Round 7:
Voluntary Movement, Cerebellum & Basal Ganglia

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3 Movement Stages

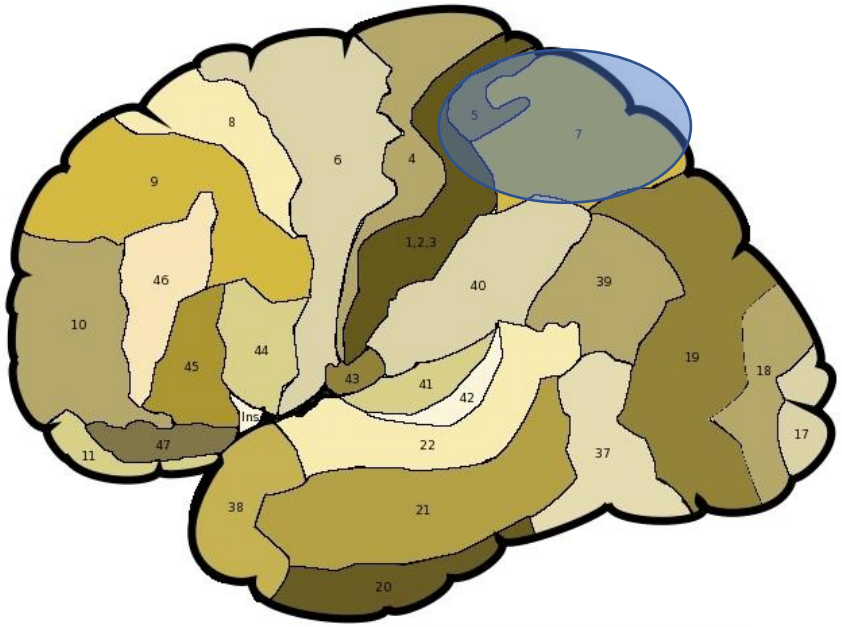
1. Identify/localize target in space

2. Select a plan of action
   - Which body parts have to move? How?
   - Temporal sequence of tendon & joint movements, forces used, joint angles
   - Counter movements to offset postural requirements

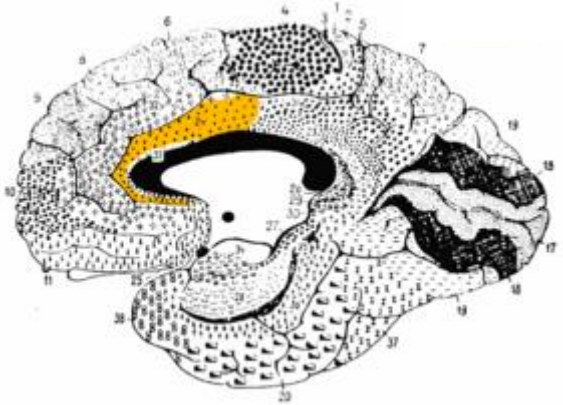
1. Execute movement

Step 1: Target Localization

- [Right] Posterior Parietal region (Brodmann's Areas 5 & 7)
  - Responsible for processing spatial information
  - Lesions
    - Unable to attend to a region in space to act -> can't localize objects in space
    - Can't recognize objects placed in the hand without vision
    - When drawing a clock they will put all of the numbers on one side and not notice that this is a problem

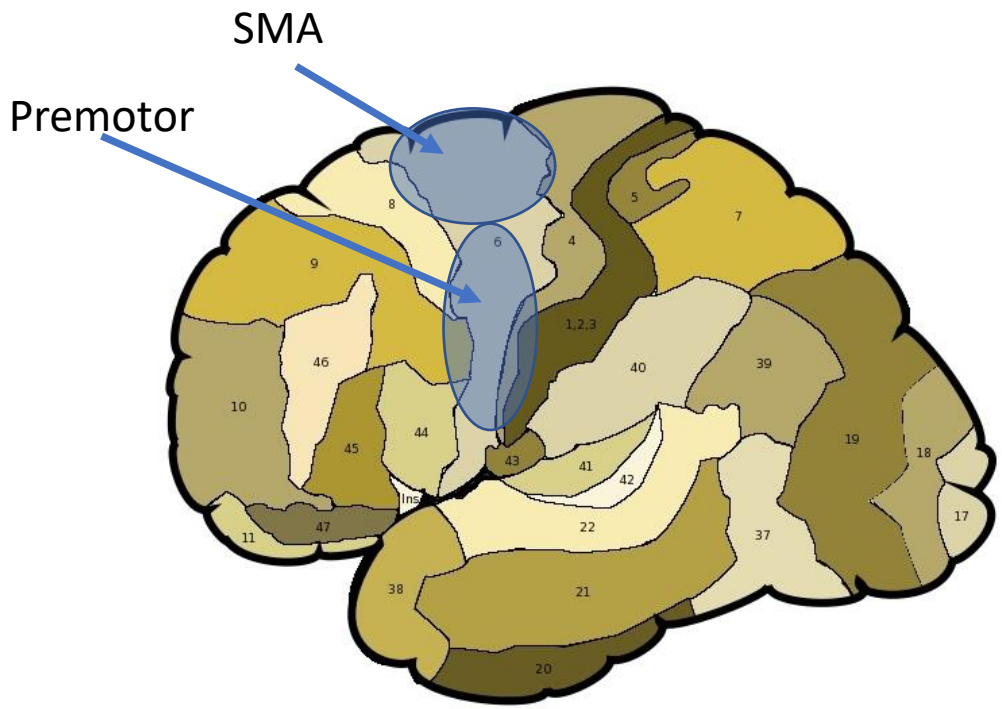


Cingulate Gyrus (24)
Limbic system - Motivation



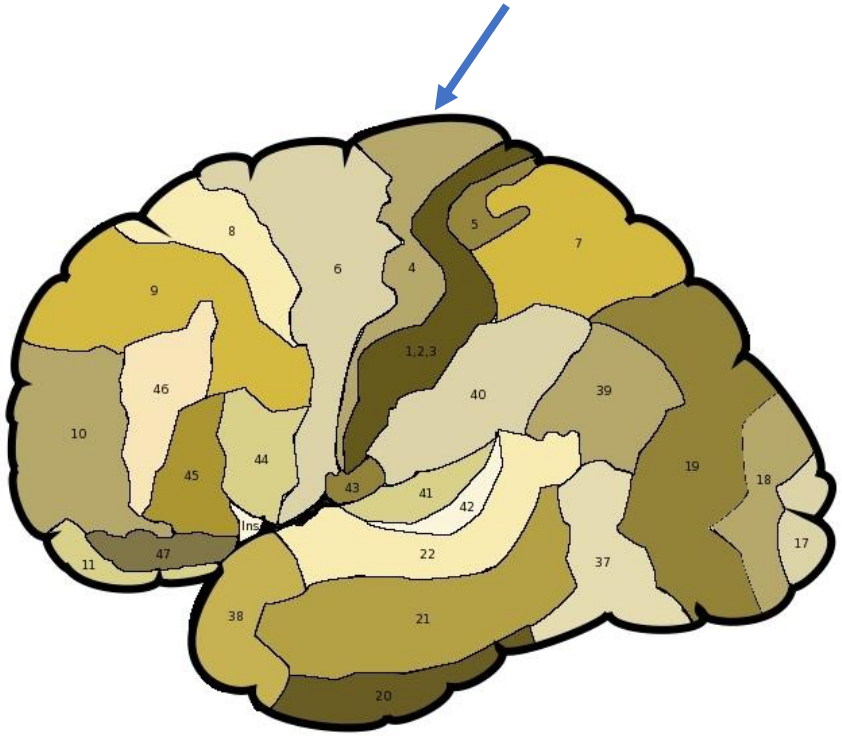
Step 2: Action Plan

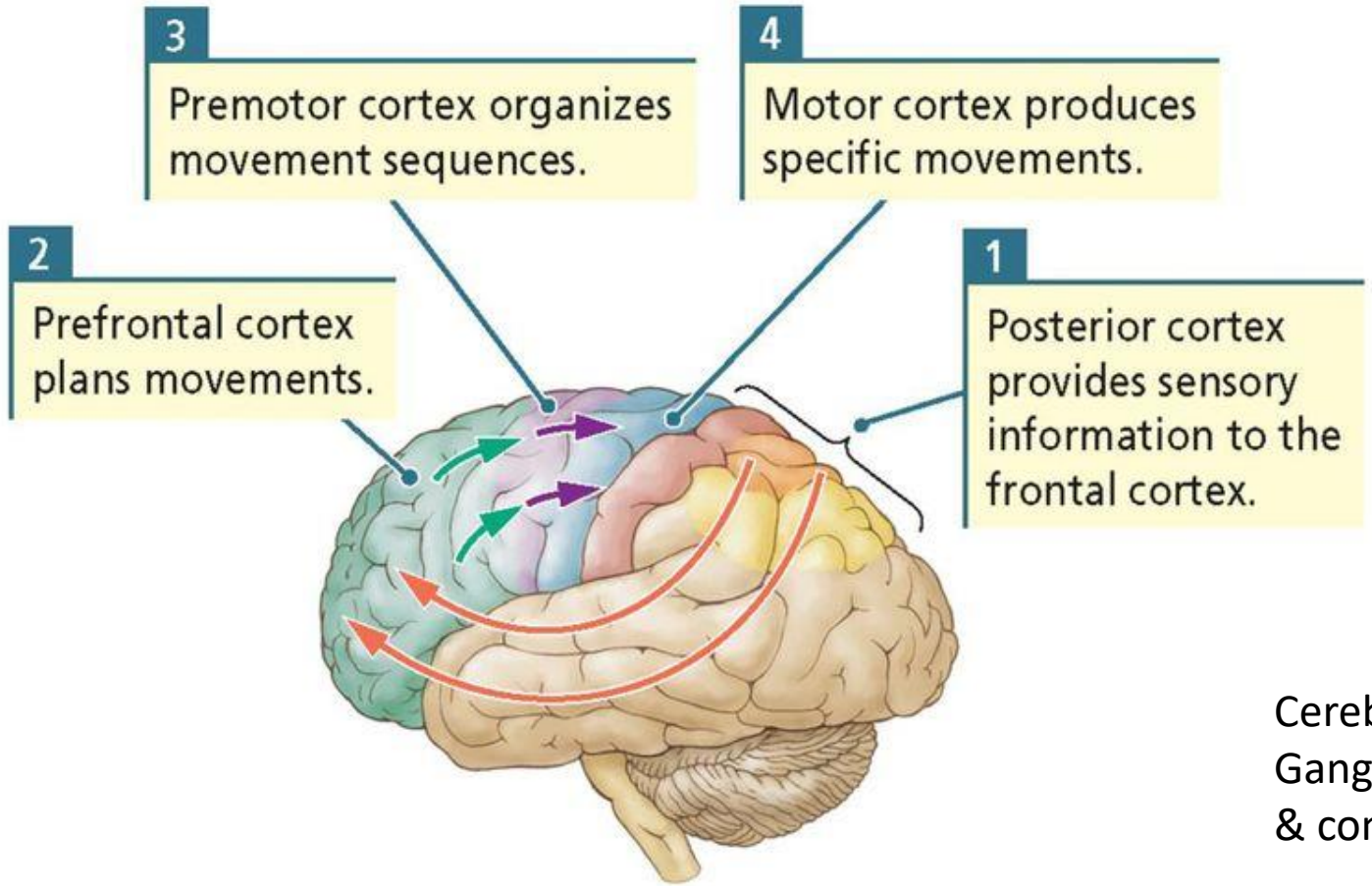
- Supplementary Motor Area & Premotor Area (Brodmann's Area 6)
  - Plans for complex movement sequences
    - Electrical stimulation evokes coordinated contractions at more than 1 joint.
  - Activation in SMA when rehearsing complex movements
  - Makes 2 plans
    - 1 for movements
    - 1 for posture adjustments
  - SMA lesions impair bimanual movements and orienting hand movements to prepare to grasp an object
  - Premotor lesions impair ability to develop an appropriate strategy for movement



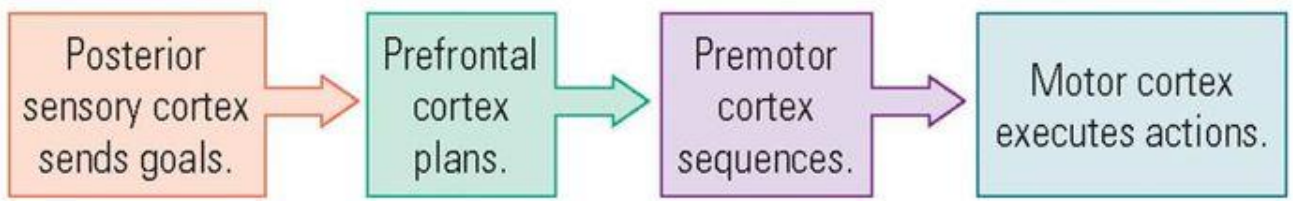
Step 3: Movement Execution

- Primary Motor Area (Brodmann's area 4)
  - Responsible for initiation and triggering movement
  - Codes for simple movement sequences
    - Electrical stimulation evokes very specific movements, sometimes of precise muscle fibers
  - Specific neurons codes for force exerted by specific muscle fibers
  - Different cells are responsible for extension and flexion
  - Populations of neurons code movement direction
  - Common movements made for different reasons activate different neurons
    - Arm movement to reach for an object vs making the same movement in an outburst of anger
    - Trained bite response vs chewing

