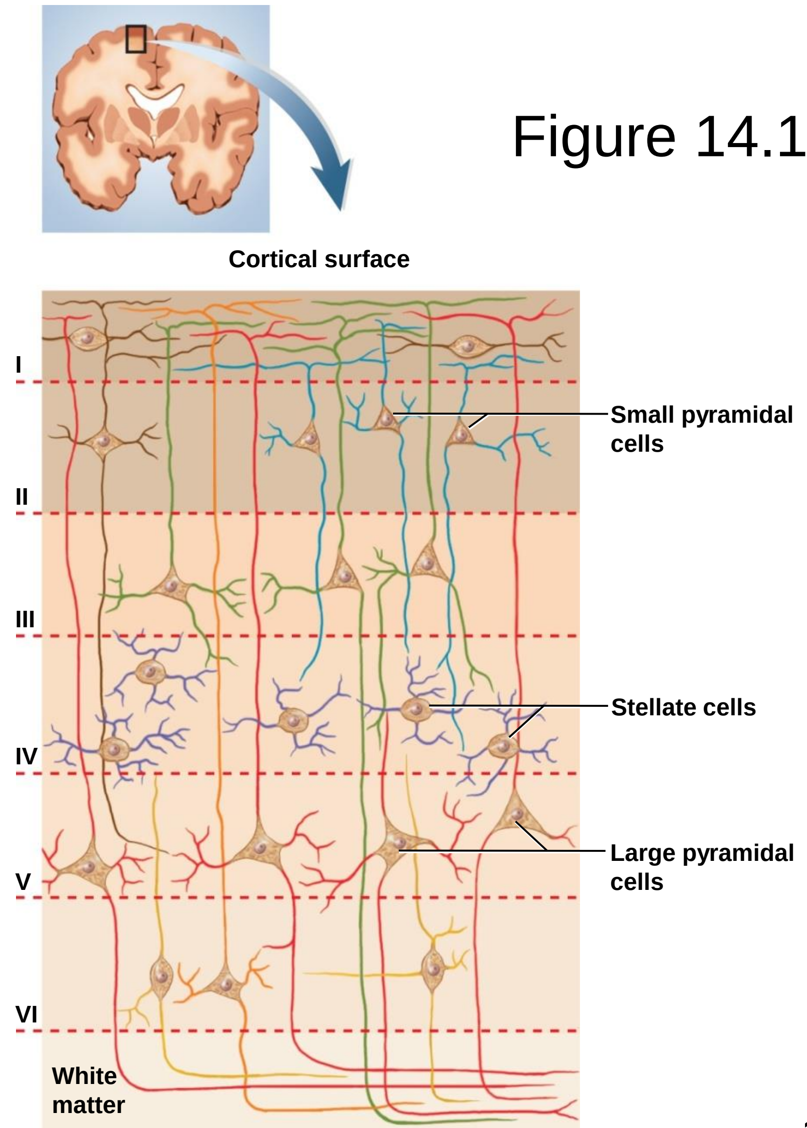


Figure 14.15

The Cerebral Cortex

- Contains **two principal types of neurons**
  - **Stellate cells**
    - Have spheroid somas with dendrites projecting in all directions
    - Receive sensory input and process information on a local level
  - **Pyramidal cells**
    - Tall, and conical, with apex toward the brain surface
    - A thick dendrite with many branches with small, knobby **dendritic spines**
    - Include the output neurons of the cerebrum
    - Only neurons that leave the cortex and connect with other parts of the CNS.

The Limbic System

- **Limbic system**—important center of emotion and learning
- **Prominent components:**
  - **Cingulate gyrus:** arches over corpus callosum in frontal and parietal lobes
  - **Hippocampus:** in medial temporal lobe (memory functions)
  - **Amygdala:** immediately rostral to hippocampus (emotion functions)
- **There is a limbic system in each cerebral hemisphere**

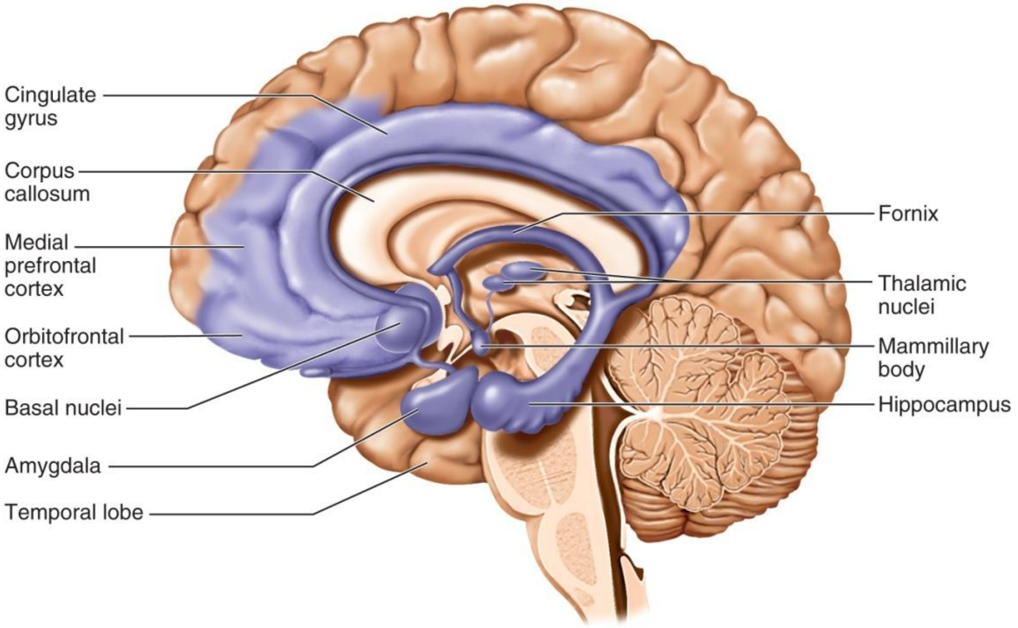


Figure 14.16

The Limbic System

- **Limbic system components are connected through a loop of fiber tracts allowing for somewhat circular patterns of feedback**

- Limbic system structures have centers for both **gratification** and **aversion**
  - **Gratification:** sensations of pleasure or reward
  - **Aversion:** sensations of fear or sorrow

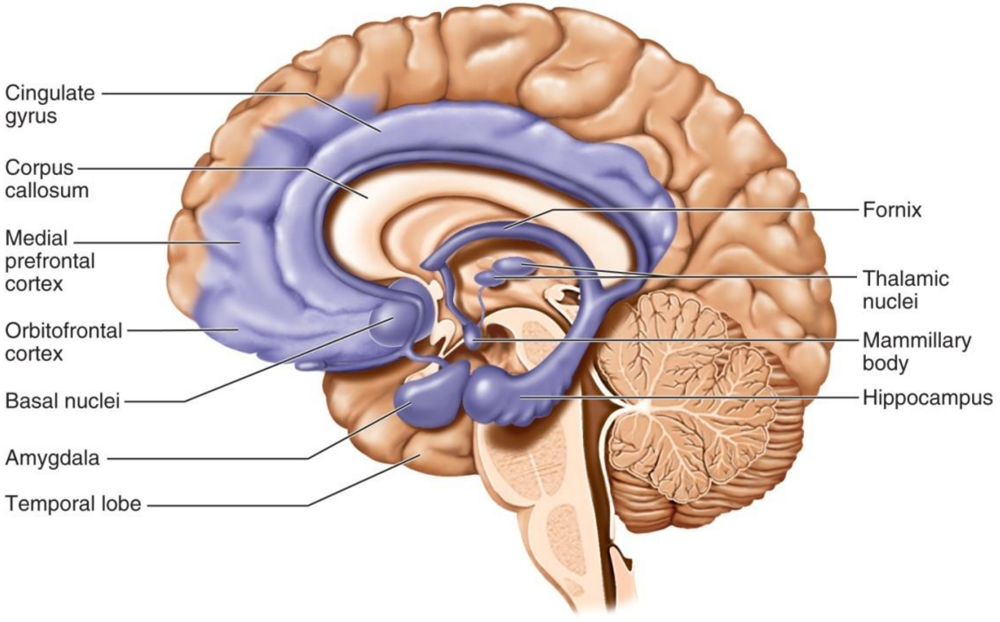


Figure 14.16

The Basal Nuclei

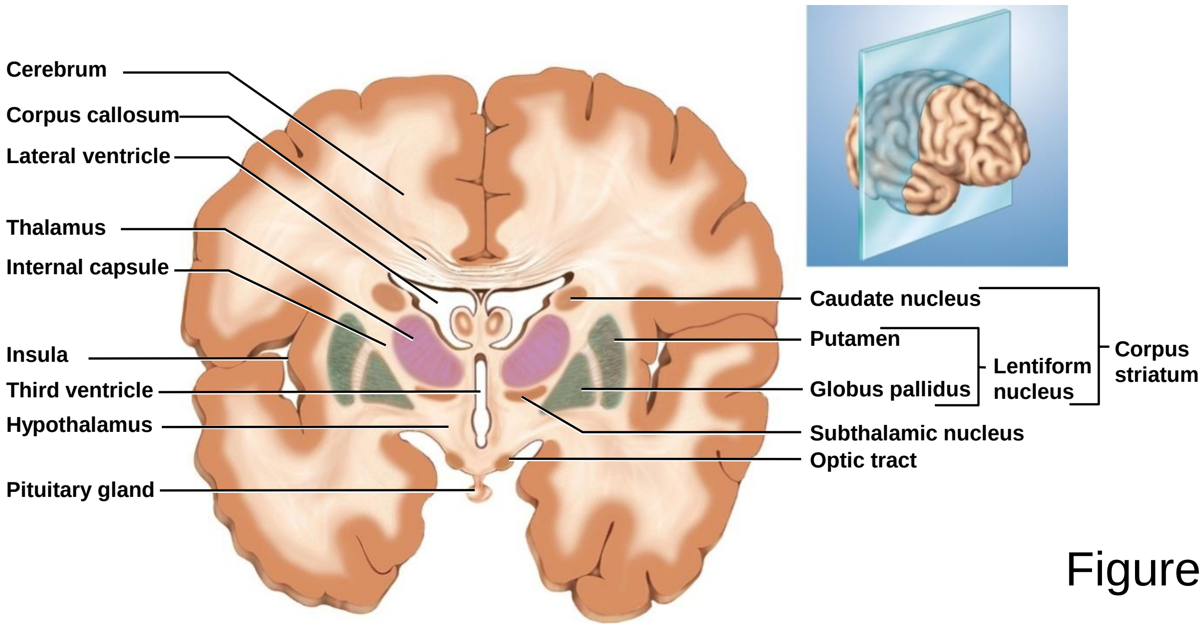


Figure 14.17

- **Basal nuclei**—masses of cerebral gray matter buried deep in the white matter, lateral to the thalamus
  - Receive input from the substantia nigra of the midbrain and the motor areas of the cortex
  - Send signals back to both of these locations
  - Involved in motor control

The Basal Nuclei

- At least three brain centers form the basal nuclei and are collectively called the **corpus striatum**
  - **Caudate nucleus**
  - **Putamen**
  - **Globus pallidus**

- **Lentiform nucleus**—putamen and globus pallidus together

Integrative Functions of the Brain

- **Expected Learning Outcomes**
  – List the types of brain waves and discuss their relationship to mental states.
  – Describe the stages of sleep, their relationship to the brain waves, and the neural mechanisms of sleep.
  – Identify the brain regions concerned with consciousness and thought, memory, emotion, sensation, motor control, and language.
  – Discuss the functional differences between the right and left cerebral hemispheres.

