



CNS
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Physiology

Modified (1)

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Neurophysiology

Control of body movements

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Motor cortex

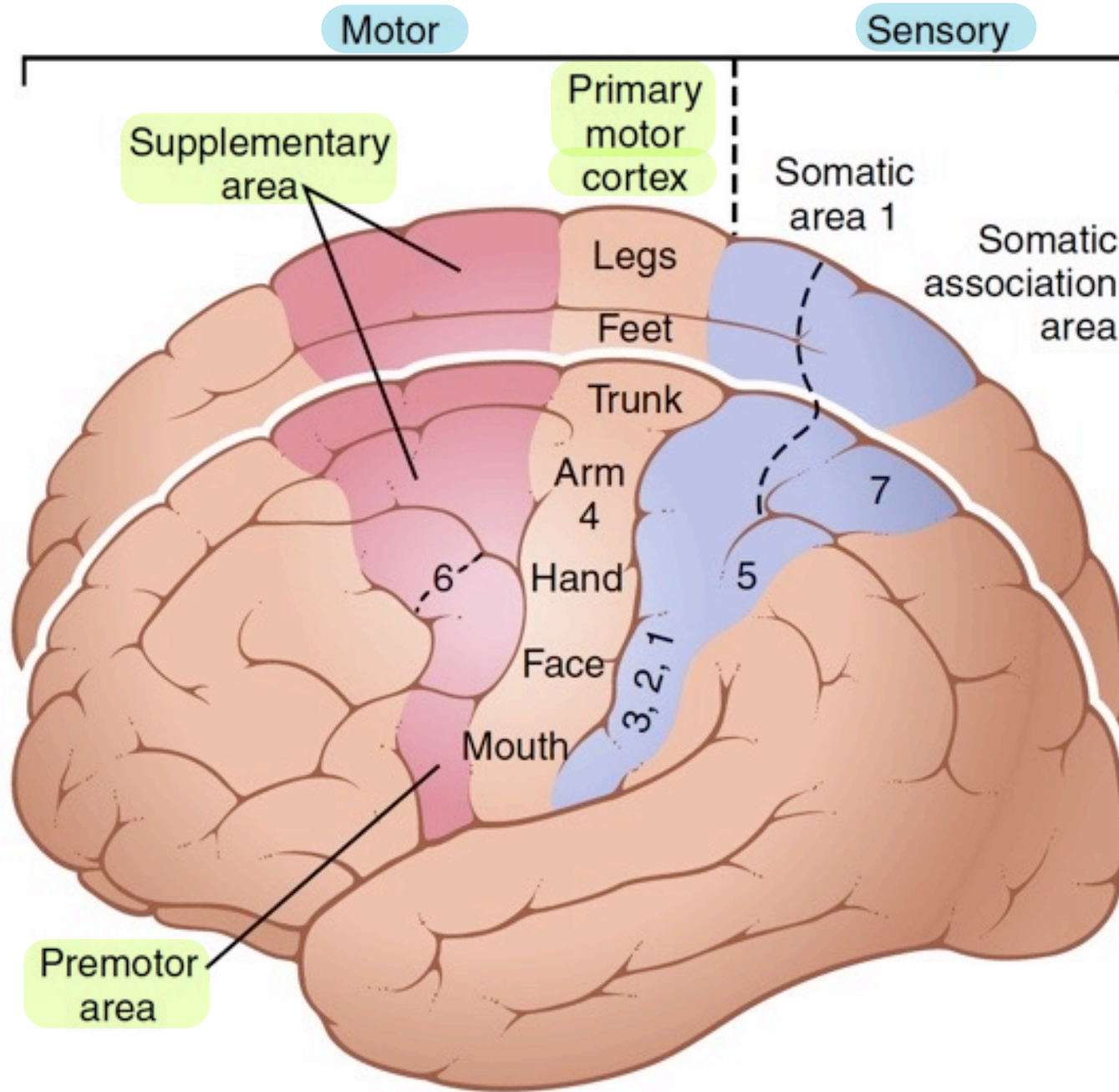
- The motor system stimulates or inhibits effector cells= muscles (skeletal, smooth, cardiac muscles) OR glands. However, our primary focus will be on the skeletal muscle system, which is part of the somatic system.
- Skeletal muscles are associated with voluntary movement, with the Cerebral Cortex serving as the integrative center [motor cortex].
- Most voluntary movements initiated by the cerebral cortex are achieved when the cortex activates patterns of function stored in lower brain areas: the cord, brain stem, basal ganglia, and cerebellum. Cortex → Lower brain areas → Lower motor neurons → Skeletal muscles
- These lower centers, in turn, send specific control signals to the muscles.

Motor cortex

- For a few types of movements, however, the cortex has almost a **direct pathway** to the anterior motor neurons of the cord, bypassing some motor centers on the way.

