Physiology of motor control

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- The **motor system** can be grossly divided into peripheral and central elements.
  - The **peripheral motor system** includes muscles, joints, and their sensory and motor innervation.
  - The **central elements** can be divided into three hierarchical levels; However, this does not imply a strictly top-down control of coordinated movement as each level of the nervous system can influence other levels (above and below) depending on task demands (i.e., flexible hierarchical theory).

Central motor system

I) Highest level (Planning) represented by the association areas of the neocortex and basal ganglia of the forebrain (also cerebellum).

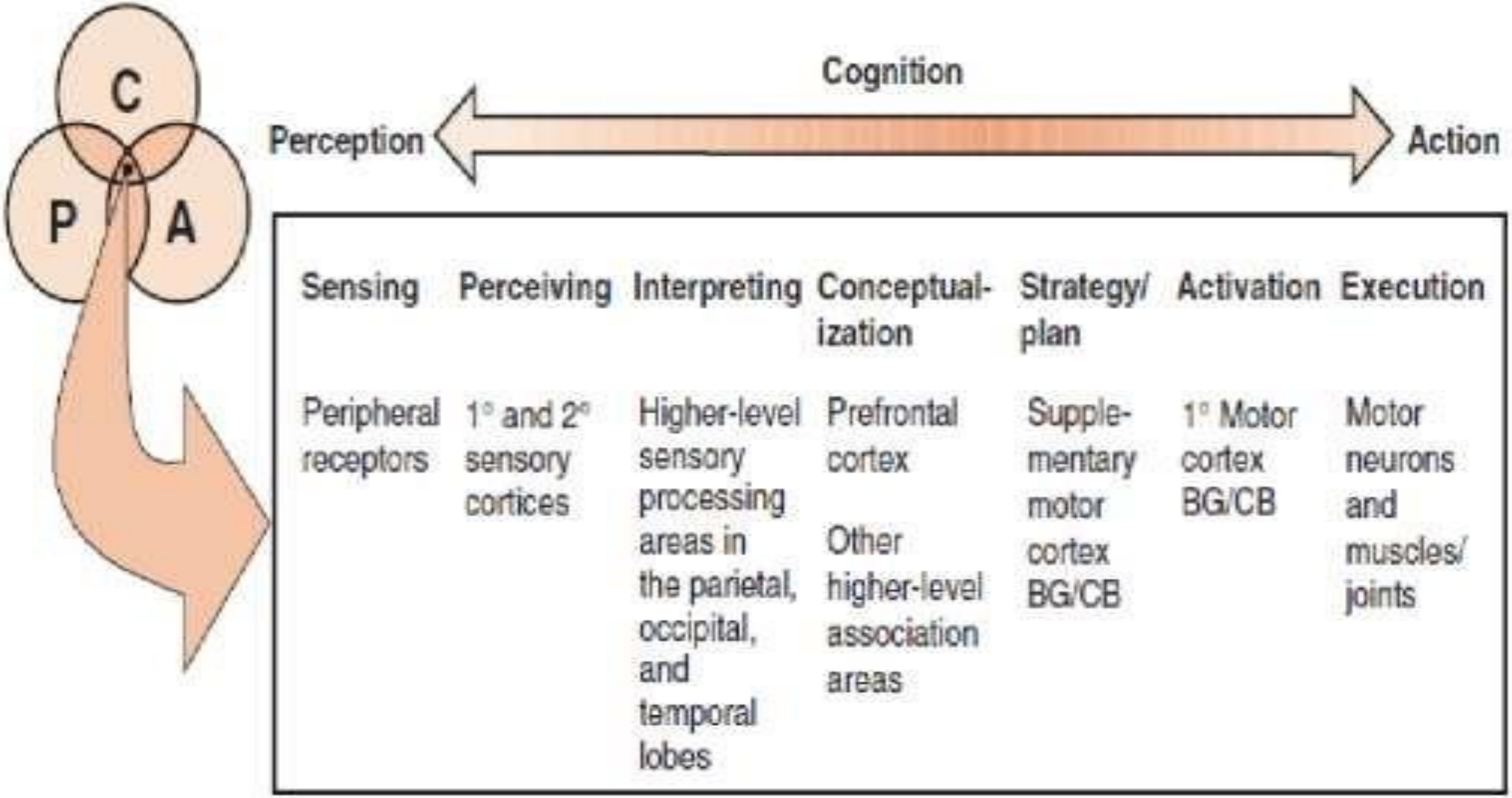
✓It is concerned with strategy :the goal of the movement and the movement strategy that best achieves the goal.

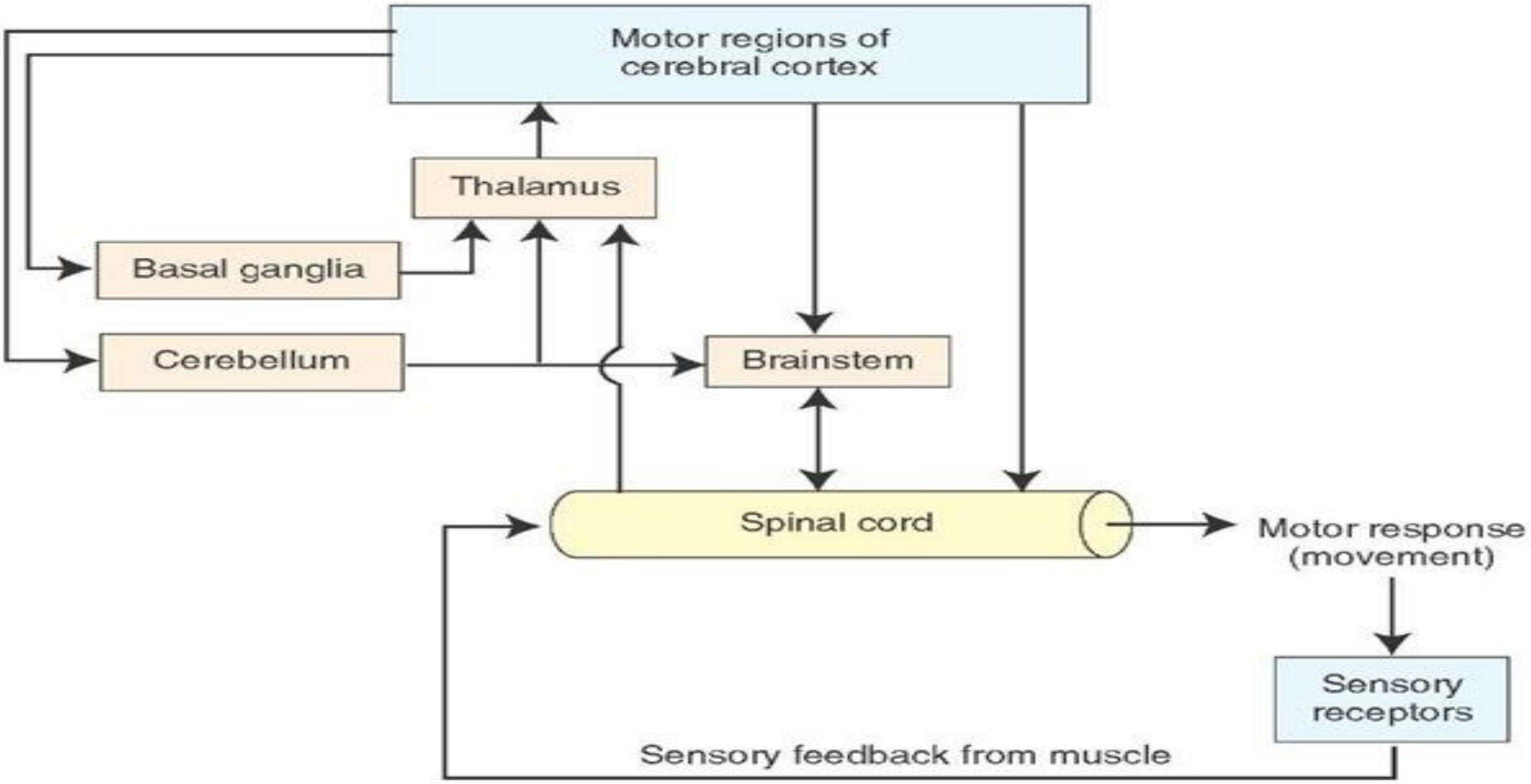
II) The middle level (initiation) represented by the motor cortex.

✓Is concerned with tactics: the sequences of muscle contractions ,arranged in space and time, required to smoothly and accurately achieve the strategic goal.

III) The lowest level(execution) represented by the brainstem and spinal cord (alpha motor neurons).

Is concerned with execution: activation of the motor neuron and interneuron pools that generate the goal-directed movement and make any necessary adjustments of posture.