Integrative Functions of the Brain

- Higher brain functions—sleep, memory, cognition, emotion, sensation, motor control, and language
- Involve interactions between cerebral cortex and basal nuclei, brainstem, and cerebellum
- Functions of the brain do not have easily defined anatomical boundaries
- Integrative functions of the brain focus mainly on the cerebrum, but involve combined action of multiple brain levels

The Electroencephalogram

Figure 14.18a

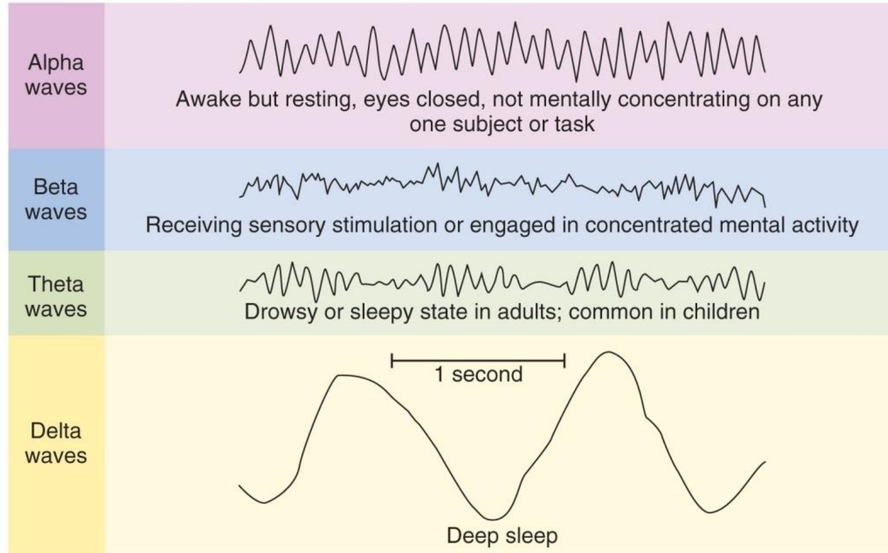


Figure 14.18b

- **Electroencephalogram (EEG)**—monitors surface electrical activity of the brain waves
  – Useful for studying normal brain functions as sleep and consciousness
  – In diagnosis of degenerative brain diseases, metabolic abnormalities, brain tumors, etc.
  – Lack of brain waves is a common criterion of brain death

The Electroencephalogram

- **Alpha waves 8 to 13 Hz**
  - Awake and resting with eyes closed and mind wandering
  - Suppressed when eyes open or performing a mental task
- **Beta waves 14 to 30 Hz**
  - Eyes open and performing mental tasks
  - Accentuated during mental activity and sensory stimulation
- **Theta waves 4 to 7 Hz**
  - Drowsy or sleeping adults
  - If awake and under emotional stress
- **Delta waves (high amplitude) <3.5 Hz**
  - Deep sleep in adults

Sleep

- Sleep occurs in cycles called **circadian rhythms**
  - Events that reoccur at intervals of about 24 hours
- **Sleep**—temporary state of unconsciousness from which one can awaken when stimulated
  - Characterized by **stereotyped posture** (lying down, eyes closed)
  - **Sleep paralysis:** inhibition of muscular activity
  - Resembles prolonged unconsciousness (such as a coma) but sleeping individuals can be aroused by sensory stimulation

Sleep

- **Four stages of sleep**
  - **Stage 1**
    - Drowsy, relaxed, eyes closed, drifting sensation, easily awakened
    - Alpha waves dominate EEG
  - **Stage 2**
    - Light sleep
    - EEG frequency decreases but amplitude increases with occasional sleep spindles
  - **Stage 3**
    - Moderate to deep sleep; muscles relax, vital signs fall
    - Theta and delta EEG waves appear
  - **Stage 4**
    - Muscles very relaxed, vitals very low, difficult to awaken
    - EEG dominated by low-frequency, high-amplitude delta EEG waves (**slow wave sleep**)

Sleep

- About five times a night, a sleeper backtracks from stage 3 or 4 to stage 2 and exhibits bouts of **rapid eye movement (REM) sleep,**
  - Eyes oscillate back and forth
  - Also called **paradoxical sleep,** because EEG resembles the waking state
  - Sleeper is harder to arouse than during any other stage
  - Vivid and long dreams
  - Sleep paralysis is stronger, preventing dreams from being acted out
  - Parasympathetic activation causes penile/clitoral erection and constriction of pupils

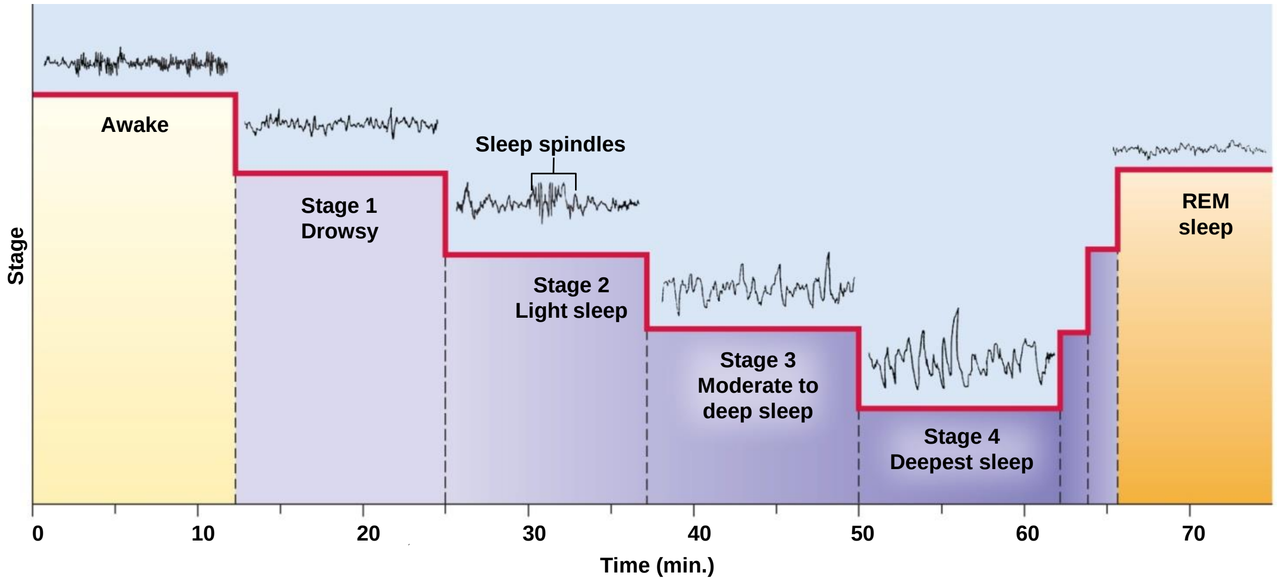
Sleep

- **Rhythm of sleep** is controlled by complex interaction between cerebral cortex, thalamus, hypothalamus, and reticular formation
- **Suprachiasmatic nucleus (SCN)**—important hypothalamic area located above optic chasm
  - Input from eye allows SCN to synchronize multiple body rhythms with external rhythms of night and day
    - Sleep, body temperature, urine production, hormone secretion, and other functions

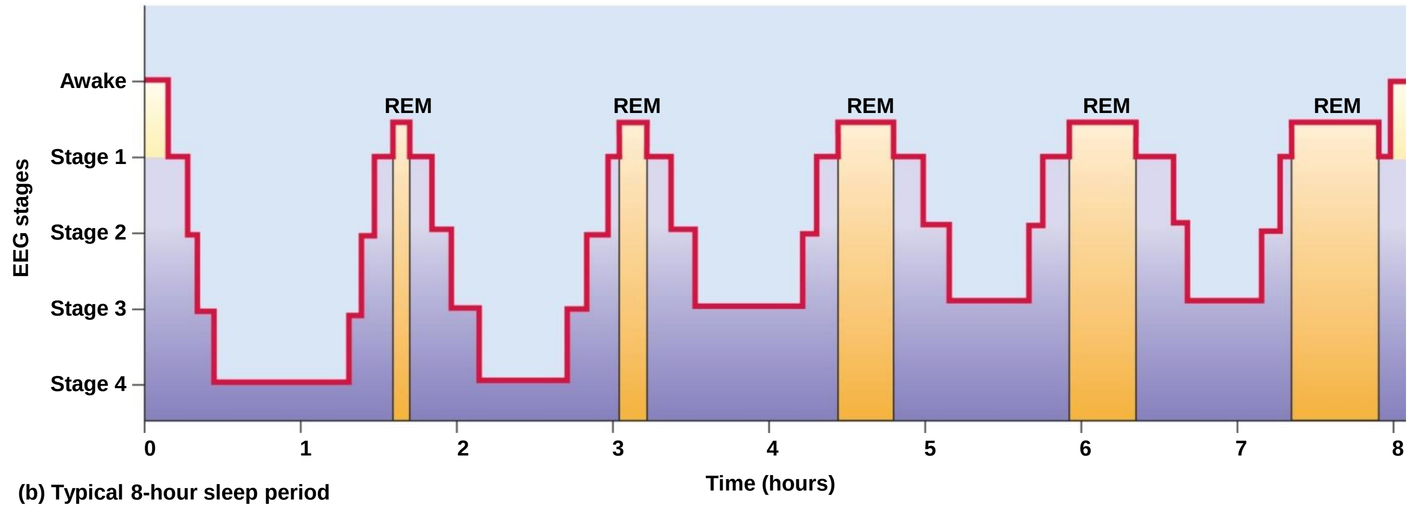
Sleep

- Hypothalamus produces **orexins**—neuropeptides that stimulate wakefulness
  - Orexin levels are low in narcolepsy (excessive daytime sleepiness)
- **Sleep has a restorative effect, and sleep deprivation can be fatal to experimental animals**
  - Sleep may be the time to replenish such energy sources as glycogen and ATP
  - REM sleep may consolidate and strengthen memories by reinforcing some synapses, and eliminating others

Sleep Stages and Brain Activity



(a) One sleep cycle



(b) Typical 8-hour sleep period

Figure 14.19

Cognition

- **Cognition**—the range of mental processes by which we acquire and use knowledge
  - Sensory perception, thought, reasoning, judgment, memory, imagination, and intuition
- Cognition is accomplished by distributed **association areas of cerebral cortex**
  - Constitute about 75% of all brain tissue
- **Researchers learn about cognition from studies of patients with brain lesions and from imaging studies using PET and fMRI**

Cognition

- **Cognitive functions in association areas of cortex:**
  - **Parietal lobe** helps perceive and attend to stimuli
    - Lesions can cause **contralateral neglect syndrome**—unaware of objects on opposite side of the body
  - **Temporal lobe** helps identify stimuli
    - Lesions can cause **agnosia**—inability to recognize, identify familiar objects; example: **prosopagnosia**—cannot recognize faces
  - **Frontal lobe** helps us think about the world, and plan and execute appropriate behaviors
    - Lesions can cause personality disorders and socially inappropriate behaviors

Memory

- **Information management entails:**
  - **Learning:** acquiring new information
  - **Memory:** information storage and retrieval
  - **Forgetting:** eliminating trivial information; as important as remembering

- **Amnesia**—defects in **declarative memory:** inability to describe past events

- **Procedural memory**—ability to tie one's shoes
  - **Anterograde amnesia:** unable to store new information
  - **Retrograde amnesia:** person cannot recall things known before the injury

Memory

- **Hippocampus**—important limbic system area for memory
  - Functions in **memory consolidation:** the process of “teaching the cerebral cortex” until a long-term memory is established in the cortex (e.g., memory of faces in temporal lobe cortex)
  - Hippocampus organizes cognitive information into a unified long-term memory but does not hold the memory itself
  - Famous case: H.M. had hippocampi surgically removed due to epilepsy; doctors later realized this abolished his ability to form new, declarative memories
- **Cerebellum**—helps learn motor skills
- **Amygdala**—emotional memory

Emotion

- **Emotional feelings and memories are interactions between prefrontal cortex and diencephalon**

- **Prefrontal cortex**—seat of judgment, intent, and control over expression of emotions

- **Feelings** (e.g., fear) arise from hypothalamus and amygdala

Emotion

- **Amygdala** receives input from sensory systems
  - Role in fear, food intake, sexual behavior, and drawing attention to novel stimuli
  - **One output** goes to **hypothalamus,** influencing somatic and visceral motor systems
    - Heart races, blood pressure rises, hair stands on end, vomiting ensues
  - **Other output** to **prefrontal cortex** important in controlling expression of emotions
    - Ability to express love, control anger, or overcome fear

- **Behavior** shaped by learned associations between stimuli, our responses to them, and the reward or punishment that results

Sensation

- **Primary sensory cortex**—sites where sensory input is first received and one becomes conscious of the stimulus
- **Association areas** near primary sensory areas process and interpret that sensory information
  - **Primary visual cortex** is bordered by **visual association areas:** make cognitive sense of visual stimuli
  - **Multimodal association areas:** receive input from multiple senses and integrate this into an overall perception of our surroundings

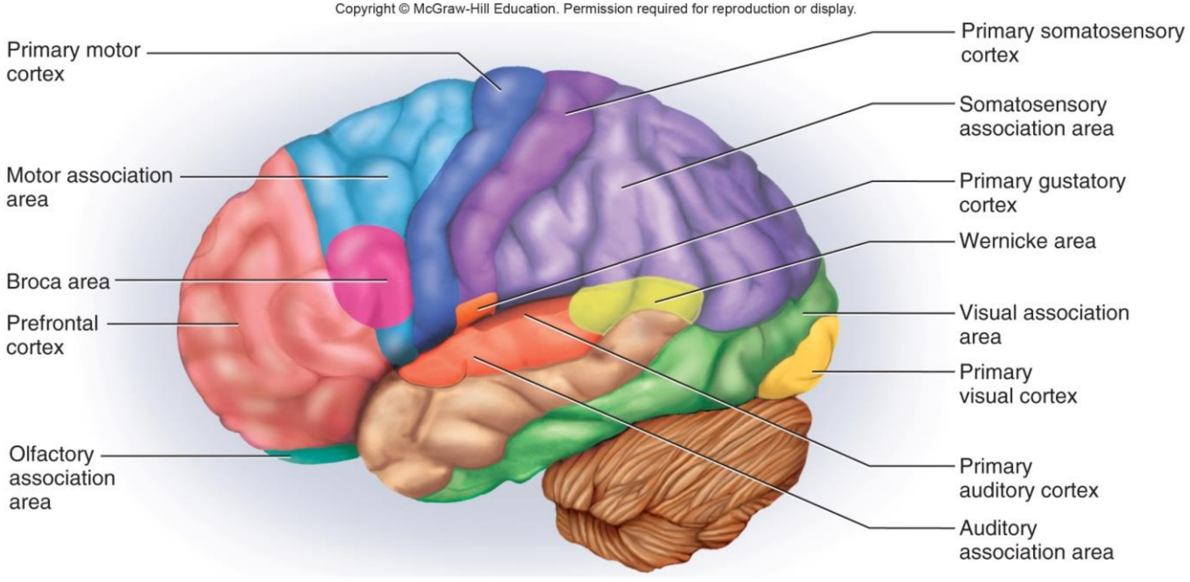


Figure 14.20

The Special Senses

- **Special senses**—limited to the head and employ relatively complex sense organs