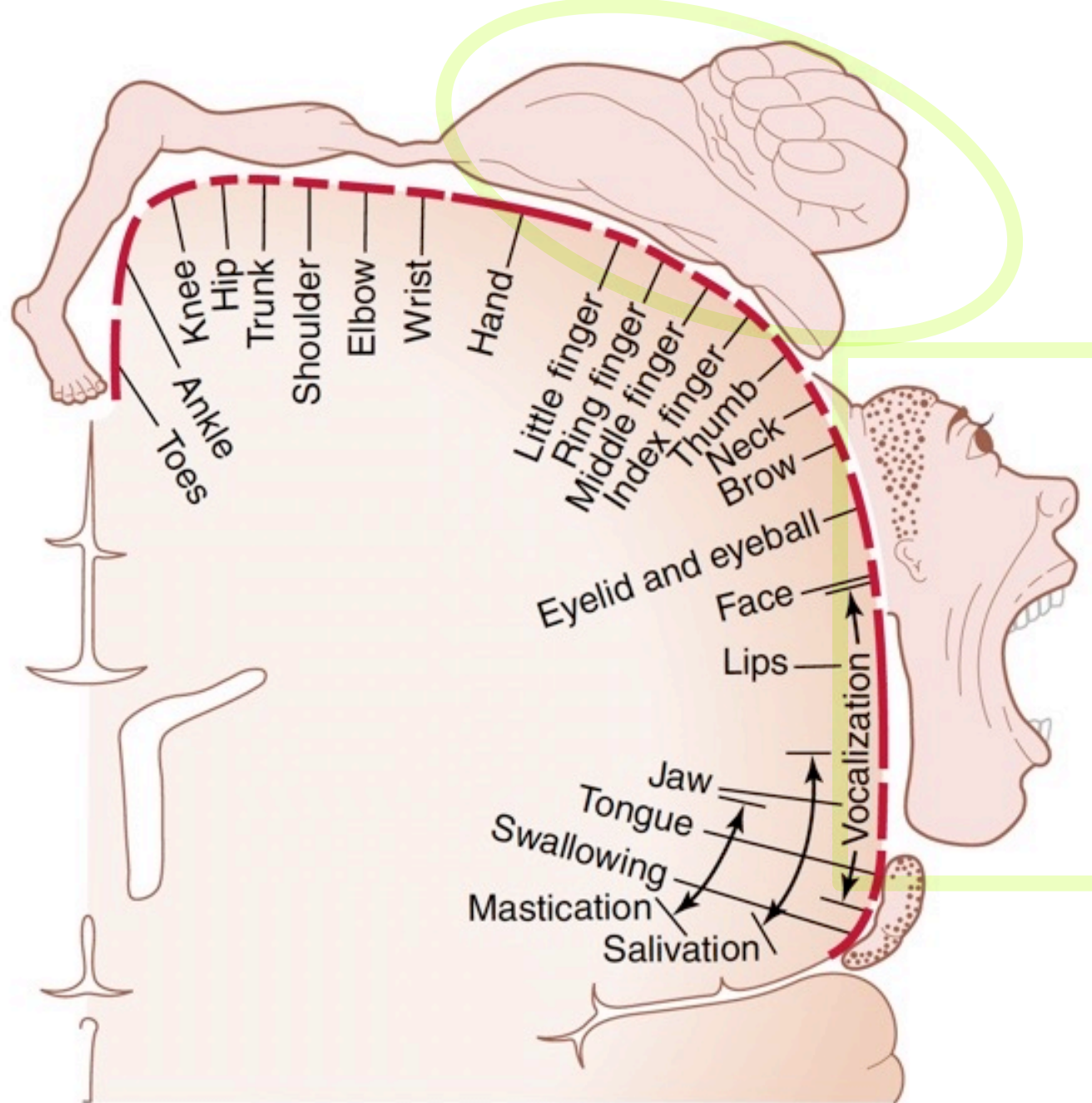
Cortex → Lower motor neurons → Skeletal muscles

- This is especially true for control of the fine dexterous movements of the fingers and hands.



The motor cortex consists of :
 [primary motor cortex],
 [supplementary area], &
 [premotor area].

- The primary motor area is situated in close proximity to the somatosensory area, facilitating sensorimotor integration, coordination, and fine motor control.
- The supplementary area and premotor area are collectively known as the **motor association area**.



- In the primary motor area, there exists a distorted representation of the body parts known as the **Motor Homunculus**, similar to the one found in the somatosensory area.
- This representation is based on the quantity of motor nerve fibers, which correlates with the precision and detail of the movement

Primary motor cortex

↳ Execution of the motor function

- more than half of the entire primary motor cortex is concerned with controlling the muscles of the hands and the muscles of speech.
- excitation of a single motor cortex neuron usually excites a specific movement rather than one specific muscle.

- From the primary motor cortex, two descending pathways are initiated:
 - (1) Direct Pathway = Corticospinal Pathway → Descending directly from the brain to the lower motor neurons in the spinal cord, this pathway provides direct innervation to skeletal muscles for motor control.
 - (2) Indirect Pathways → Utilize various areas within the central nervous system (CNS), including the basal nuclei, red nucleus, cerebellum, vestibular nuclei, and reticular nuclei, these pathways are involved in determining the final movement.

Premotor area

↳ Planning & Sequential organization

- The premotor area in the brain is involved in the detailed planning and sequential organization of specific movements. Once a movement plan, including the excitation of specific muscles, is formulated in the premotor area, it is then relayed to the primary motor cortex. The primary motor cortex is responsible for generating the definitive motor commands necessary to initiate and execute the planned movement.

Premotor area

- The most anterior part of the premotor area first develops a “motor image” of the total muscle movement that is to be performed.
- Then, in the posterior premotor cortex, this image excites each successive pattern of muscle activity required to achieve the image.
- it sends signals either directly to the primary motor cortex or to the basal ganglia and thalamus back to the primary motor cortex. primary motor cortex بالحالتين لازم نمر بال

Premotor area

- A special class of neurons called **mirror neurons** becomes active when a person performs a specific motor task or when he or she observes the same task performed by others.
- Thus, the activity of these neurons “mirrors” the behavior of another person as though the observer was performing the specific motor task.
- important for understanding the actions of other people and for learning new skills by imitation.