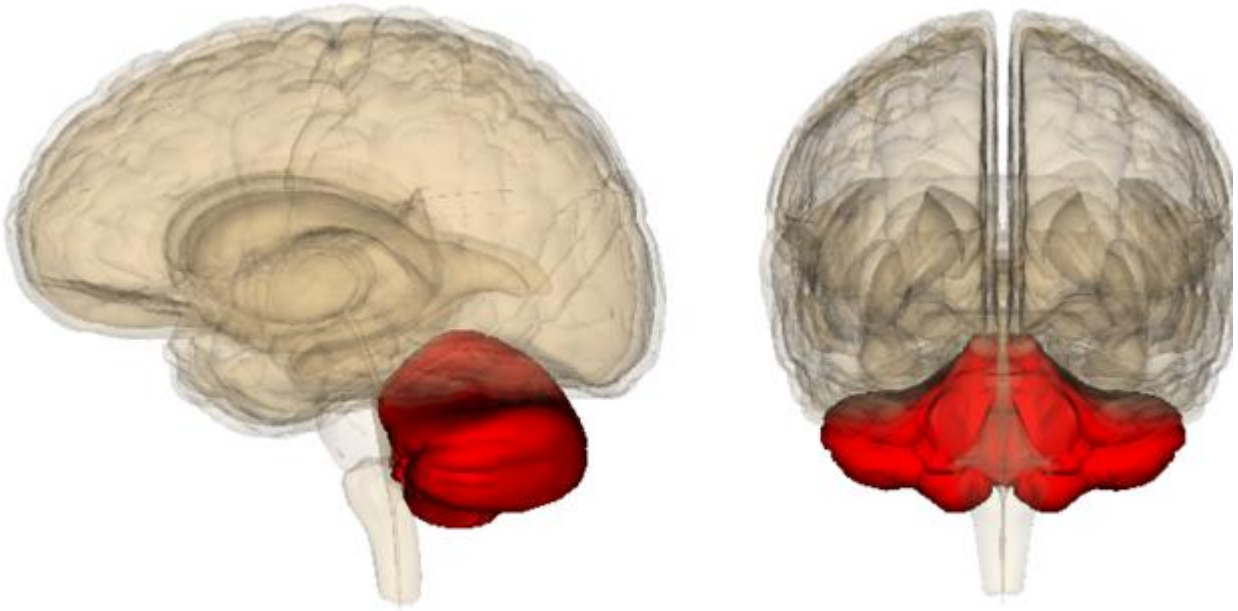




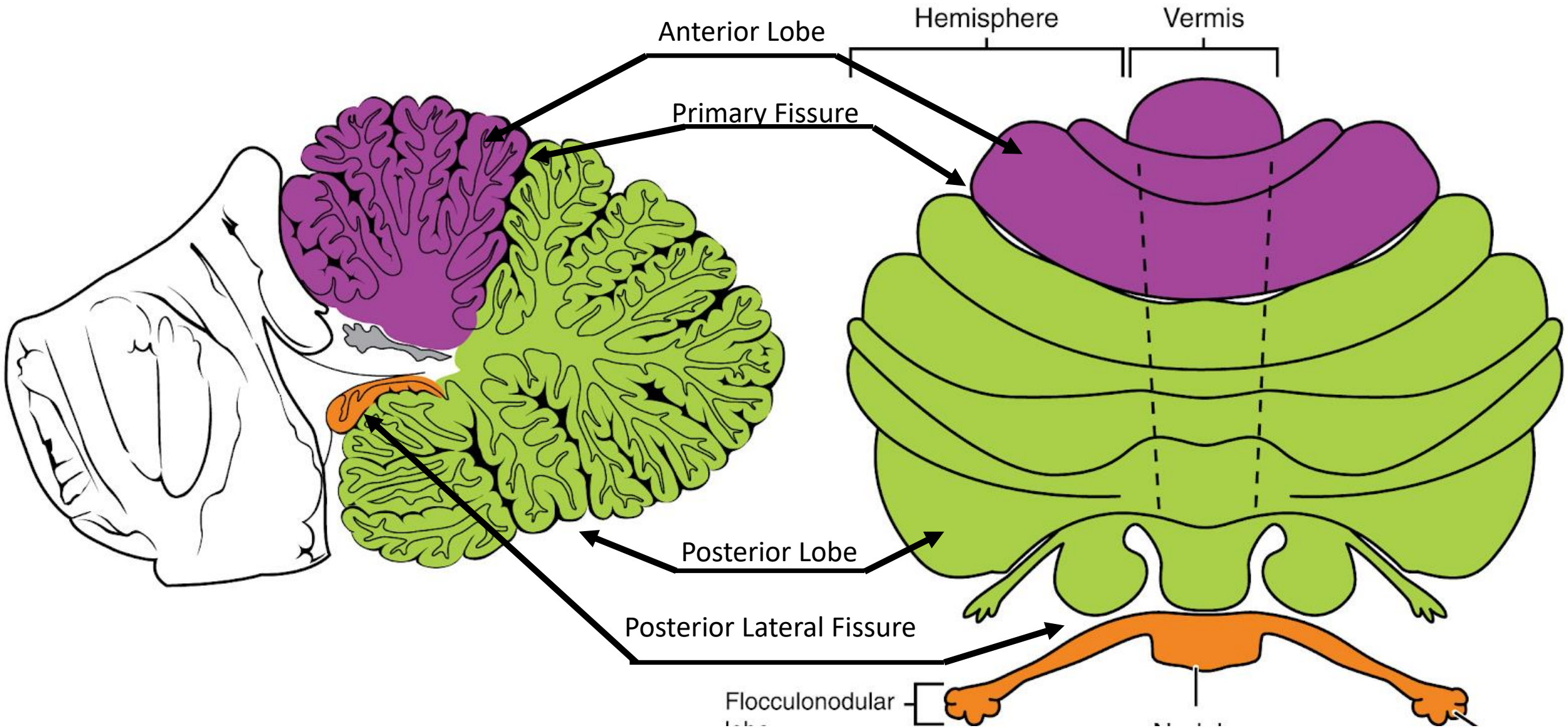
Cerebellum & Basal Ganglia refine motor plans & commands

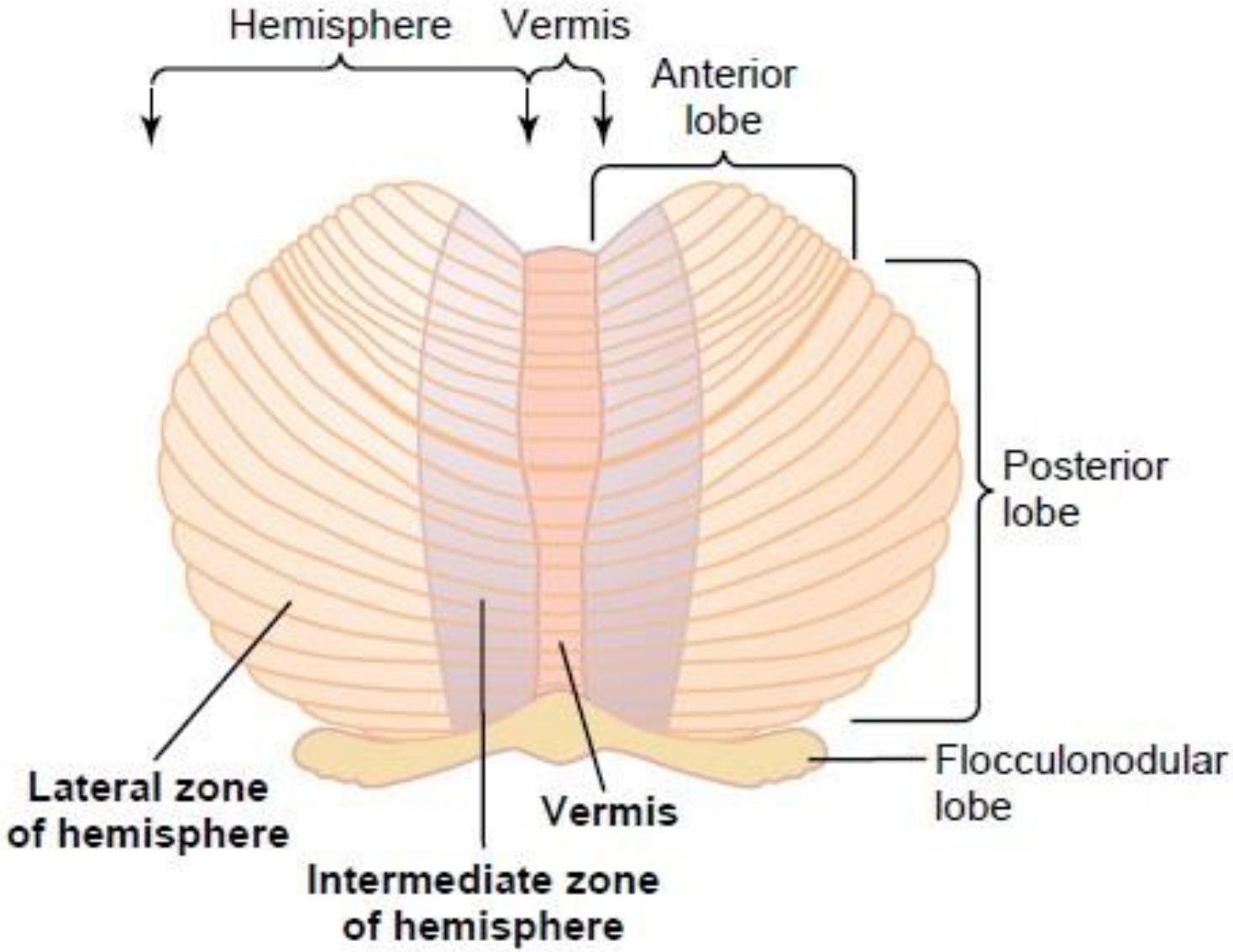


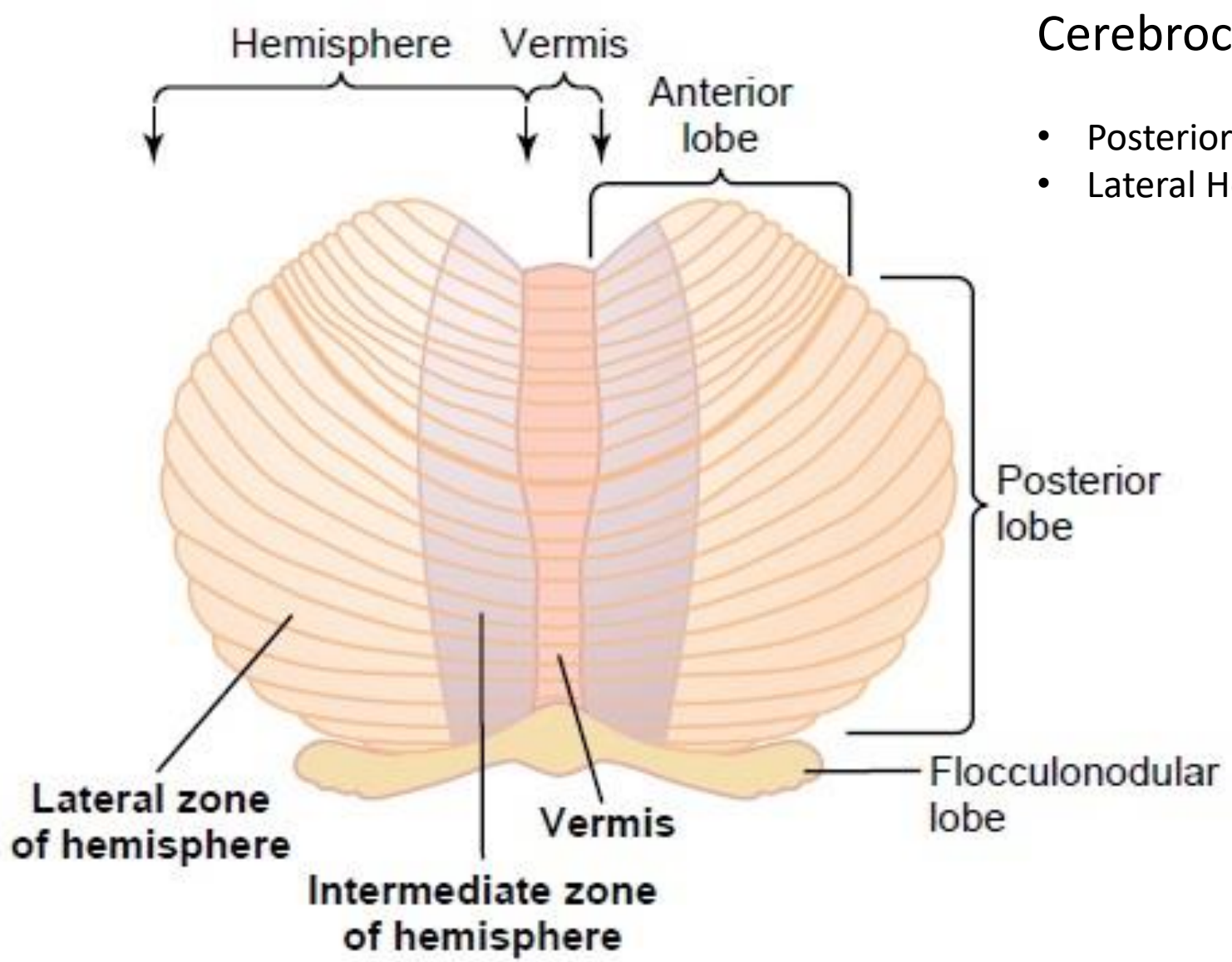
The Cerebellum



- Regulates movement by monitoring and compensating for errors (i.e., if actual movement deviates from intended movement).
    - Monitors internal feedback (*Corollary Discharge*)
        - Receives information about movement plans from regions responsible for programming and execution of movement
    - Monitors external feedback (*Reafferent Feedback*)
        - Receives information coming from the periphery about movements
    - Projects to descending motor systems