- **Vision**
  - **Visual primary cortex** in far posterior region of occipital lobe
  - **Visual association area:** anterior, and occupies all the remaining occipital lobe
    - Much of inferior temporal lobe deals with recognizing faces and familiar objects

- **Hearing**
  - **Primary auditory cortex** in the superior region of the temporal lobe and insula
  - **Auditory association area:** temporal lobe deep and inferior to primary auditory cortex
    - Recognizes spoken words, a familiar piece of music, or a voice on the phone

The Special Senses

- **Equilibrium**
  - **Signals for balance and sense of motion** project mainly to the cerebellum and several brainstem nuclei concerned with head and eye movements and visceral functions
  - **Association cortex** in the roof of the lateral sulcus near the lower end of the central sulcus
    - Seat of consciousness of our body movements and orientation in space
- **Taste and smell**
  - **Gustatory (taste) signals** received by **primary gustatory cortex** in inferior end of the postcentral gyrus of the parietal lobe and anterior region of insula
  - **Olfactory (smell) signals** received by the **primary olfactory cortex** in the medial surface of the temporal lobe and inferior surface of the frontal lobe

The General Senses

- **General (somesthetic, somatosensory,** or **somatic) senses**—distributed over entire body and employ simple receptors
  - Include touch, pressure, stretch, movement, heat, cold, and pain
- **For the head, cranial nerves carry general sensory information**
- **For the rest of the body, ascending tracts bring general sensory information to the brain**
  - **Thalamus** processes the input from contralateral side
  - Selectively relays signals to **postcentral gyrus** of parietal lobe
    - Cerebral fold that is immediately caudal to the central sulcus
    - Functionally known as the **primary somesthetic cortex**
    - Provides awareness of stimulus
  - **Somesthetic association area:** caudal to the postcentral gyrus and in the roof of the lateral sulcus
    - Makes cognitive sense of stimulus

The General Senses

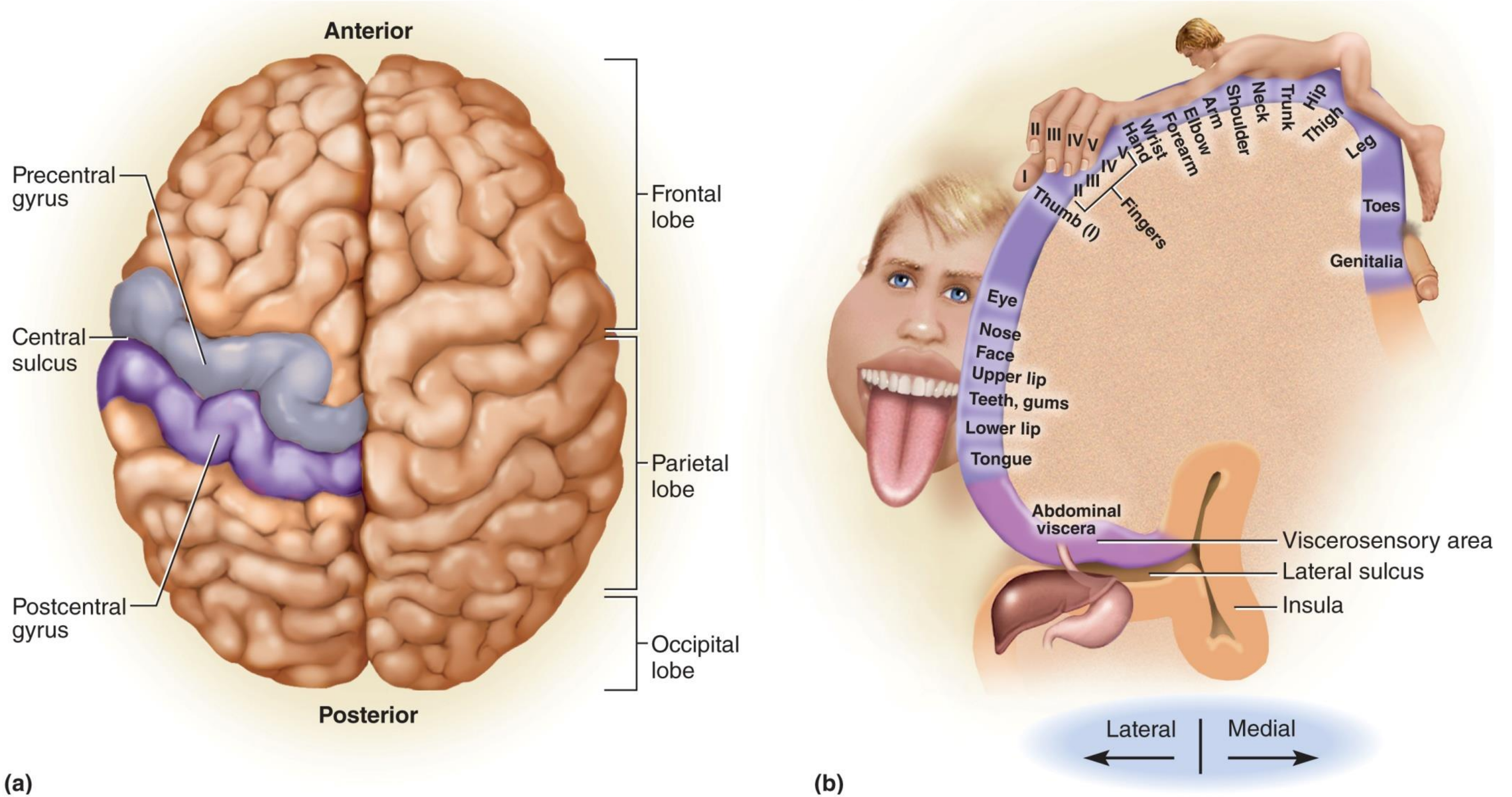


Figure 14.21

The General Senses

- **Sensory homunculus**—diagram of the primary somesthetic cortex which resembles an upside-down sensory map of the contralateral side of the body
- **Shows receptors in lower limbs projecting to superior and medial parts of the gyrus**
- **Shows receptors from face projecting to the inferior and lateral parts of the gyrus**
- **Somatotopy**—point-to-point correspondence between an area of the body and an area of the CNS

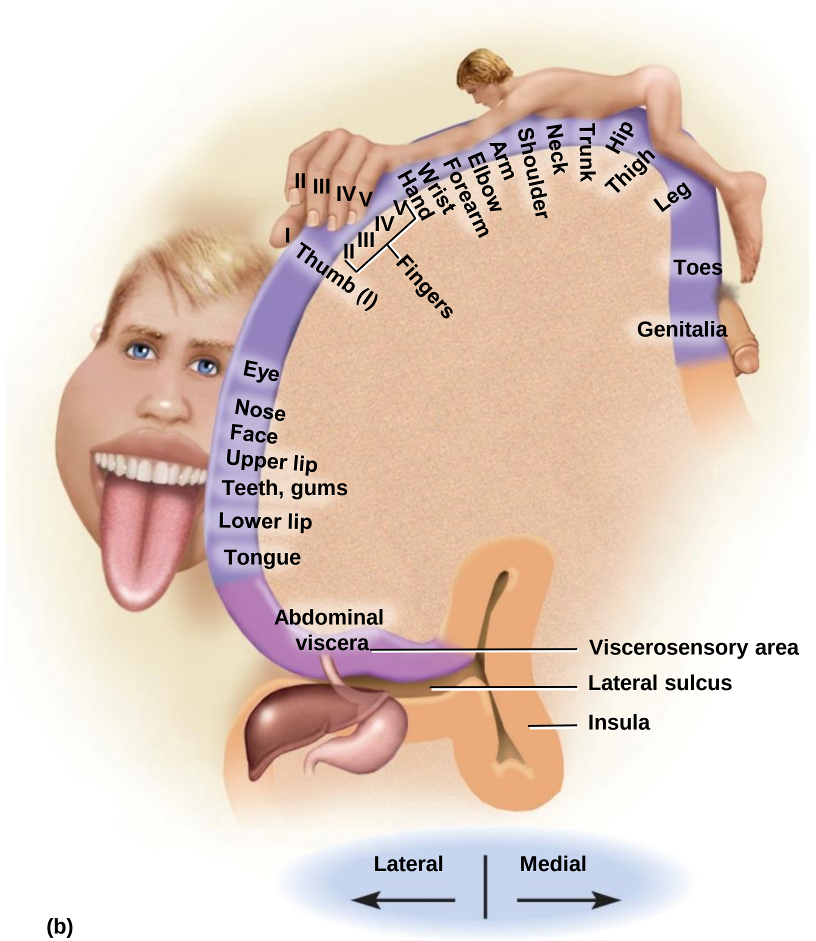


Figure 14.21b

Motor Control

- The intention to contract a muscle begins in **motor association (premotor) area** of frontal lobes
  - Where we plan our behavior
  - Where neurons compile a program for degree and sequence of muscle contraction required for an action
- Program transmitted to neurons of the **precentral gyrus (primary motor area)**
  - Most posterior gyrus of the frontal lobe
  - These neurons send signals to the brainstem and spinal cord leading ultimately to muscle contractions

Motor Control

- **Precentral gyrus** also exhibits **somatotopy**
  - Neurons for toe movement are deep in the longitudinal fissure of the medial side of the gyrus
  - The summit of the gyrus controls the trunk, shoulder, and arm
  - The inferolateral region controls the facial muscles
  - **Motor homunculus** has a distorted look because the amount of cortex devoted to a given body region is proportional to the number of muscles and motor units in that body region (not body region size)

Motor Homunculus

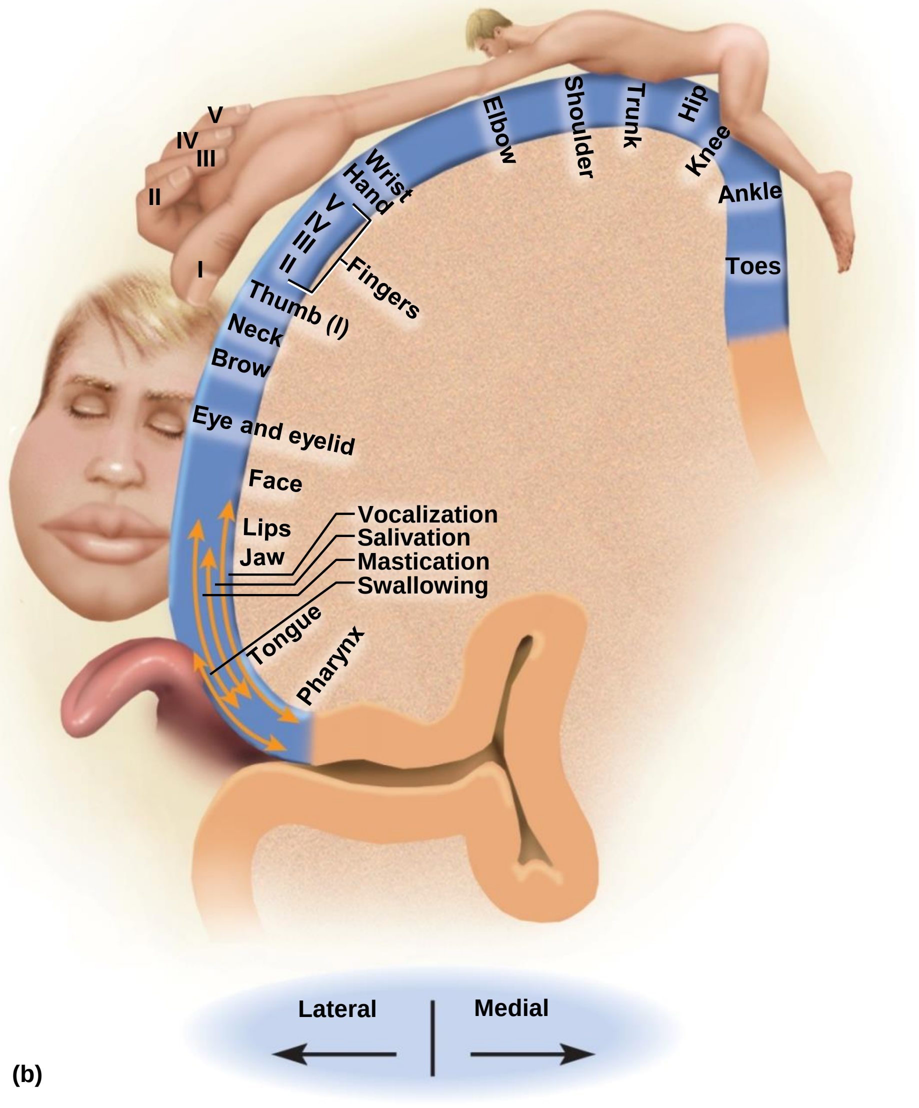


Figure 14.22b

Motor Control

- Pyramidal cells of the precentral gyrus are called **upper motor neurons**
  - Their fibers project caudally
  - About 19 million fibers ending in nuclei of the brainstem
  - About 1 million forming the corticospinal tracts
  - Most fibers decussate in lower medulla oblongata
  - Form lateral corticospinal tracts on each side of the spinal cord
- In brainstem or spinal cord, the fibers from upper motor neurons synapse with **lower motor neurons** whose axons innervate skeletal muscles
- **Basal nuclei** and **cerebellum** are also important in muscle control