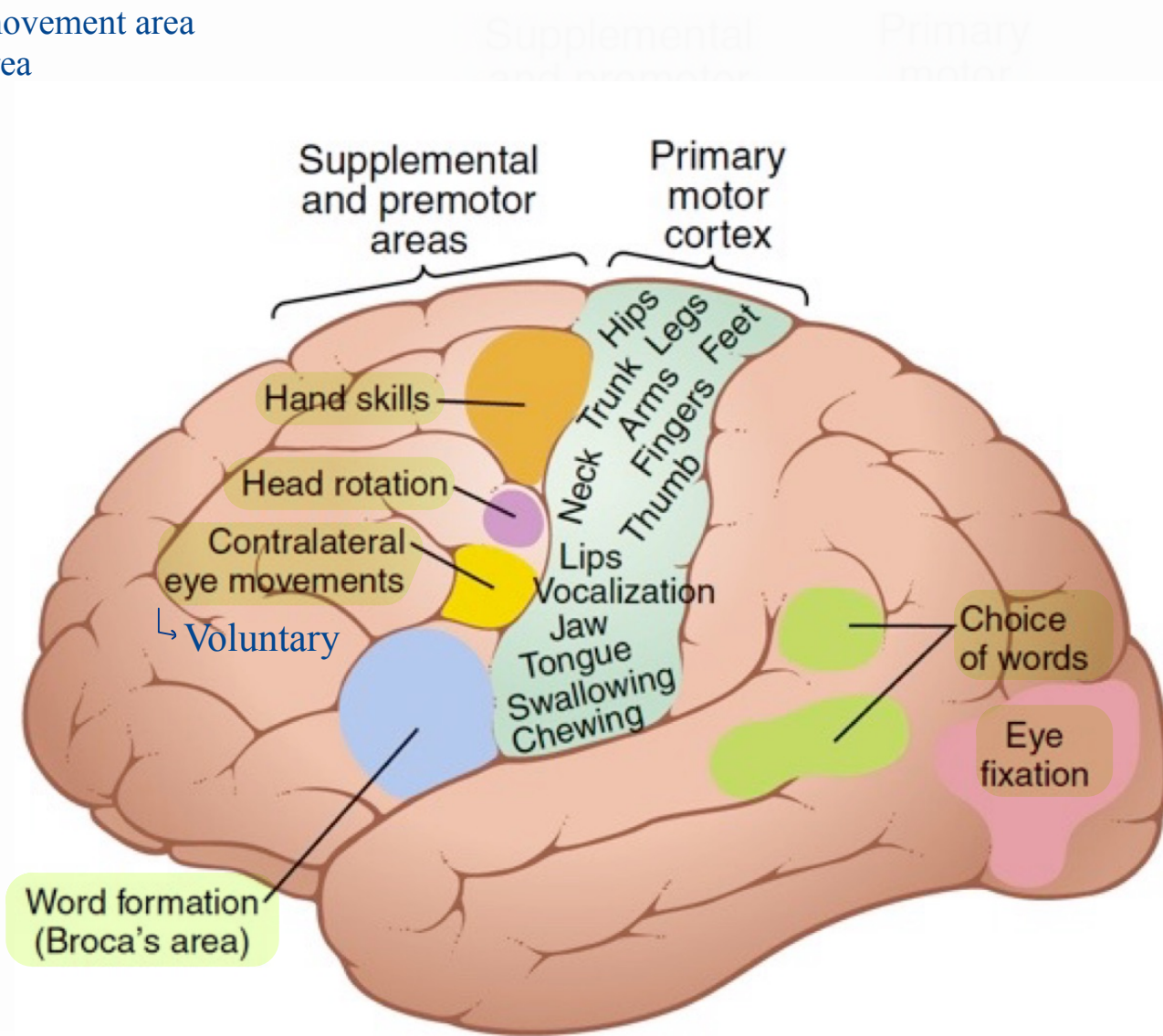
Supplementary area

↳ Organization & Coordination & Background Support

- Contractions elicited by stimulating this area are often bilateral rather than unilateral.
 - In general, this area functions in concert with the premotor area to provide body-wide attitudinal movements, fixation movements of the different segments of the body, positional movements of the head and eyes, and so forth, as background for the finer motor control of the arms and hands by the premotor area and primary motor cortex.
- The storage of motor function memories is important for efficiently utilizing movement information as needed, rather than planning from scratch to do same movements; this is how we learn.
 - **Attitudinal movements** involve the alignment and orientation of different body segments, such as the head, trunk, limbs, and eyes, to achieve a desired posture or spatial relationship.

Other areas involved in controlling specific movements:

- Broca's area
- Voluntary eye movement area
- Head rotation area
- Hand skills area



How is speech learned ?

- Initially, sensory information is obtained through auditory or visual impulses, which are processed in the primary cortex corresponding to the specific sensory modality involved.
- Auditory information related to sound frequencies and loudness, or visual information related to lip and facial movements, are analyzed in the **Wernicke's area**. Once this analysis is complete, the processed information is then directed to Broca's area, which is responsible for the motor functions involved in speech production.
- **Broca's area**, often referred to as the speech center, coordinates the precise movements of the speech muscles, including those of the mouth, tongue, and vocal cords, required for fluent speech.

Broca's

↳ Word-forming area

- Damage to it does not prevent a person from vocalizing but makes it impossible for the person to speak whole words.
- A closely associated cortical area also causes appropriate respiratory activation of the vocal cords that occur simultaneously with the movements of the mouth and tongue during speech. you will move certain respiratory muscles along with the movement of the vocal cords
- Thus, the premotor neuronal activities related to speech are highly complex.

- Expressive Aphasia or Broca's aphasia ⇒ damage to Broca's area. Patients with this condition can vocalize but struggle to express their thoughts through speaking or writing.

