Behavioral Neuroscience A
14: Body Movement Planning

Richard Veale

Graduate School of Medicine
Kyoto University

https://youtu.be/9GKmwkpi4Cc

Lecture Video at above link.

Today’s Goals

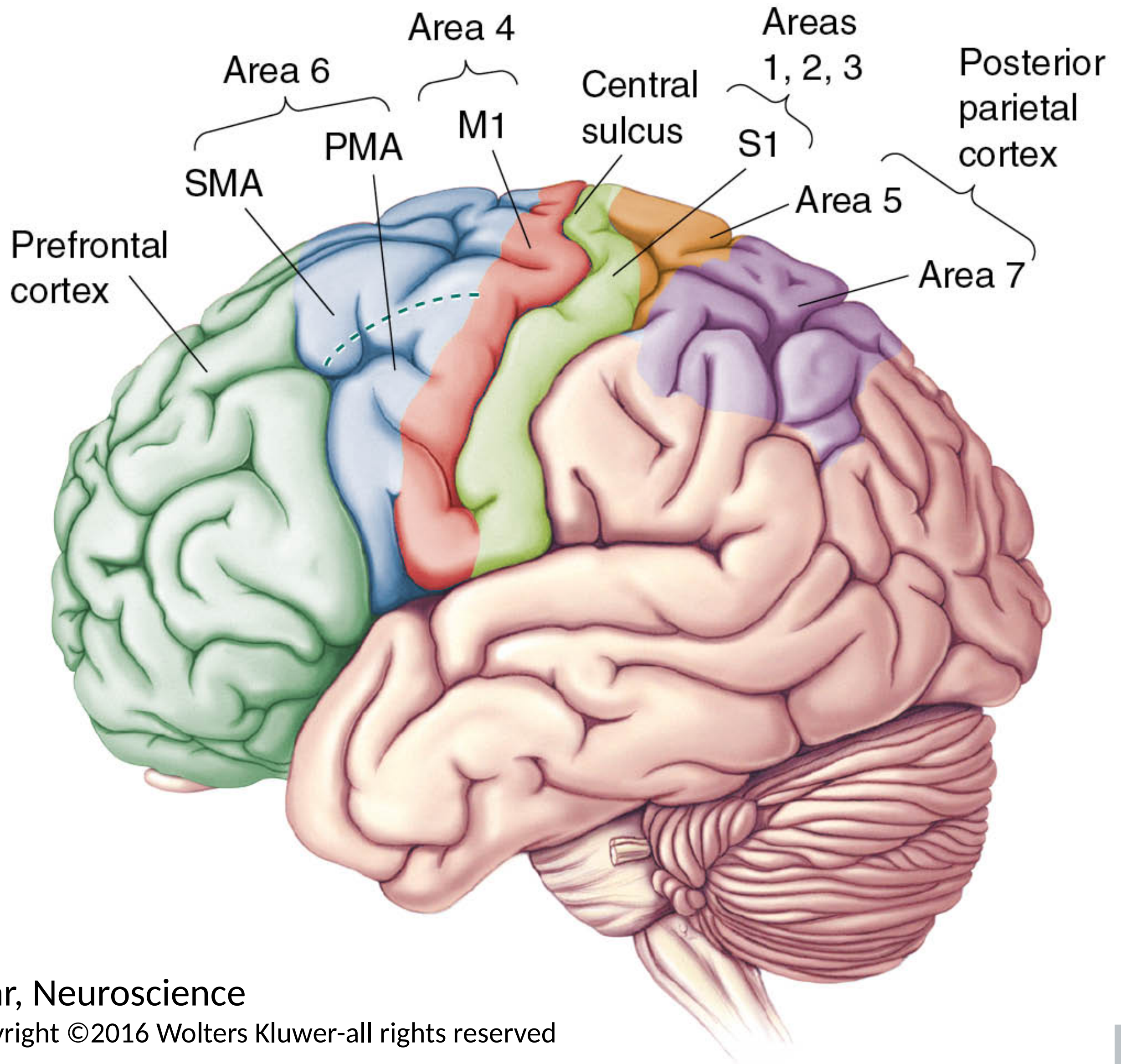
- Last class, we learned how muscles work and are stimulated

  Today:
  - To learn about the different inputs to lower motor neurons and their functional role.
  - To understand how motor cortex sends motor programs to the lower motor neurons.
  - To understand how additional loops via basal ganglia and cerebellum contribute to movements.

Today's Contents

1) Motor pathways
2) Motor cortex: M1, Supplementary motor area (SMA) and premotor area (PMA)
3) Cerebellum
4) Basal ganglia

Cortical Areas involved in Motor Planning



<u>Motor cortex</u>:
Area 4 + Area 6

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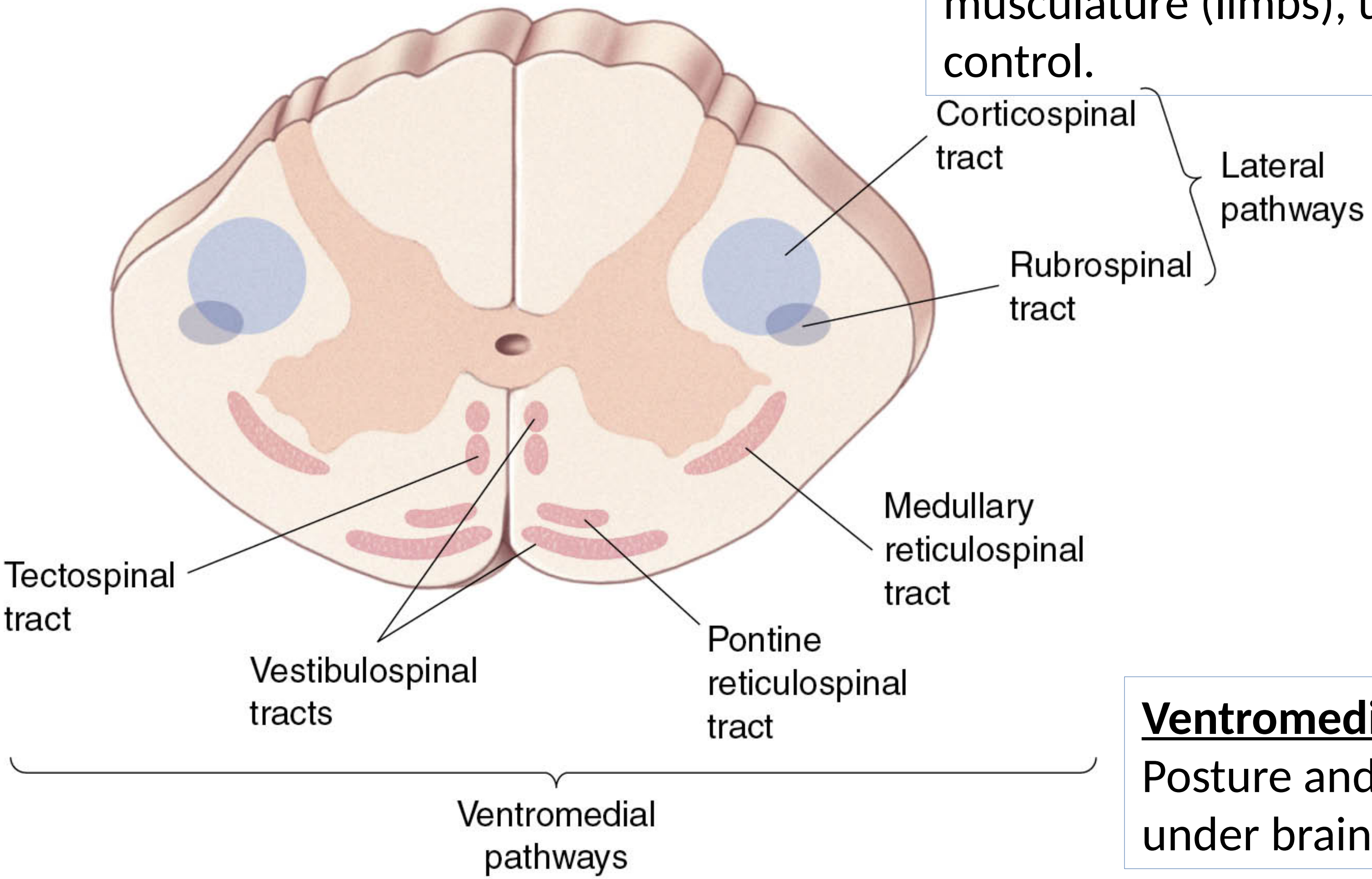
Motor Pathways

Lateral pathways:
Voluntary movement of distal musculature (limbs), under cortical control.



Ventromedial pathways:
Posture and locomotion, under brain stem control.

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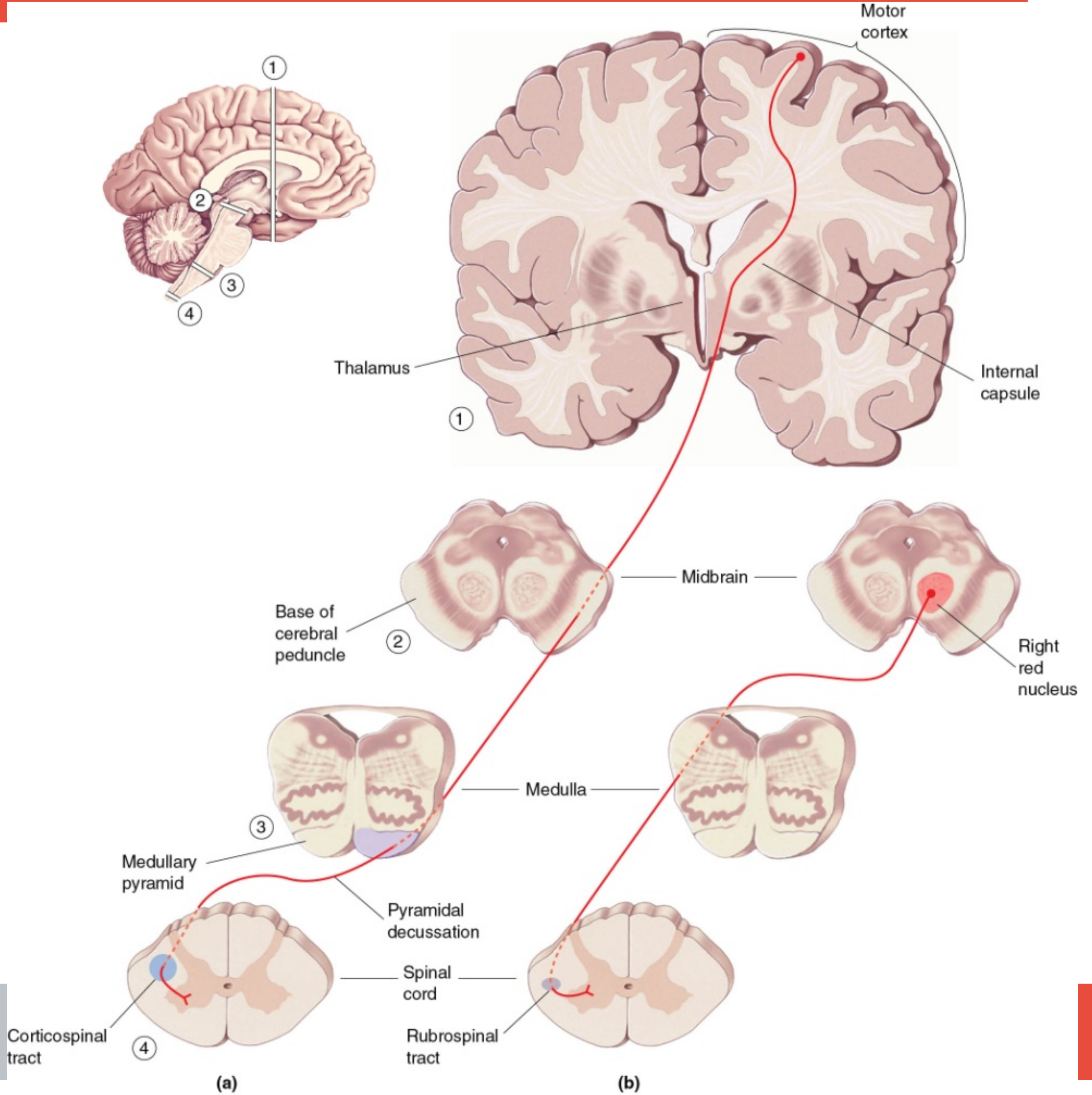
Lateral Pathways (1 and 2)

Corticospinal tract:
Main tract for control of contralateral limbs by motor cortex (crossing at the pyramidal decussation).