C
P
A
Cognition
Perception
Action
Sensing
Perceiving
Interpreting
Conceptual-ization
Strategy/plan
Activation
Execution
Peripheral receptors
1° and 2° sensory cortices
Higher-level sensory processing areas in the parietal, occipital, and temporal lobes
Prefrontal cortex
Other higher-level association areas
Supple-mentary motor cortex BG/CB
1° Motor cortex BG/CB
Motor neurons and muscles/joints

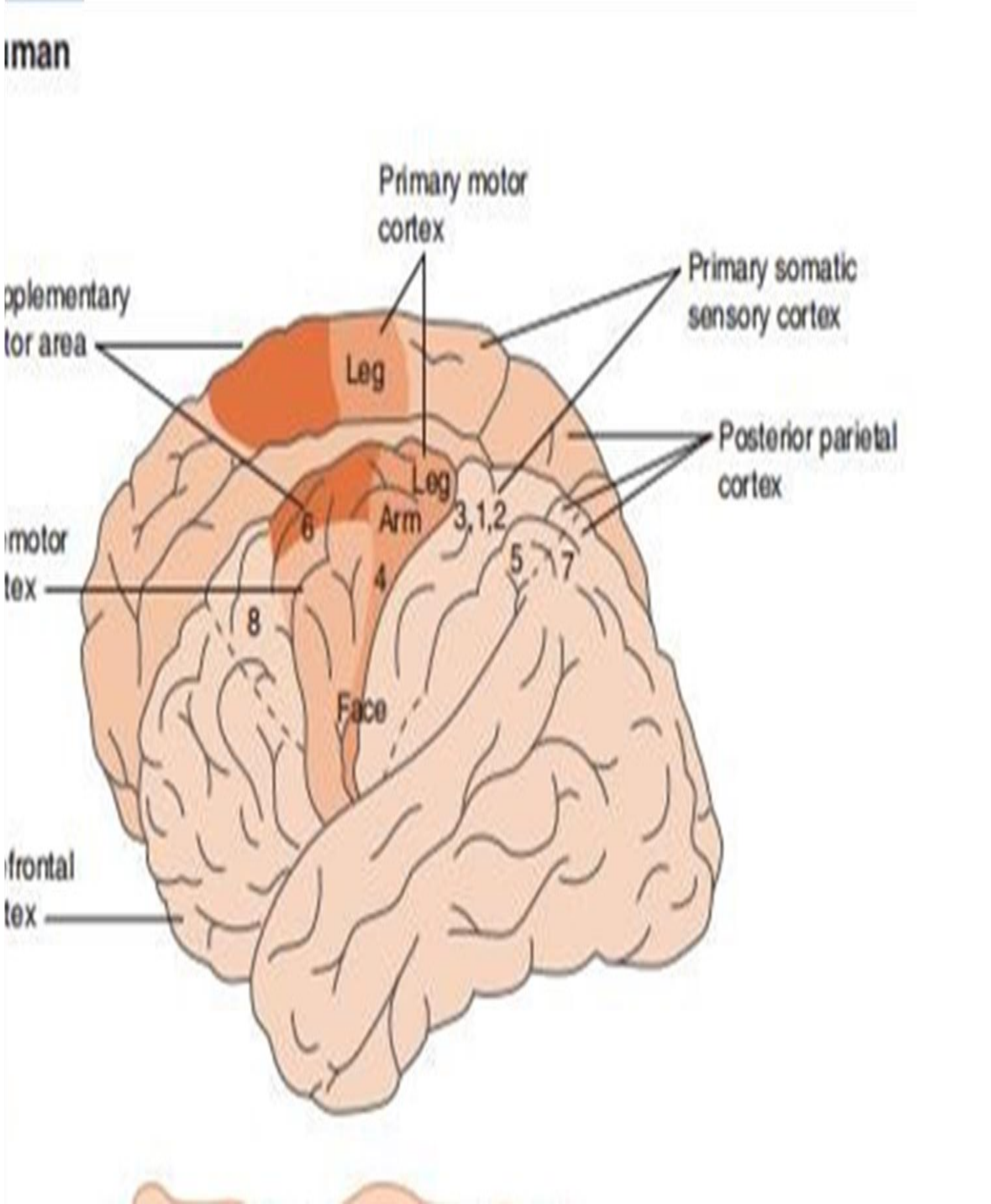


Motor regions of cerebral cortex
Thalamus
Basal ganglia
Cerebellum
Brainstem
Spinal cord
Motor response (movement)
Sensory receptors
Sensory feedback from muscle

The Motor Cortex

primary motor cortex **(PMC)(MI) (area 4)**

- ✓ It lies anterior to the central sulcus on the precentral gyrus and controls contralateral voluntary movements.
- ✓ This area is electrically excitable.
- ✓ the first cortical area to be directly associated with motor function.
- ✓ It called spokesperson.



Area(4) connections

- **receives inputs from other cortical regions**

✓ **basal ganglia**,

✓ the **cerebellum**

✓ **(area 6)** which include premotor area (PMA) & supplementary motor area (SMA)

✓ **sensory areas**, including **the periphery (via the thalamus), SI, and sensory association areas** in the parietal lobe.

- **Outputs exists**

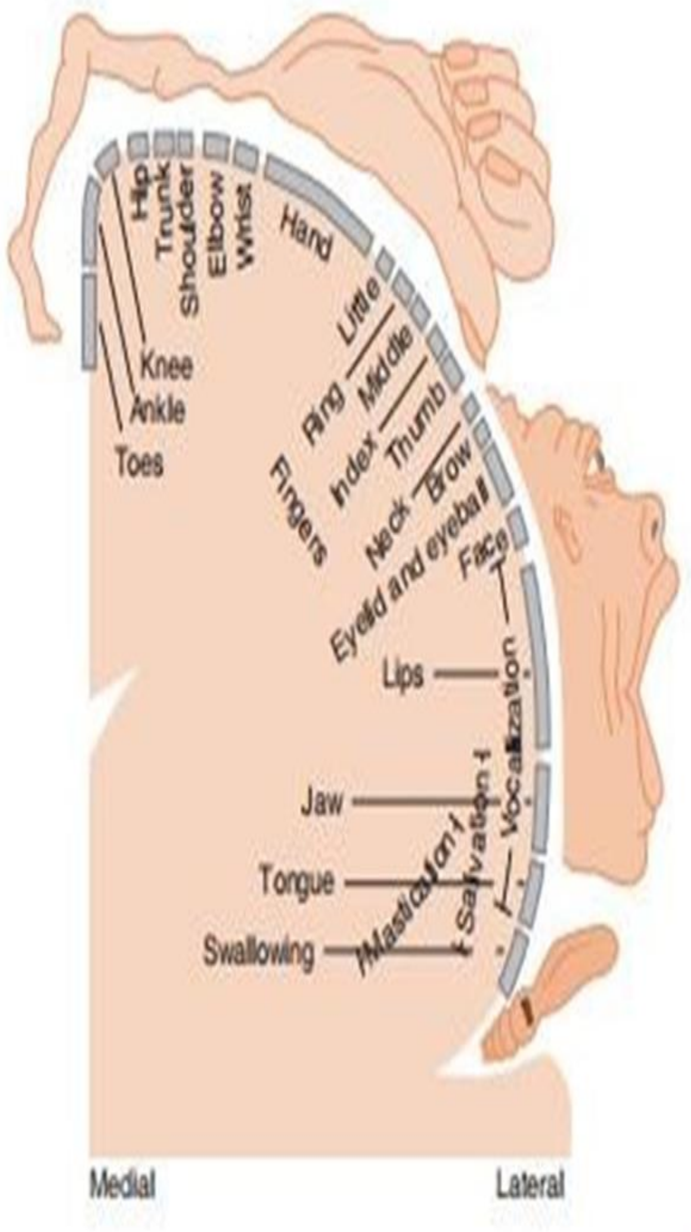
✓**corticospinal/corticobulbar tract** (also called the pyramidal tract).

It responsible for :

- ✓**force of a movement** (regardless of which individual muscles are used, alpha motor neurons, in turn, translate the commands of the motor cortex neurons and control the amount of force generated by individual muscles).
- ✓**direction of movement**(one cell may fire strongly when the hand is moved to the left, it will be inhibited when the hand is moved to the right).
- ✓**extent of movement(**the firing of some neurons is correlated with the **distance of a movement**; other neurons are related to **direction of movement long /short distance).**
- ✓**speed of movement.**

Somatotopic organization

- The **medial part** of the primary motor cortex is involved in **leg** movements.
- the **middle part** involved in **arm movemen**ts
- the most **lateral part plays** a role in movements **of face, mouth, and speech muscles.**
- Since each part of the soma (body) is mapped to different parts of the primary motor cortex.
- **distal muscles of the hand** have the **largest representation**.
- The amount **of primary motor cortex devoted to finger control** is much **greater than** the **amount of primary motor cortex devoted to intercostal muscle control.** The intercostal muscle representation is smaller because the intercostal muscles work together as a unit to support breathing, whereas the intrinsic muscles of the hand operate almost independently of each other to permit a richness of manipulatory behavior