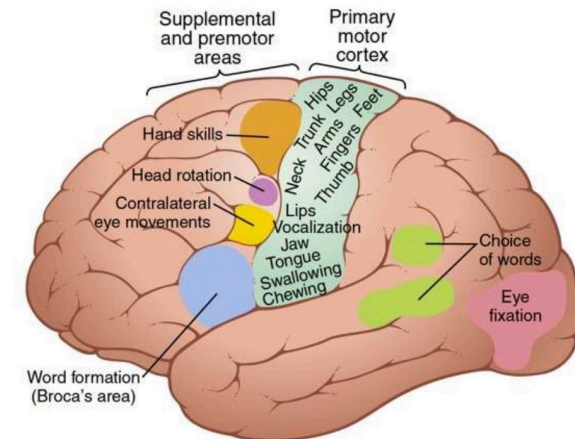
Voluntary eye movement area

- Allows a person to voluntarily move the eyes toward different objects.
- When damaged, the eyes tend to lock involuntarily onto specific objects, an effect controlled by signals from the occipital visual cortex.
- This area also controls eyelid movements such as blinking.

• The process of eye fixation, blinking, and voluntary eye movements is regulated by specialized brain regions dedicated to oculomotor control. These regions, including the brainstem nuclei, superior colliculus, and frontal & occipital eye fields, work together to coordinate and control the precise movements of the eyes. However, if the voluntary eye movement area is damaged, the occipital visual cortex (Eye fixation area) will override its function, leading to involuntary fixation onto specific objects. This can result in difficulties in visually scanning the environment (fixation of the eyeballs).

Head rotation area

- This area is closely associated with the eye movement field; it directs the head toward different objects.
- Head & eye movements go synergistically hand in hand.



Hand skills area

- destruction in this area causes hand movements to become uncoordinated and nonpurposeful, a condition called motor apraxia.

Frontal cortex

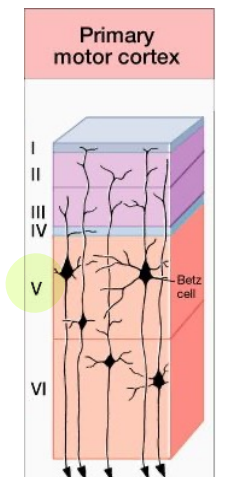


Appropriateness of certain movements

- The frontal cortex is responsible for assessing the appropriateness of certain movements, inhibiting actions when necessary, making judgments, and deciding whether to initiate or suppress specific movements. It plays a crucial role in evaluating the context and consequences of actions, enabling us to make informed decisions about how to proceed with our movements.

Columns in motor cortex

- Each column of cells functions as a unit, usually stimulating a group of synergistic muscles, or just a single muscle.
- Also, each column has six distinct layers of cells, as is true throughout nearly all the cerebral cortex.
- The pyramidal cells that give rise to the corticospinal fibers all lie in the 5th layer. *responsible for initiating of the corticospinal pathway.*



Columns in motor cortex

- The neurons of each column operate as an integrative processing system, using information from multiple input sources to determine the output response from the column.
- In addition, each column can function as an amplifying system to stimulate large numbers of pyramidal fibers to the same muscle or to synergistic muscles simultaneously.
- This ability is important because stimulation of a single pyramidal cell seldom excites a muscle.

Dynamic vs static signals

- each column of cells excites two populations of **pyramidal cell neurons**, one called dynamic neurons and the other static neurons.
- The **dynamic neurons** are excited at a high rate for a short period at the beginning of a contraction, causing the initial rapid development of force.
- The **static neurons** then fire at a much slower rate, but they continue firing at this slow rate to maintain the force of contraction as long as the contraction is required.

Motor pathways

- Motor signals are transmitted directly from the cortex to the spinal cord through the corticospinal tract and indirectly through multiple accessory pathways that involve the basal ganglia, cerebellum, and various nuclei of the brain stem.
- In general, the direct pathways are concerned with discrete and detailed movements, especially of the distal segments of the limbs, particularly the hands and fingers.