Motor Control

- **Basal nuclei**
  - Important motor functions include helping to control:
    - Onset and cessation of intentional movements
    - Repetitive hip and shoulder movements in walking
    - Highly practiced, learned behaviors such as writing, typing, driving a car
  - Lie in a feedback circuit from the cerebrum, to the basal nuclei, to the thalamus, and back to the cerebrum
  - **Dyskinesias**: movement disorders caused by lesions in the basal nuclei involving abnormal movement initiation

Motor Control

(continued)

- **Cerebellum**
  - Highly important in motor coordination
  - Aids in learning motor skills
  - Maintains muscle tone and posture
  - Smooths muscle contraction
  - Coordinates eye and body movements
  - Coordinates motions of different joints with each other
  - Lesions can cause **ataxia**: clumsy, awkward gait

Motor Pathways Involving the Cerebellum

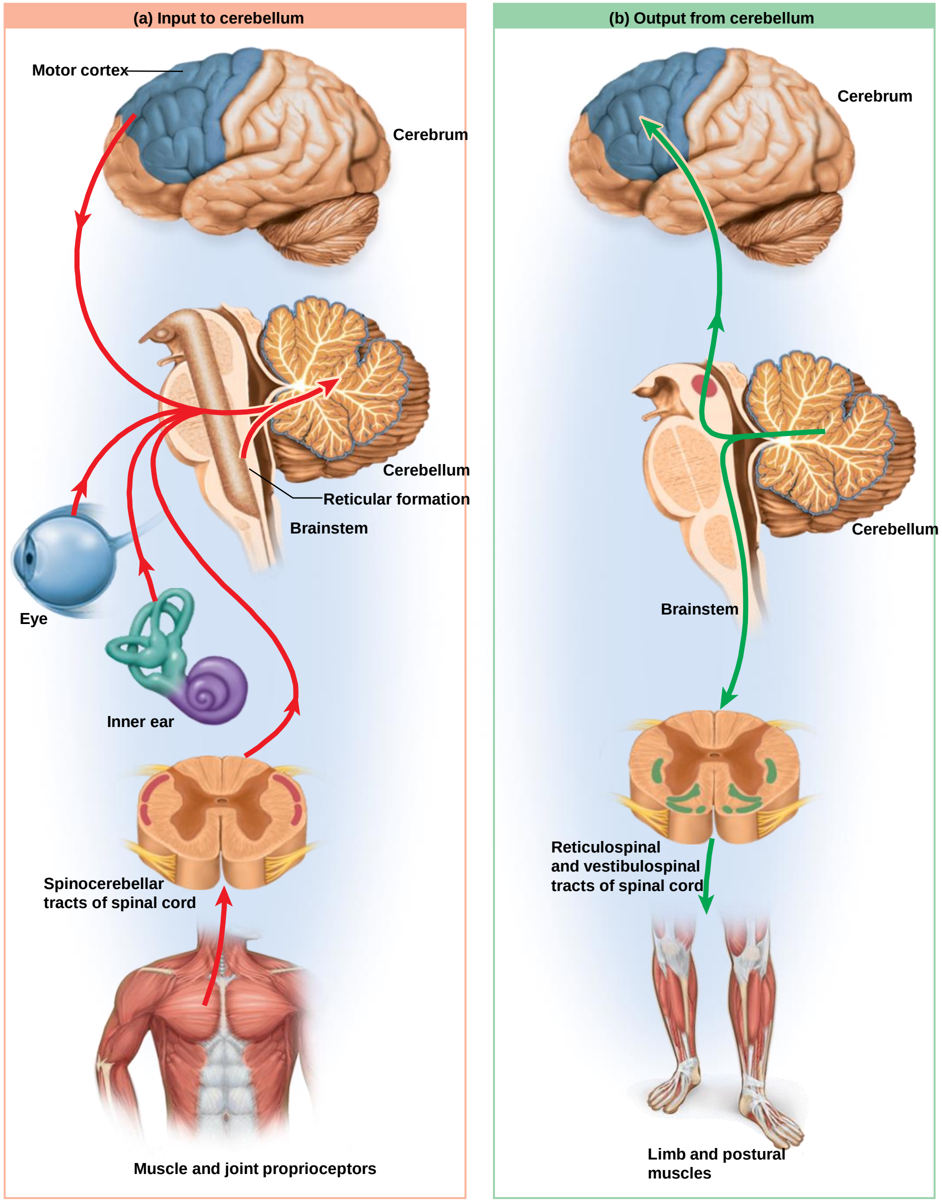


Figure 14.23

Language

- Language includes several abilities: **reading, writing, speaking,** and **understanding words**
- **Wernicke area**
  - Posterior to lateral sulcus usually in left hemisphere
  - Permits recognition of spoken and written language
  - When we intend to speak, Wernicke area formulates phrases and transmits plan of speech to Broca area
- **Broca area**
  - Inferior prefrontal cortex usually in left hemisphere
  - Generates motor program for the muscles of the larynx, tongue, cheeks, and lips for speaking and for hands when signing
  - Transmits program to primary motor cortex for commands to the lower motor neurons that supply relevant muscles
- **Affective language area** usually in right hemisphere
  - Lesions produce **aprosody**—flat emotionless speech

Language Centers of the Left Hemisphere

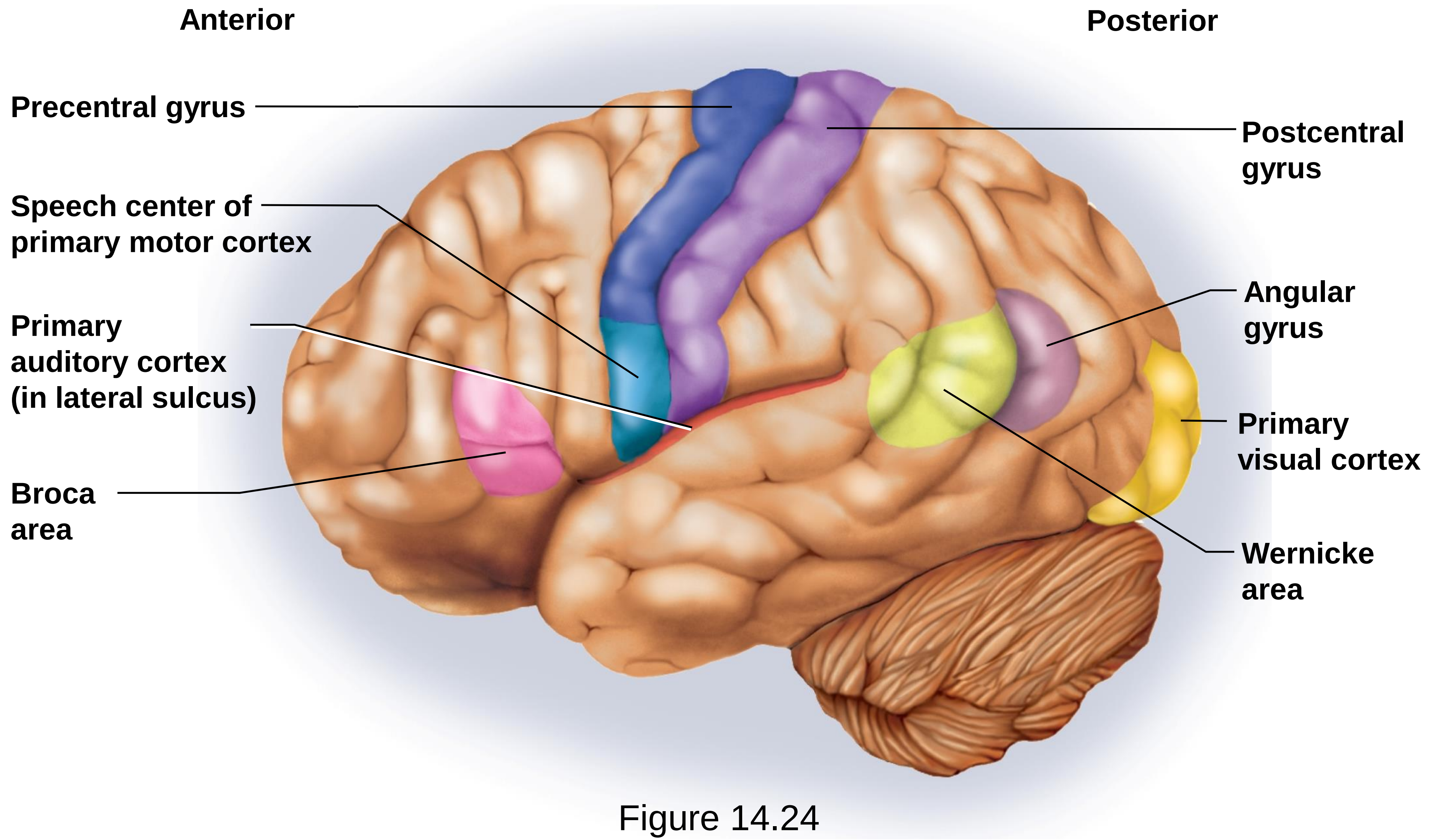


Figure 14.24

Aphasia

- **Aphasia**—a language deficit from lesions to hemisphere with Wernicke and Broca areas
- **Nonfluent (Broca) aphasia**
  - Lesion in Broca area
  - Slow speech, difficulty in choosing words, using words that only approximate the correct word
- **Fluent (Wernicke) aphasia**
  - Lesion in Wernicke area
  - Speech normal and excessive, but uses senseless jargon
  - Cannot comprehend written and spoken words
- **Anomic aphasia**
  - Can speak normally and understand speech, but cannot identify written words or pictures

Cerebral Lateralization

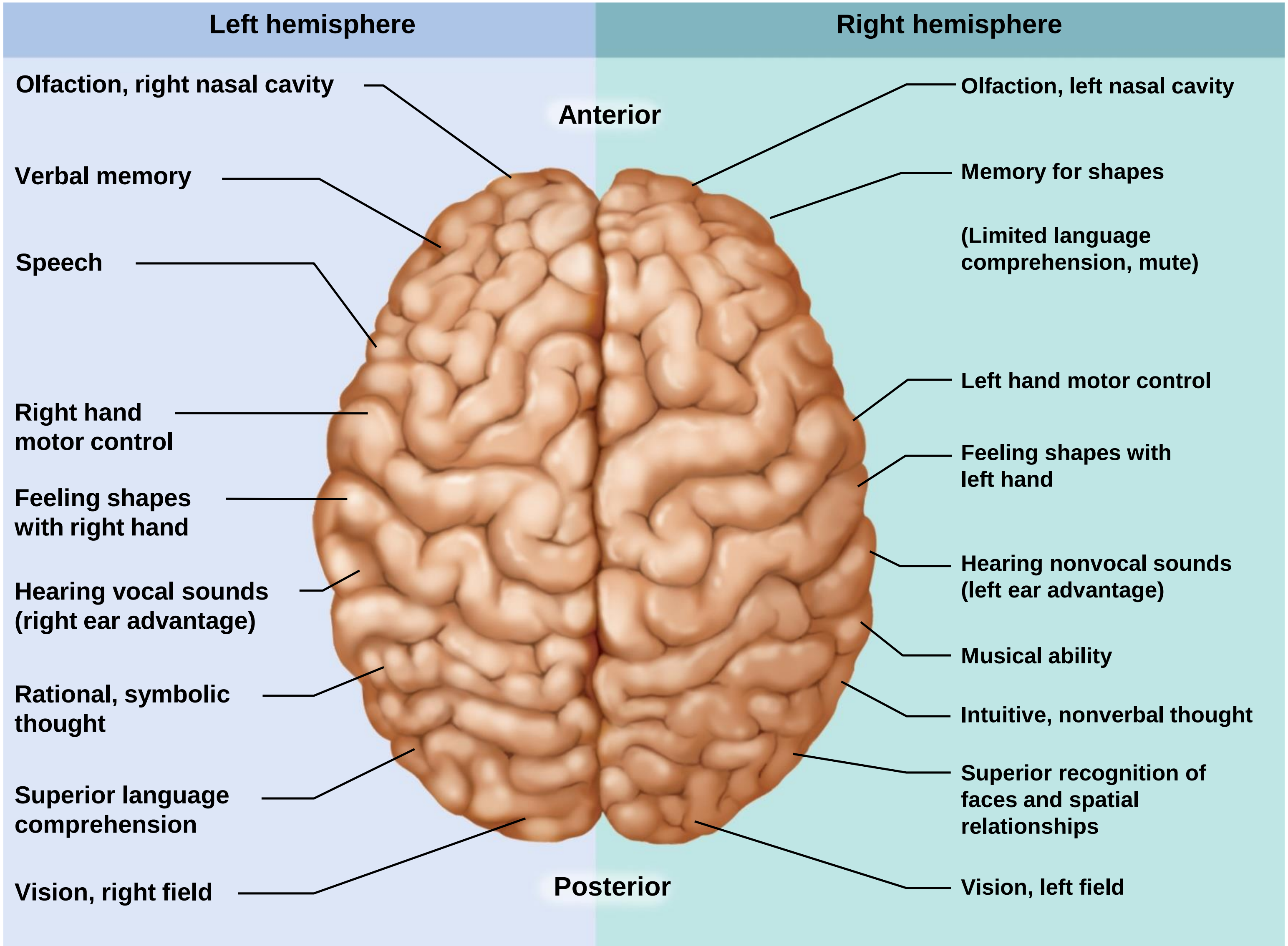


Figure 14.25

Cerebral Lateralization

- **Cerebral lateralization**—the difference in the structure and function of the cerebral hemispheres
- **Left hemisphere**—usually the categorical hemisphere
  - Specialized for spoken and written language
  - Sequential and analytical reasoning (math and science)
  - Breaks information into fragments and analyzes it
- **Right hemisphere**—usually the representational hemisphere
  - Perceives information in a more integrated way
  - Seat of imagination and insight
  - Musical and artistic skill
  - Perception of patterns and spatial relationships
  - Comparison of sights, sounds, smells, and taste

Cerebral Lateralization

- Lateralization is correlated with **handedness**
  - Right handed people: left hemisphere is the categorical one in 96% of righties (right hemisphere is categorical for other 4%)
  - Left-handed people: left hemisphere is the categorical one in 70% of lefties; right hemisphere is categorical for 15%; neither hemisphere specialized in other 15%

- **Lateralization differs with age and sex**
  - Children more resilient to lesions on one side
  - Males exhibit more lateralization than females and suffer more functional loss when one hemisphere is damaged

The Cranial Nerves

- **Expected Learning Outcomes**
  - List the 12 cranial nerves by name and number.
  - Identify where each cranial nerve originates and terminates.
  - State the functions of each cranial nerve.