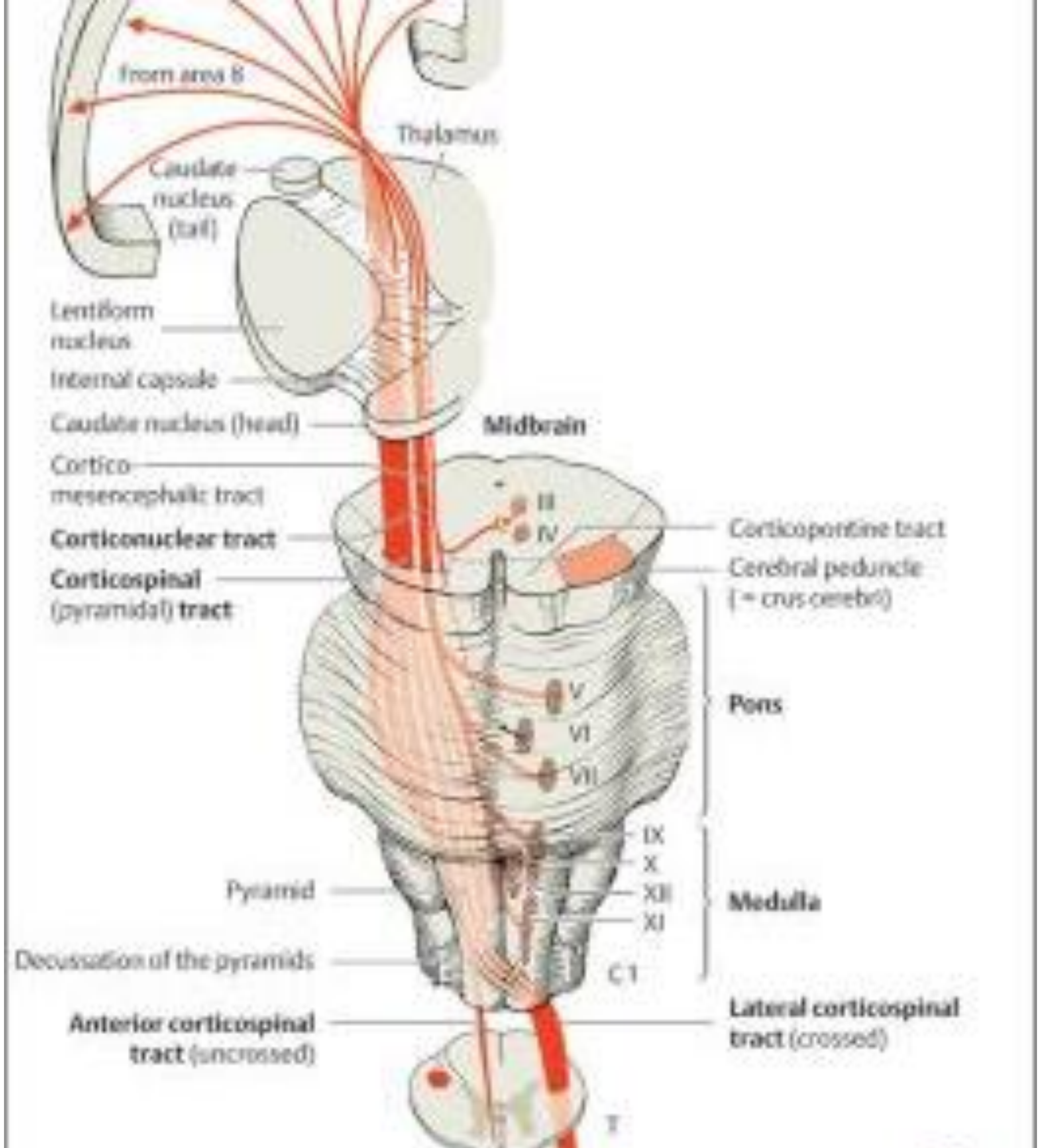


Pyramidal tract

Functionally:

A-Corticospinal: musculature of the body.

B-Corticobulbar: musculature of the head and neck.



Corticospinal tract (CST)

- Is a collection of axons that carry movement related information from the cerebral cortex to the spinal cord.
- **Origin:**
- Primary motor cortex (about 50%).
- Premotor areas including supplementary motor cortex, dorsal and ventral premotor cortex.
- Somatosensory cortex.

Pathway:

- From the cortex originating from **Betz cells in the motor area corona radiate internal capsule(ant. 2l3 of post. Limb) brain stem** via medulla where majority of the fibers(80-95%) cross in the lower medulla called **lateral corticospinal tract of the cord** terminates in interneurons controlling **precise movements** of the distal muscles of the limb. The remaining (10-15)% continue uncrossed controlling less precise movements of the proximal muscles of the limbs called **Anterior (or ventral) corticospinal tract** Most of it cross just before they terminate in the ventral horn of the spinal cord. Most axons enter the ventral horn and terminate in the intermediate and ventral areas on interneurons and motor neurons.

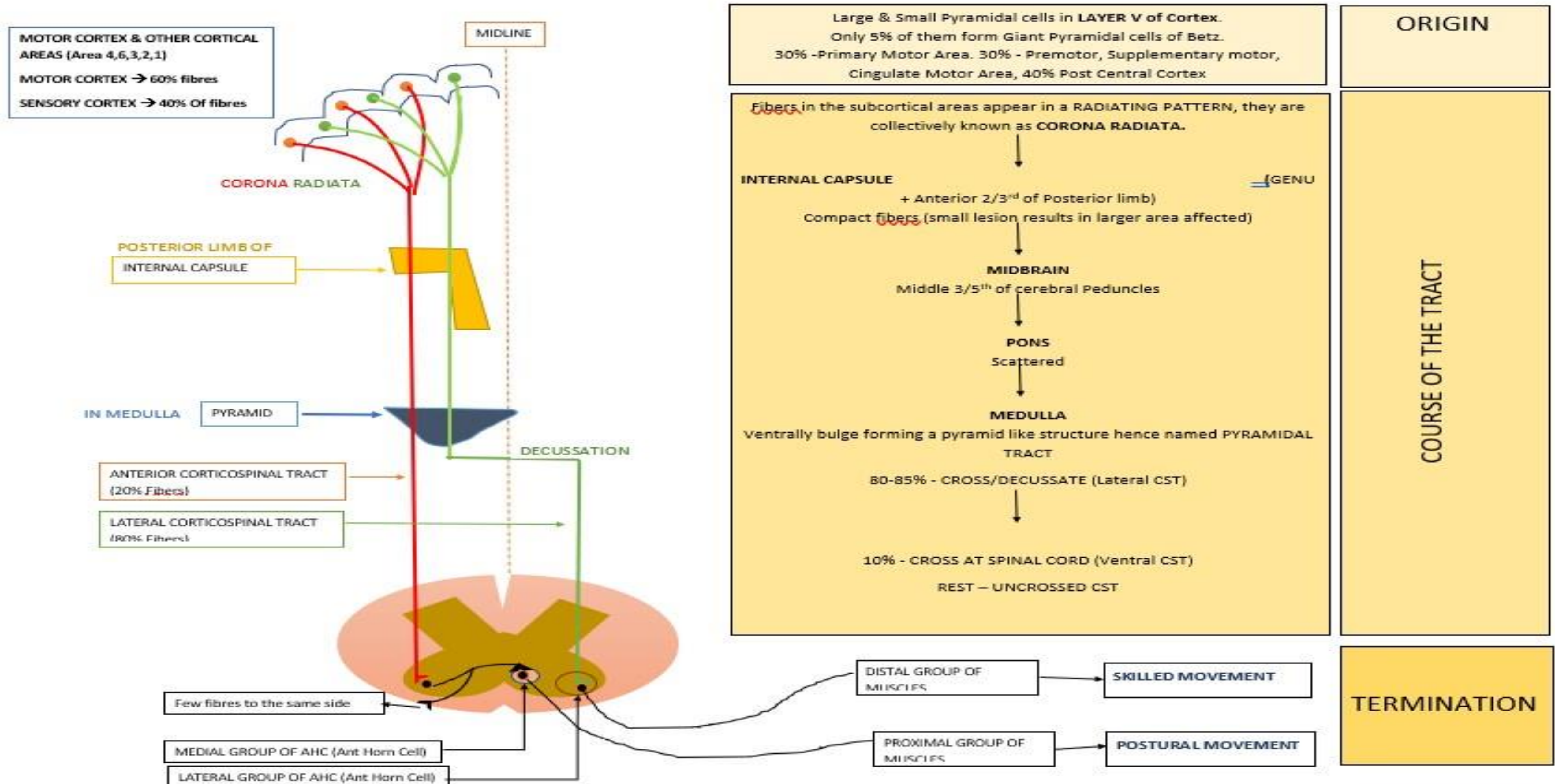
Termination of Corticospinal tract

- Cervical levels : 55% .
- Thoracic levels: Approximately 20%.
- Lumbosacral levels :25% .
- Functions:

✓Lateral corticospinal tract primarily controls the movement of distal muscles in the limbs.