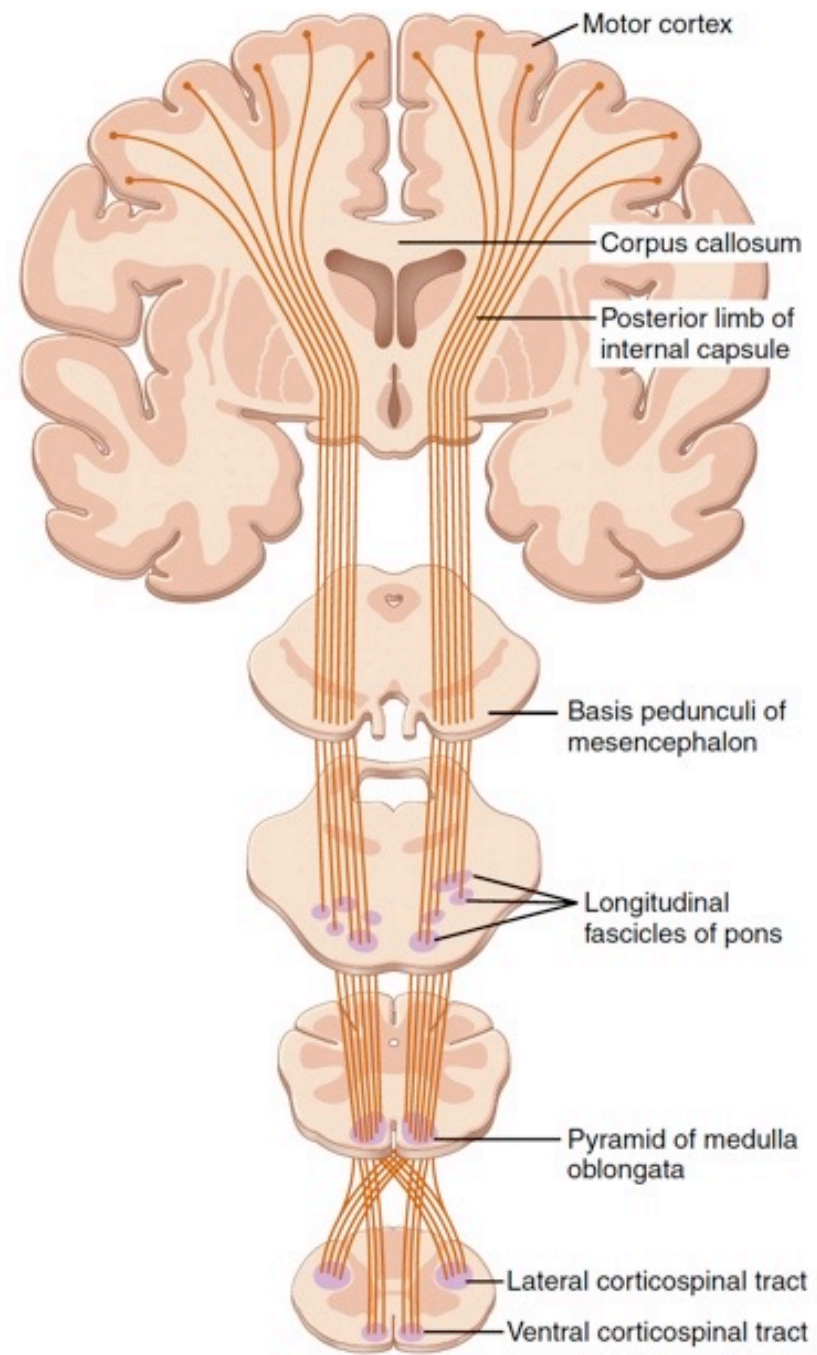
Corticospinal tract

- The most important output pathway from the motor cortex is the corticospinal tract, also called the pyramidal tract.

↳ to ensure rapid conduction velocity

- Giant pyramidal cells, called **Betz cells**, have the most rapid rate of transmission of any signals from the brain to the cord.

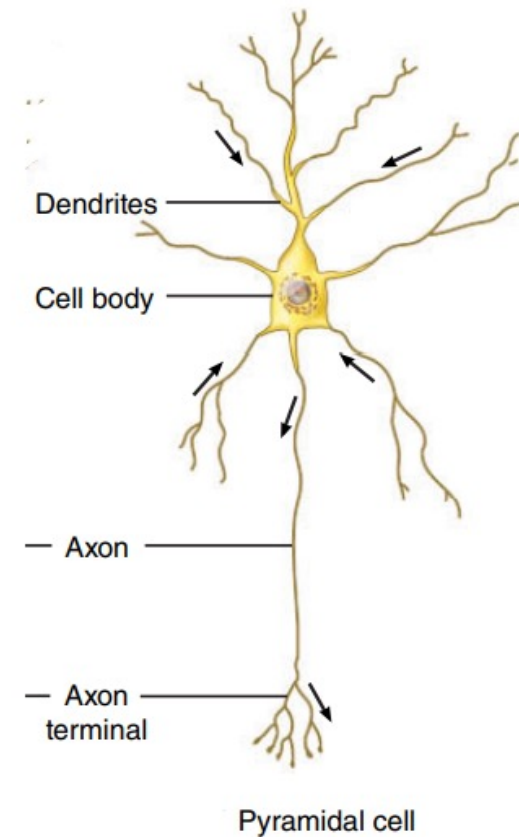
- The corticospinal tract originates from the primary motor cortex.



Direct motor pathways, also known as the **pyramidal pathways**.

Pyramidal cells are upper motor neurons that have pyramid-shaped cell bodies. They are the main output cells of the cerebral cortex.

The direct motor pathways consist of corticospinal pathways and the corticobulbar pathway



Corticospinal pathways

- Axons of UMNs in the cerebral cortex form the corticospinal tracts, which descend through the internal capsule of the cerebrum and the cerebral peduncle of the midbrain.
- In the medulla oblongata, the axon bundles of the corticospinal tracts form the ventral bulges known as the pyramids.
- About 90% of the corticospinal axons decussate to the contralateral side in the medulla oblongata and then descend into the spinal cord where they synapse with a local circuit neuron or a lower motor neuron.
 - ↳ Lateral Corticospinal... acts on distal muscles... fine movement