The Cranial Nerves

- **Brain must communicate with rest of body**
  - **12 pairs of cranial nerves** arise from the base of the brain
  - Exit the cranium through **foramina**
  - Lead to muscles and sense organs located mainly in the **head and neck**

Cranial Nerve Pathways

- Most **motor fibers** of the cranial nerves begin in nuclei of brainstem and lead to glands and muscles
- **Sensory fibers** begin in receptors located mainly in head and neck and lead mainly to the brainstem
- **Most cranial nerves carry fibers between brainstem and ipsilateral receptors and effectors**
  - Lesion in brainstem causes sensory or motor deficit on same side
  - **Exceptions:** optic nerve—half the fibers decussate; and trochlear nerve—all efferent fibers lead to a muscle of the contralateral eye

Cranial Nerve Classification

- Some cranial nerves are classified as **motor,** some **sensory,** others **mixed**
  - Sensory (**I, II,** and **VIII**)
  - Motor (**III, IV, VI, XI,** and **XII**)
    - Stimulate muscle but also contain fibers of proprioception
  - Mixed (**V, VII, IX, X**)
    - Sensory functions may be quite unrelated to their motor function
      - Facial nerve (VII) has sensory role in taste and motor role in facial expression

The Cranial Nerves

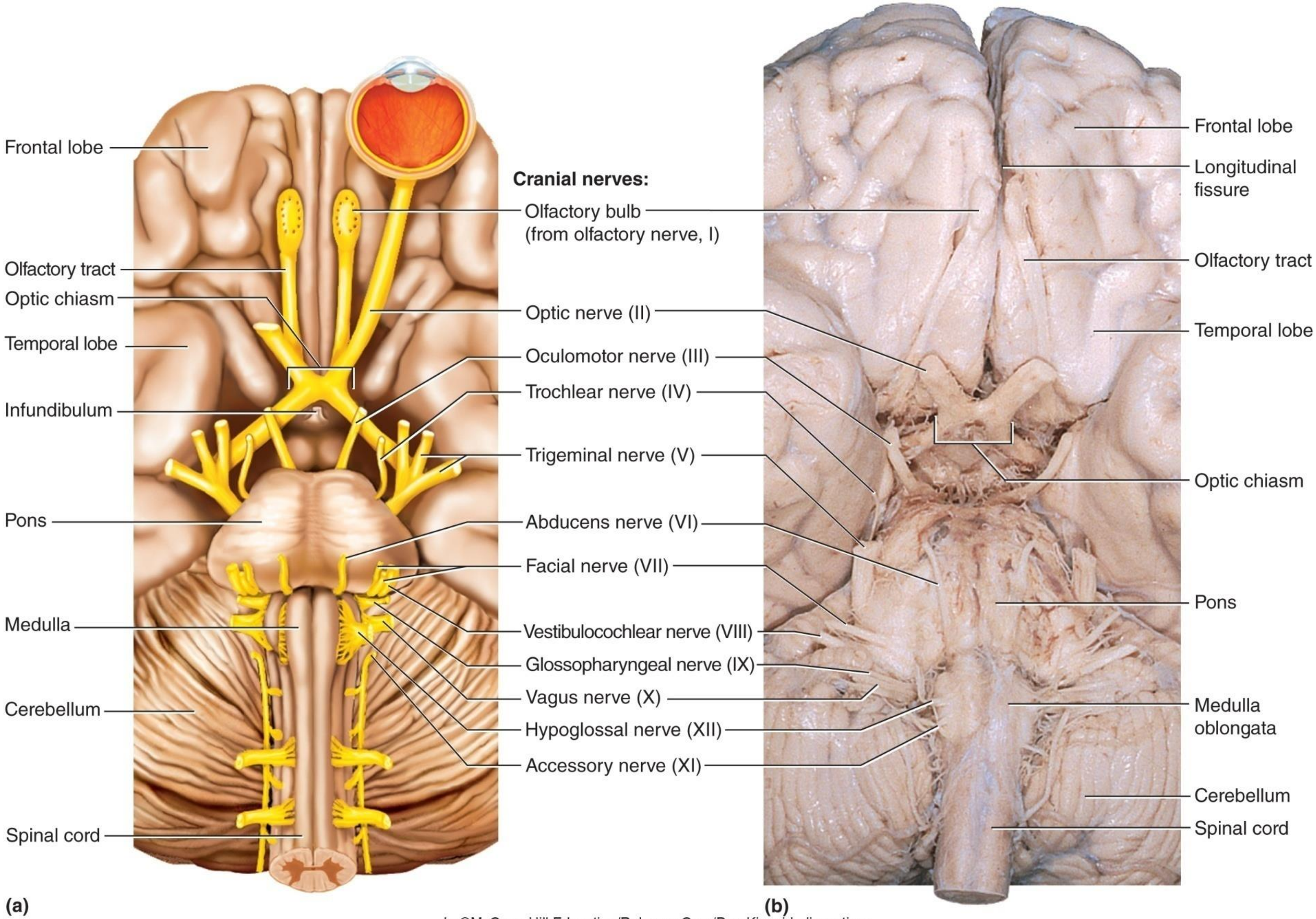


Figure 14.26

The Olfactory Nerve (I)

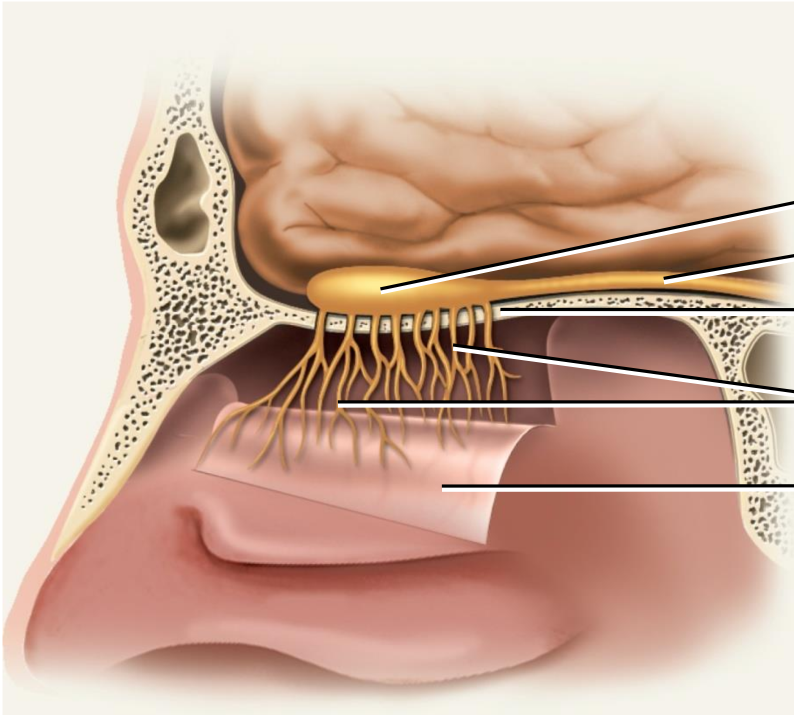


Figure 14.27

- **Sense of smell**
- **Damage causes impaired sense of smell**

The Optic Nerve (II)

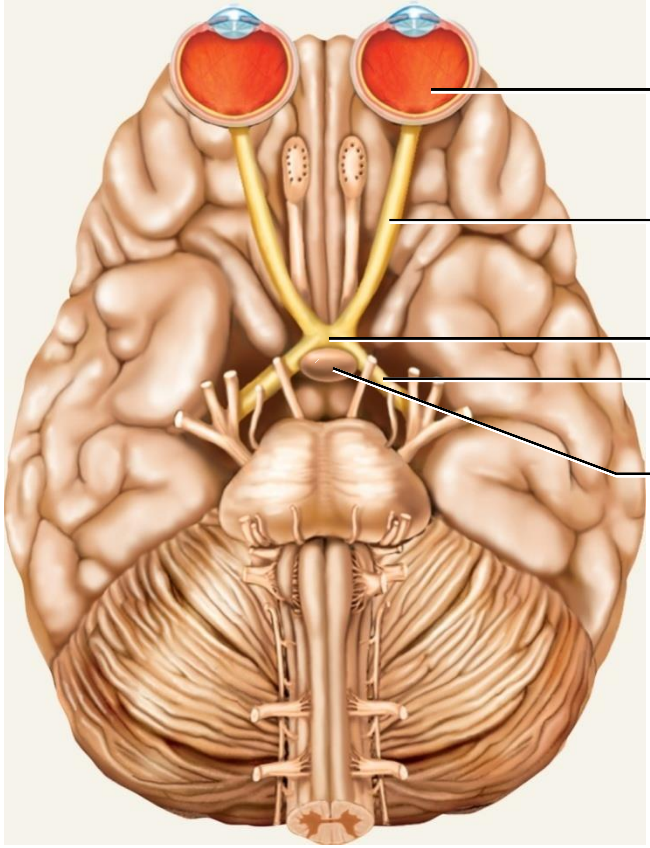


Figure 14.28

- **Provides vision**
- **Damage causes blindness in part or all of visual field**

The Oculomotor Nerve (III)

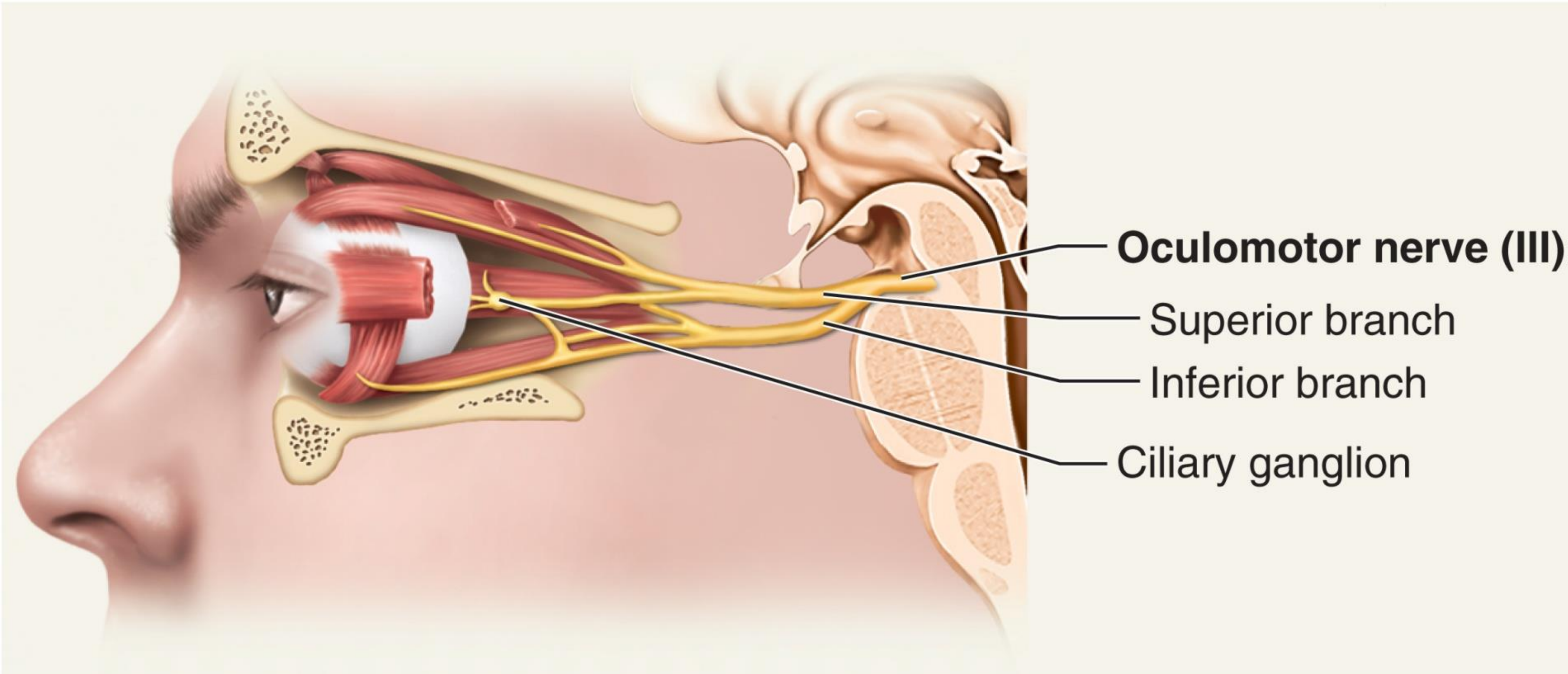


Figure 14.29

- **Controls muscles that turn the eyeball up, down, and medially, as well as controlling the iris, lens, and upper eyelid**
- **Damage causes drooping eyelid, dilated pupil, double vision, difficulty focusing, and inability to move eye in certain directions**

