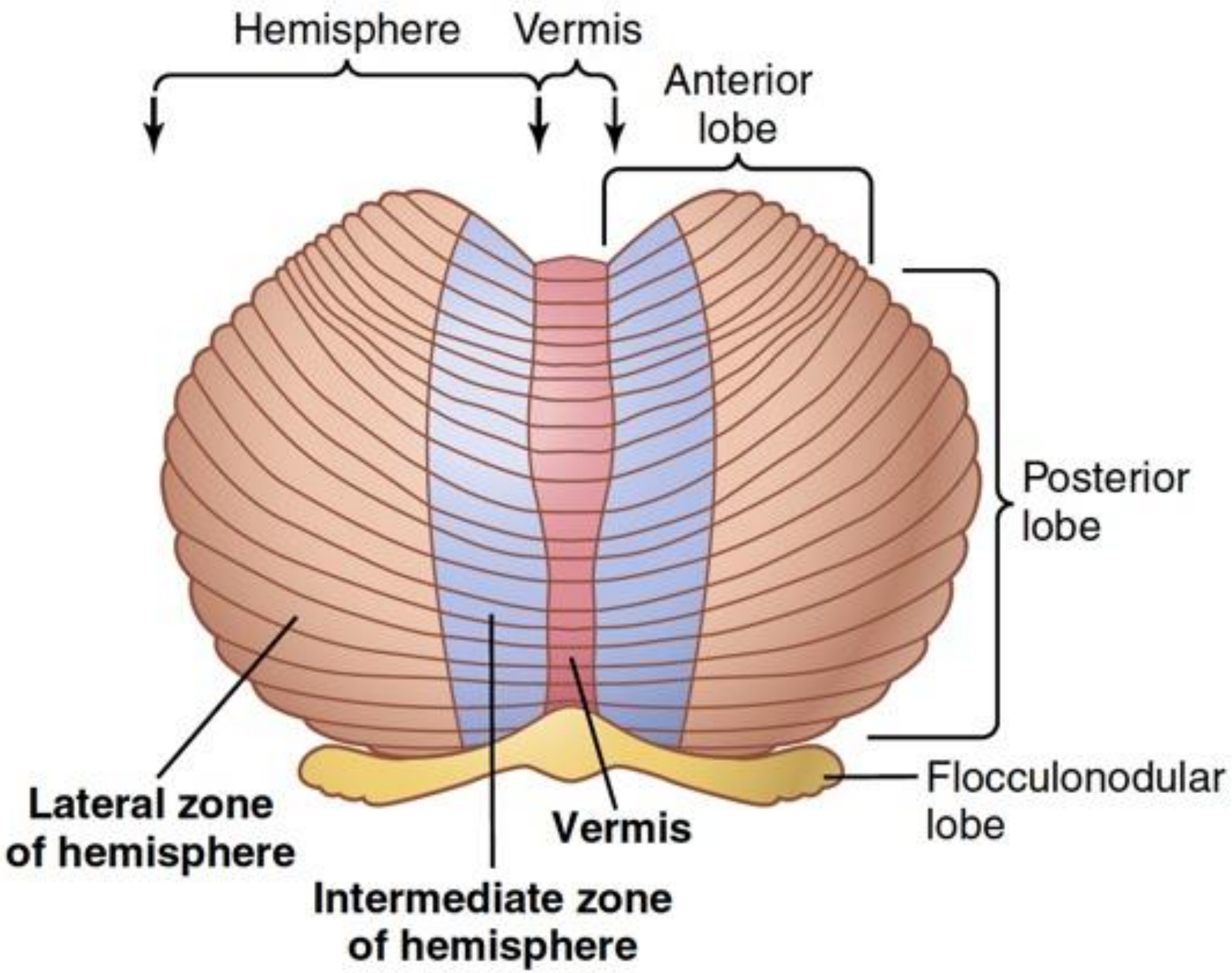
Neurophysiology

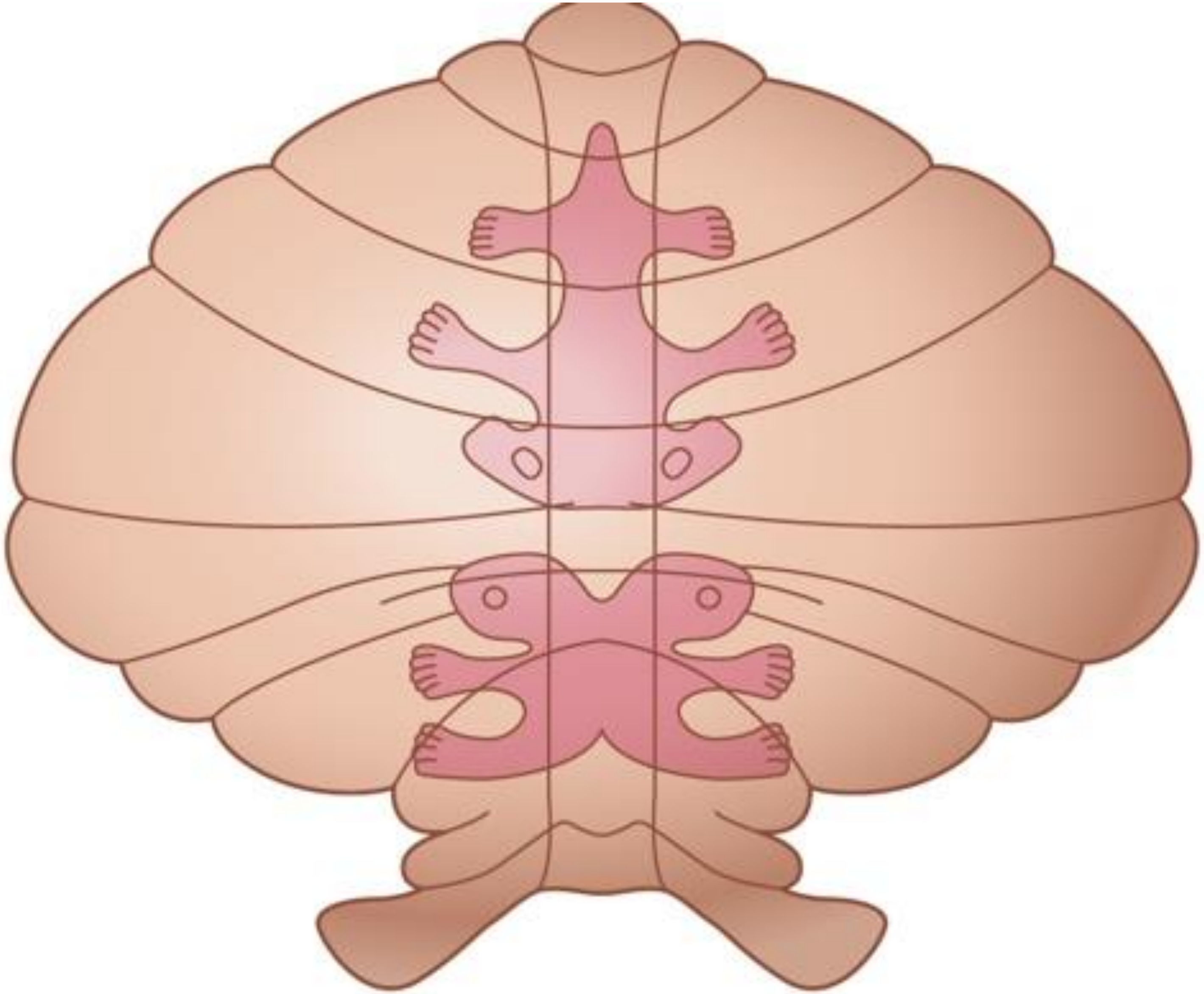