✓Anterior corticospinal tract is involved with movement of the muscles of the trunk, neck, and shoulders.

pathway



MOTOR CORTEX & OTHER CORTICAL AREAS (Area 4,6,3,2,1)
MOTOR CORTEX → 60% fibres
SENSORY CORTEX → 40% Of fibres
MIDLINE
CORONA RADIATA
POSTERIOR LIMB OF
INTERNAL CAPSULE
IN MEDULLA
PYRAMID
DECUSSATION
ANTERIOR CORTICOSPINAL TRACT (20% Fibers)
LATERAL CORTICOSPINAL TRACT (80% Fibers)
Few fibres to the same side
MEDIAL GROUP OF AHC (Ant Horn Cell)
LATERAL GROUP OF AHC (Ant Horn Cell)
ORIGIN
Large & Small Pyramidal cells in LAYER V of Cortex.
Only 5% of them form Giant Pyramidal cells of Betz.
30% -Primary Motor Area. 30% - Premotor, Supplementary motor, Cingulate Motor Area, 40% Post Central Cortex
COURSE OF THE TRACT
Fibers in the subcortical areas appear in a RADIATING PATTERN, they are collectively known as CORONA RADIATA.
INTERNAL CAPSULE (GENU + Anterior 2/3rd of Posterior limb)
Compact fibers (small lesion results in larger area affected)
MIDBRAIN
Middle 3/5th of cerebral Peduncles
PONS
Scattered
MEDULLA
Ventrally bulge forming a pyramid like structure hence named PYRAMIDAL TRACT
80-85% - CROSS/DECUSSATE (Lateral CST)
10% - CROSS AT SPINAL CORD (Ventral CST)
REST – UNCROSSED CST
TERMINATION
DISTAL GROUP OF MUSCLES
SKILLED MOVEMENT
PROXIMAL GROUP OF MUSCLES
POSTURAL MOVEMENT

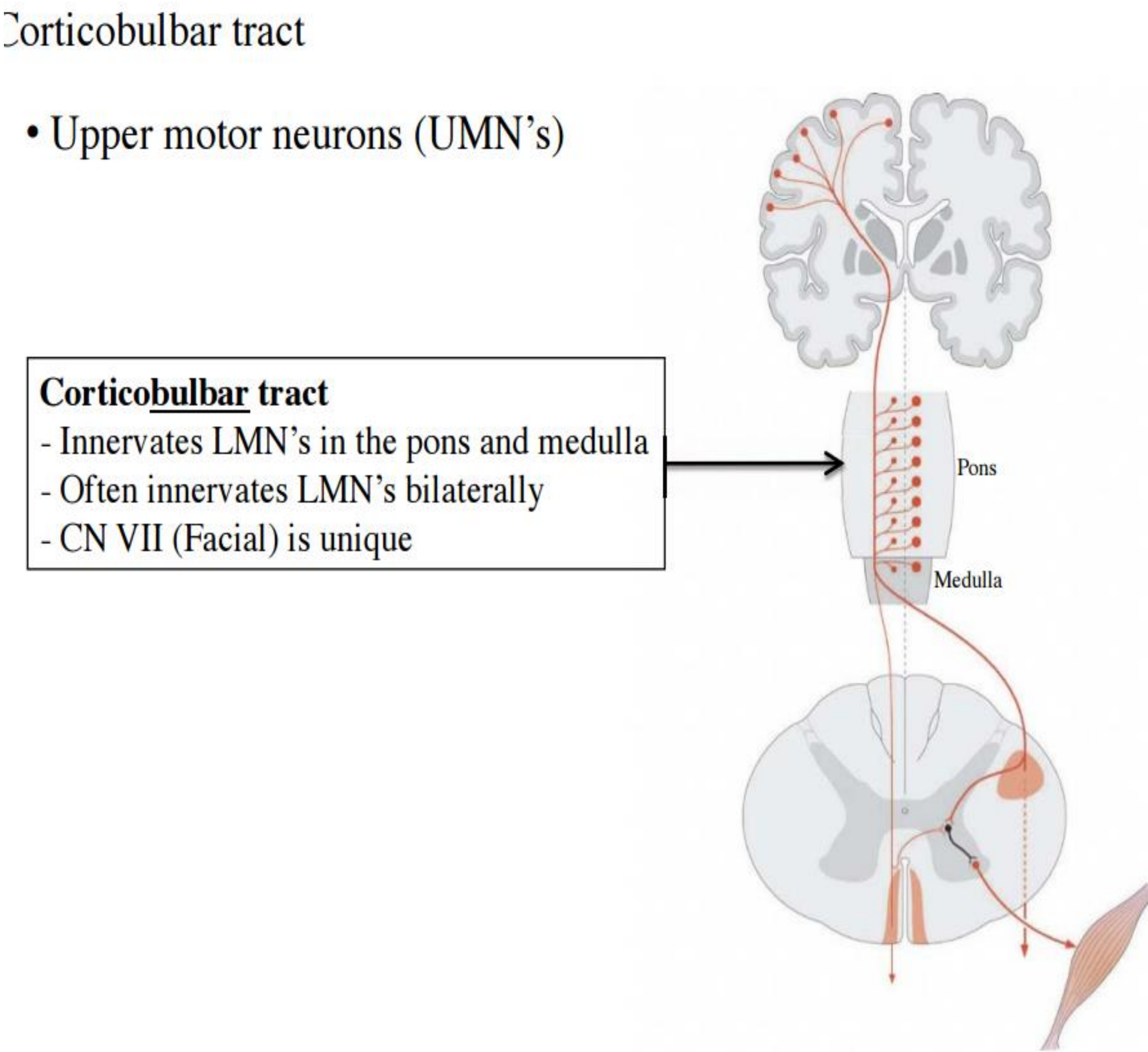
Corticobulbar tract

Origin

- ➢ Precentral gyrus & area 8 corona radiate then enter genu of internal capsule then descend in brainstem.
- ➢ Fibers project directly to motor cranial nerve (CN) nuclei (e.g., trigeminal , facial, hypoglossal), and others to the reticular formation before reaching cranial nerve nuclei(only 50% of fibers decussate).

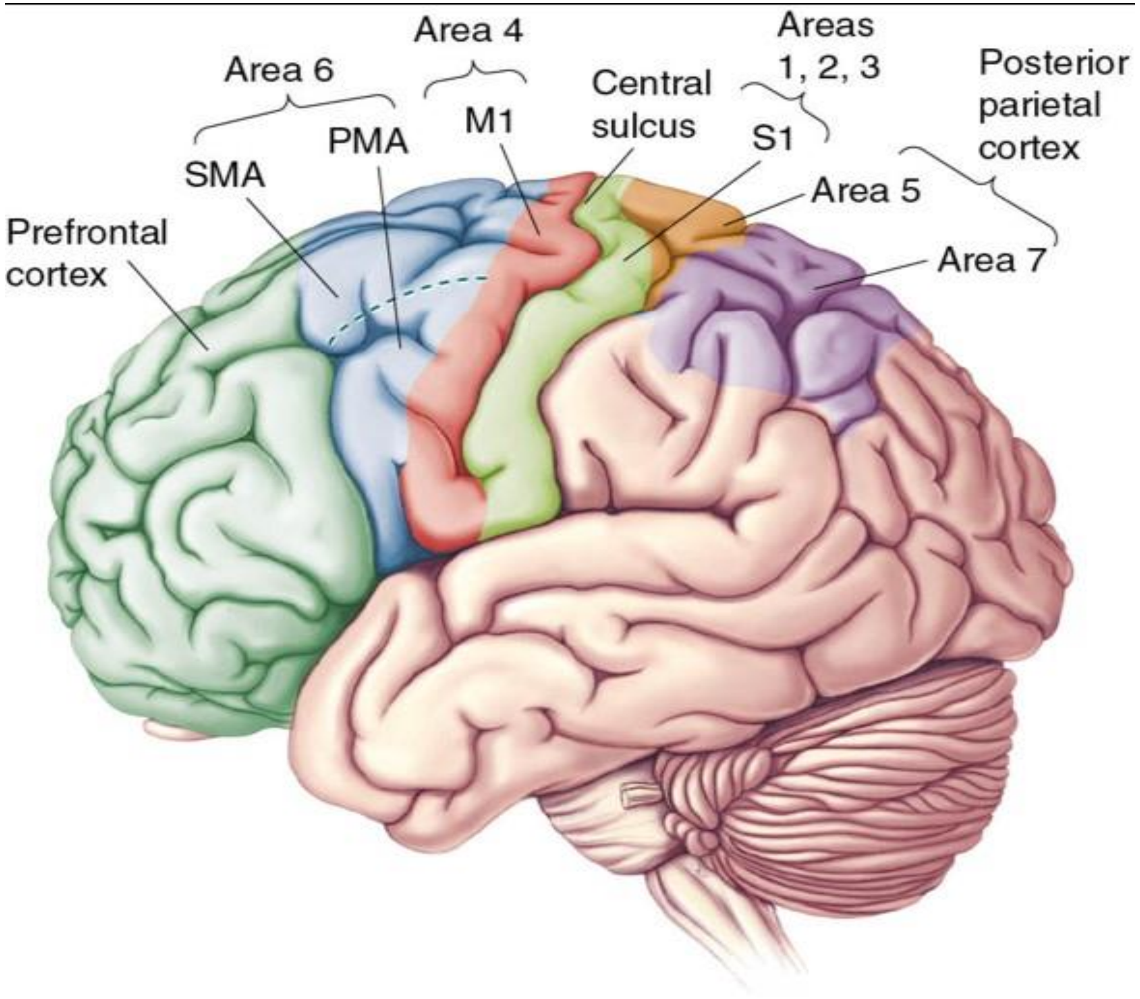
Function: Innervates muscles of the face, tongue, jaw, and pharynx, via the cranial nerves.