Anterior Lobe
Hemisphere
Vermis
Primary Fissure
Posterior Lobe
Posterior Lateral Fissure
Flocculonodular

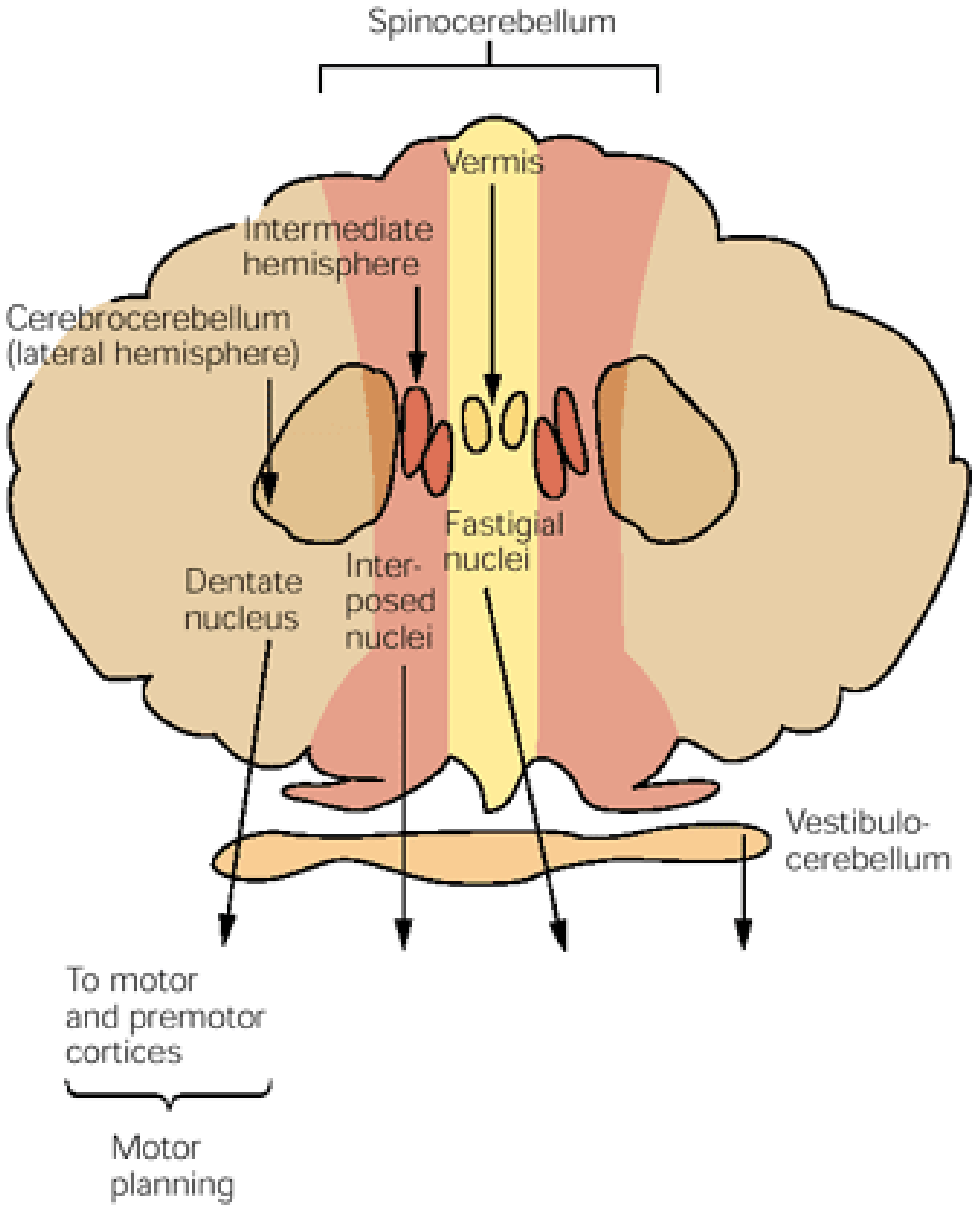

Hemisphere
Vermis
Anterior lobe
Posterior lobe
Flocculonodular lobe
Lateral zone of hemisphere
Intermediate zone of hemisphere
Vermis



Cerebrocerebellum –

- Posterior Lobe
- Lateral Hemispheres

Cerebrocerebellum



- Receive information from cortex about intended movement
- Sends information about calculated motor plan to motor areas
- Deep cerebellar nuclei - Dentate
- Responsible for movement initiation, planning, and timing

Areas 4 & 6

Cerebrocerebellar Tract – Planning of movement

- Calculates specific motor plans re: precision control of rapid limb movements & task that require fine dexterity
  - May be related to a cognitive ability of setting up an "internal clock" – motor deficits in timing but also deficits in judgment of elapsed time

- Receives most input from sensory & motor cortices and from premotor & posterior parietal cortices

- Lateral zone of cerebellum -> dentate nucleus -> superior cerebellar peduncle -> thalamus -> motor & premotor cortices

- Lesions produce
  - Delays in movement initiation & termination
  - Tremor at the end of movement
  - Disorder in the temporal coordination of movements at multiple joints
  - Disorder of spatial coordination of hand & fingers

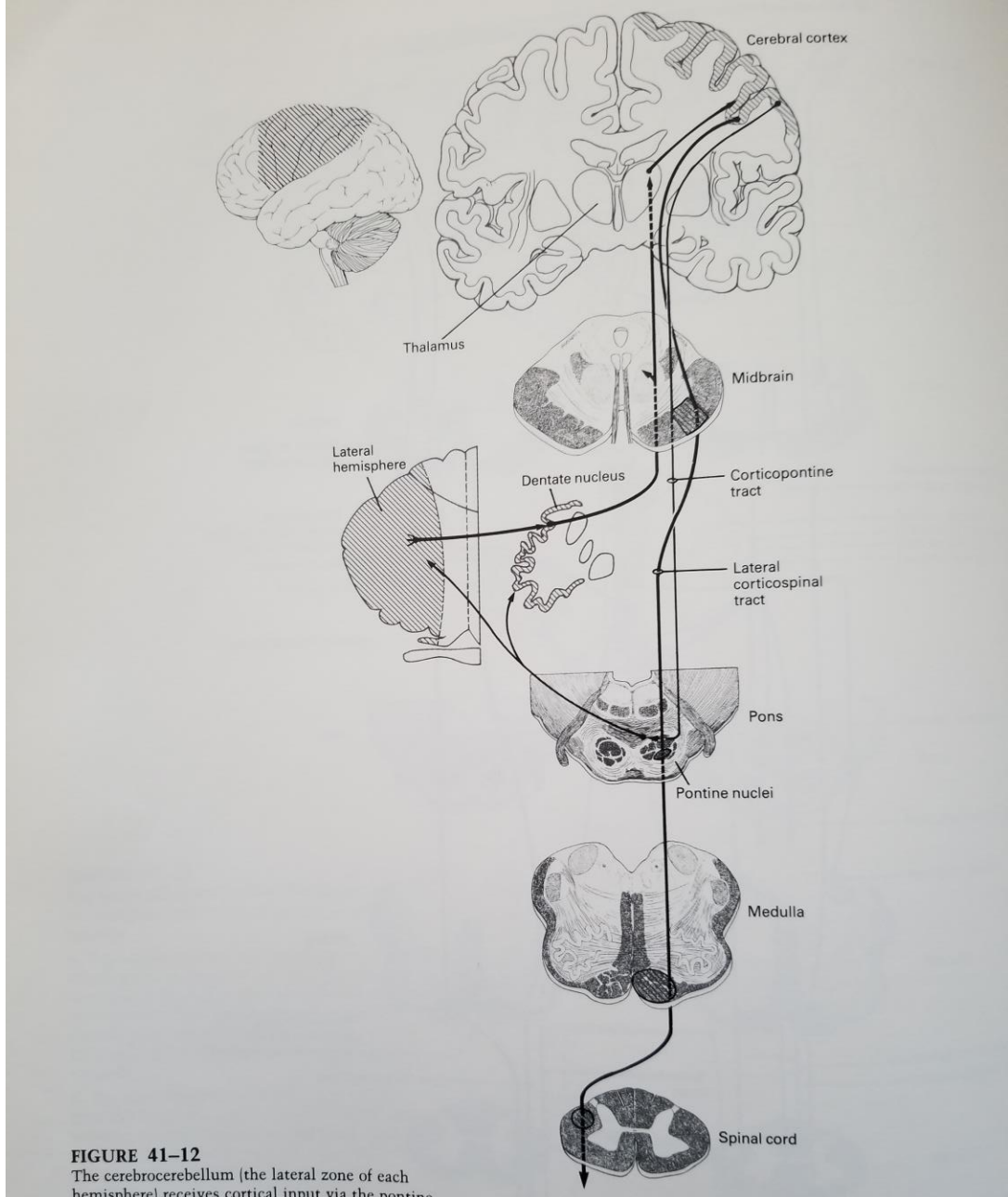
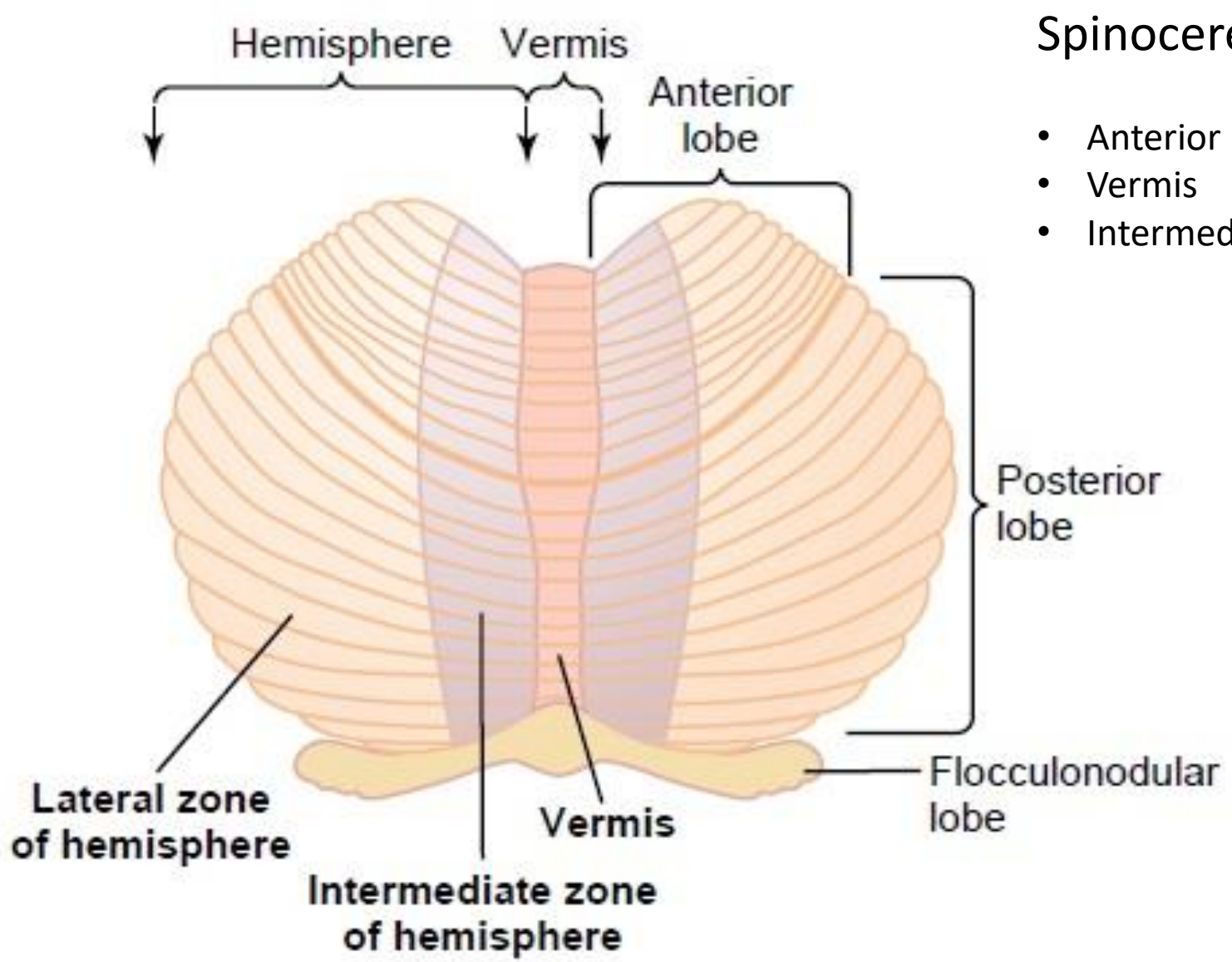
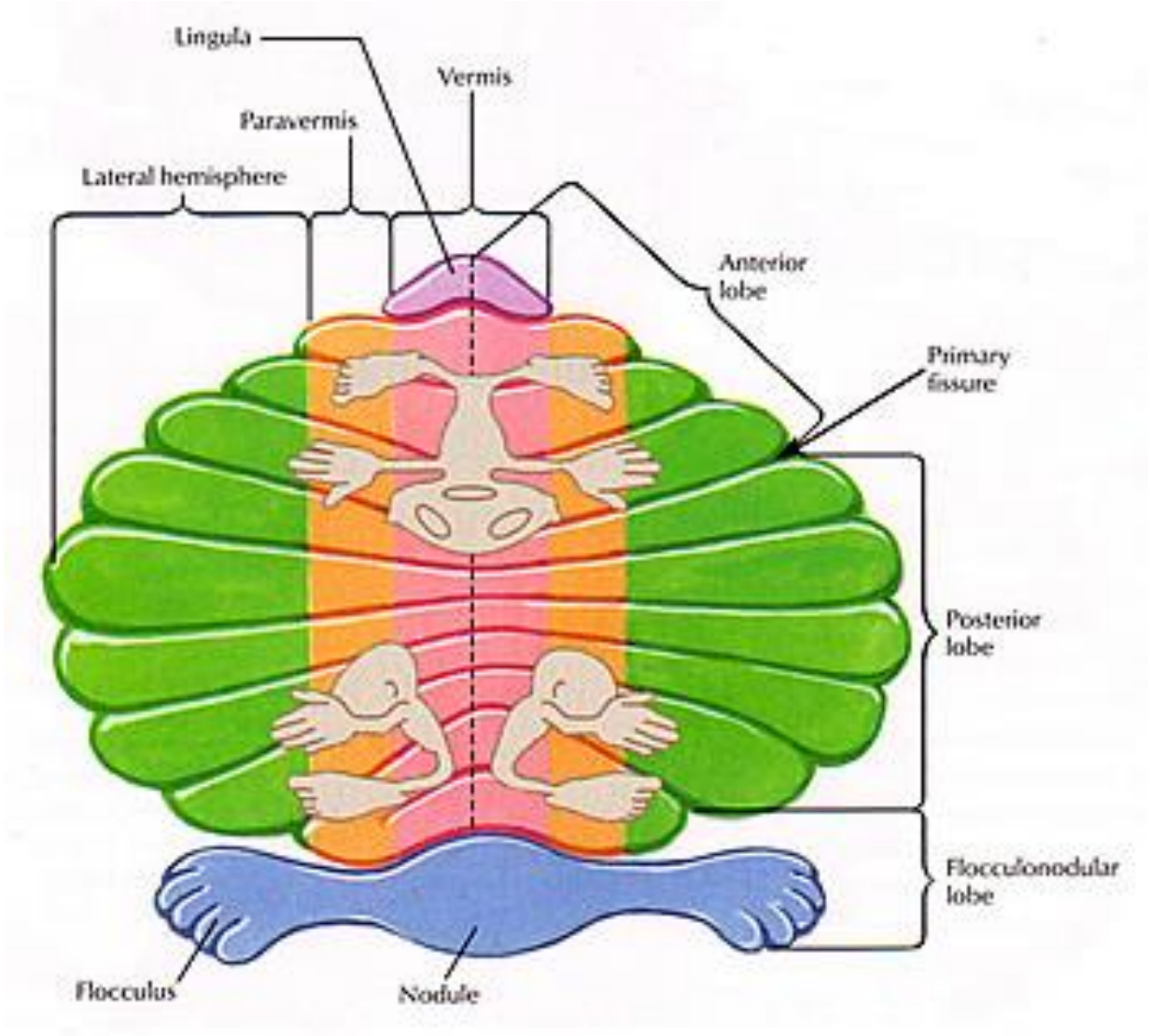