Cerebellum

Fatima Ryalat, MD, PhD

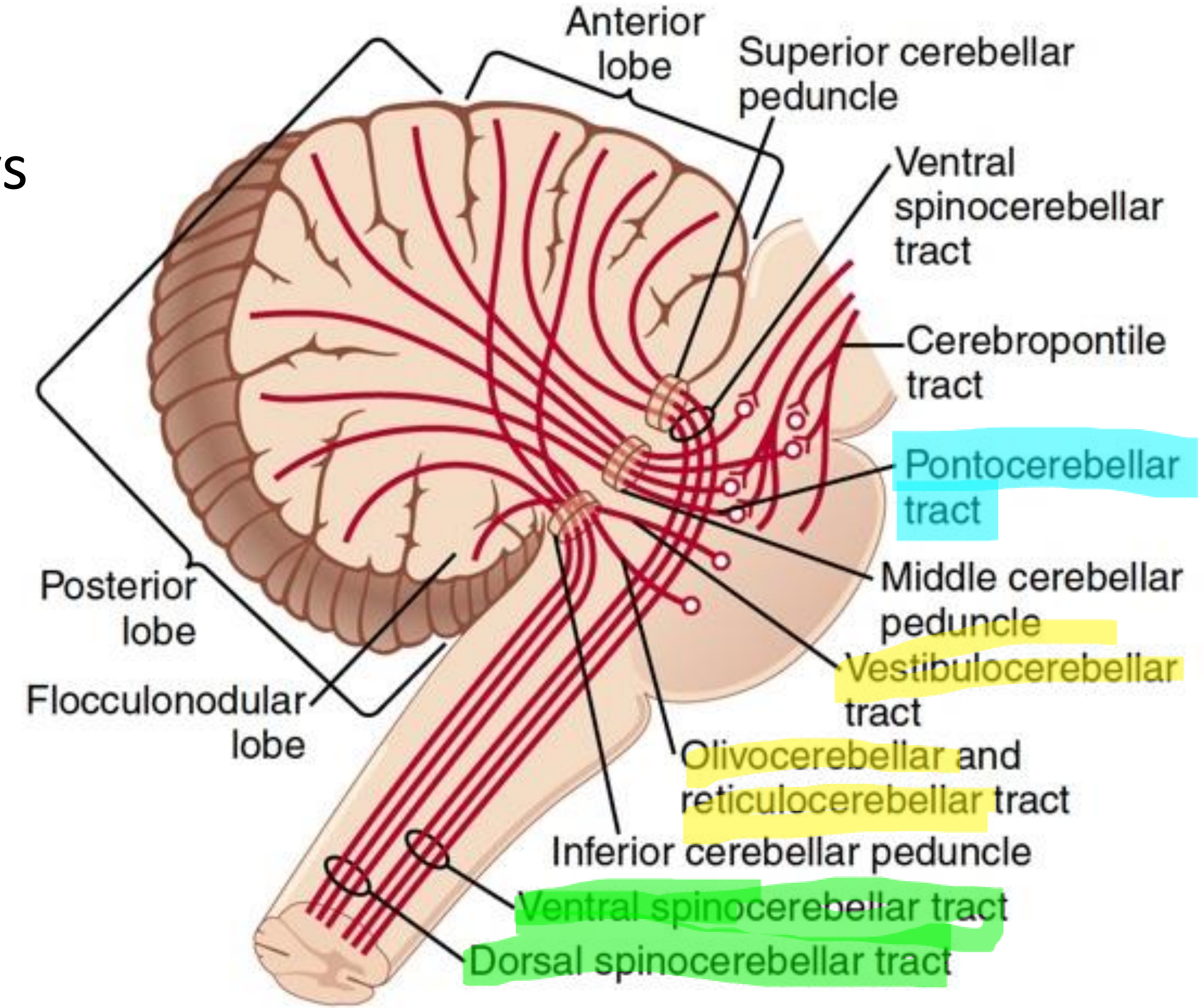