Corticospinal pathways

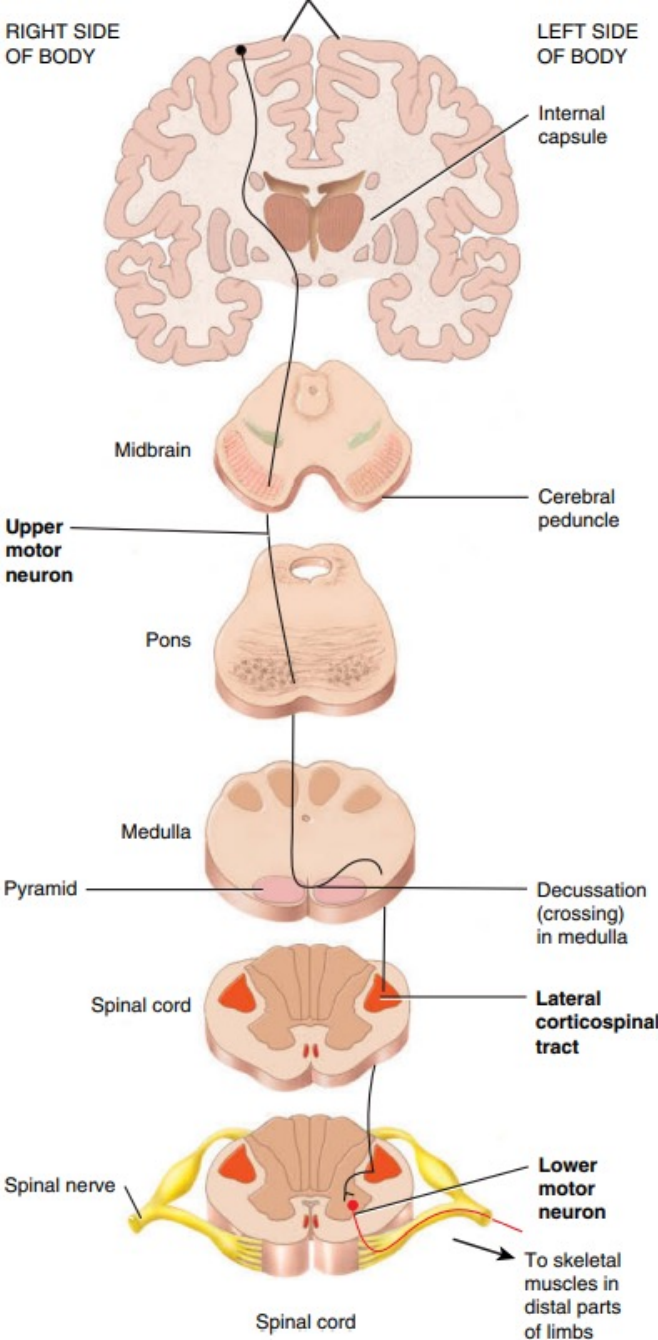
↳ Anterior Corticospinal... acts on proximal muscles

- The 10% that remain on the ipsilateral side eventually decussate at the spinal cord levels where they synapse with a local circuit neuron or lower motor neuron.
- Thus, the right cerebral cortex controls most of the muscles on the left side of the body, and the left cerebral cortex controls most of the muscles on the right side of the body.
- There are two types of corticospinal tracts: the lateral corticospinal tract and the anterior corticospinal tract

Lateral corticospinal tract

- Corticospinal axons that decussate in the medulla form the lateral corticospinal tract in the lateral white column of the spinal cord.
- These axons synapse with local circuit neurons or lower motor neurons in the anterior gray horn of the spinal cord.
- Axons of these lower motor neurons exit the cord in the anterior roots of spinal nerves and terminate in skeletal muscles that control movements of the **distal parts of the limbs**.
- The distal muscles are responsible for precise, agile, and highly skilled movements of the hands and feet.
- The muscles of the hands are of utmost importance to control, which is why we have a backup pathway for the corticospinal tract: the **Rubrospinal tract**.

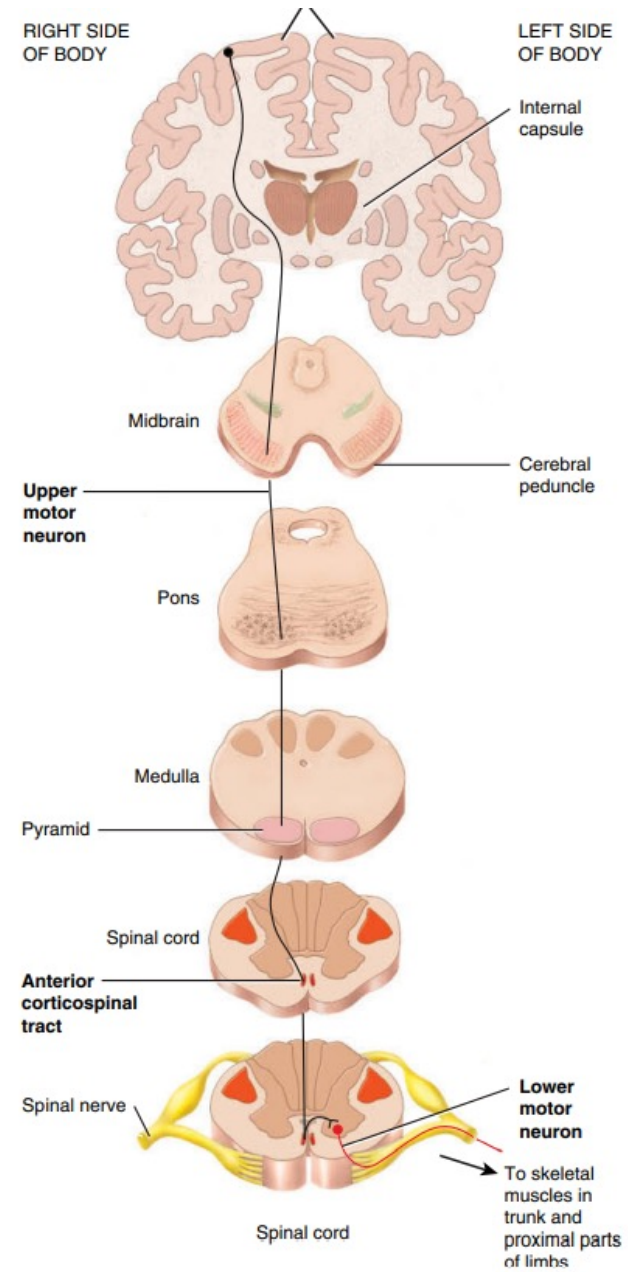
Lateral corticospinal tract



Anterior corticospinal tract

- Corticospinal axons that do not decussate in the medulla form the anterior corticospinal tract in the anterior white column of the spinal cord.
- At each spinal cord level, some of these axons decussate via the anterior white commissure. Then, they synapse with local circuit neurons or lower motor neurons in the anterior gray horn.
- Axons of these lower motor neurons exit the cord in the anterior roots of spinal nerves. They terminate in skeletal muscles that control movements of the **trunk and proximal parts of the limbs**
- Responsible for contributing to the maintenance of posture.