The Trochlear Nerve (IV)

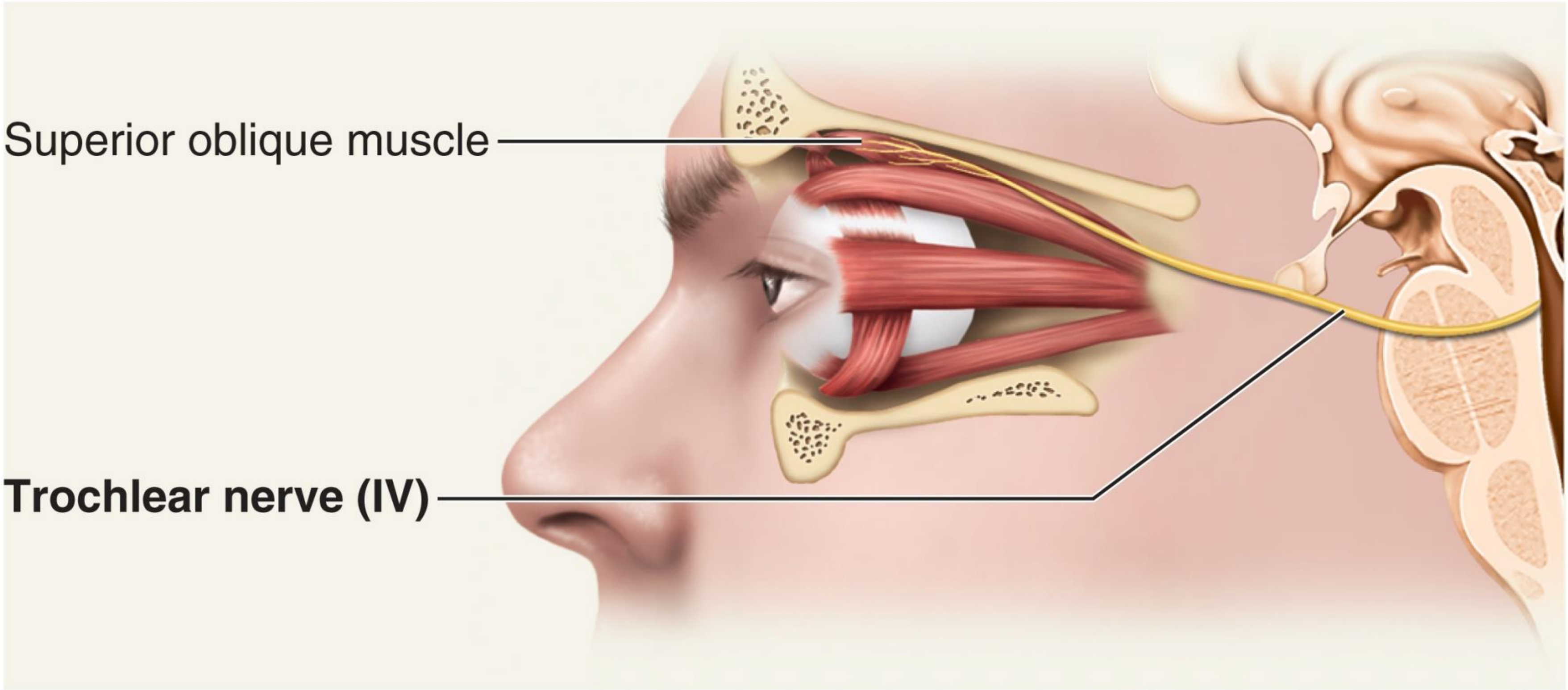


Figure 14.30

- **Eye movement (superior oblique muscle)**
- **Damage causes double vision and inability to rotate eye inferolaterally**

The Trigeminal Nerve (V)

- **Largest cranial nerve**
- **Most important sensory nerve of the face**
- **Forks into three divisions**
  - **Ophthalmic division** (V_1): sensory
  - **Maxillary division** (V_2): sensory
  - **Mandibular division** (V_3): mixed

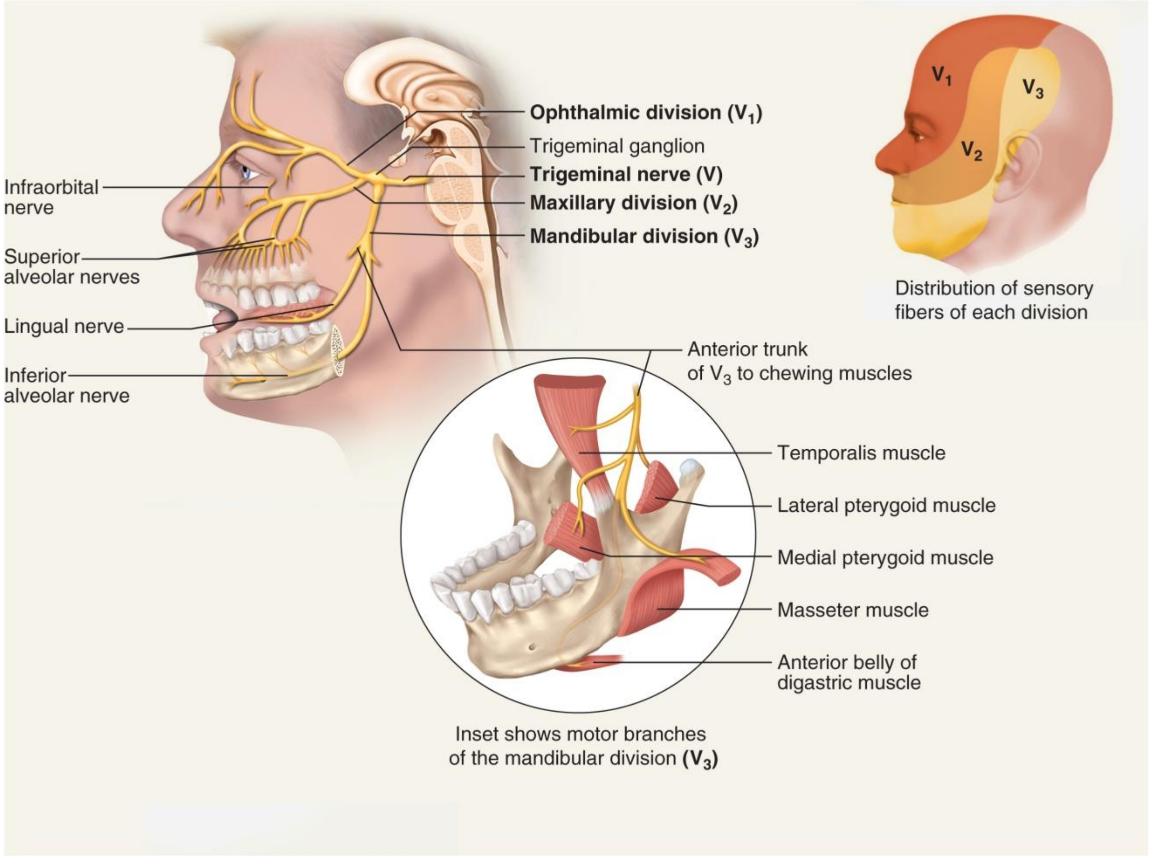


Figure 14.31

The Abducens Nerve (VI)

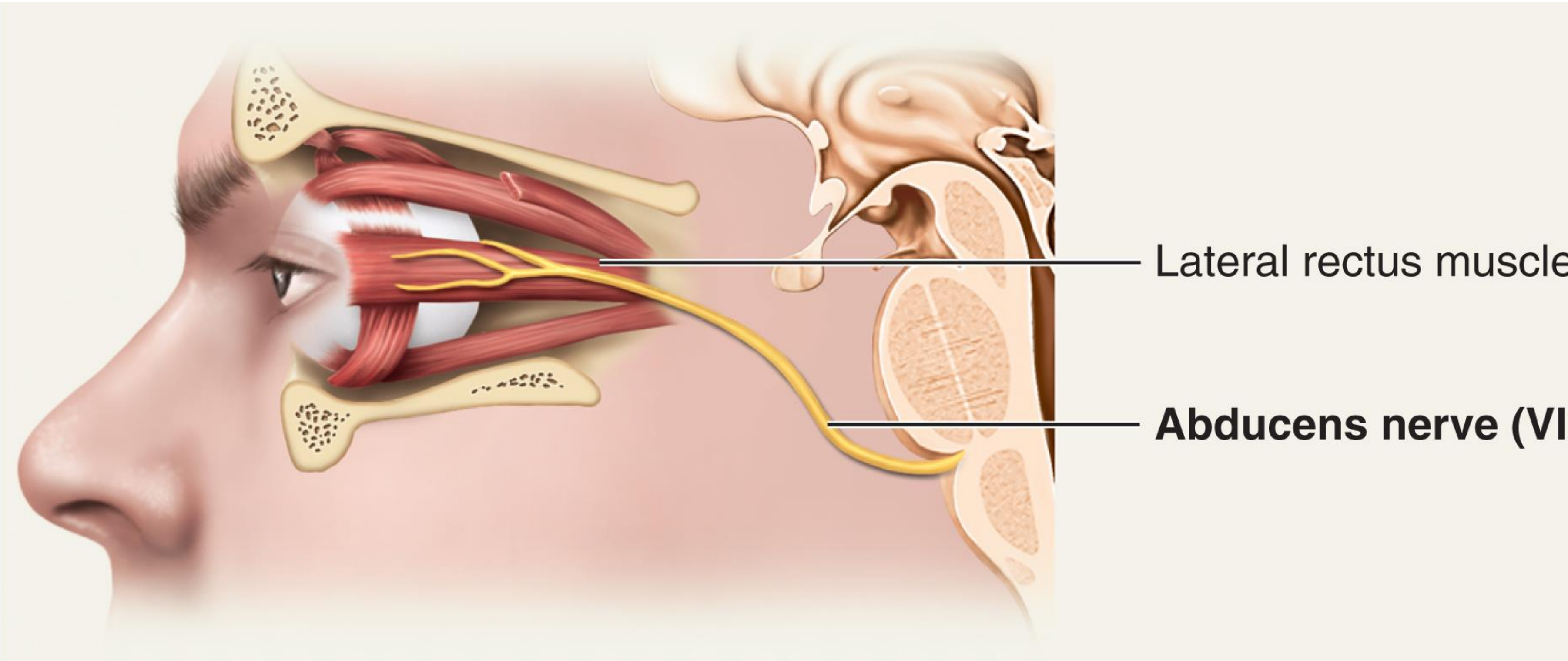


Figure 14.32

- **Provides eye movement (lateral rectus m.)**
- **Damage results in inability to rotate eye laterally and at rest, eye rotates medially**

The Facial Nerve (VII)

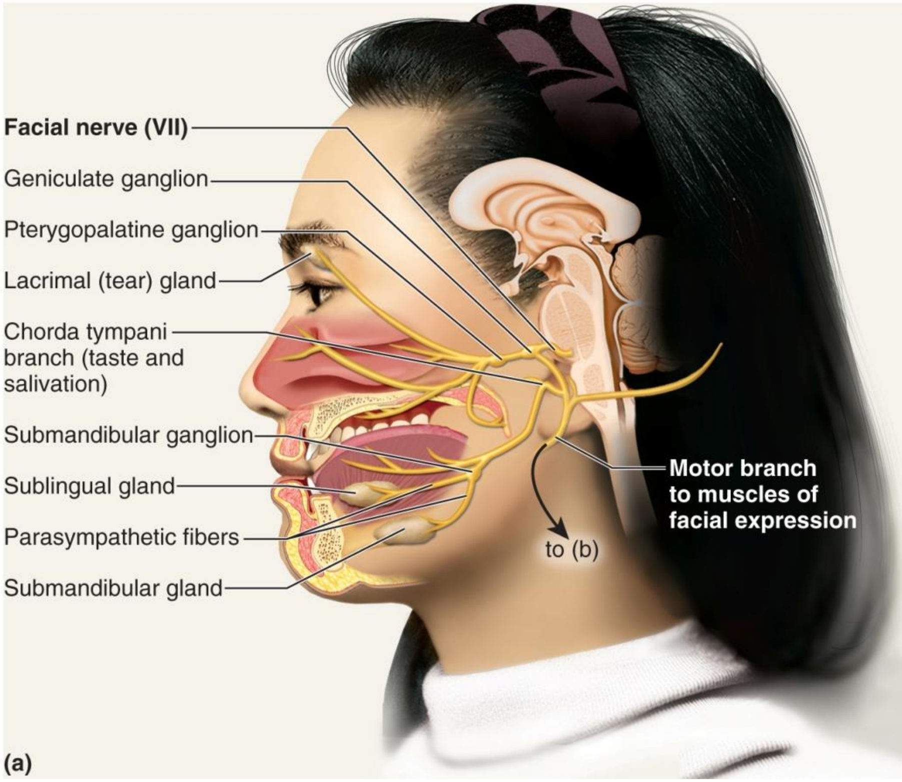


Figure 14.33a

- **Motor—major motor nerve of facial muscles: facial expressions; salivary glands and tear, nasal, and palatine glands**
- **Sensory—taste on anterior two-thirds of tongue**
- **Damage produces sagging facial muscles and disturbed sense of taste (no sweet and salty)**