N.B It innervates cranial motor nuclei **bilaterally** except for those nuclei(lower facial and hypoglossal).



Premotor area (area 6)

- ➢ Send projections to primary motor cortex and also, to the spinal cord.
- ➢ Is also electrically excitable but requires stimuli of higher intensities to cause a motor response.
- ➢ It supplies pyramidal , extrapyramidal systems.
- ➢ It lies just anterior to area 4 and is subdivided into:
- ✓ The superiorly placed **supplementary motor area (SMA) .**
- ✓ inferiorly positioned **premotor area (PMA).**



supplementary motor area (SMA) .

- uses (internal cue) gives rise to axons that directly innervate motor units involved in:

✓Initiation of movement.

✓ rehearsal task.

✓Simultaneous bilateral grasping movements.

✓ Planning of sequential, complex tasks.

✓Orientation of the eyes and head.

premotor area (PMA).

- Uses(external cue) provides input to the reticulospinal neurons innervating motor units that control:

✓Trunk and proximal limb movements.

✓Contributes to anticipatory postural changes.

✓Movements that are activated by external stimuli e.g., a visual cue such as a traffic light changing from red to green are controlled primarily by the lateral premotor area),so its role is selecting motor programs based on visual stimuli

Performing a **simple task** (simple repetitive movements of the index fingeror pressing a spring between the thumb and index finger) the blood flow increase was only in **primary motor and sensory cortex.**

In contrast, when they were asked to perform a **complex task** (a sequence of movements involving all four fingers, touching the thumb in different orders), subjects showed a blood flow increase in the **supplementary motor area, bilaterally**, and **the primary motor and sensory areas.**

Finally, when they were asked to **rehearse the task,** but not perform it, the blood flow increase was **only** in the **supplementary motor area**, not the primary sensory or motor cortex

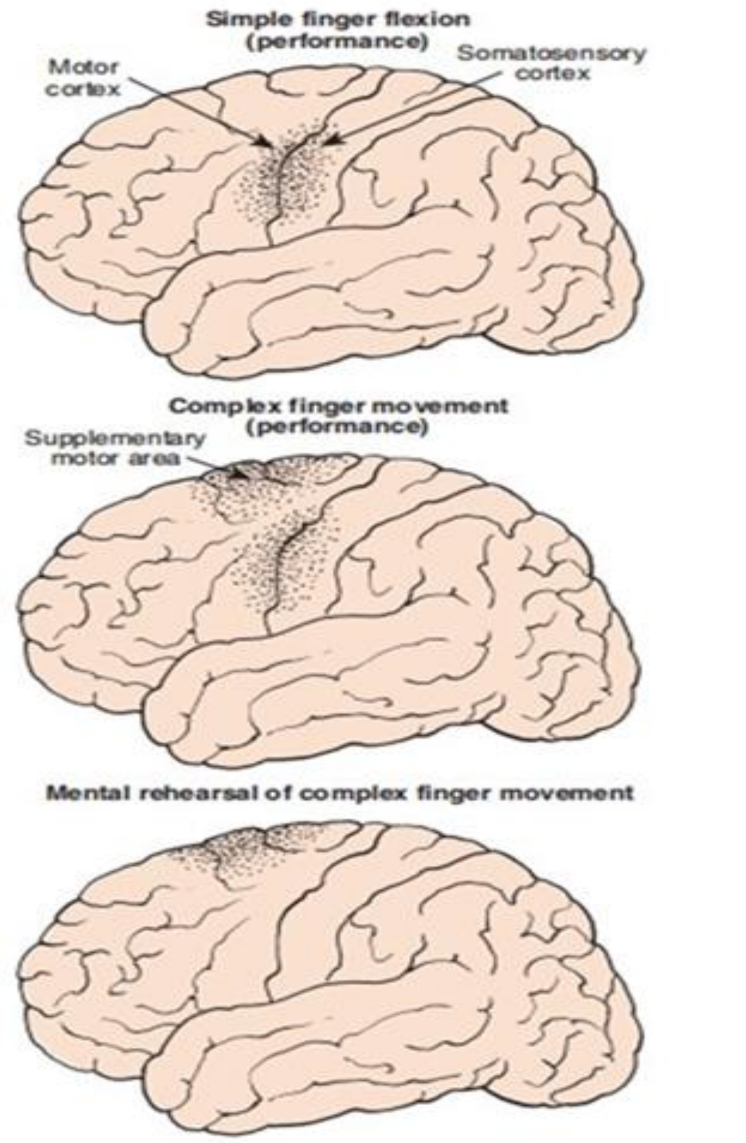


FIGURE 3.14 Changes in blood flow during different motor behaviors, indicating the areas of the motor cortex involved in the behavior. (Adapted with permission from Roland PE, Larsen B, Lassen NA, Skinhof E. Supplementary motor area and other cortical areas in organization of voluntary movements in man. J Neurophysiol 1980;43:118—136.)

Extrapyramidal tracts

1) **Tectospinal tract**
2) **Reticulospinal tract**
3) **Vestibulospinal tracts**
4) **Rubrospinal tract.**
5) **Olivospinal tract**

Tectospinal tract

- Originate at Tectum of midbrain (superior colliculus) cross then descend and terminate at cervical segment of spinal cord.
- Important in guiding the skeletal muscles of the head, neck and eyes in response to visual, auditory stimuli(visuo-spinal reflexes & auditory spinal reflex).
- It may be defensive mechanism (an example defensive reflex in turning the head away on seeing a threatening danger or hearing the sound of near car.

Reticulospinal tract (medial a& lateral)

- Medial (pontine) reticulospinal tract originate at pons and descend ipsilaterally close to mide line to enter the ventral funiculus of spinal cord.
- Lateral (medullary) reticulospinal tract originate at medulla descend bilaterally to enter ventral part of lateral funiculus of spinal cord.
- it play a vital role in regulation of motor function & maintain posture.
- Both tracts act on proximal limb and axial muscle motor neurons(mainly it facilitate extensors and antigravity muscle).
- Their influence on muscletone and reflex activity is by affecting the activity of gamma motor neuron **(γ-α coactivation).**