Rubrospinal tract:
Less important (and small) in humans. Red nucleus receives input from motor cortex, too.



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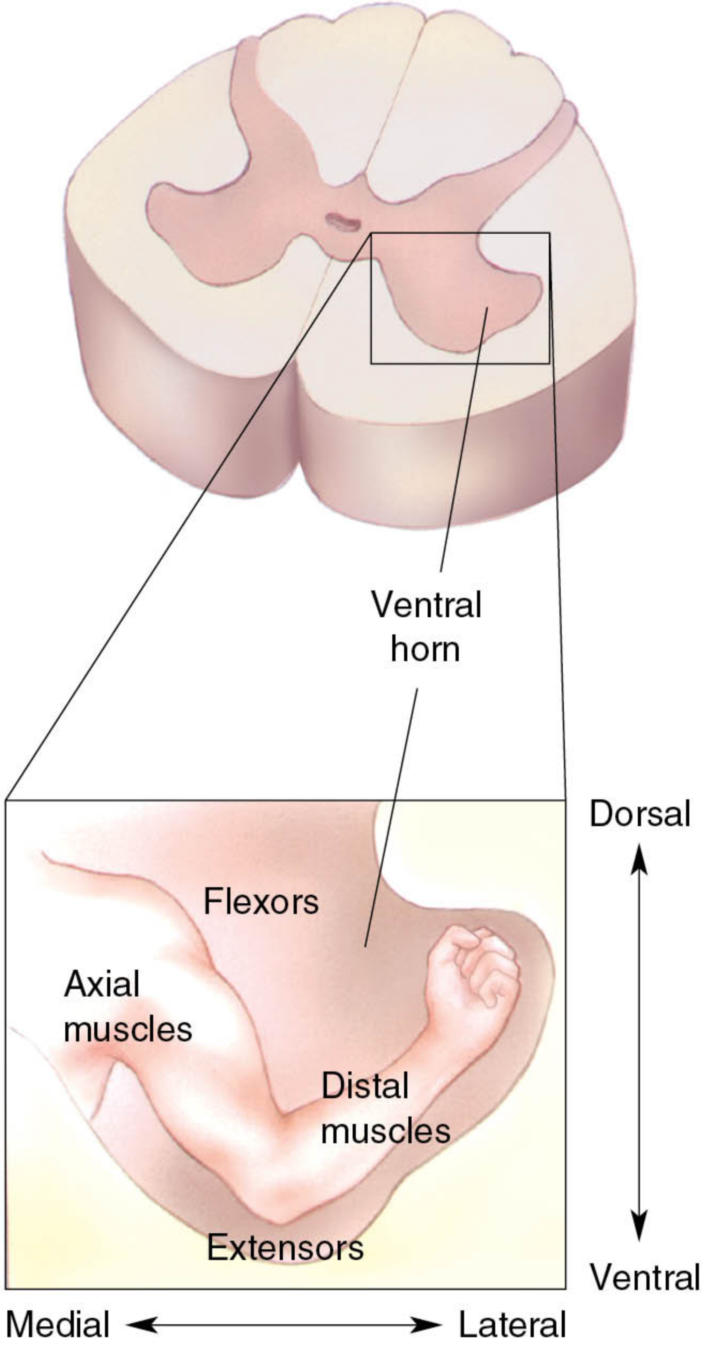
Lower Motor Neurons

The lower motor neurons in the ventral horn of the spinal cord are spatially organized such that:

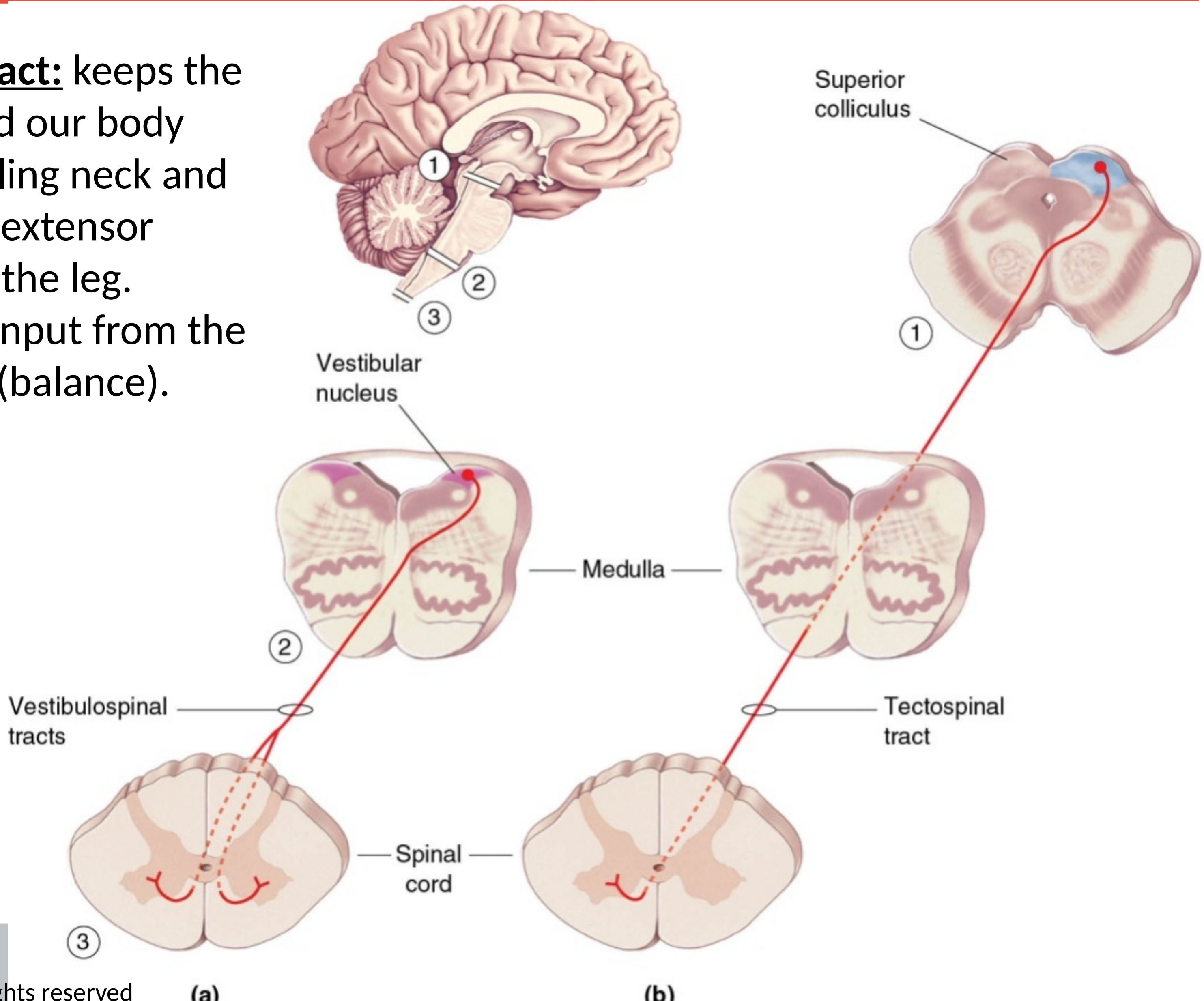
- Extensor muscles are ventral to flexor muscles.

- Distal muscles are lateral to axial muscles.



Ventromedial Pathways (1)

<u>Vestibulospinal tract:</u> keeps the head balanced and our body upright by controlling neck and back muscles and extensor motor neurons of the leg. Receives sensory input from the vestibular system (balance).



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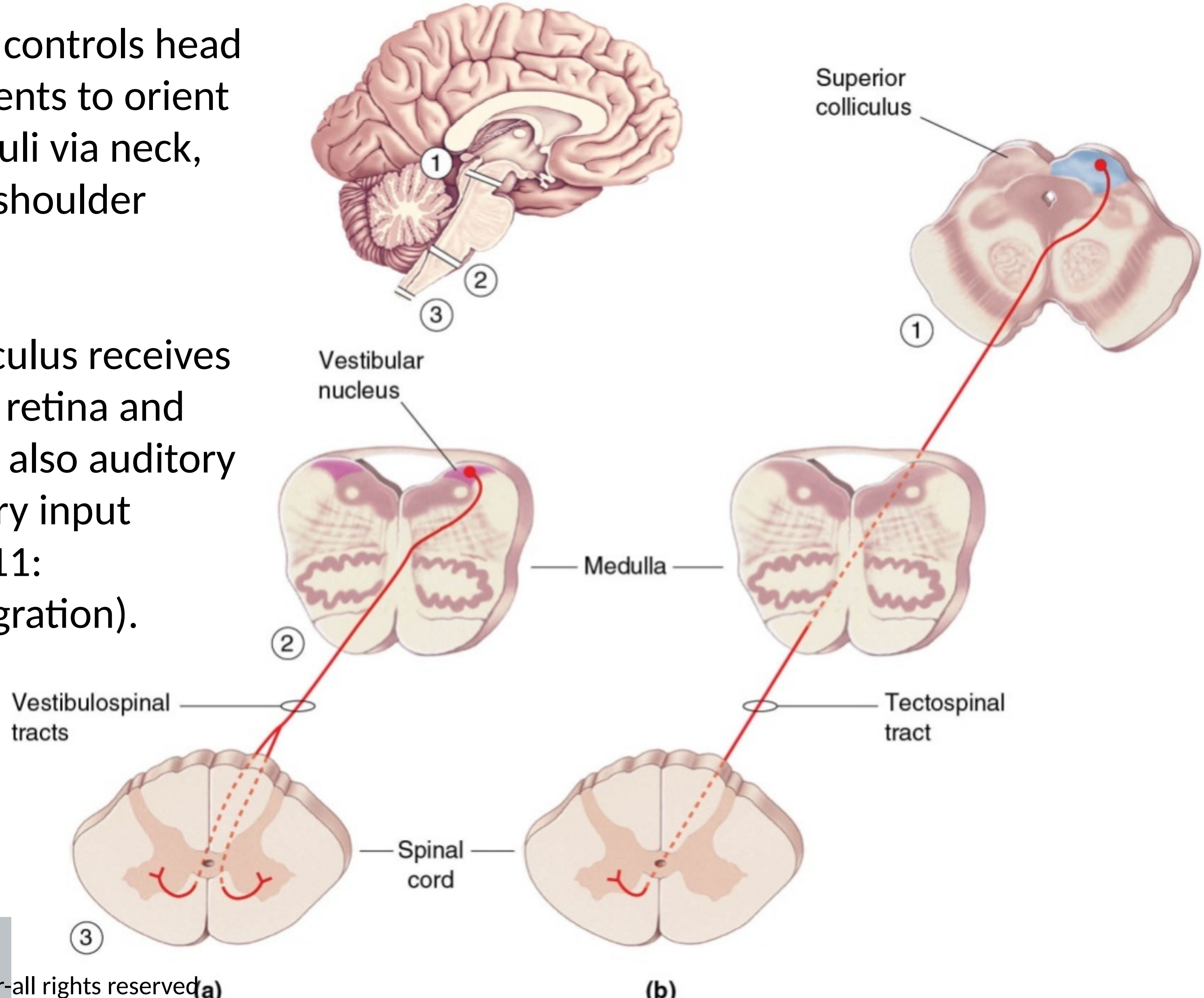
Ventromedial Pathways (2)

<u>Tectospinal tract:</u> controls head (and eye) movements to orient towards new stimuli via neck, upper trunk, and shoulder muscles.

The superior colliculus receives visual input (from retina and visual cortex), but also auditory and somatosensory input (remember class 11: multisensory integration).