Five Branches of Facial Nerve

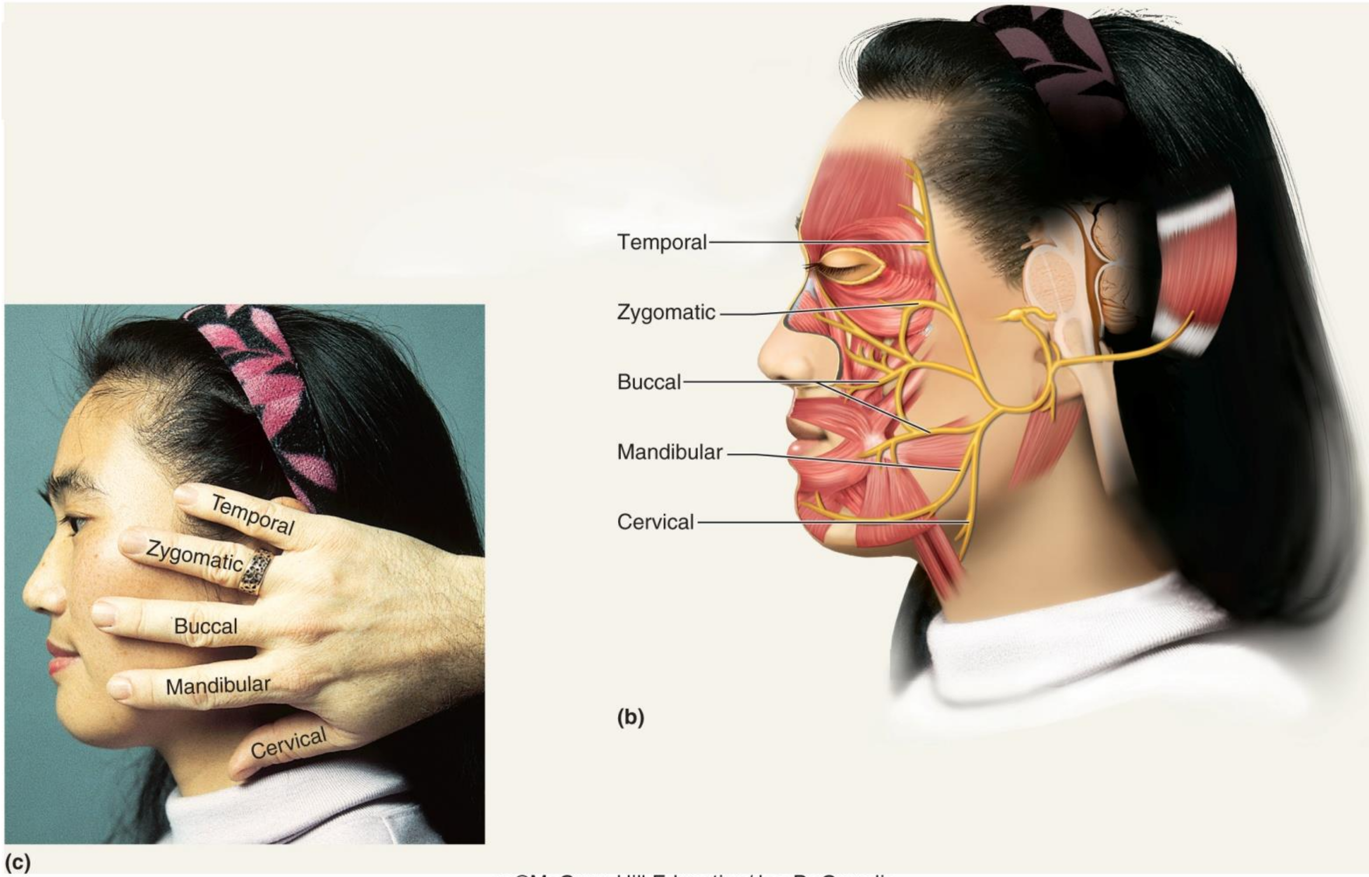


Figure 14.33b,c

Clinical test: test anterior two-thirds of tongue with sugar, salt, vinegar, and quinine; test response of tear glands to ammonia fumes; test motor functions by asking subject to close eyes, smile, whistle, frown, raise eyebrows, etc.

The Vestibulocochlear Nerve (VIII)

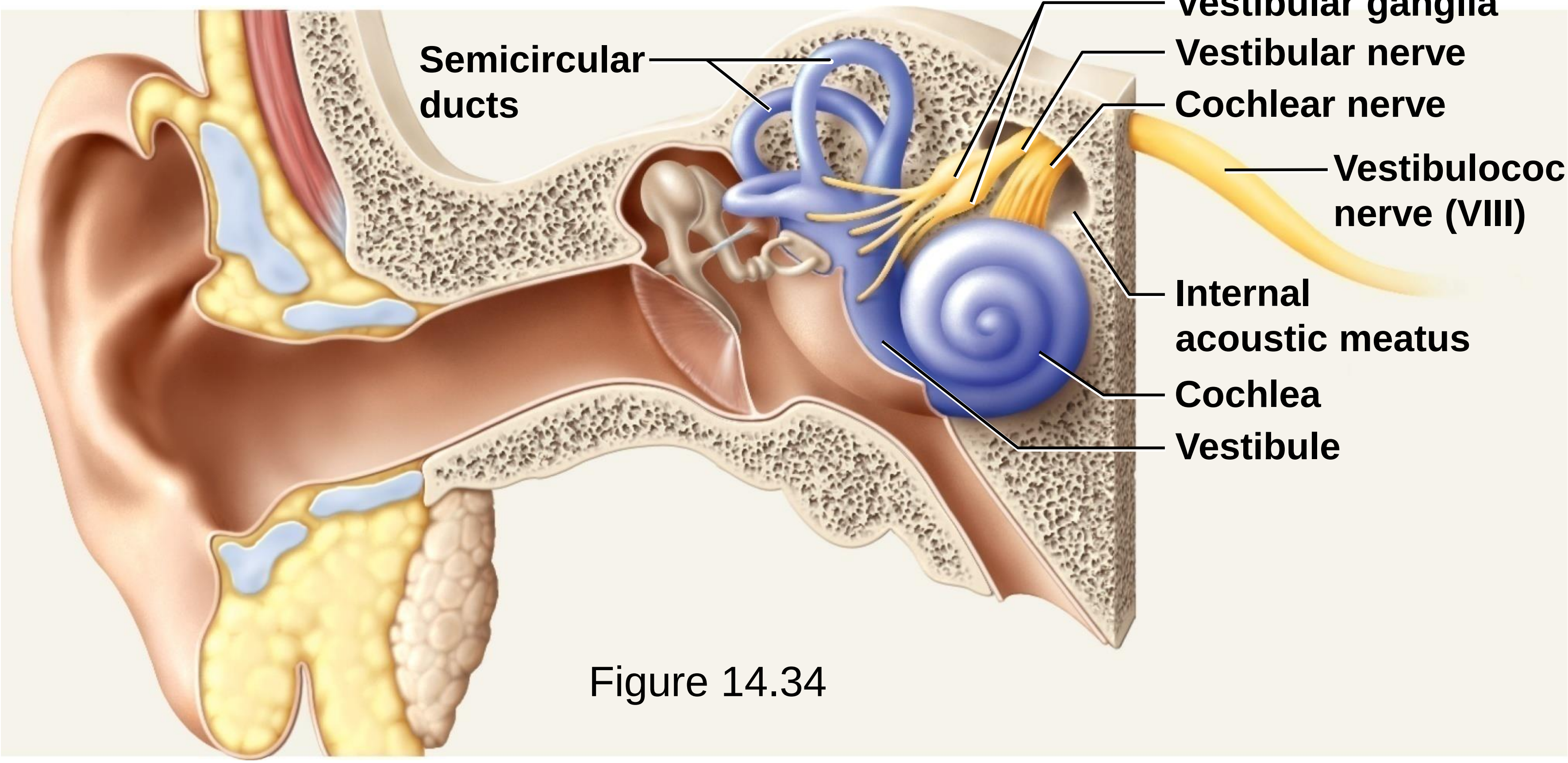


Figure 14.34

- **Nerve of hearing and equilibrium**
- **Damage produces deafness, dizziness, nausea, loss of balance, and nystagmus (involuntary rhythmic oscillation of the eyes)**

The Glossopharyngeal Nerve (IX)

- **Swallowing, salivating, gagging, controlling BP and respiration**
- **Sensations from posterior one-third of tongue**
- **Damage results in loss of bitter and sour taste and impaired swallowing**

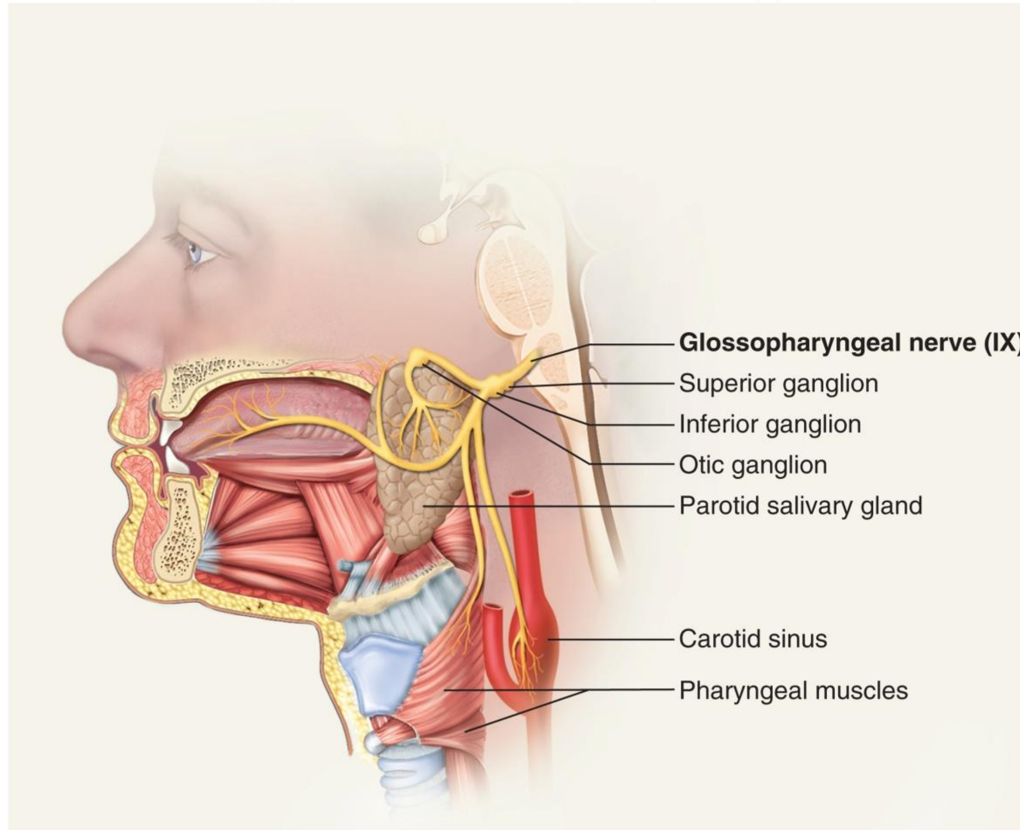


Figure 14.35

The Vagus Nerve (X)

- **Most extensive distribution of any cranial nerve**
- **Major role in the control of cardiac, pulmonary, digestive, and urinary function**
- **Swallowing, speech, regulation of viscera**
- **Damage causes hoarseness or loss of voice, impaired swallowing, and fatal if both are cut**

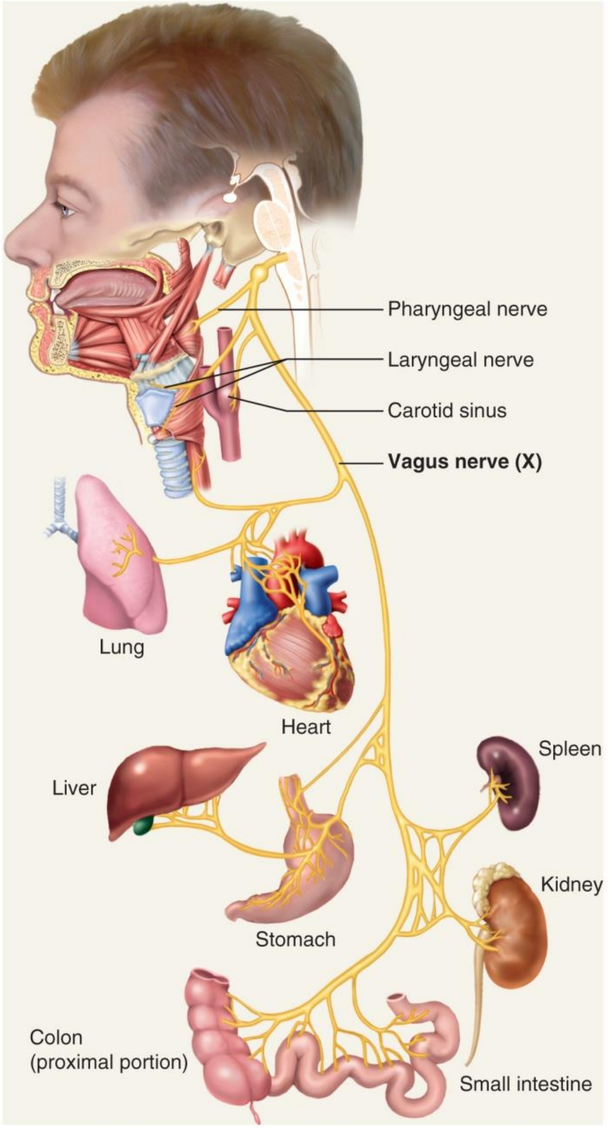


Figure 14.36

The Accessory Nerve (XI)