FIGURE 41–12
The cerebrocerebellum (the lateral zone of each hemisphere) receives cortical input via the pontine nuclei and influences the motor and premotor cortices via the ventral lateral nucleus of the thalamus.



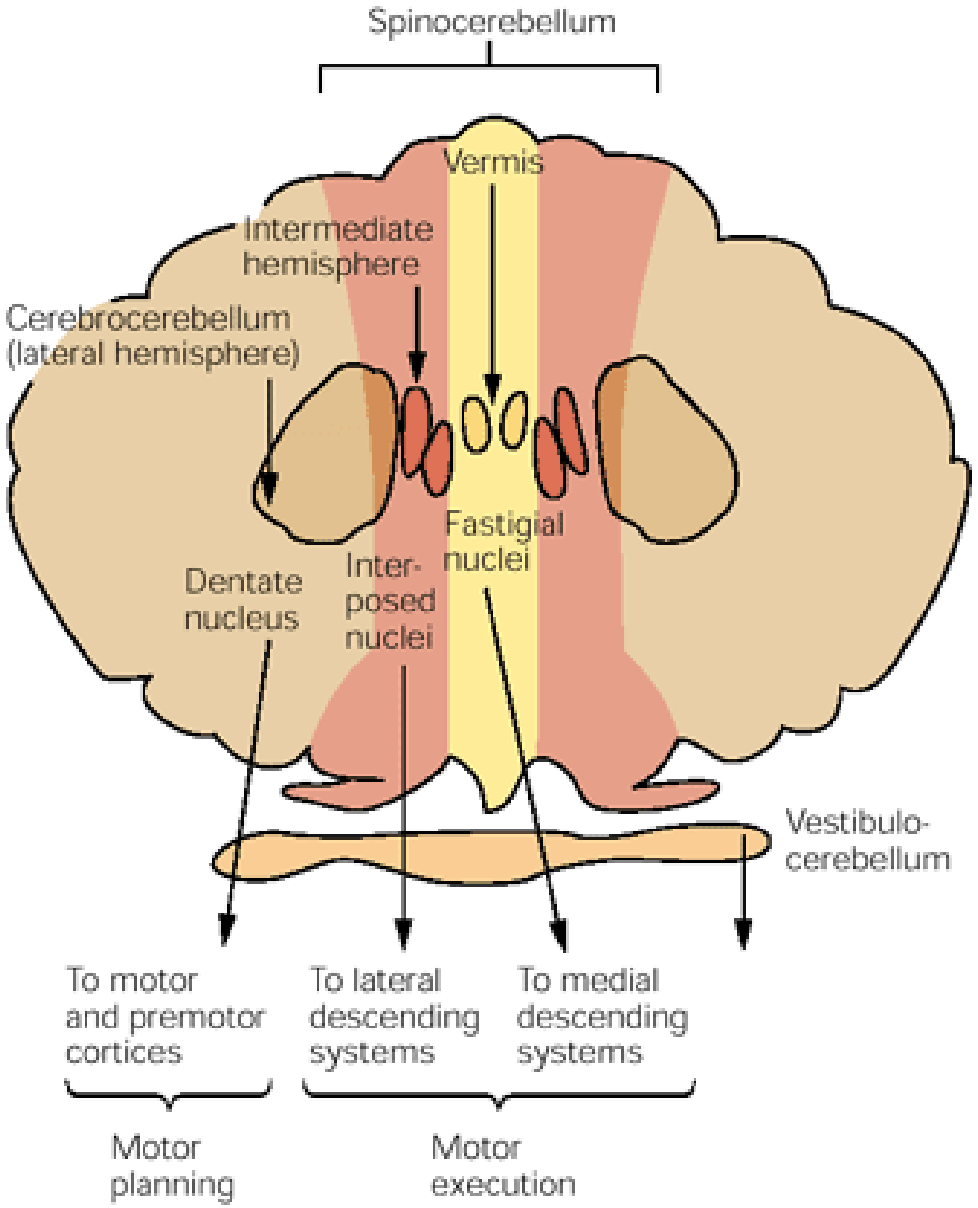
Spinocerebellum

- Anterior lobe
- Vermis
- Intermediate zone



Cerebellar Homunculi

- Vermis receives information from head, neck, & trunk
- Intermediate zone receives information from limbs



Areas 4 & 6

Spinocerebellum

- modulates cortical commands for movement through brain stem and descending systems

- Interposed Nuclei (Emboliform & Globose) in Intermediate zone
  - Receives spinal afferents -> red nucleus -> motor cortex
  - Controls ongoing motor control of limbs

- Fastigial Nuclei in Vermis
  - Receives information from vestibular system, head, neck, trunk, visual & auditory inputs -> Vestibular nucleus -> reticular formation -> motor cortex
  - Controls ongoing motor control of head, neck, trunk

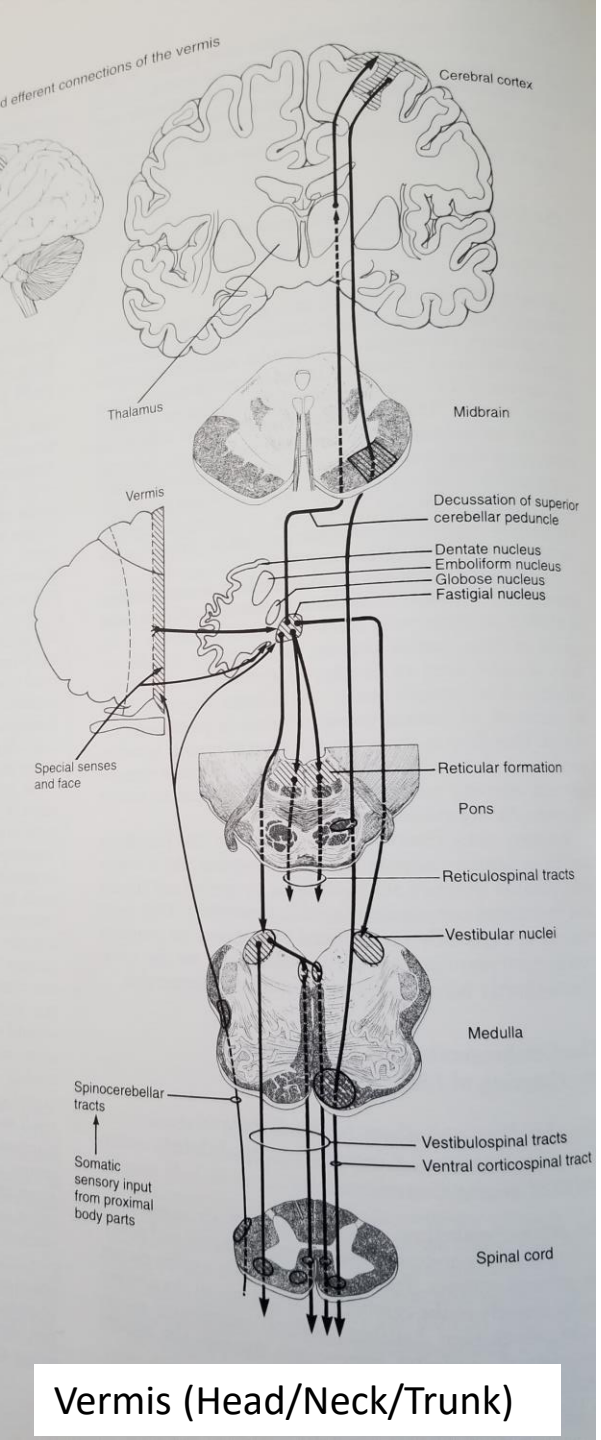
Spinocerebellar Tract –

- Controls
  - Ongoing execution of movement
  - Feedback adjustments
  - Regulates muscular apparatus to compensate for small variations in loads encountered during movement & to smooth out tremor

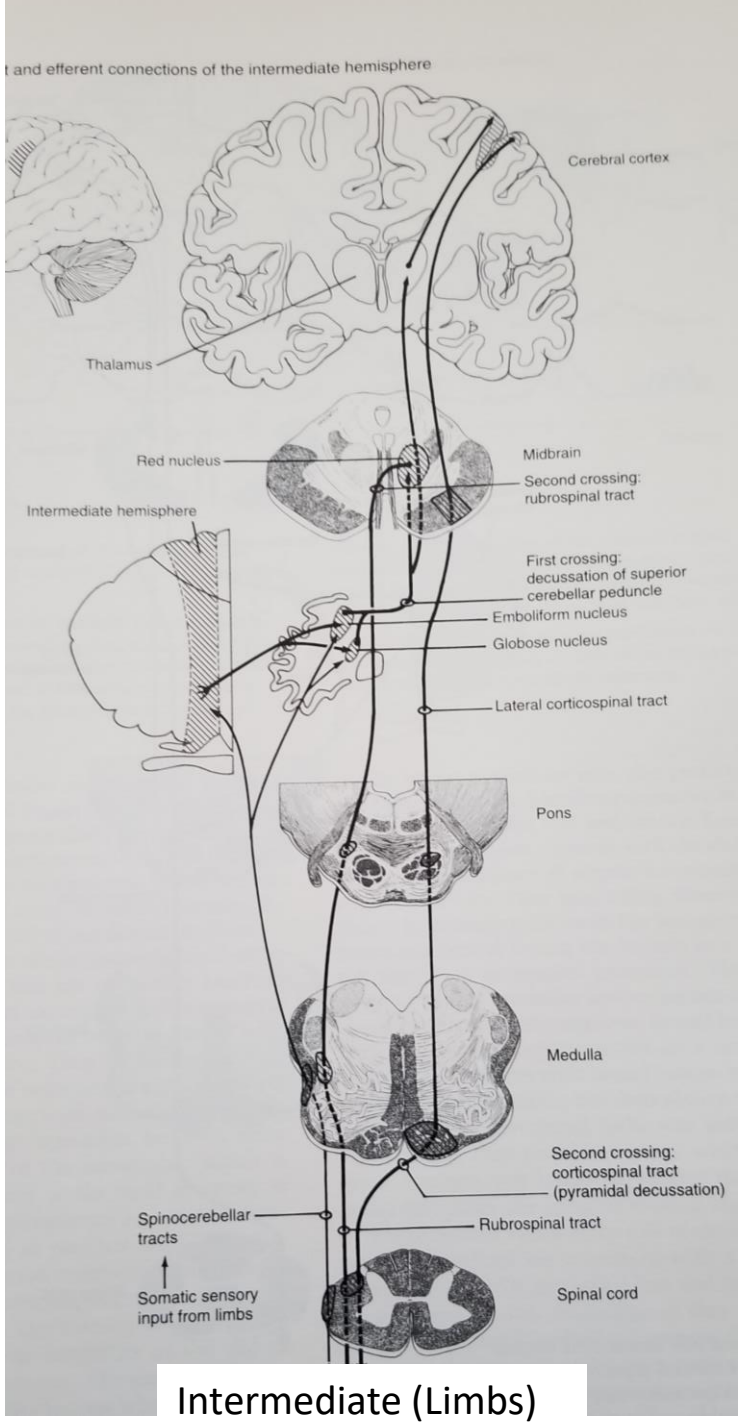
- Responds to proprioception, touch, & pressure