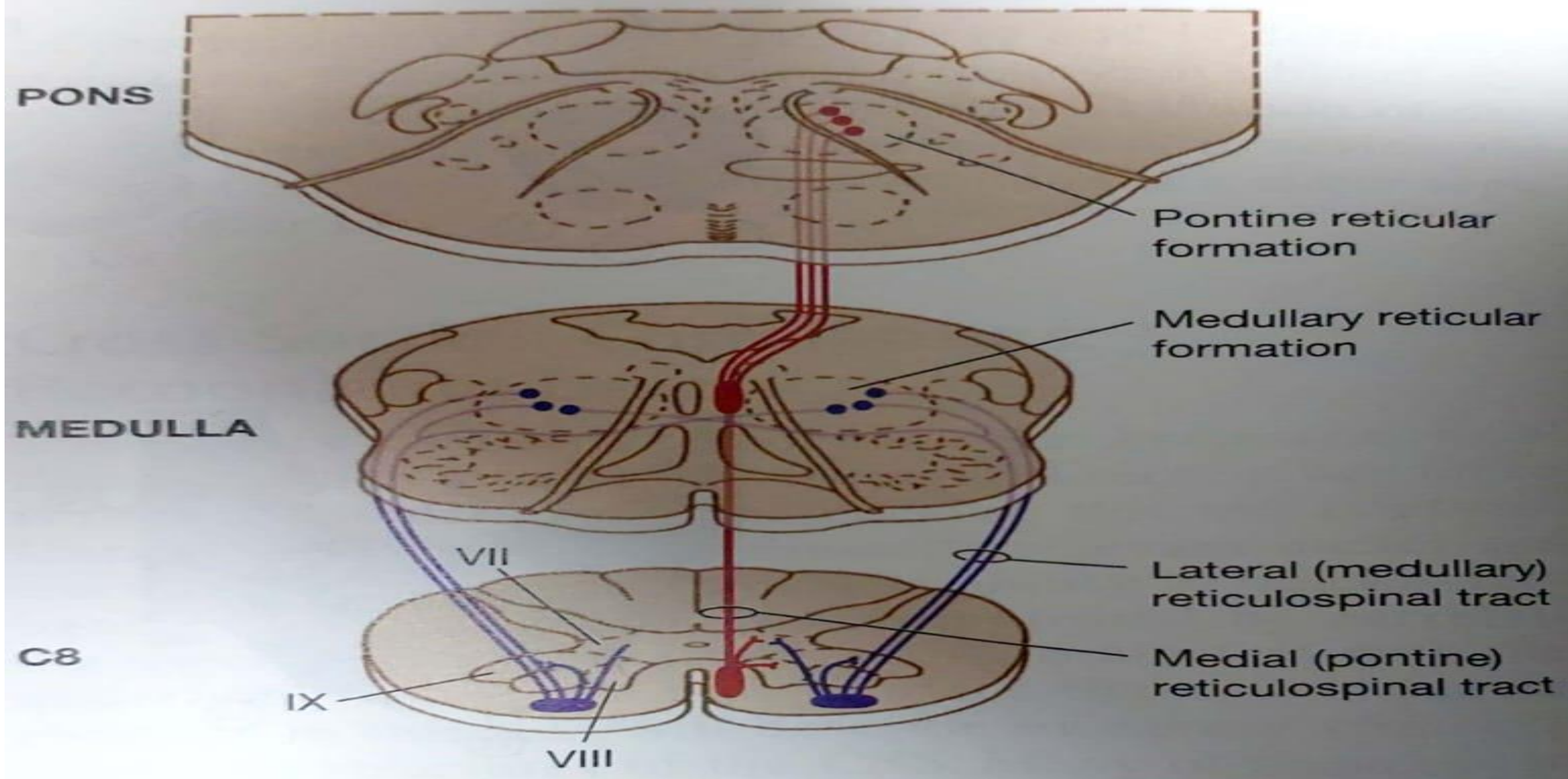


FIGURE 5-22 Section through rostralmost medulla showing the subdivisions of the reticular formation. Magnocellular neurons in the medial subdivision give rise to the long descending (reticulospinal) tracts. In contrast, parvocellular neurons in the lateral reticular formation function as interneurons involved, for example, in integrating reflexes mediated by local cranial nerves. Abbreviations: MLF, medial longitudinal fasciculus; ML, medial lemniscus; PYR, pyramids; MCP, middle cerebellar peduncle.

Vestibulospinal tracts (medial and lateral)

- **Medial vestibulospinal tract (MVST)** originate at medial vestibular nuclei then descends in medial longitudinal fasciculus(MLF) the bulk of fibers ends at cervical level with some projections to more rostral thoracic segment concerned with innervation of upper back (axial muscle).
- It Stabilizing the head in relation to the body, head righting reflexes, eye righting reflex (Vestibulo-ocular reflex).
- **Lateral vestibulospinal tract (LVST)** originate at lateral vestibular nuclei entirely ipsilaterally and descend in anterolateralfasiculus of spinal cord , it axons terminate at all cord levels.
- It facilitate and maintain extensor muscle tone in trunk and limbs that essential to support body against gravity lead to maintain of upright posture

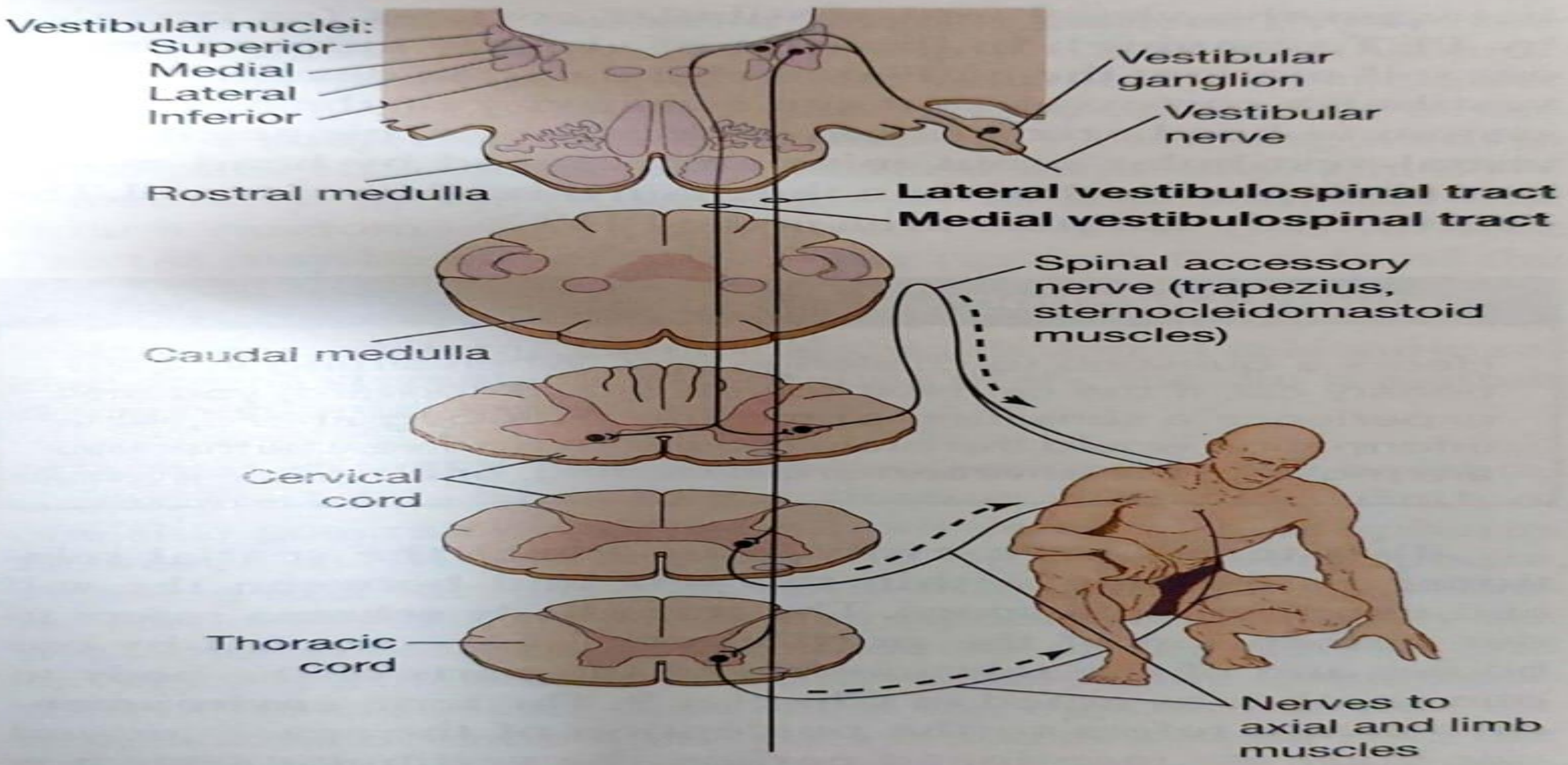


FIGURE 17-27 The vestibular motor system. Upper motor neurons project from the vestibular nuclei forming the lateral and medial vestibulospinal tracts. The lateral vestibulospinal tract descends ipsilaterally in the anterolateral spinal cord and terminates in the ventral gray of all levels of the spinal cord. The medial vestibulospinal tract descends in the medial longitudinal fasciculus and has bilateral connections cervical and rostral thoracic levels of the spinal cord.

Rubrospinal tract

- Originate at Red nucleus of midbrain.
- Excitation of the motor neurons controlling tone of limb flexor muscles and inhibitory to extension.
- Neural activity in the red nucleus is related to force, velocity and direction of movement.
- **Olivaspinal tract**

IMPAIRMENTS IN THE ACTION SYSTEMS

- Motor Weakness (Paresis).
- Abnormal Synergies.
- Coactivation.
- Abnormal Muscle Tone (Spasticity).

Motor Weakness

- Weakness is defined as an inability to generate normal levels of force; it is a major impairment of motor function in patients with upper motor neuron lesions.
- Depending on the extent of the lesion, weakness in the patient with a cerebral cortex lesion can vary in severity from total or severe loss of muscle activity, called paralysis or plegia to mild or partial loss of muscle activity, called paresis.
- Paresis and plegia are often referred to by their distribution: Hemiplegia (or hemiparesis) is weakness affecting one side of the body, paraplegia affects the lower extremities, and tetraplegia affects all four limbs.

Abnormal Synergy

- It is stereotypical pattern of movement that cannot be changed or adapted to changes in task or environmental demands.
- Abnormal synergies also called abnormal patterns or mass patterns of movement
- It reflects a lack of fractionation, defined as the ability to move a single joint without simultaneously generating movement joints.

Coactivation

- Coactivation of agonist and antagonist muscles during functional movements has been observed in many adults and children with pathophysiology in a wide variety of motor systems, including motor cortex, basal ganglia, and cerebellum.
- Coactivation is also present in the early stages of learning a skilled movement in neurologically intact adults and children. In addition, it is found during the early stages of postural development in healthy infants and children just learning to balance.