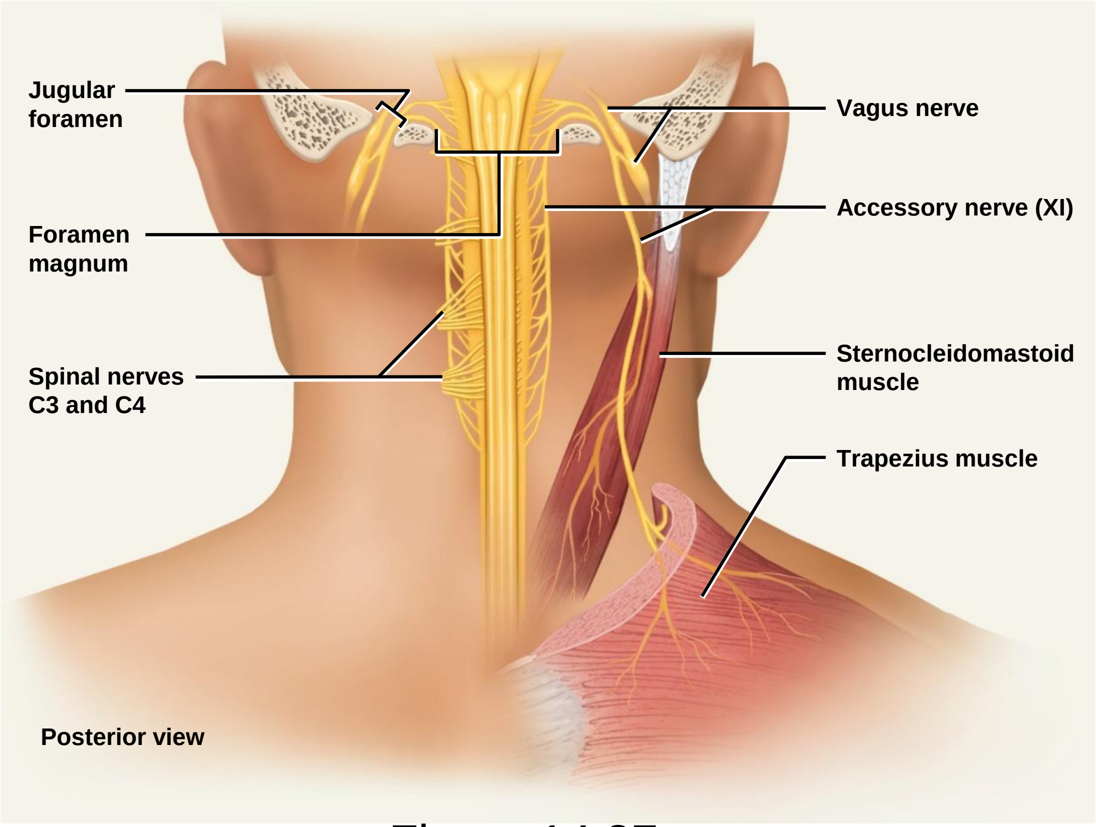


Figure 14.37

- **Swallowing; head, neck, and shoulder movement**
  - Damage causes impaired head, neck and shoulder movement; head turns toward injured side

The Hypoglossal Nerve (XII)

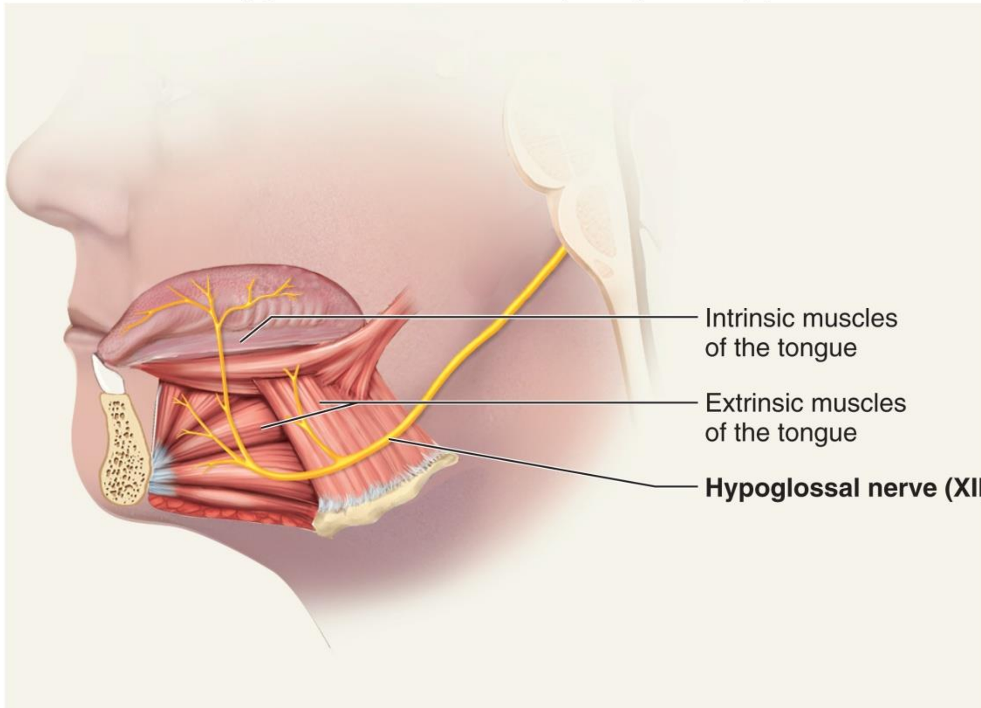


Figure 14.38

- **Tongue movements for speech, food manipulation, and swallowing**
  - If both are damaged: cannot protrude tongue
  - If one side is damaged: tongue deviates toward injured side; ipsilateral atrophy

The Cranial Nerves

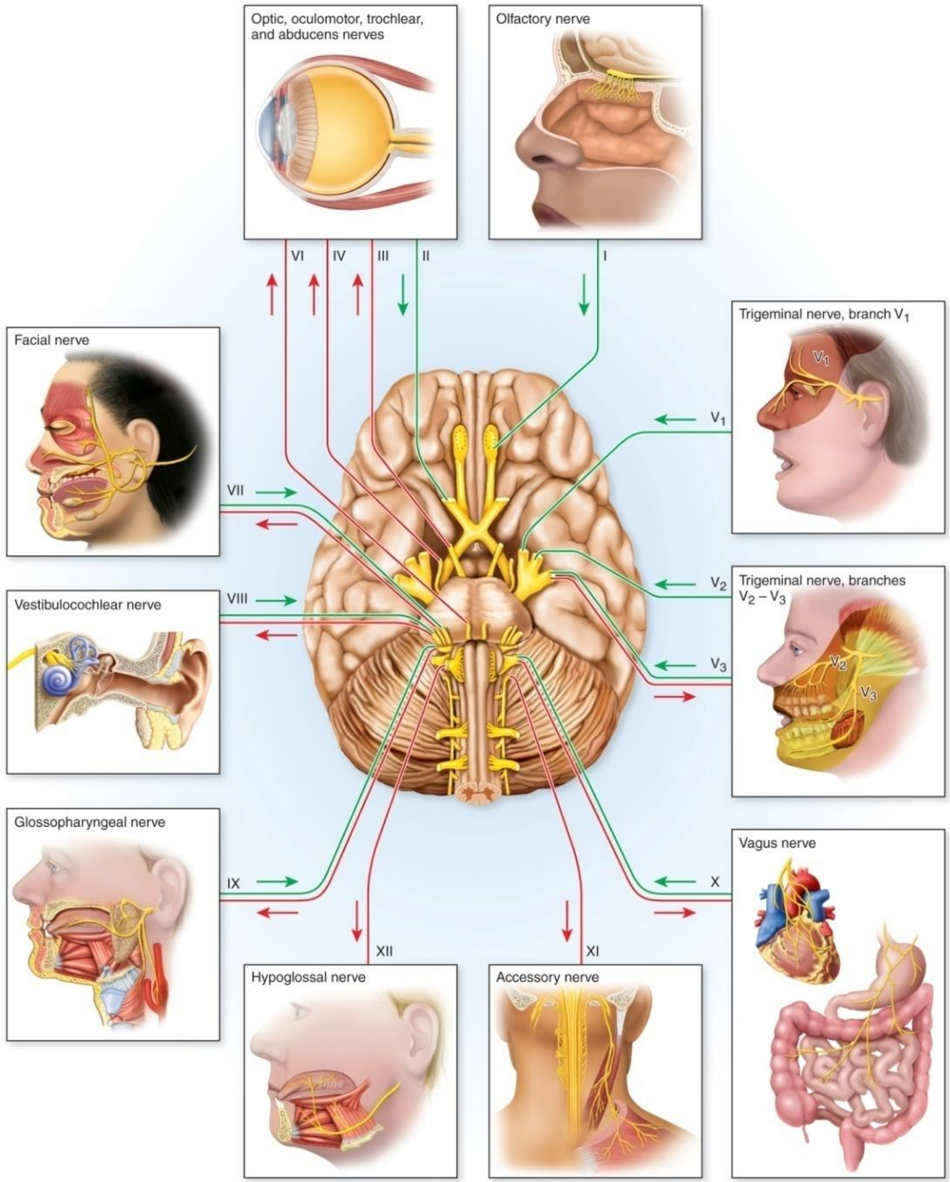


Figure 14.39

Cranial Nerve Disorders

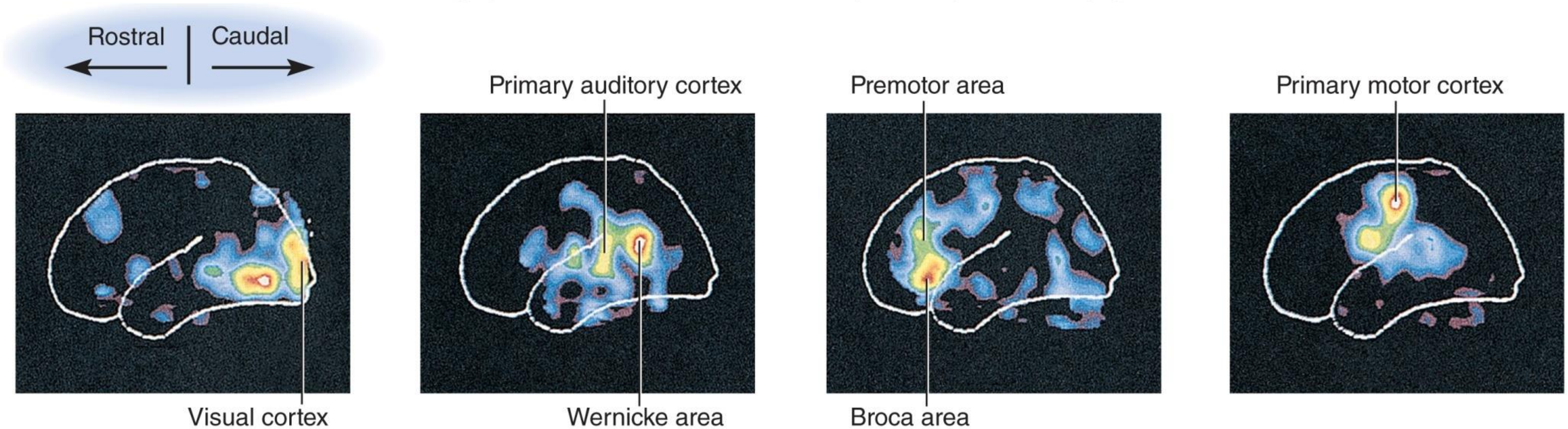
- **Trigeminal neuralgia (tic douloureux)**
  - Recurring episodes of intense stabbing pain in trigeminal nerve area (near mouth or nose)
  - Pain triggered by touch, drinking, washing face
  - Treatment may require cutting nerve

Images of the Mind

- **Positron emission tomography (PET)** allows researchers to visualize increases in blood flow when brain areas are active
  - Involves injection of radioactively labeled glucose
    - Busy areas of brain “light up”

- **Functional magnetic resonance imaging (fMRI)** looks at increase in blood flow to an area—magnetic properties of hemoglobin depend on how much oxygen is bound to it

Images of the Mind



1 The word *car* is seen in the visual cortex.

2 Wernicke area conceives of the verb *drive* to go with it.

3 Broca area compiles a motor program to speak the word *drive*.

4 The primary motor cortex executes the program and the word is spoken.

Figure 14.40