- Relies on information from cortical motor areas about intended motor commands and on feedback from the spinal cord about evolving movements to correct deviations from intended movement

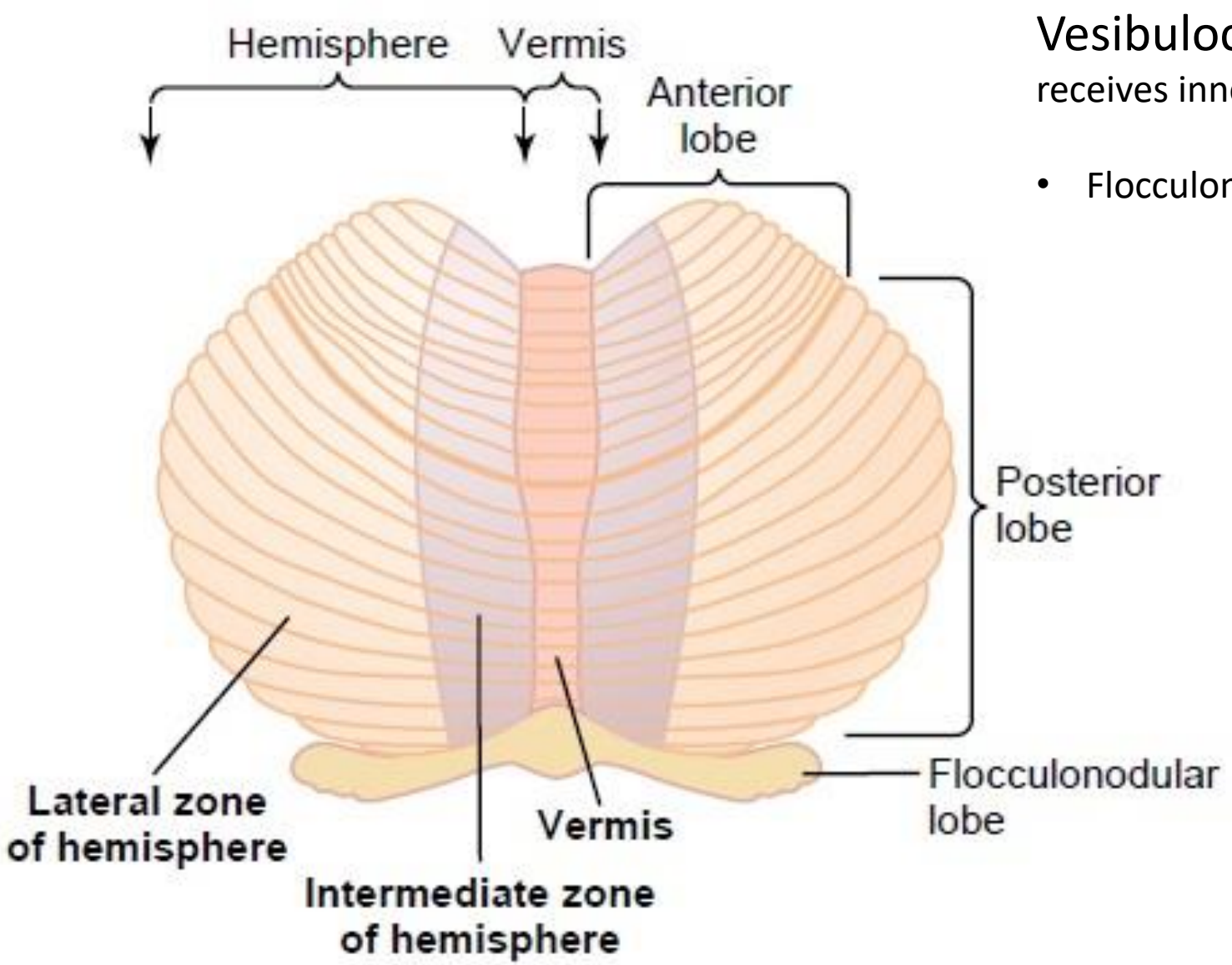
- Distinct Pathways
  - Dorsal – sensory events & information about evolving movements
  - Ventral – internal feedback from interneurons that are driven by central commands



Vermis (Head/Neck/Trunk)



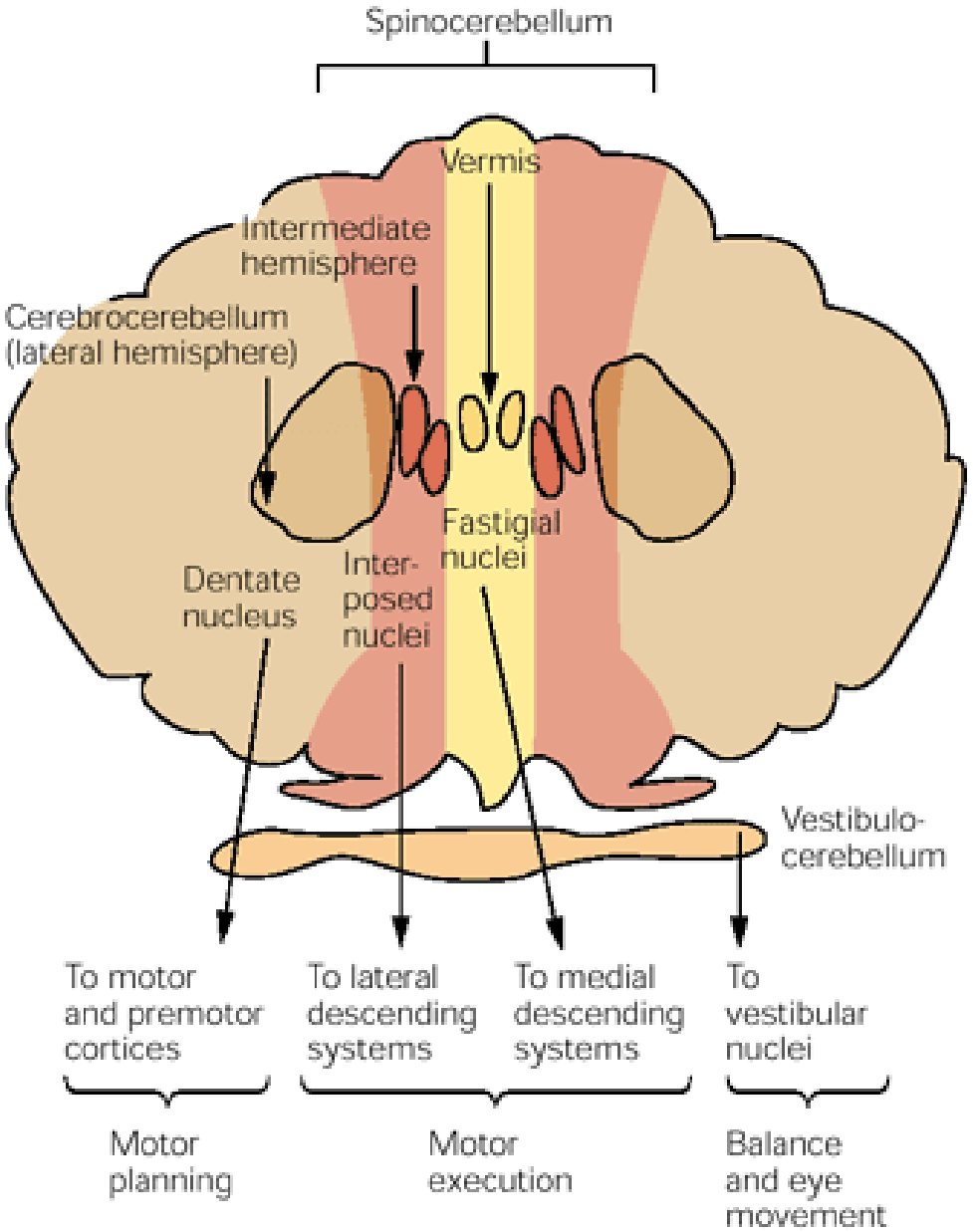
Intermediate (Limbs)