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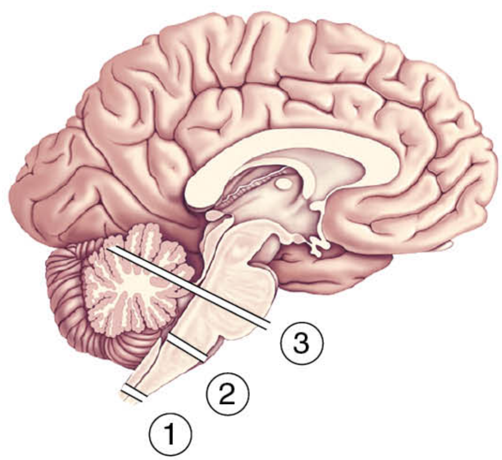
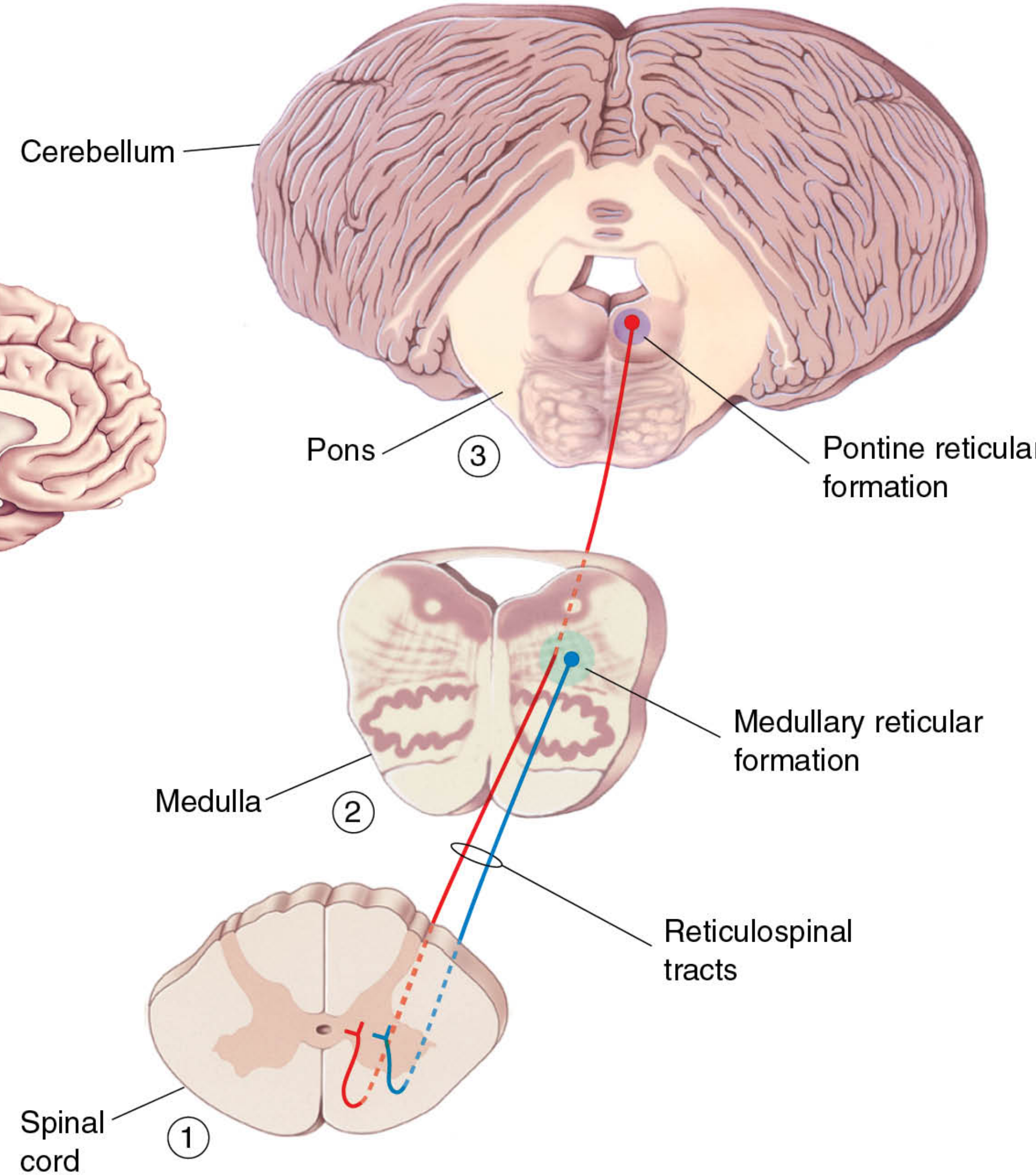
Ventromedial Pathways (3 and 4)

Pontine reticulospinal tract:
helps keeping a standing posture by enhancing the antigravity reflexes of the spinal cord.





Medullary reticulospinal tract:
frees the antigravity musculature (legs) from spinal cord control.

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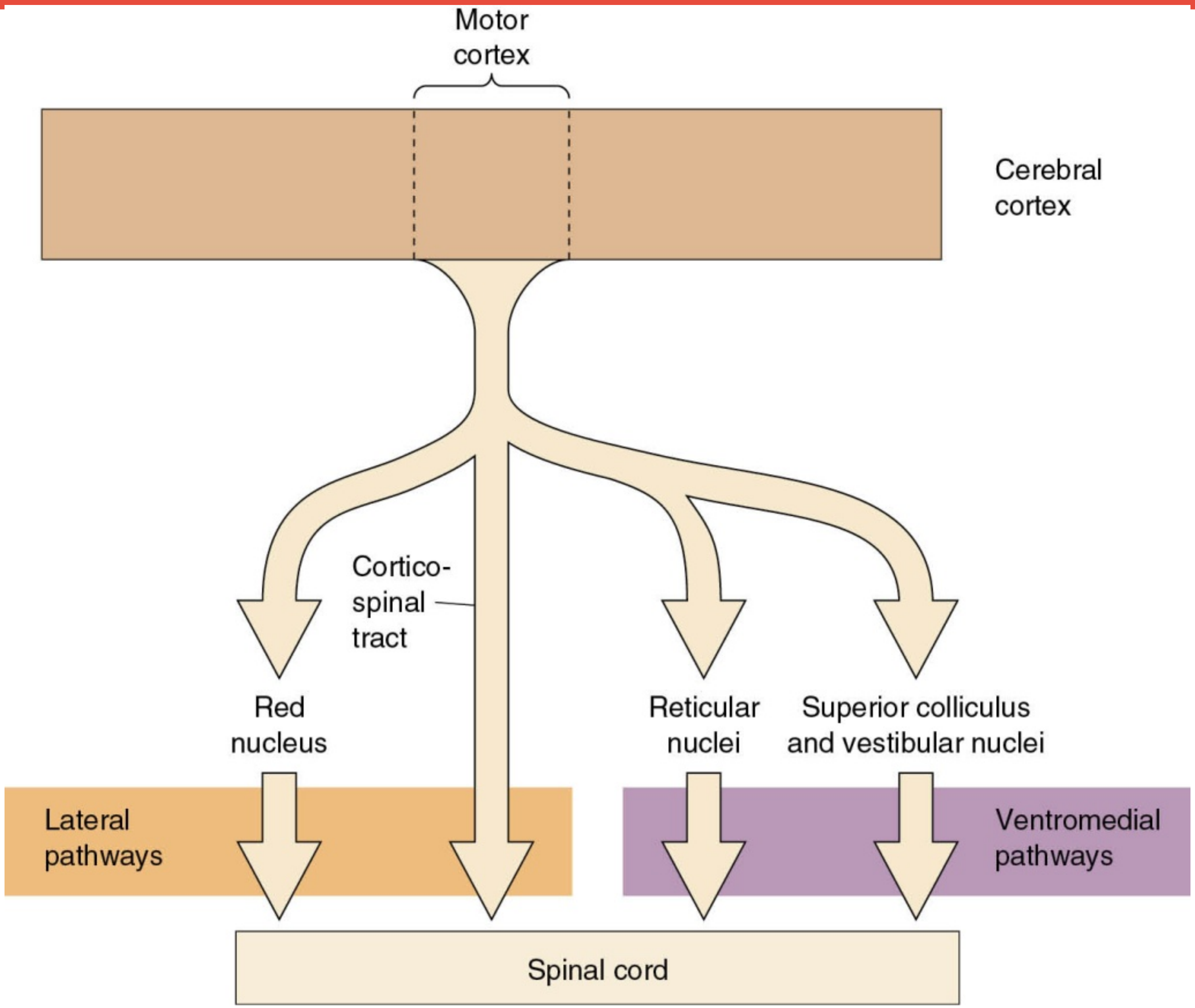
Pathways from Motor Cortex



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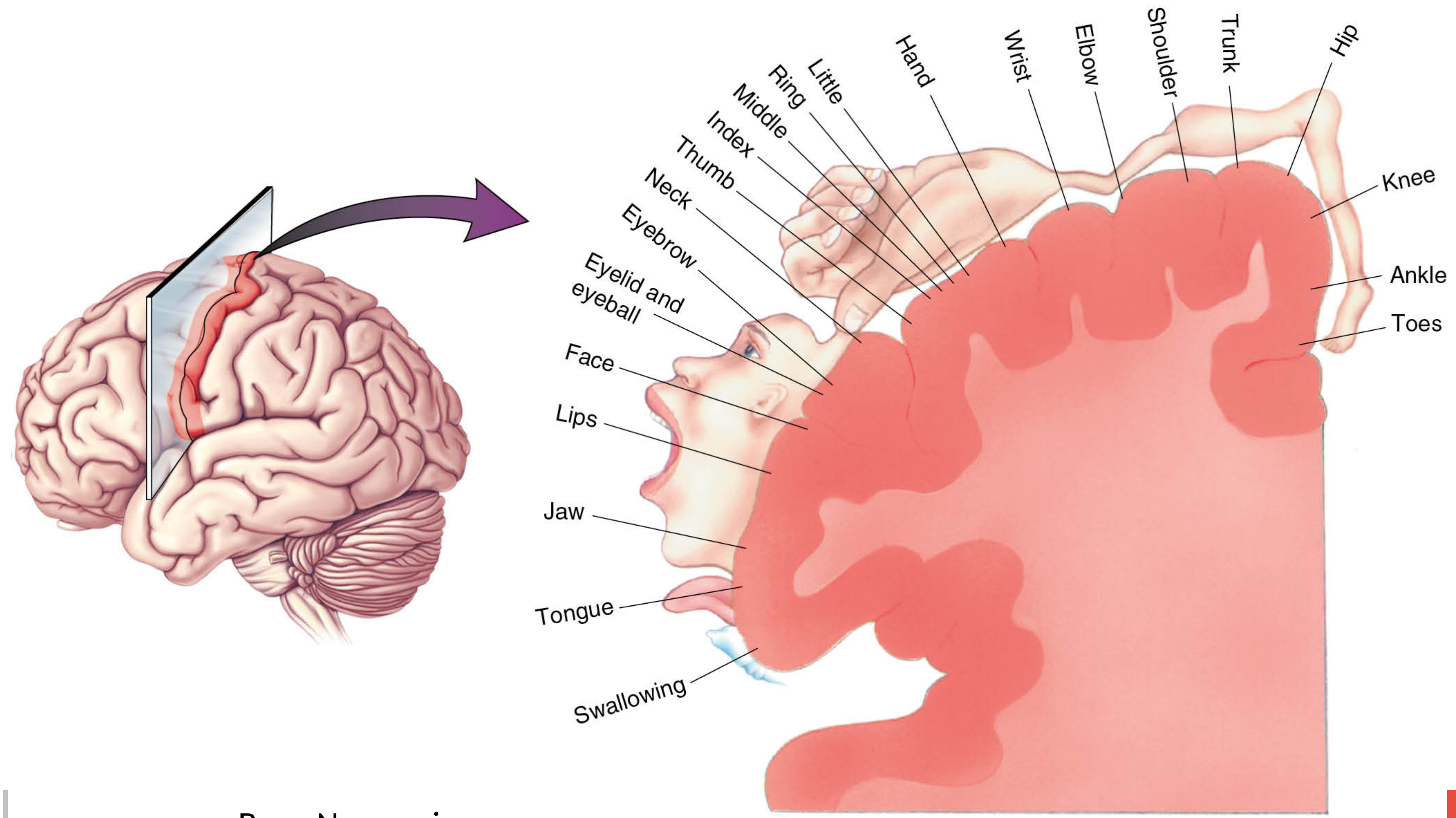
Motor Cortex: Organization