Assistant Professor, Department of Physiology and Biochemistry
School of Medicine, University of Jordan

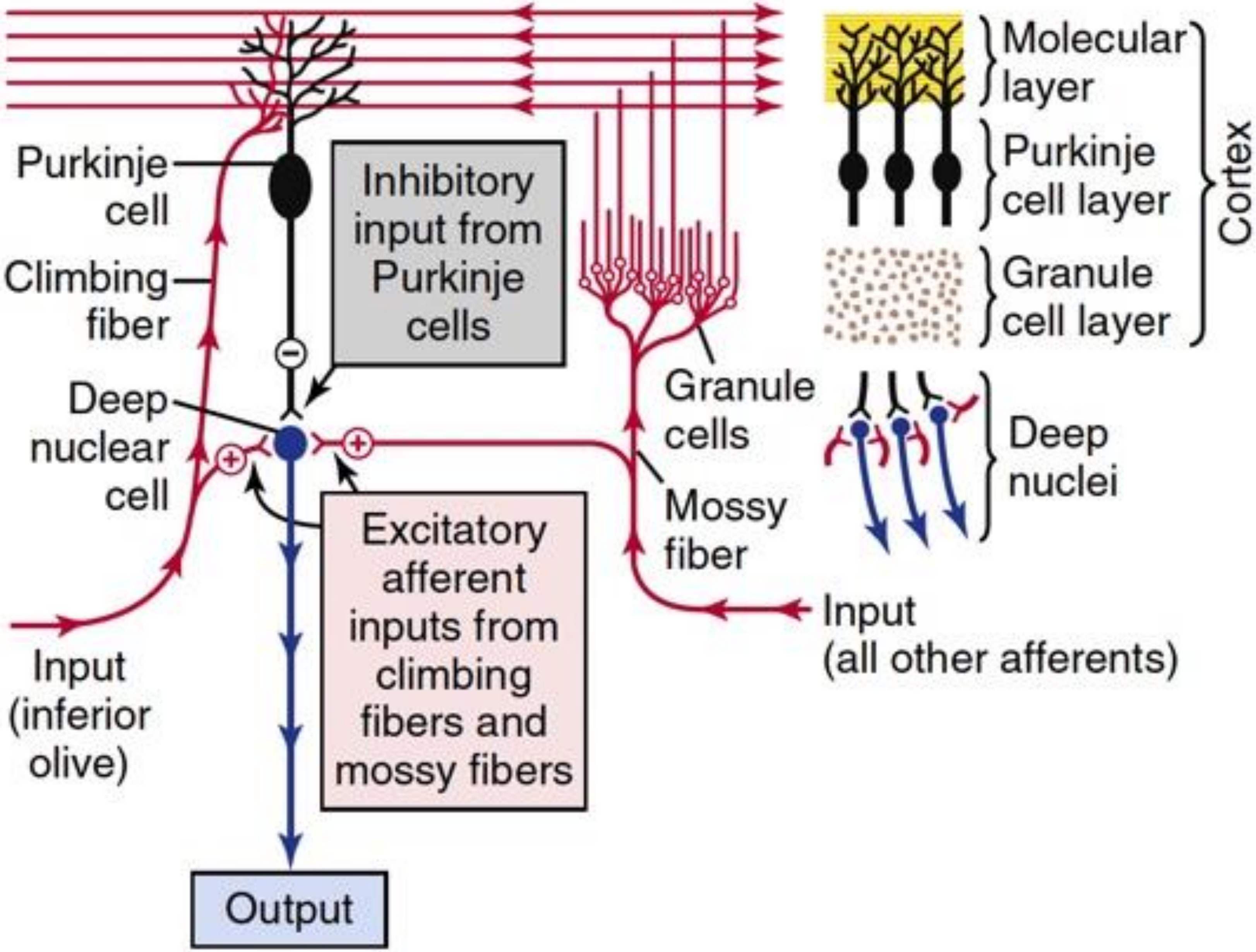


Hemisphere
Vermis
Anterior lobe
Posterior lobe