Vesibulocerebellum –

receives inner ear information

- Flocculonodular Lobe

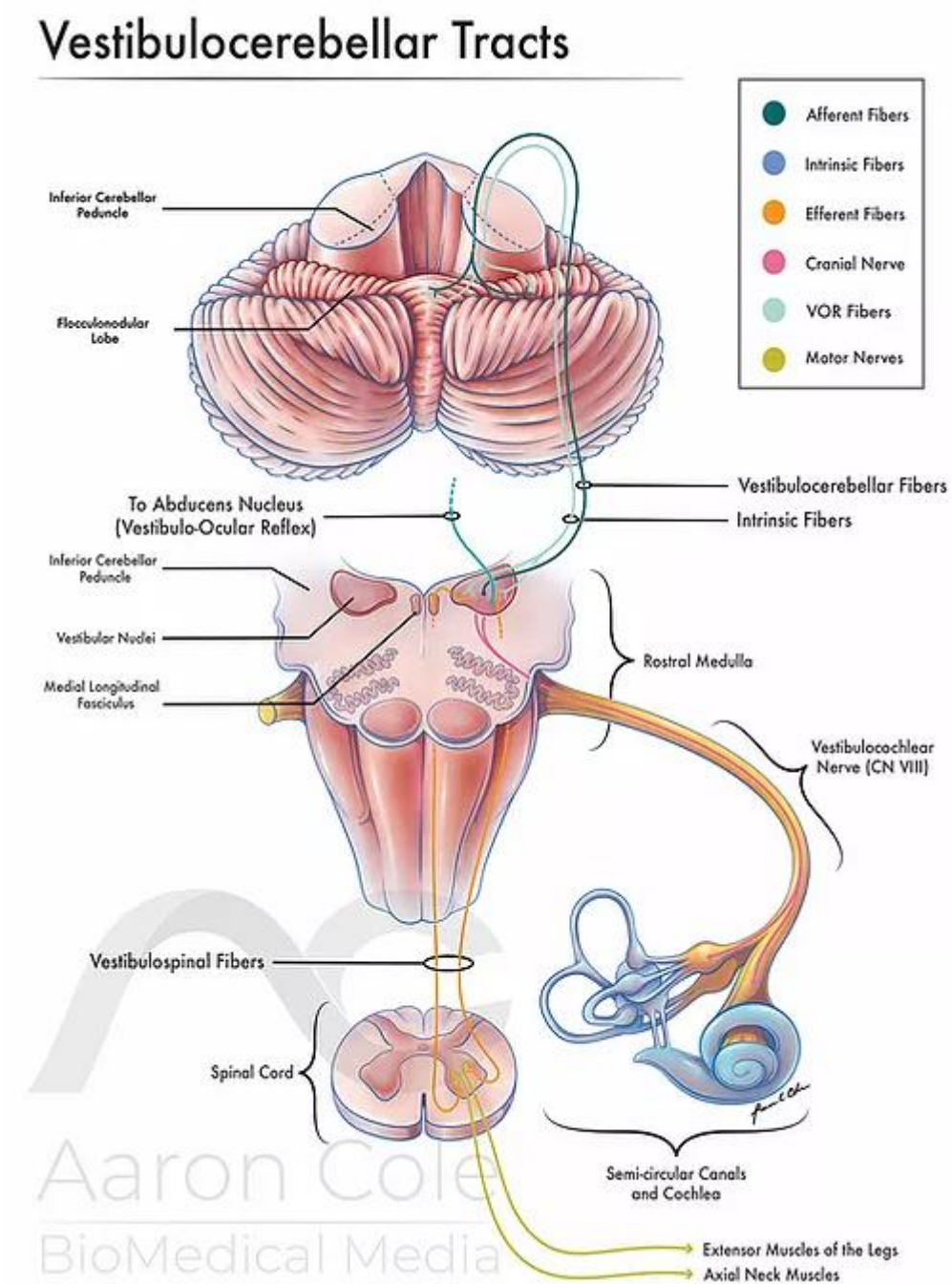


Areas 4 & 6

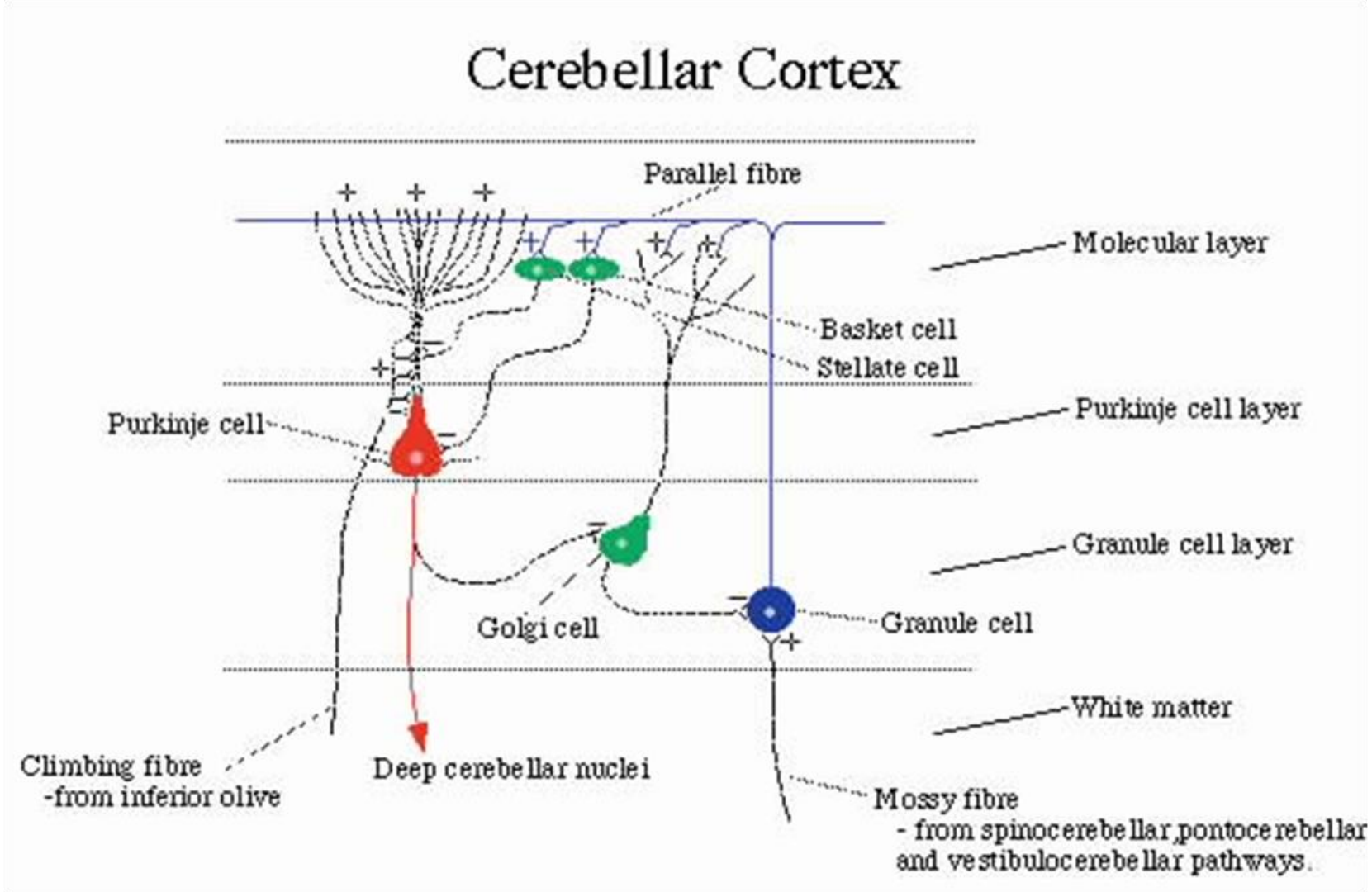
Vesibulocerebellum – receives inner ear information

- Flocculonodular Lobe

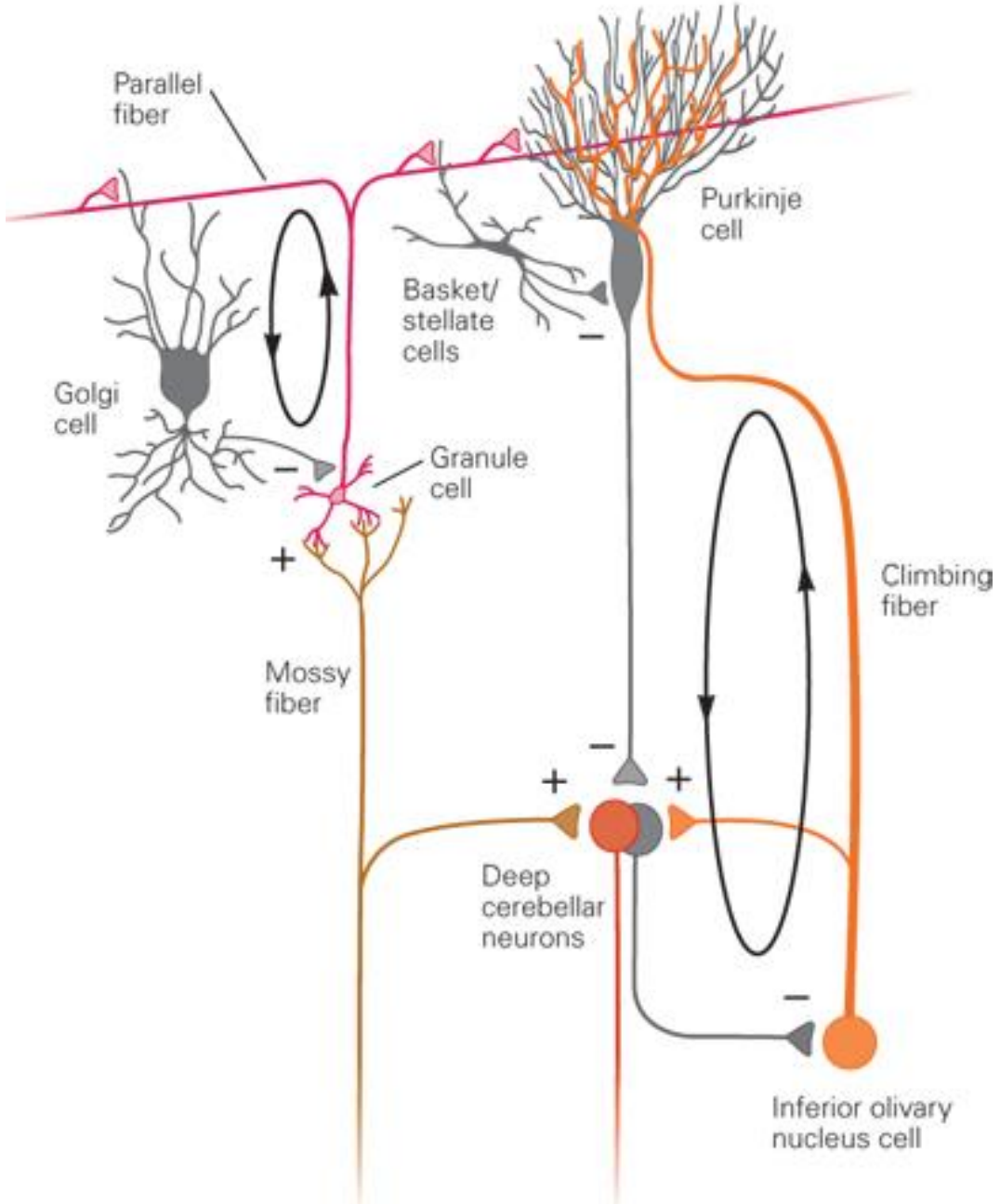
- Path
    - Inner-ear -> Medulla -> Flocculonodular Lobe
        - Also receives visual input via LGN
- Oldest part cerebellum (evolved first)
- Governs eye movements & body equilibrium during stance and gait



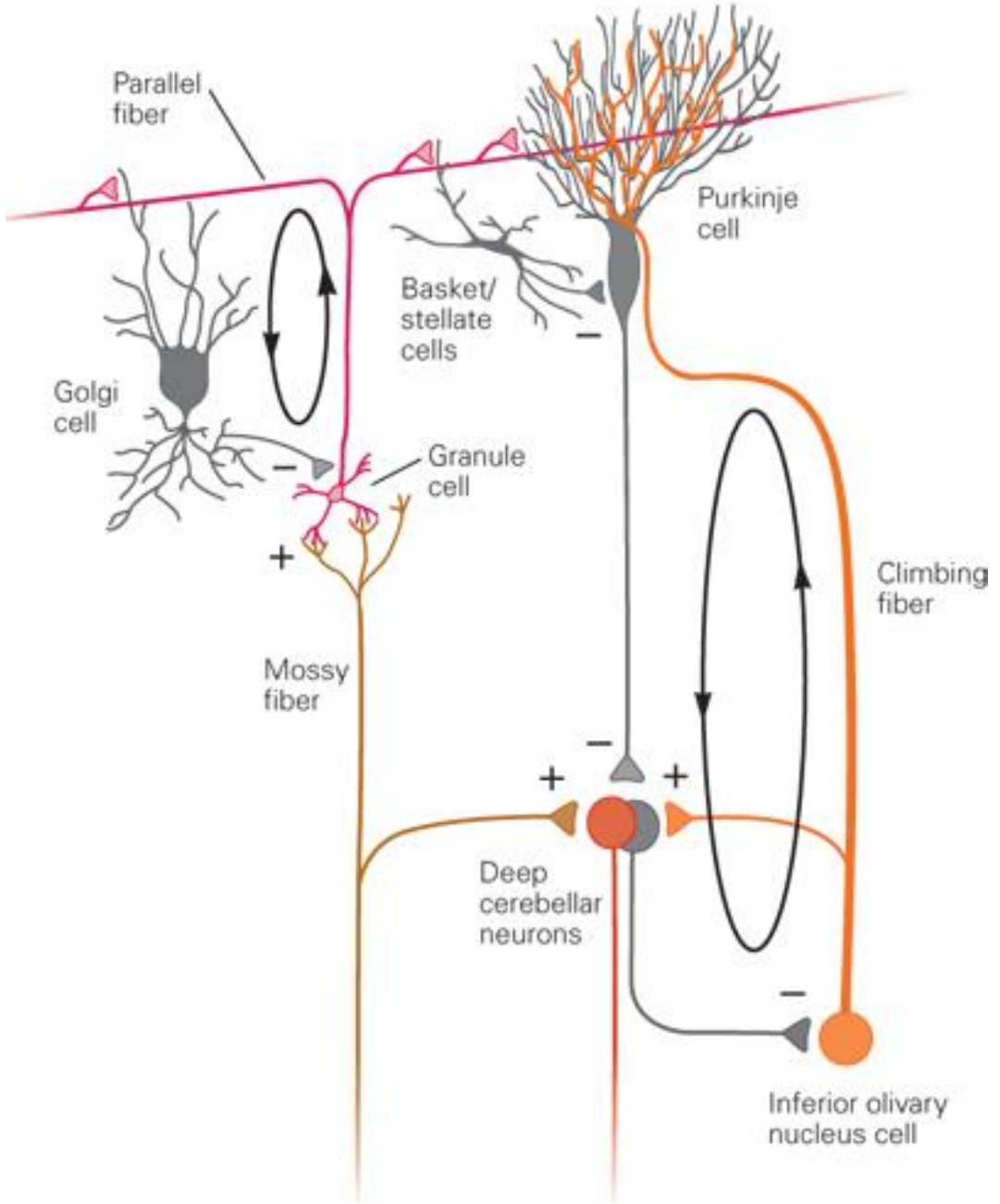
Cerebellar Cortex



- Information comes in through Inferior Olives via <u>climbing fibers</u>
    - Go directly to deep cerebellar nuclei (DCN)
        - Releases excitatory neurotransmitter aspartate which stimulates DCN
    - Also ascends to stimulate Purkinje cells
        - Releases inhibitory neurotransmitter GABA synapse onto DCN
        - Controls overshooting (neural sharpening)



- Information comes in from sensory pathways via <u>mossy fibers</u>
    - Go directly to DCN
        - Releases excitatory neurotransmitter glutamate which stimulates DCN
    - Also ascends to granular layer & synapse to granule cells & golgi cells (inhibit granule cells)
    - Granule cells ascend to molecular layer to parallel fibers
        - Stimulate Purkinje, Stellate & Basket cells
            - Stellate & Basket cells inhibit Purkinje cells



Cerebellar Damage

- Role in classical conditioning -prevent acquisition & retention of conditioned eyeblink

- Gordon Holmes studied soldiers who received gunshot wounds to the cerebellum in WW1