Primary motor cortex (M1) exhibits a somatotopic motor map: a map of the body



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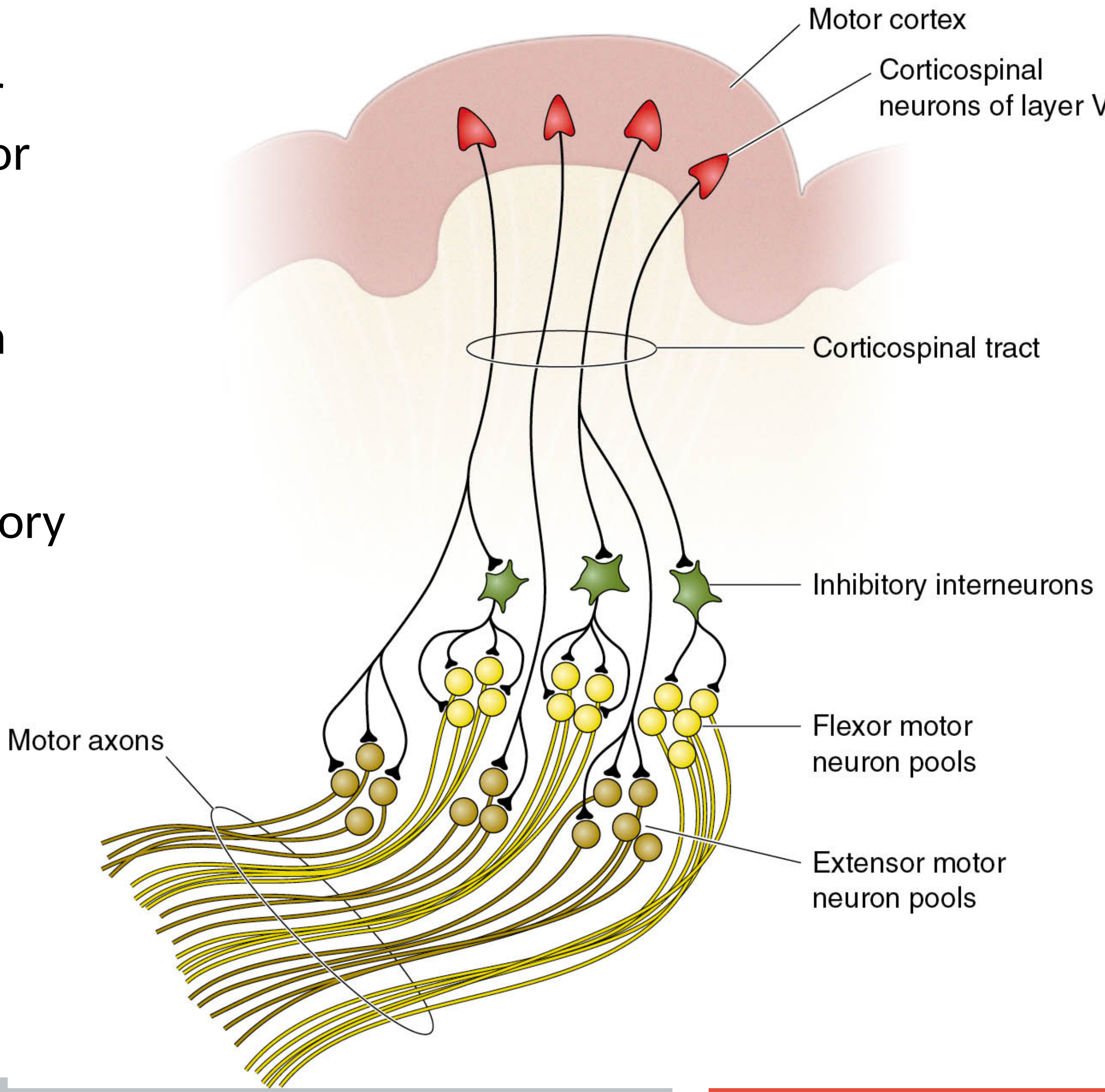
Motor Cortex → Spinal Cord

Upper motor neurons have their cell bodies in layer V of the motor cortex, project axons via the corticospinal tract and synapse with the lower motor neurons in the spinal cord.

Further connections with inhibitory interneurons help to inhibit the antagonistic muscle groups.



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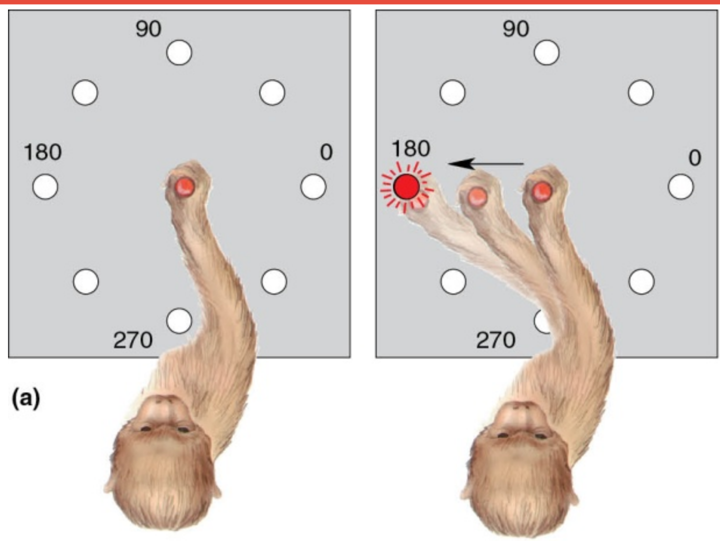
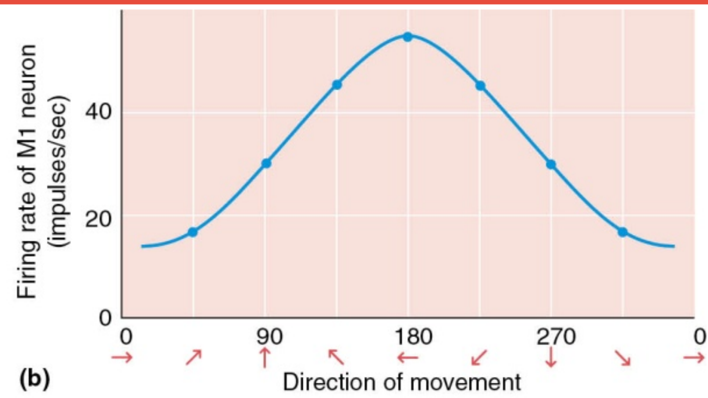
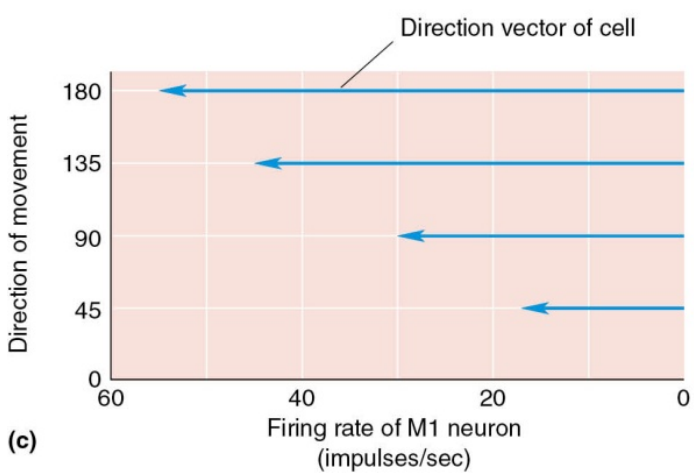
How do Motor Cortex Neurons encode a certain movement? “Population Coding”



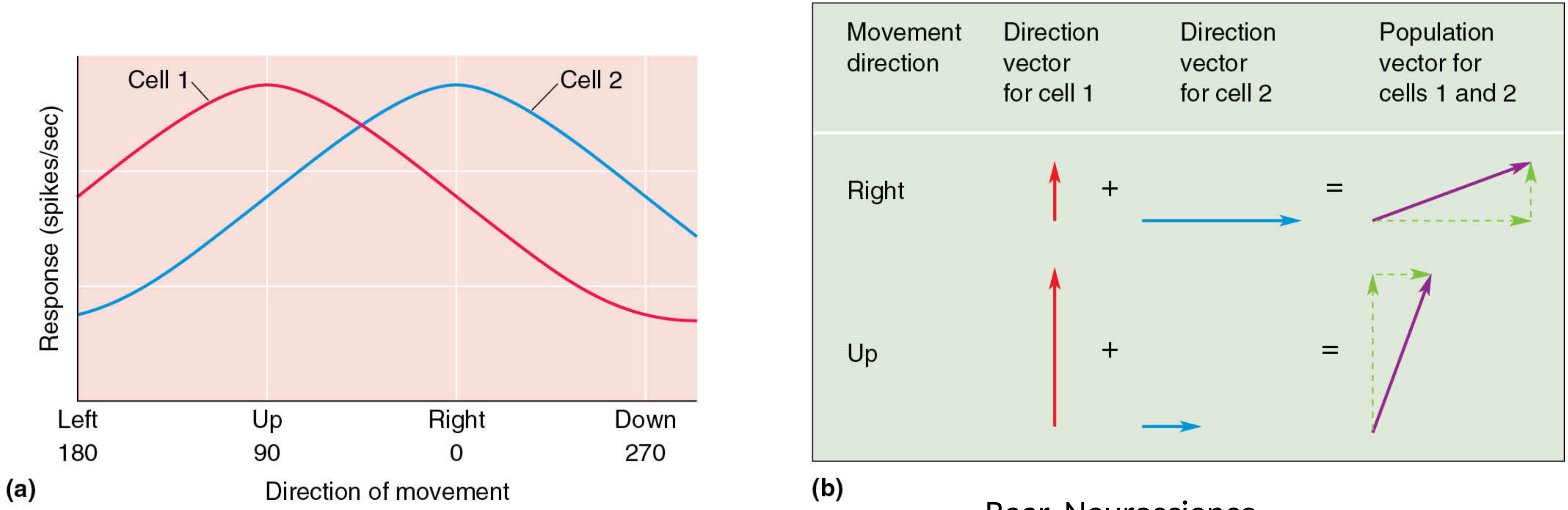




Single M1 cells fire immediately before and during a voluntary movement. A single M1 cell can lead to activity in several muscles moving a limb toward a goal (a).

The M1 cells are broadly ‘tuned’ to certain directions (b,c). They also have higher firing rate for stronger force. Thus, two aspects of movements are encoded: force and direction.

Population Coding in M1



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The tuning of M1 cells to movement direction is broad (a), but if the information from many cells is combined (b, vector sum or population vector), we get a fine-tuned prediction of the movement direction: population coding.

Population Coding in M1: Vector "tuning" of neurons

In the graph, the direction of single neurons shows their preferred motion direction (strongest response when a movement is performed in this direction).

The length of the vector shows their firing rate when motion is performed in the direction indicated by position on the 'clock' (0˚, 45˚, 90˚, 135˚, etc.).

The summed response vectors of many cells (population vector) predict limb movement well.

For example, if you compute the vector sum of the firing rate of neurons at the 12 o'clock position it predicts a 90˚ motion.