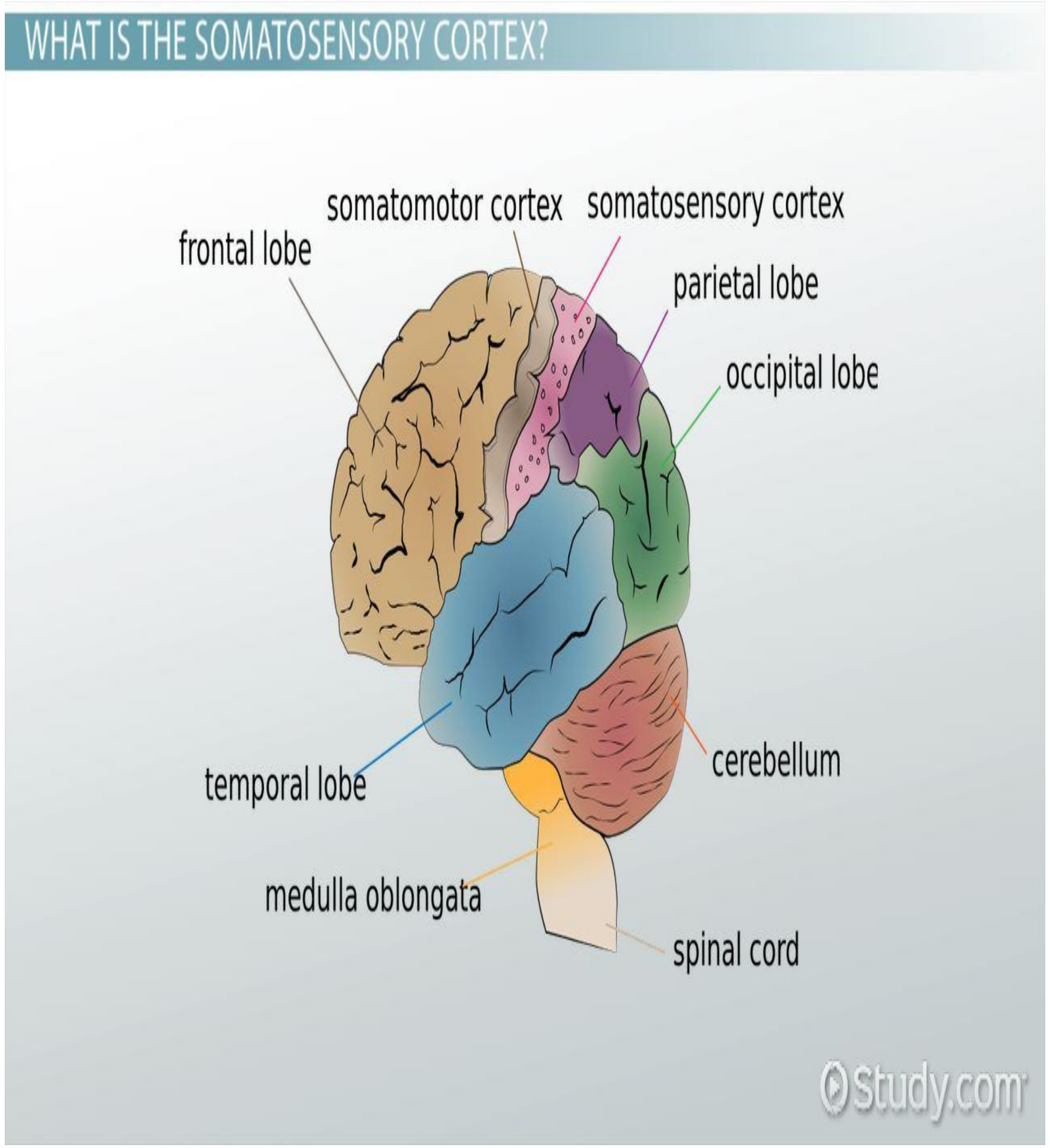
Abnormal Muscle Tone

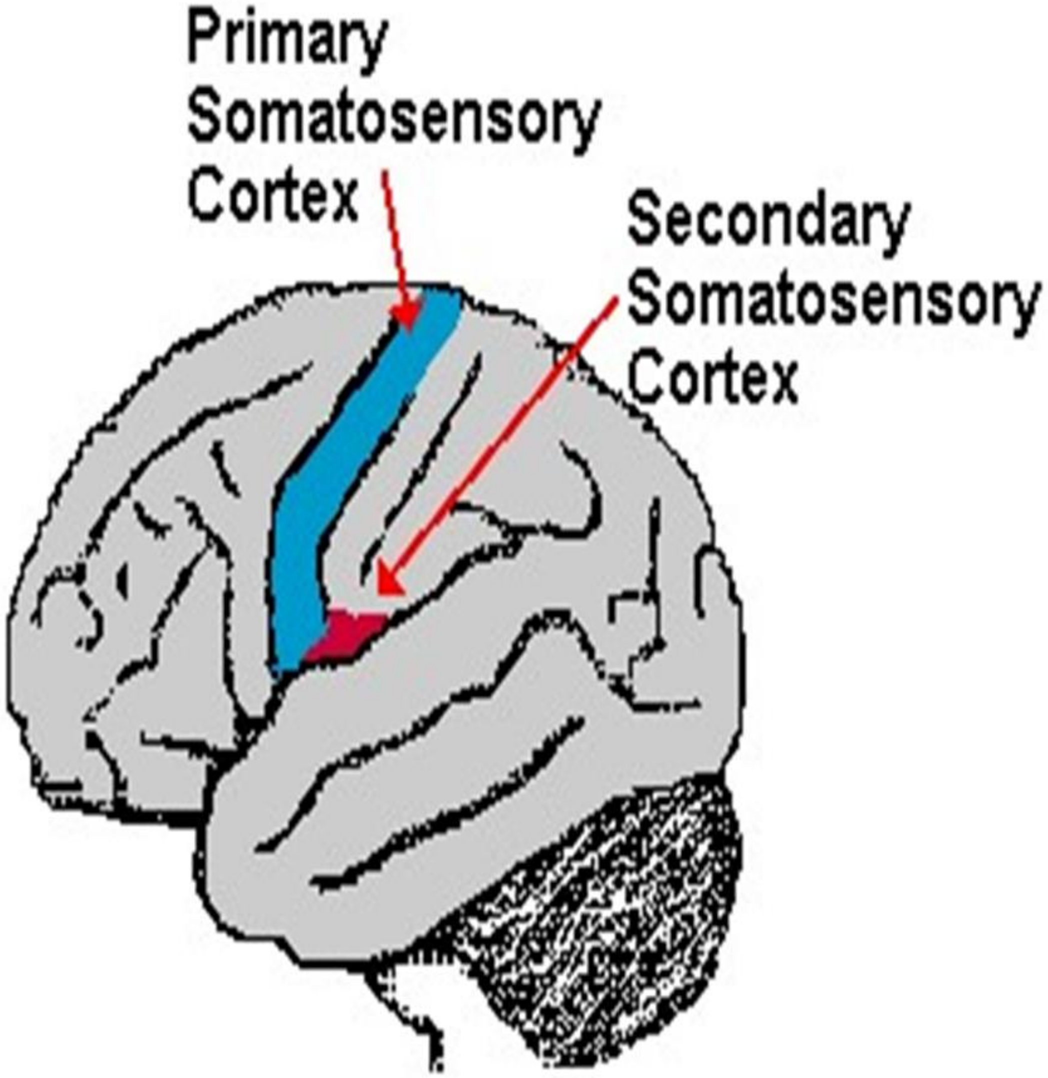
- Muscle tone is characterized by a muscle‘s resistance to passive stretch and a certain level of tone is typical in normal muscles.
- The presence of abnormalities of muscle tone in persons with CNS pathology is well known.
- Hypertonicity, manifested by **spasticity** or **rigidity.**
- Spasticity is defined as a motor disorder characterized by a velocity dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, resulting from hyperexcitability of the stretch reflex, and is one component of the upper motor neuron syndrome.