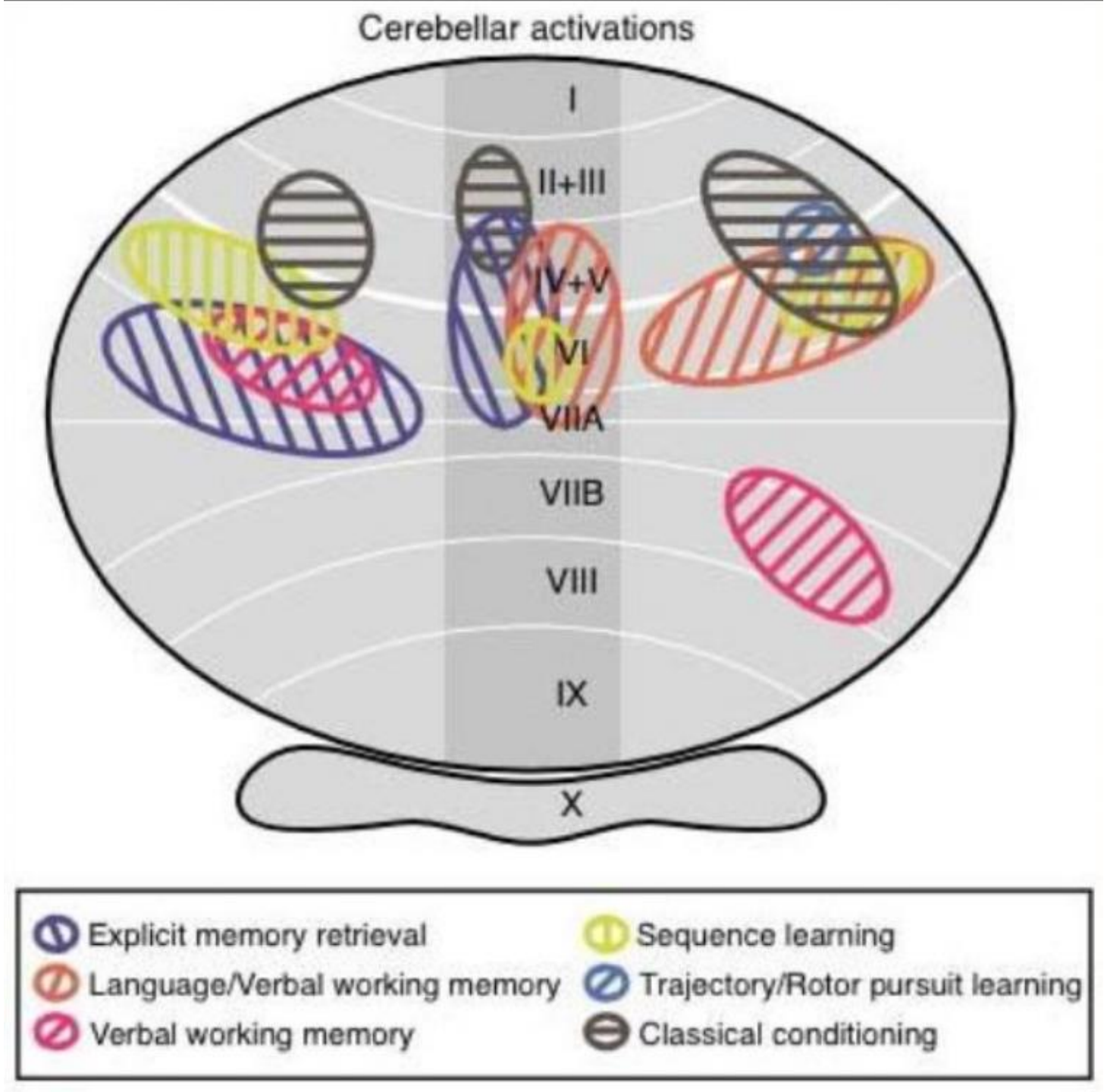
    - Hypotonia – diminished resistance to passive limb displacements & delay in response – inability to stop limb from rapidly overshooting target

    - Ataxia –
        - delay in initiating responses, errors in range, force, rate & regularity
        - cannot sustain rhythm in alternate tapping
        - don't brace against forces generated by movement

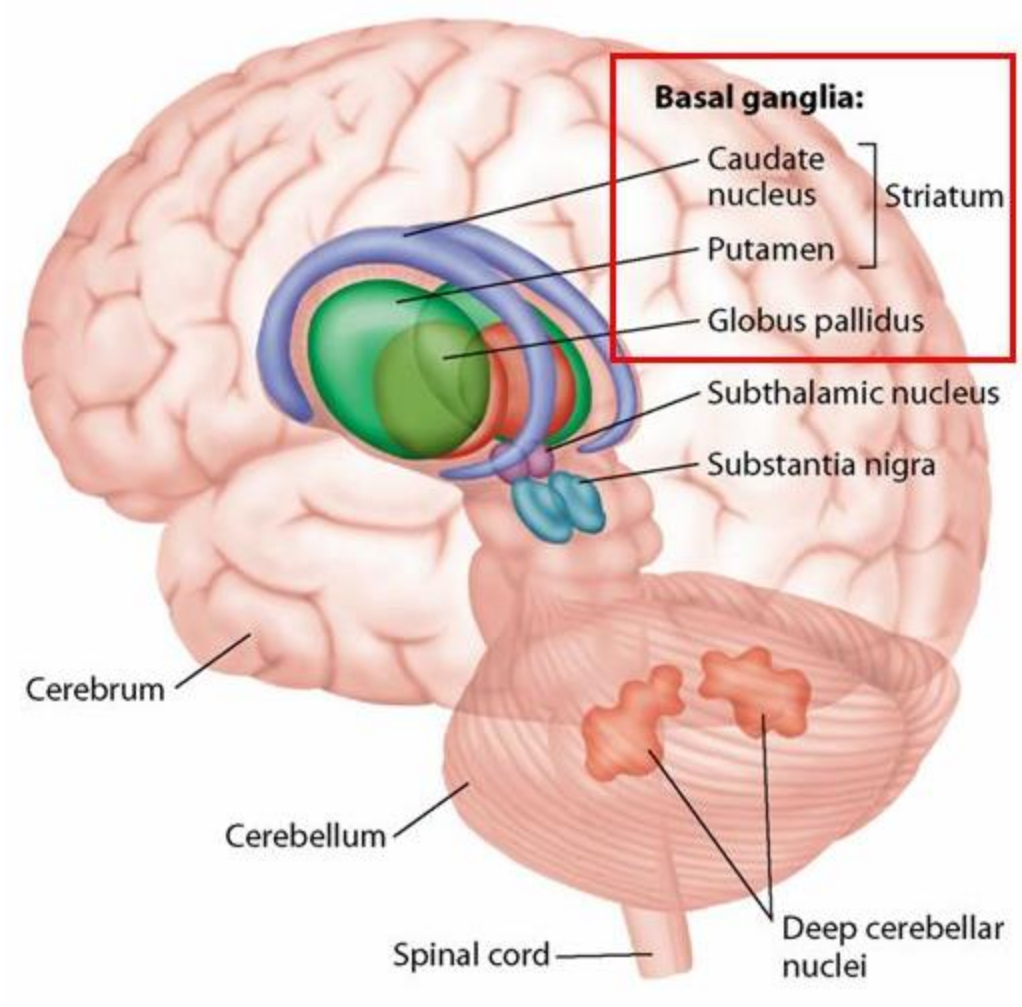
    - Tremor at end of movement

    - Damage & effect ipsilateral

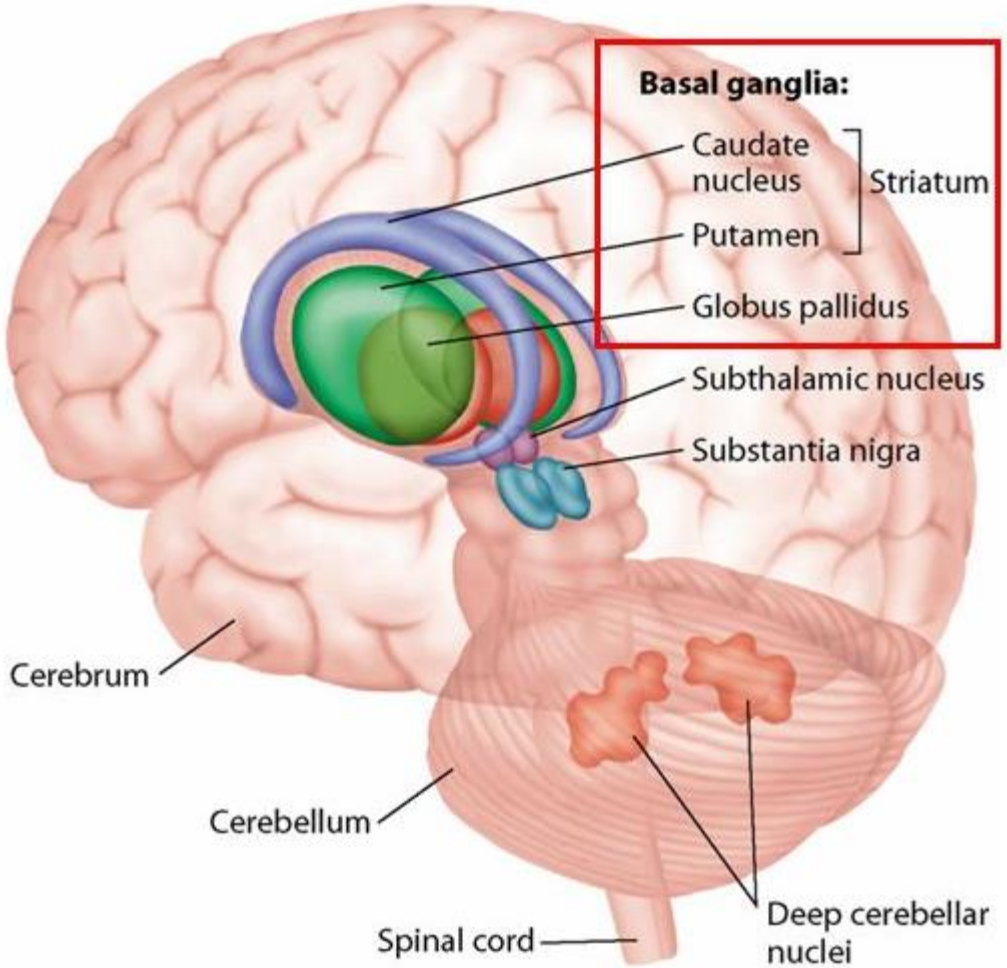
    - Vermis lesions
        - disturb trunk movements
        - problems w/ speech (e.g., slur or singsong quality)


Cerebellar activations
I
II+III
IV+V
VI
VIIA
VIIB
VIII
IX
X
Explicit memory retrieval
Language/Verbal working memory
Verbal working memory
Sequence learning
Trajectory/Rotor pursuit learning
Classical conditioning

The Basal Ganglia



- Caudate – Integrates spatial information and motor behavior. Also, part of the reward system and helps selection actions based on changing values of goals
- Putamen – Extent and amplitude of movement
- Globus Pallidus – Inhibitory action that works to allow smooth movements (i.e., reduce tremors and jerks)
- Substantia Nigra – GABA & dopaminergic pathways, learning – observation of environment and location in space (spatial learning), movement timing
- Subthalamic Nucleus – action selection, role in impulsive choice between two equally rewarding stimuli



Basal Ganglia do not connect directly to spinal cord

Involved in higher-order, cognitive aspects of motor control (e.g., planning & execution of complex motor strategies)

Cerebellum connects directly to spinal cord

Directly regulates movement execution

The Basal Ganglia play a role in a number of Circuits and pathways

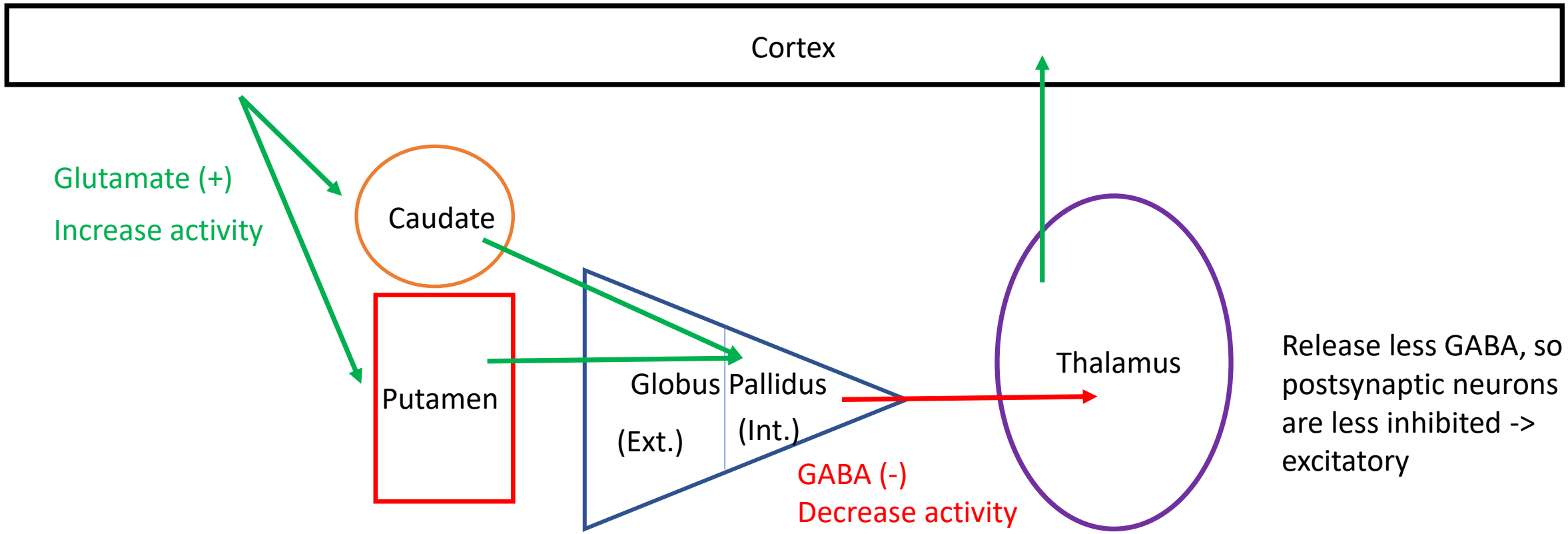
- Oculomotor Circuit
  - Control saccadic eye movement
  - Caudate -> superior colliculus -> frontal eye fields -> thalamus