Anterior corticospinal tract



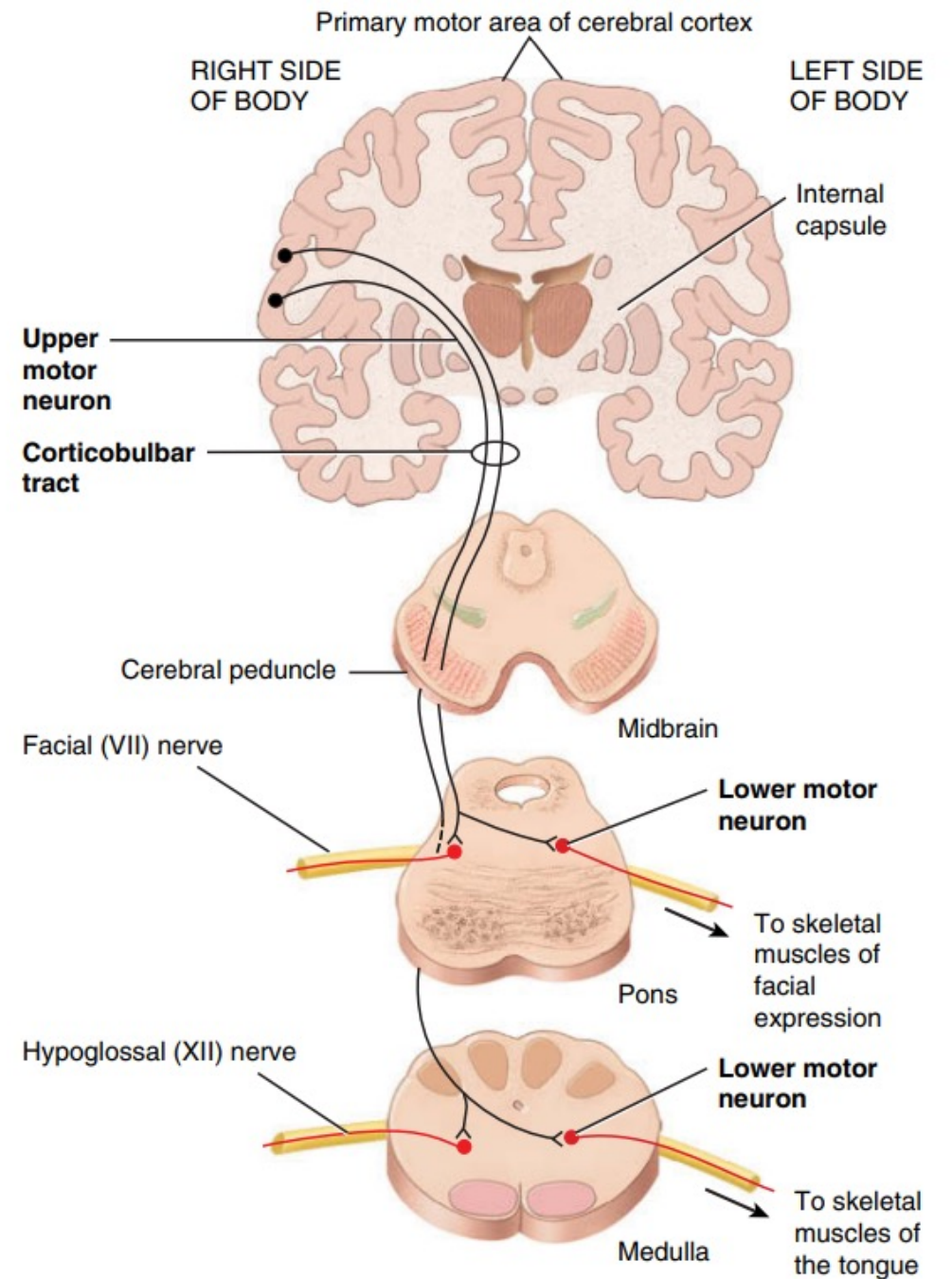
Corticobulbar tract

- Conducts impulses for the control of skeletal muscles in the head.
- Axons of upper motor neurons from the cerebral cortex form the corticobulbar tract, which descends along with the corticospinal tracts through the internal capsule of the cerebrum and cerebral peduncle of the midbrain.
- **Some** of the axons of the corticobulbar tract decussate; others do not.

Corticobulbar tract

- The axons terminate in the motor nuclei of 9 pairs of cranial nerves in the brain stem: the oculomotor (III), trochlear (IV), trigeminal (V), abducens (VI), facial (VII), glossopharyngeal (IX), vagus (X), accessory (XI), and hypoglossal (XII). *the remaining 3 nerves are sensory (optic, olfactory, vestibulochoclear)*
- The lower motor neurons of the cranial nerves convey impulses that control precise, voluntary movements of the eyes, tongue, and neck, plus chewing, facial expression, speech, and swallowing.

Corticobulbar tract



Other pathways from motor cortex

- The motor cortex gives rise to large numbers of additional, mainly small fibers that go to deep regions in the cerebrum and brain stem.

Incoming sensory pathways to motor cortex

- The functions of the motor cortex are controlled mainly by nerve signals from the sensory system.
- Once the sensory information is received, the motor cortex operates in association with the basal ganglia and cerebellum to excite appropriate motor actions.
- These incoming sensory pathways serve to transmit sensory information related to body position and movement (proprioception), vision, the sense of touch, and the perception of pressure.