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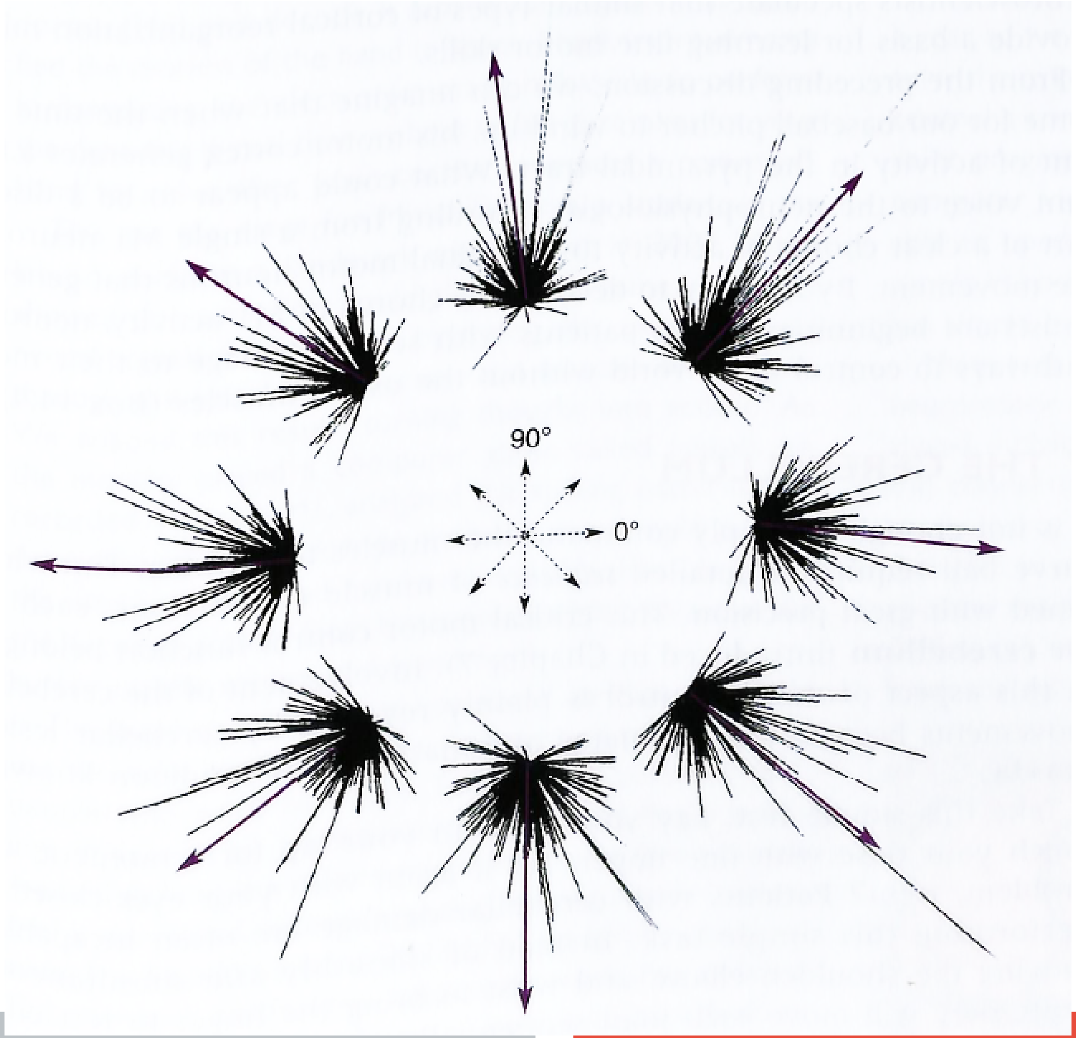
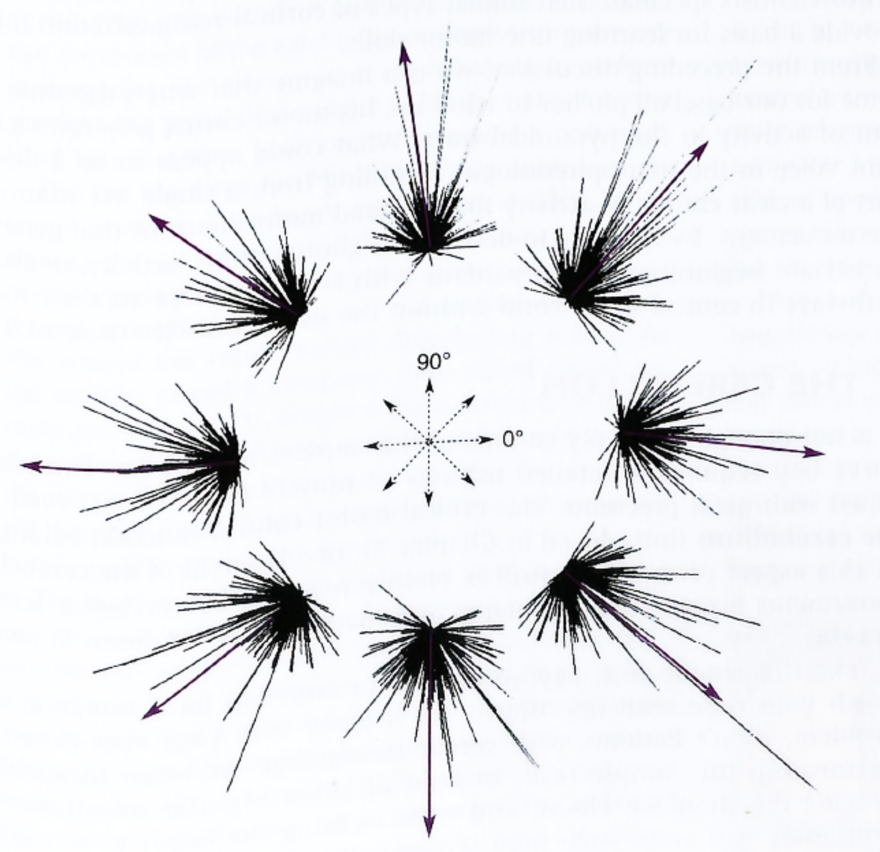
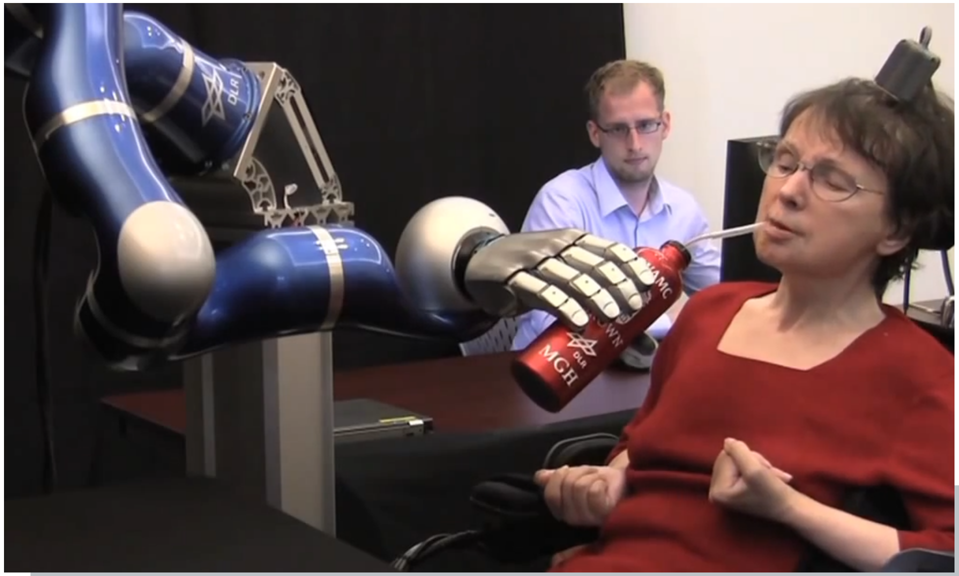


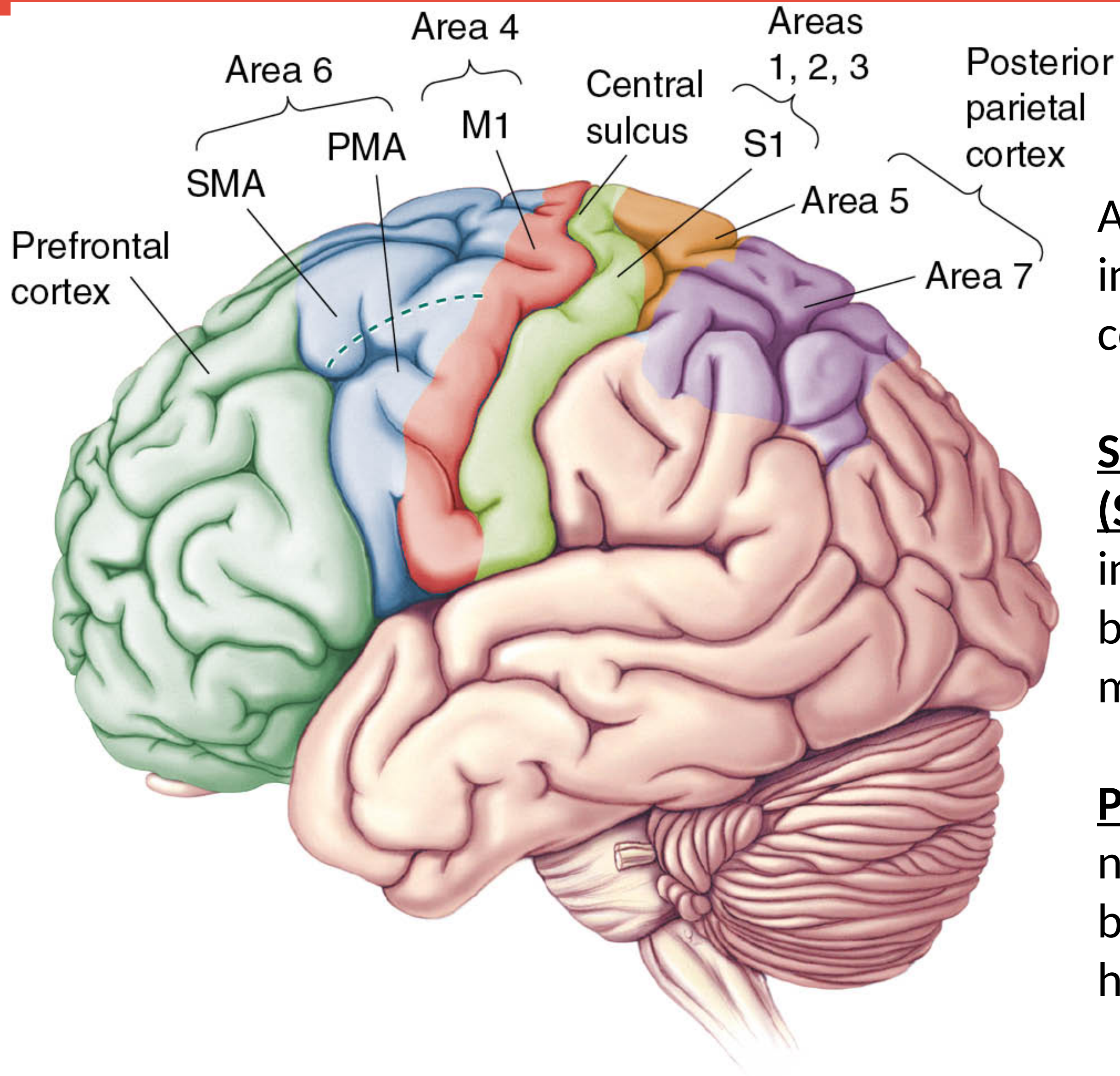
“Decoding” movement

The recordings of neural populations in motor cortex can be used for a brain-machine-interface: the population vector of an intended movement controls a robot arm (from Nature video).





Cortical areas for motor planning



Area 6 contains two areas involved in the planning of complex movements:

Supplementary motor area (SMA): e.g., cells in this area increase firing about 1s before a hand/wrist movement.

Premotor Area (PMA): e.g., neurons here are active before a specific movement has to be performed.

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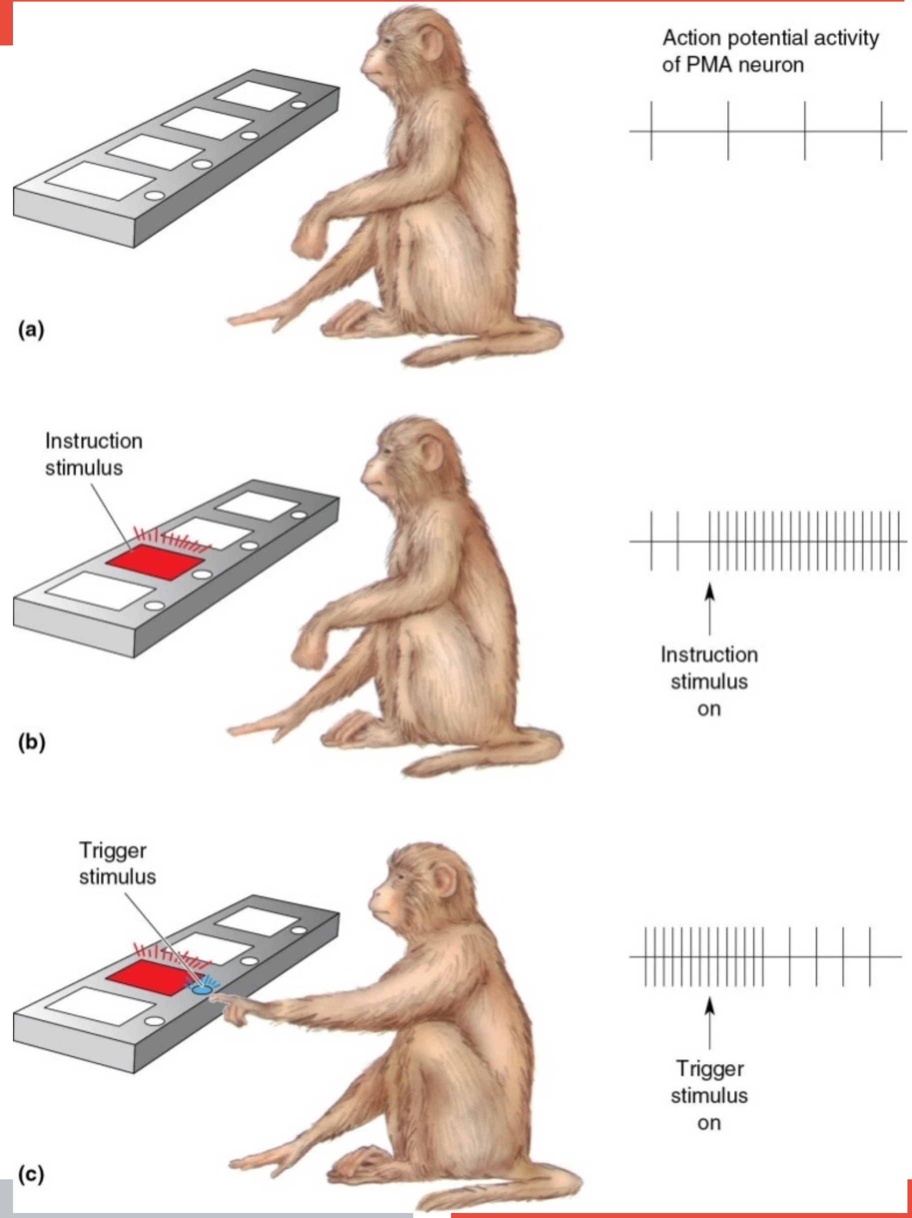
Pre-motor area (PMA)

a) In this experiment, a monkey waits for a cue that tells him what movement to perform.

b) Now, the light tells him to push a specific button, but not before the trigger stimulus is on. A PMA neuron increases its firing rate.

c) Now, the trigger tells the monkey to perform the movement. The PMA neuron fires until after initiation of the movement.