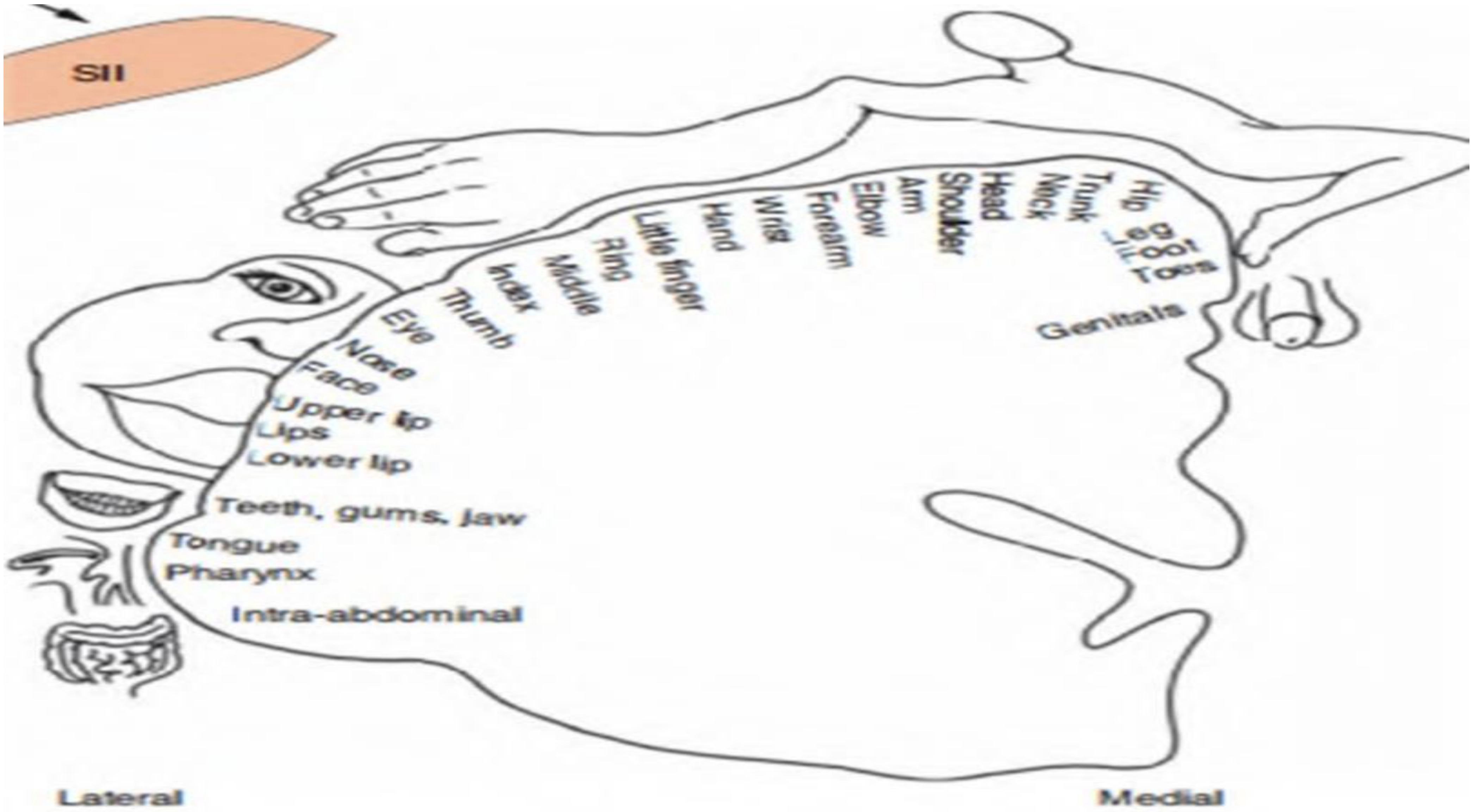
Somatosensory Cortex

- The somatosensory cortex is a major processing area for all the somatosensory modalities, and the beginning of conscious awareness of somatosensation.
- Information from **joint receptors**, **muscle spindle** and **cutaneous receptors** is now integrated to give us information about movement in a given body area.
- The somatosensory cortex is divided into **two major areas**:

1) Primary somatosensory cortex (SI)(also called Brodmann‘s areas3,1,2/ 3a, and 3b)
2) Secondary somatosensory cortex (SII).


WHAT IS THE SOMATOSENSORY CORTEX?
somatomotor cortex
somatosensory cortex
frontal lobe
parietal lobe
occipital lobe
temporal lobe
cerebellum
medulla oblongata
spinal cord
Study.com


Primary Somatosensory Cortex
Secondary Somatosensory Cortex


SII
Hip
Leg
Foot
Toes
Genitals
Trunk
Neck
Head
Shoulder
Arm
Elbow
Forearm
Wrist
Hand
Little finger
Ring
Middle
Index
Thumb
Eye
Nose
Face
Upper lip
Lips
Lower lip
Teeth, gums, jaw
Tongue
Pharynx
Intra-abdominal
Lateral
Medial

Contrast sensitivity

- Is very important to movement control, since it allows the **detection of the shape and edges of objects.**
- Easily **identification and discrimination** between **different objects through touch**.
- The receptive fields of the somatosensory neurons have an excitatory center and inhibitory surround.
- This inhibitory surround aids in two-point discrimination through lateral inhibition.
- The throat, mouth(lips) and hands are heavily represented more than trunk an abdomen.

- The receptive fields of neurons in the somatosensory cortex are not fixed in size.
- Both injury and experience can change their dimensions considerably **(training).**
- Persons that use their tactile sense to an extraordinary degree in everyday life (e.g., violinists, readers of Braille) have an expanded representation of the trained part in the primary somatosensory cortex.
- Somatosensory cortex also has descending connections to the **thalamus, dorsal column nucleus, and the spinal cord**, allowing the ability to modulate ascending information.

The Primary Somatosensory Cortex (SI)

- **Site:** post central gyrus (area 312).
- It receives information from tactile, discrimination of various grade of temperature, localization of fast pain and proprioceptive receptors from the opposite side of the body.
- Show spatial orientation :

✓Body is represented upside down except face.

✓Area of presentation according to number receptors in this area.

- Neurons in Brodmann‘s area 1 sense object size, having large receptive fields covering many fingers.
- Other cells, in area 2, respond best to moving stimuli and are sensitive to direction, one does not find this feature in the **dorsal columns or in the thalamus.**

The Secondary Somatosensory Cortex (SII)

- **Site**: behind and below SI
- Bilateral (SII) is presumed to perform sensorimotor **integration**, especially **integration of the two body halves**.
- Also involved in integration of pain stimuli and movement preparation .
- Also it is **active during motor activity**, **movement observation**, and **mental imaging of movements.**

The Posterior Parietal Cortex

- A Multimodal Association Area.
- Consisting of

✓**Brodmann's areas 5, 7(sensory association area**)

✓**Area 39**(Angular gyrus, language and number processing) alexia & agraphia

✓**area 40** (Supramarginal gyrus, area of Wernicke phonological processing and emotional responses) in humans.

- **Integrating visual and somatosensory information**.
- Uses this information to issue commands to the **premotor cortical areas**, particularly with regard to visually **guided movements**.
- A key **role in spatial representation of objects.**

N.B **Anterior parietal cortex** in humans comprises **primary somatosensory areas.**

Association Cortices

- **Sites:**

✓Parietal, temporal, and occipital lobes, include centers for **higher level sensory processing** and **higher level abstract cognitive processing.**

- It represents the transition from perception to action.
- Interplay between cognitive and perceptual processing.
- Receiving sensory information (SI)
- Brodmann‘s area 5 (integrates information between body parts),
- Area 7 of the parietal lobe(also receives processed visual information) combines eye–limb processing in most visually triggered or guided activities.
- Lesions in Brodmann‘s area 5 or 7 : Causes problems with **learning skills** that use information regarding the position of the body in space.

- Parietal lobe participates in processes involving attention to the position and manipulation of objects in space.
- Parietal lobe lesion: Deficits in body image and perception of spatial relations, which may be very important in both postural control and voluntary movements.
- **Body image** is defined as a visual and mental image of one‘s body that includes feelings about one‘s body, especially in relation to health and disease.
- **Body scheme** refers to a postural model of the body, including the relationship of body parts to each other and the relationship of the body to the environment.

Perceptual disorders

Perception	
Body scheme/body image impairments	Unilateral neglect Anosognosia Somatoagnosia Right–left discrimination Finger agnosia
Spatial relation impairments (complex perception)	Figure–ground discrimination Form discrimination Spatial relations Position in space Topographical disorientation Depth and distance perception Vertical disorientation
Agnosias	Visual object agnosia Auditory agnosia Tactile agnosia
Apraxia	Ideomotor apraxia Ideational apraxia Buccofacial apraxia

- **Unilateral neglect** is the inability to register and integrate stimuli and perceptions from one side of the body (body neglect) and the environment or hemispace (spatial neglect of the area surrounding one side of the body), which is not due to a sensory loss.
- **Asomatoagnosia,** or impairment in body scheme, is a lack of awareness of the body structure and the relationship of body parts to oneself or to others. Asomatognosia is also referred to as autopagnosia or simply body agnosia.
- **Anosognosia** is a severe condition including denial and lack of awareness of the presence or severity of one‘s paralysis.
- **Right–Left Discrimination**: the inability to identify the right and left sides of one‘s own body or of that of the examiner.
- **Finger agnosia** can be defined as the inability to identify the fingers of one‘s own hands or of the hands of the examiner(Bilateral,common is middle 3 fingers).

Thalamus

- The thalamus is located deep within the brain. Two thalami connected by interthalamic adhesion.
- It is a part of the diencephalon.
- It contains two major subdivisions:

✓the thalamus and the hypothalamus.

✓The thalamus is a large egg-shaped collection of 50 to 60 nuclei.

- **Function:**

✓ Plays a crucial role in gating, processing, and transferring the majority of sensory information to and from the cerebral cortex.

✓ Modulate behaviors, influences the level of attention and consciousness.

- **Connection**: Cerebral cortex, basal ganglia (BG), the red nucleus and the cerebellum.
- The **thalamic nuclei** are classed into four groups: Anterior, medial,

ventrolateral, and posterior.

- All pathways that carry sensory information from the receptors in

the body to the cerebral cortex (except for olfactory) pass through the thalamus .

- The thalamus is also involved in **descending inhibition** to **modulate**

nociceptive inputs at the dorsal horn of the spinal cord.

- Cortex can influence thalamic processing and consequently shape the nature of its own input.