- Dorsolateral Prefrontal Circuit
  - Memory re: spatial orientation
  - Caudate -> thalamus -> dorsolateral prefrontal cortex

- Lateral Orbitofrontal Circuit
  - Changing behavioral set
  - Ventromedial caudate -> lateral orbitofrontal cortex

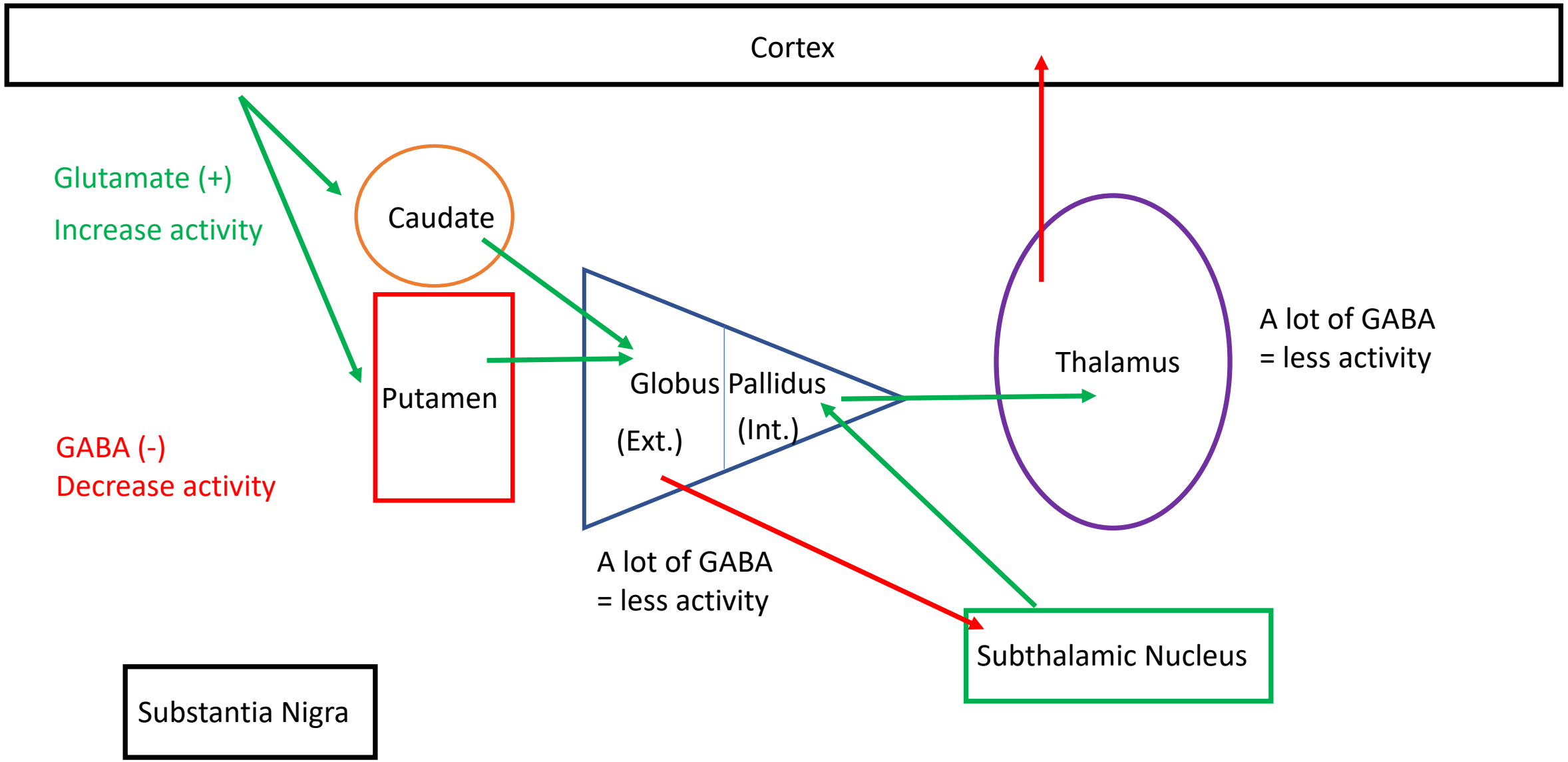
The Direct Pathway

Increase Motor Activity



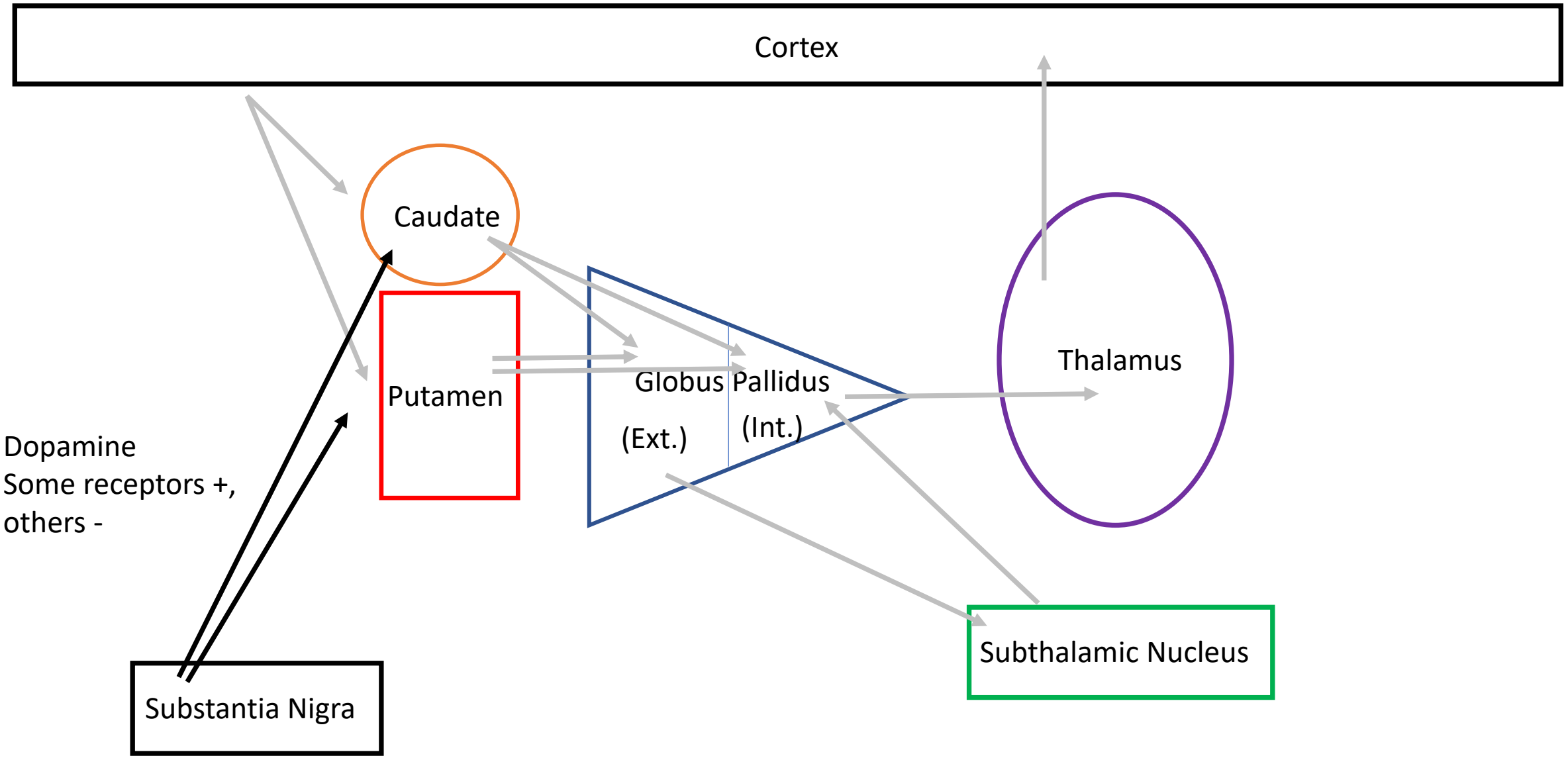
The Indirect Pathway

Decrease Unwanted Motor Activity



The Nigrostriatal Pathway

Modulate/Amplify Direct & Indirect Pathways

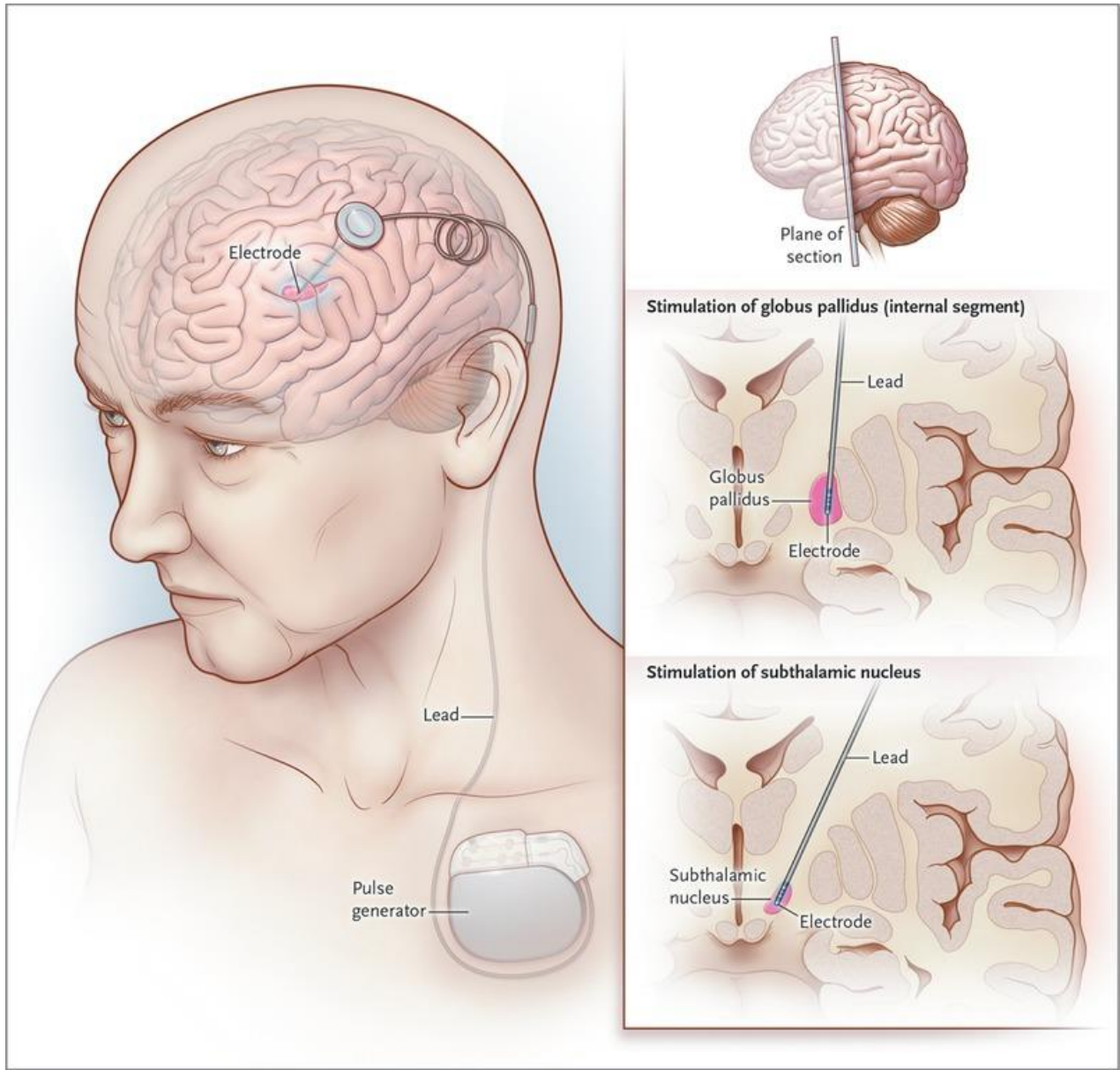


Parkinson’s Disease

- James Parkinson (1817)
- Rhythmical tremor at rest, rigid tone, difficulty initiating movement, slow execution of movement

- 80% of dopamine is in the BG
- Degeneration of nigrostriatal pathway, up to 90% of dopaminergic neurons degenerate

- Traditional treatment L-DOPA -> dopamine
- Deep brain stimulation



Huntington's Disease

- George Huntington (1872)

- Extremely hereditable (50% chance), onset in 40s/50s, death 15-20 years after onset
  - Most of the cases on the east coast have been traced back to two ancestors who emigrated from Suffolk, England to Salem, MA in 1630
  - Traced through 12 generations (300 years), expressed in each generation

- Onset: Absent-mindedness, irritability, depression, fidgeting, clumsiness, sudden falls
- Mid-disease: Chorea, dementia, slurred speech
- End-stage: Speech eventually stops, confinement to wheelchair, cognitive functions/ability to reason fails

- Loss of cholinergic & GABAergic neurons in caudate & putamen (chorea), dorsolateral prefrontal (cognitive symptoms)

- No treatment available

- ADHD: Frequently reduction in volume & activation in:
    - prefrontal cortex
    - Caudate
    - Ventral striatum
    - Globus pallidus
    - cerebellar vermis
- Reduced density of dopamine receptors
- Projections from premotor -> basal ganglia -> cerebellum guide behavioral output (hyperactivity/impulsivity)
- Behavior sequencing (dyslexia)