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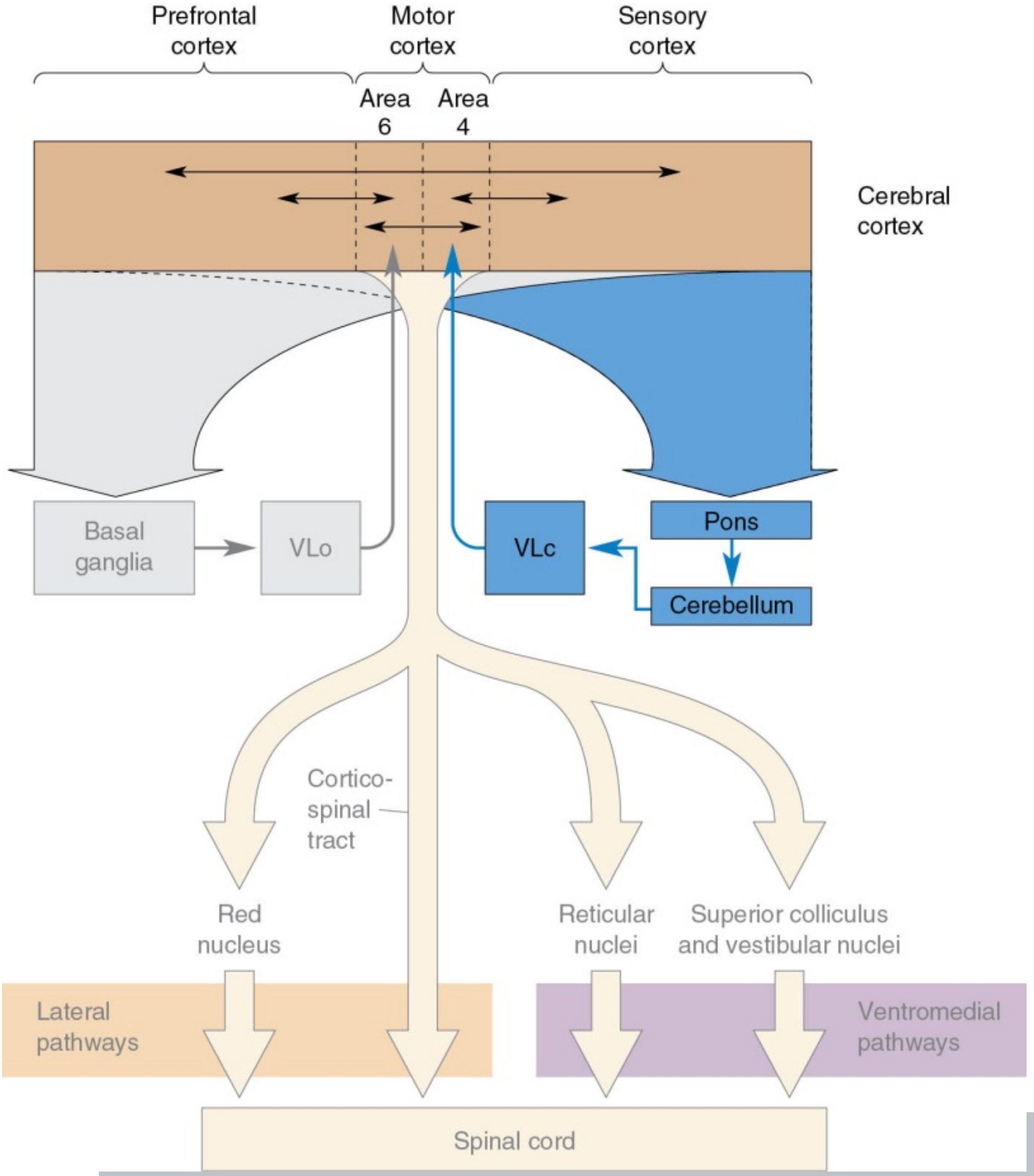
Cerebellum



Cerebellar lesions lead to uncoordinated and inaccurate movements, ataxia.

Other symptoms are an inability to stand or walk, diminished resistance to passive limb movements, and intention tremor (oscillation around the end point of a movement).

The cerebellum also has an important role in controlling precise sequences of muscle contractions and in learning these sequences.

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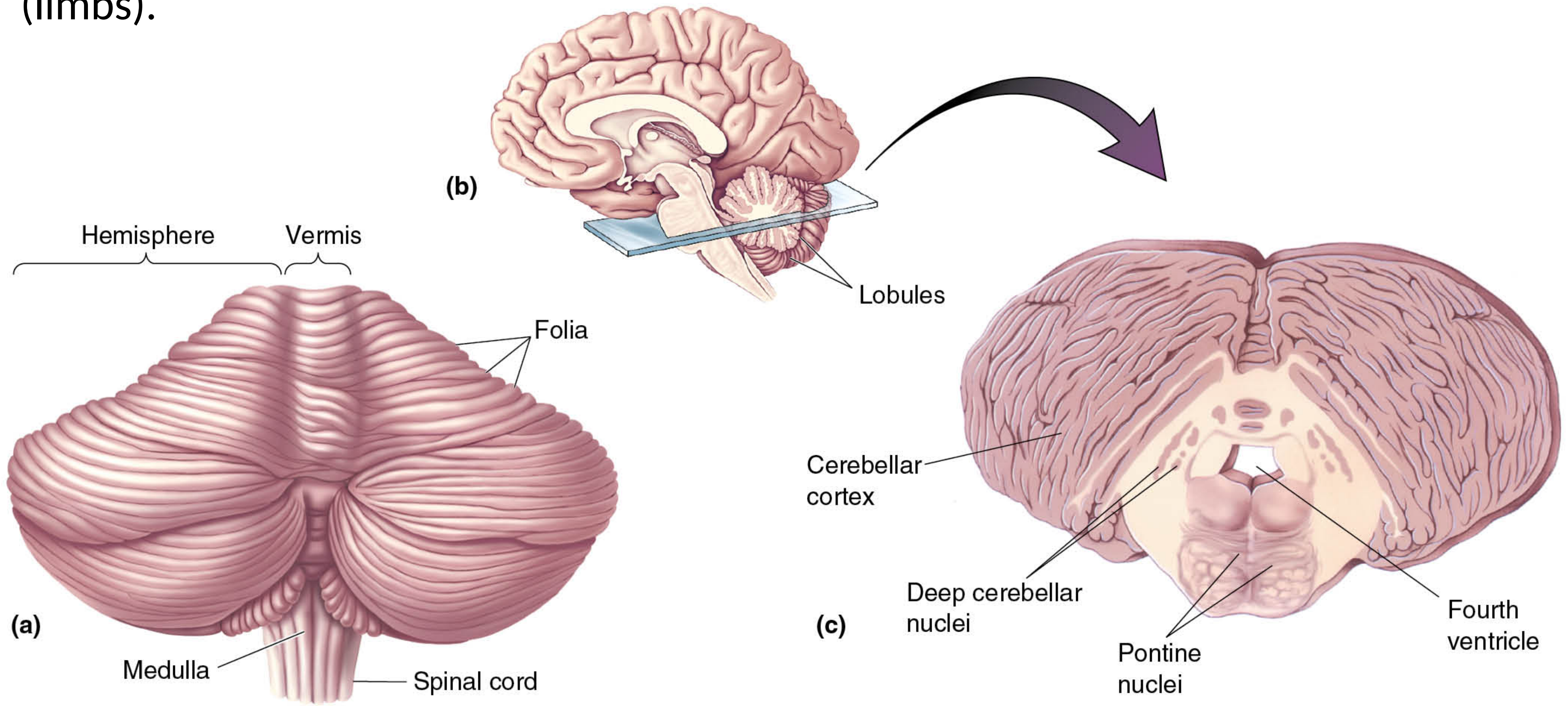
Cerebellum

Neurons in the cerebellum are densely packed: it constitutes only 10% of the volume, but 50% of all neurons in the brain.
The vermis sends output to structures of the ventromedial motor pathway (axial musculature), the hemispheres to structures that contribute to the lateral pathway (limbs).