Incoming sensory pathways to motor cortex

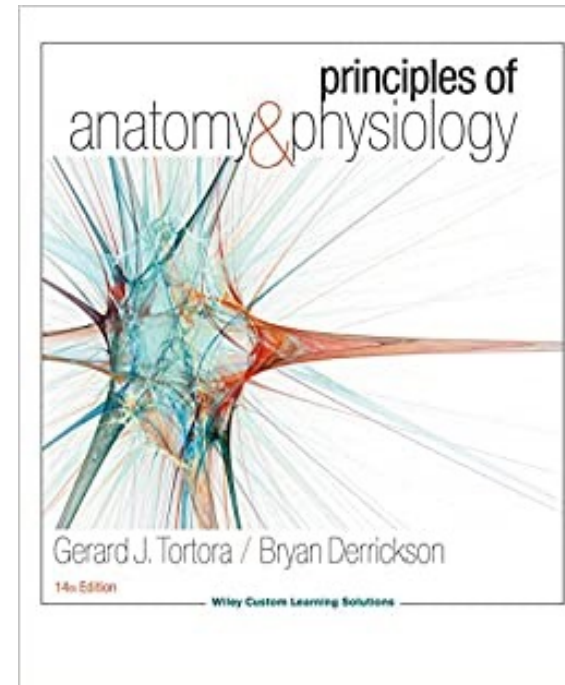
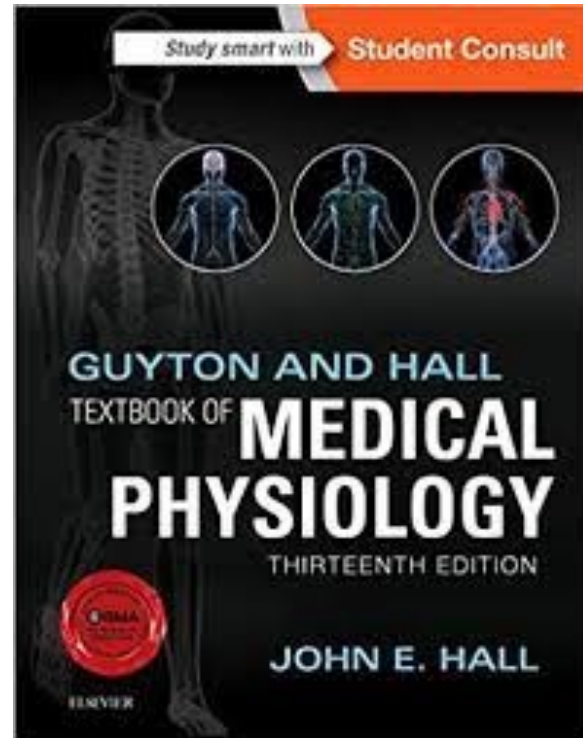
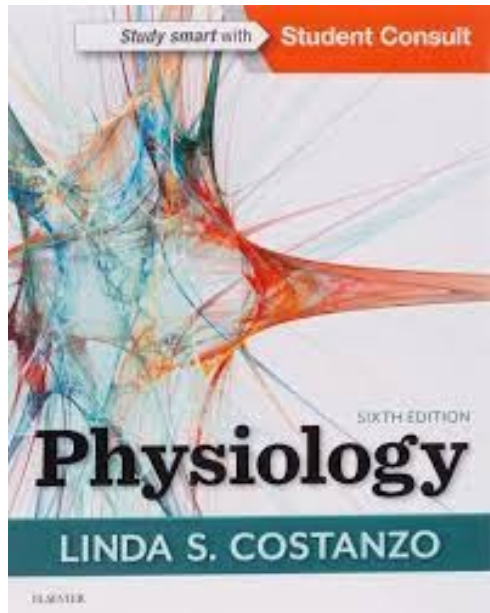
- The most important incoming fiber pathways to the motor cortex are:
 - fibers from adjacent regions of the cerebral cortex.
 - fibers that arrive through the corpus callosum from the opposite cerebral hemisphere.
 - Fibers from different thalamic nuclei.

Recap

- The **cerebral cortex** plays a crucial role in initiating voluntary movements by activating lower brain areas such as the spinal cord, brain stem, basal ganglia, and cerebellum.
- The **premotor area** develops a (motor image) of the desired muscle movement and sends signals to the primary motor cortex or other motor centers to execute the movement.
- **Mirror neurons** in the premotor area become active when performing or observing a specific motor task, aiding in understanding the actions of others and learning through imitation-المحاكاة.
- The **supplementary area** works in conjunction with the premotor area to coordinate body-wide attitudinal movements and provide a background for fine motor control.
- Damage to **Broca's area** affects speech production = Aphasia
- Different areas in the motor cortex control voluntary eye movements, head rotation, hand skills, and other specific motor functions.

- The motor cortex is organized into **columns**, with each column responsible for stimulating a group of muscles or a single muscle.
- **Dynamic** and **static** neurons within each column contribute to the initiation and maintenance of muscle contractions.
- Motor signals are transmitted from the cortex to the spinal cord through the **corticospinal tract** and other **accessory pathways** involving the basal ganglia, cerebellum, and brain stem.
- The **corticospinal tract**, consisting of pyramidal cells, is the primary output pathway from the motor cortex, controlling detailed movements of the limbs.
- The **corticobulbar** tract controls skeletal muscles in the head, with its axons terminating in cranial nerve motor nuclei.
- The motor cortex receives sensory information from somatosensory cortex, information from adjacent cortical regions, the corpus callosum, and thalamic nuclei to coordinate appropriate motor actions.

References



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Edition

Human Physiology From Cells to Systems

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