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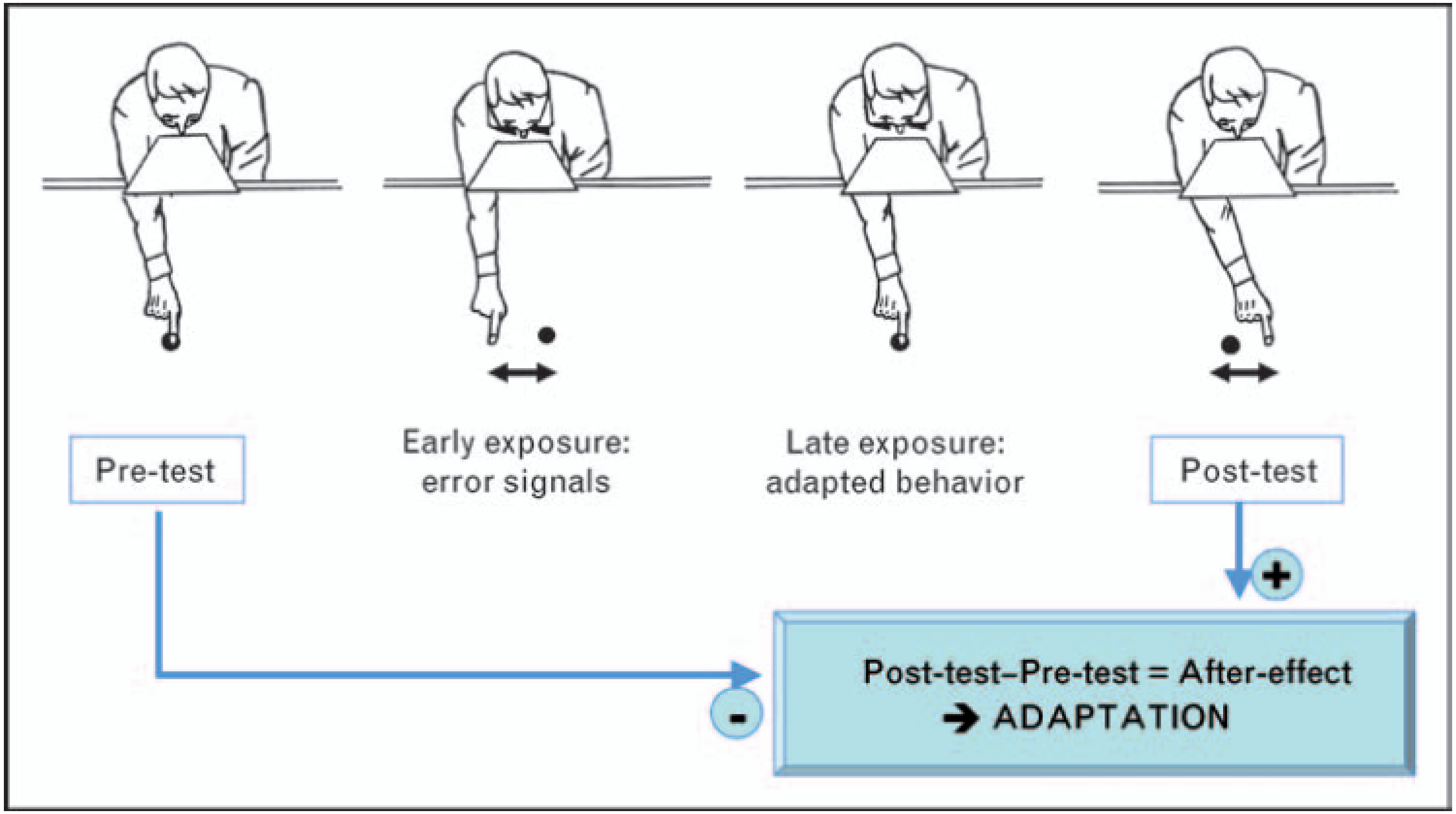
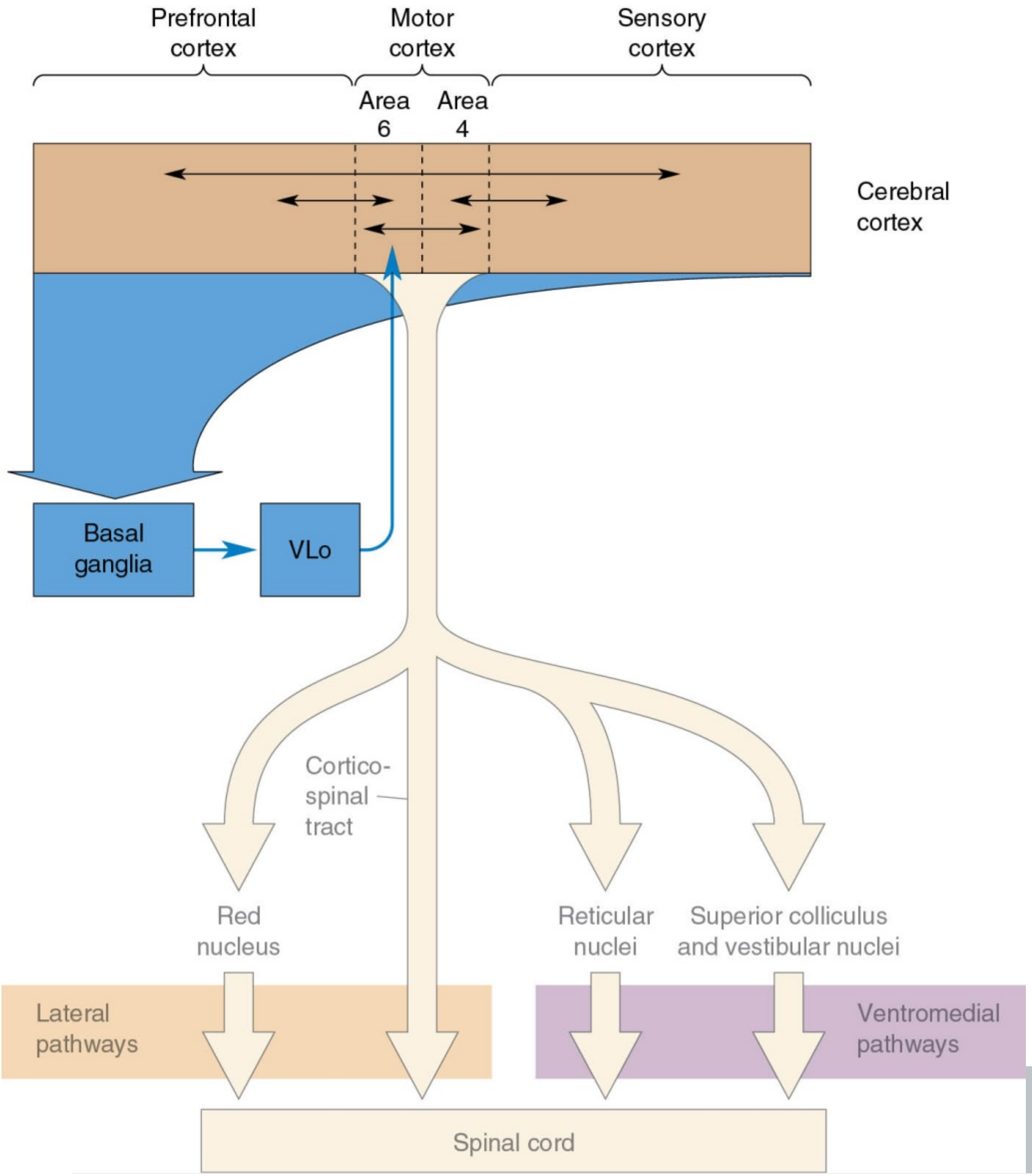
Prism adaptation

A prism goggle shifts vision (here by 10˚) horizontally to the right: first, eye-hand coordination is difficult, but improves after practice –> prism adaptation.

Lesion studies suggest involvement of the cerebellum and partially the posterior parietal cortex in prism adaptation.



Basal Ganglia



The basal ganglia loop is important for movement selection and initiation:

Cortex->
Basal ganglia->
VLo (Thalamus)–>
Cortex (SMA)

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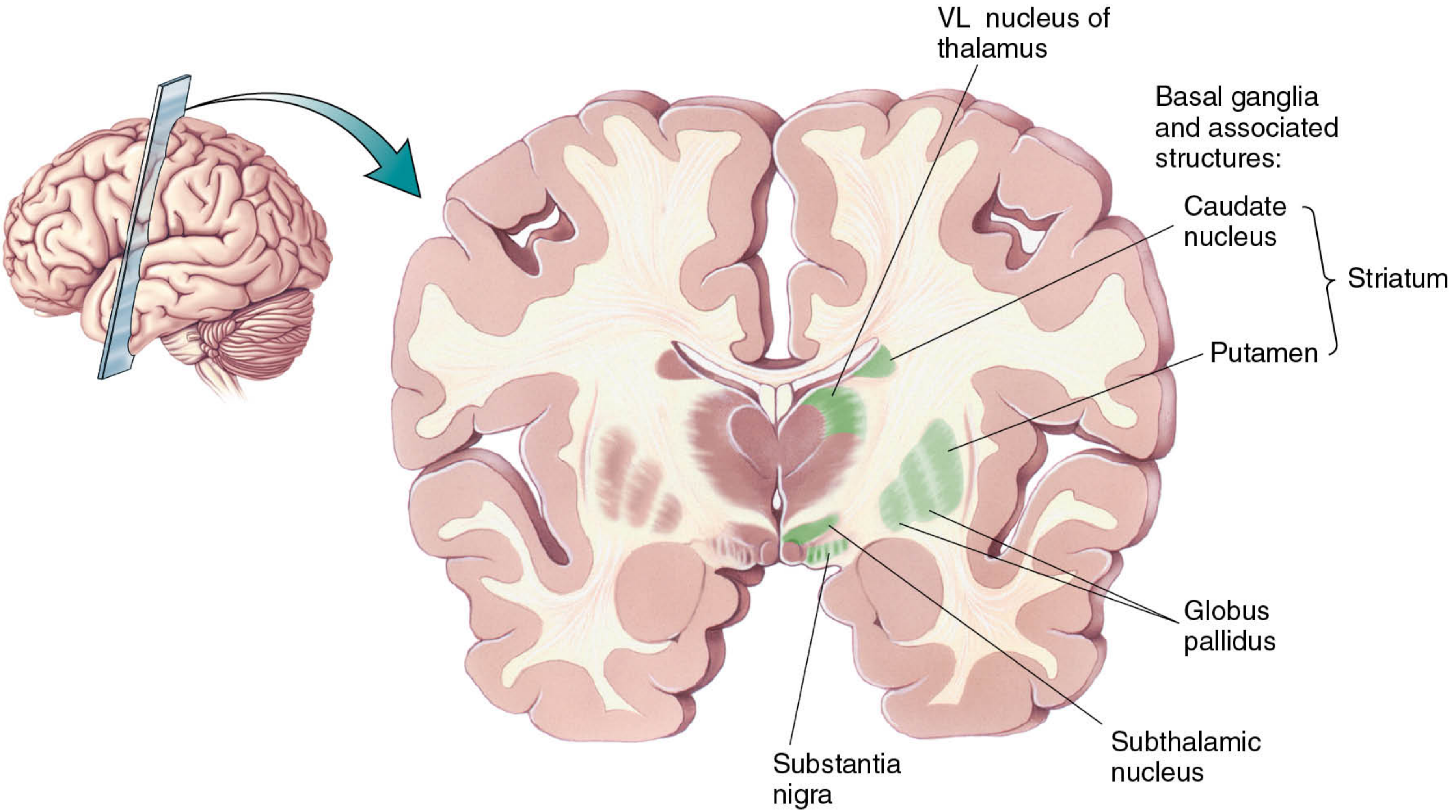
Basal Ganglia



VL nucleus: ventrolateral nucleus

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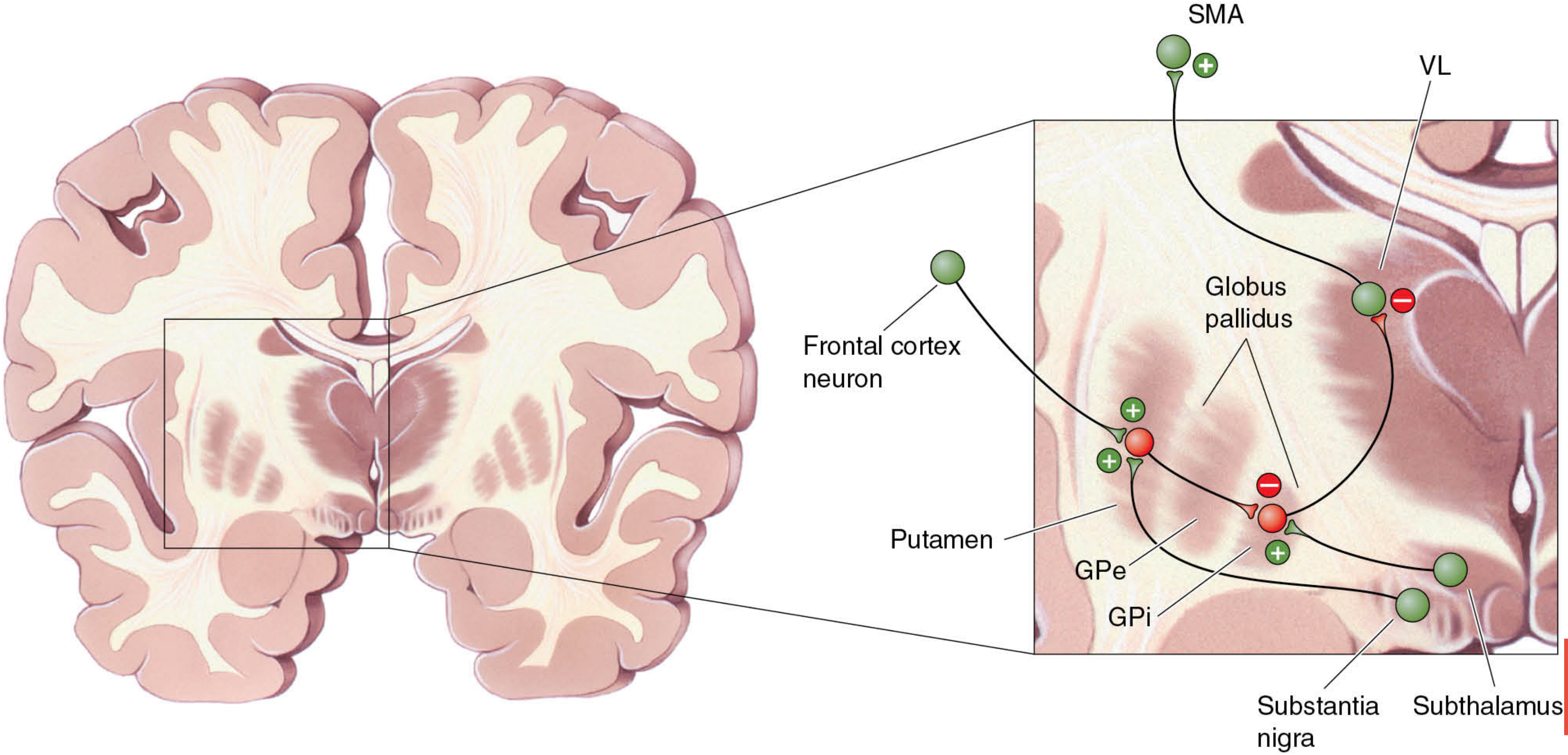
Basal Ganglia: “Direct” pathway

<u>Direct pathway</u>:
Cortex excites -> Putamen inhibits -> Globus Pallidus (internal segment: GPi) inhibits -> VL excites –> Cortex (SMA): movement-related activity in SMA is **facilitated**.

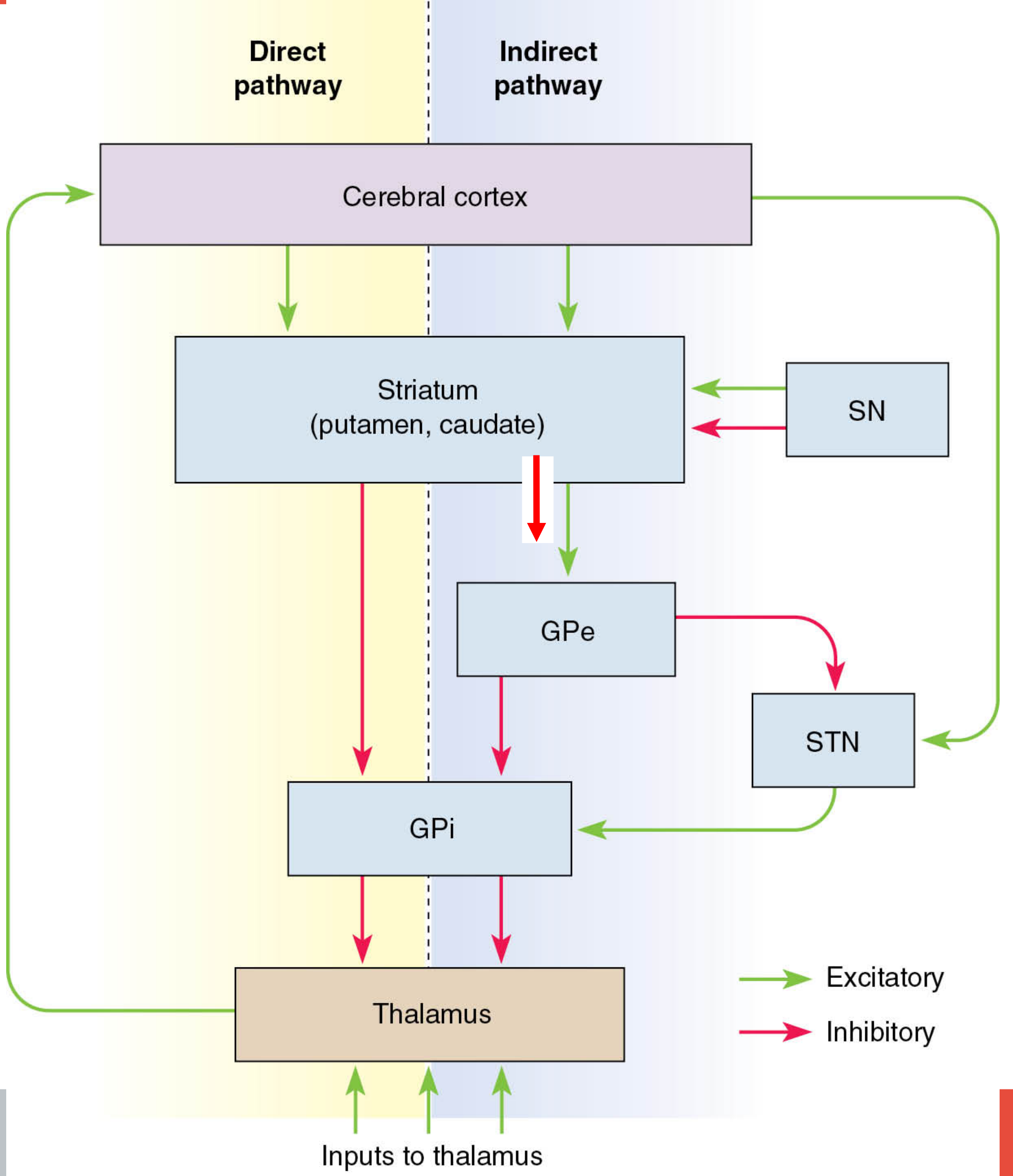
In sum: Cortex excites SMA via basal ganglia and thalamus (VL)



Basal Ganglia: "Indirect" pathway

The indirect pathway helps to **inhibit** the thalamus and thus movement-related activity in cortex (SMA).

Thus, the direct pathway helps to select motor actions, while the indirect pathway suppresses other motor programs.



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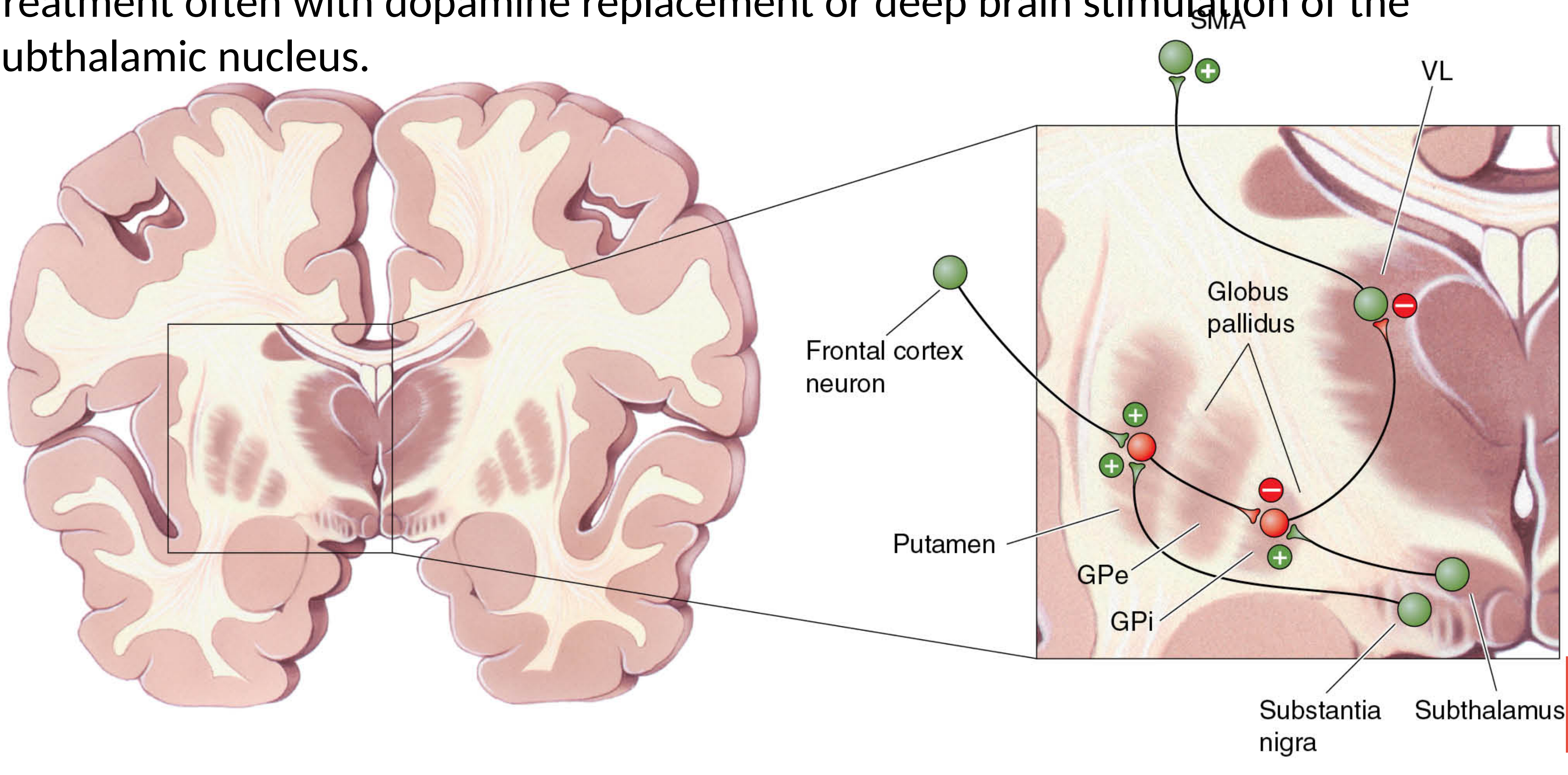
Basal Ganglia: Parkinson’s Disease

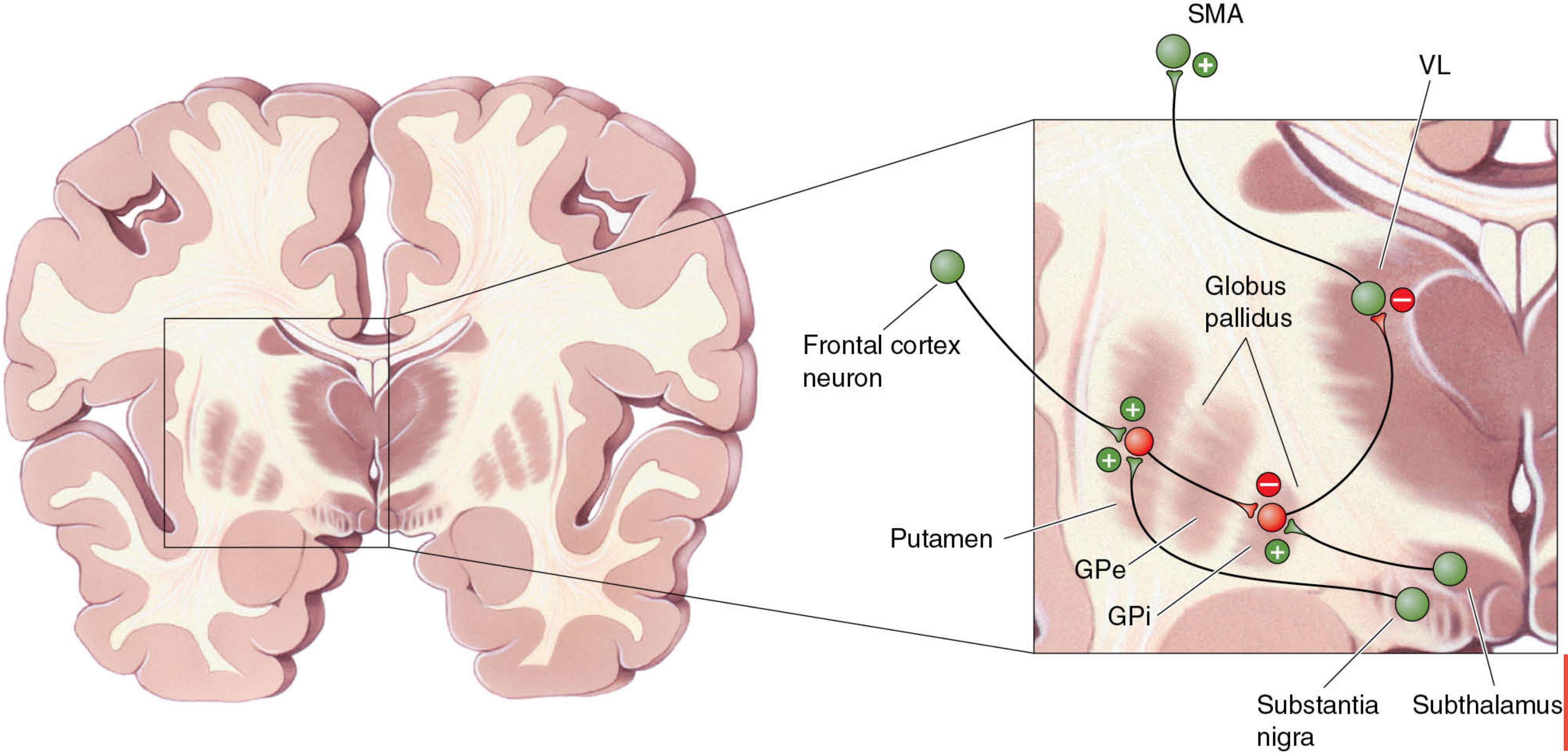
Parkinson’s disease degenerates substantia nigra dopaminergic neurons -> Globus pallidus is not inhibited by putamen -> Globus pallidus inhibits VL

Symptoms: slow movement (bradykinesia), inability to initiate movement (akinesia), increased muscle tone and tremors (hand/jaw).
Treatment often with dopamine replacement or deep brain stimulation of the subthalamic nucleus.



Basal Ganglia: Huntington's Disease

Huntington's disease: hereditary disease that results in hyperkinesia (excessive movement) and dyskinesia (abnormal movements), dementia, and personality changes.
It is accompanied by neuron loss in caudate nucleus, putamen, and Globus pallidus (and cortex), affecting mostly the indirect pathway.



Summary: Movement Planning

- There are several motor pathways with different roles: lateral motor pathways are important for limb movements, ventromedial pathways for control of the axial musculature.

- Motor cortex consists of several cortical regions: M1: primary motor cortex, SMA: supplementary motor area, PMA: premotor area.

- Additional loops contribute to selection and initiation of movements (basal ganglia); and the precise and well-timed sequencing of movements, as well as motor learning and movement adjustments (cerebellum).