Flocculonodular lobe
Lateral zone of hemisphere
Vermis
Intermediate zone of hemisphere

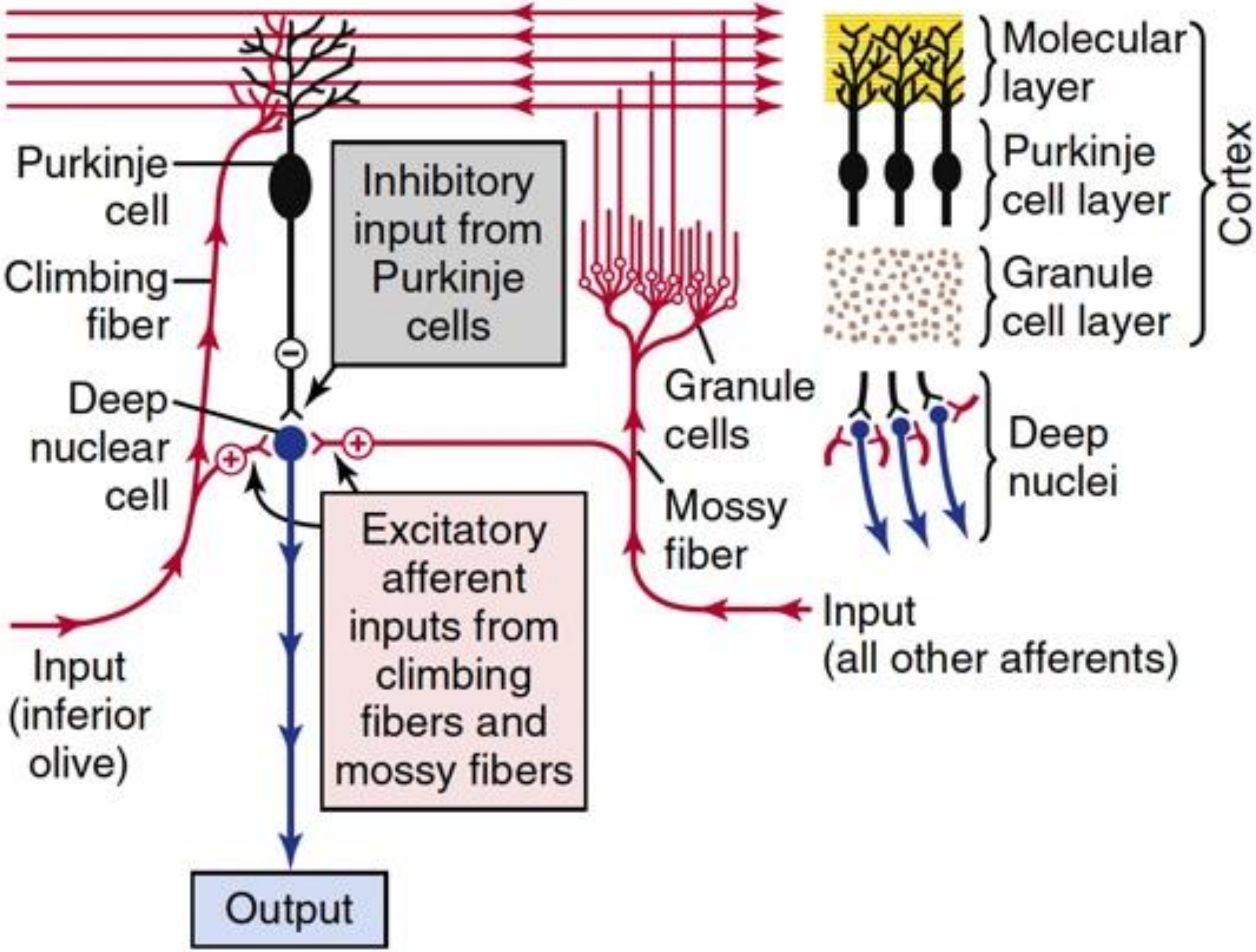


Input pathways



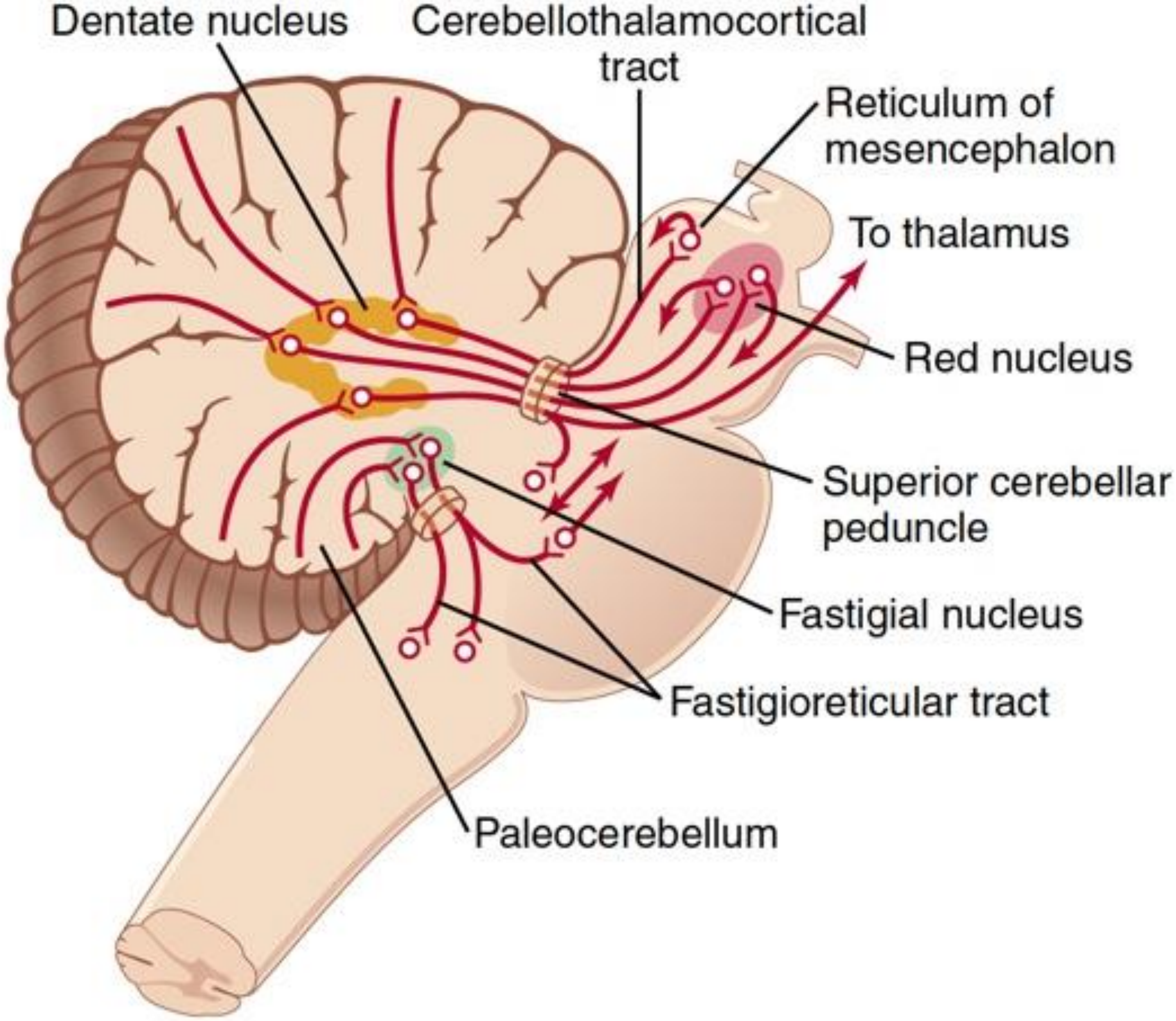


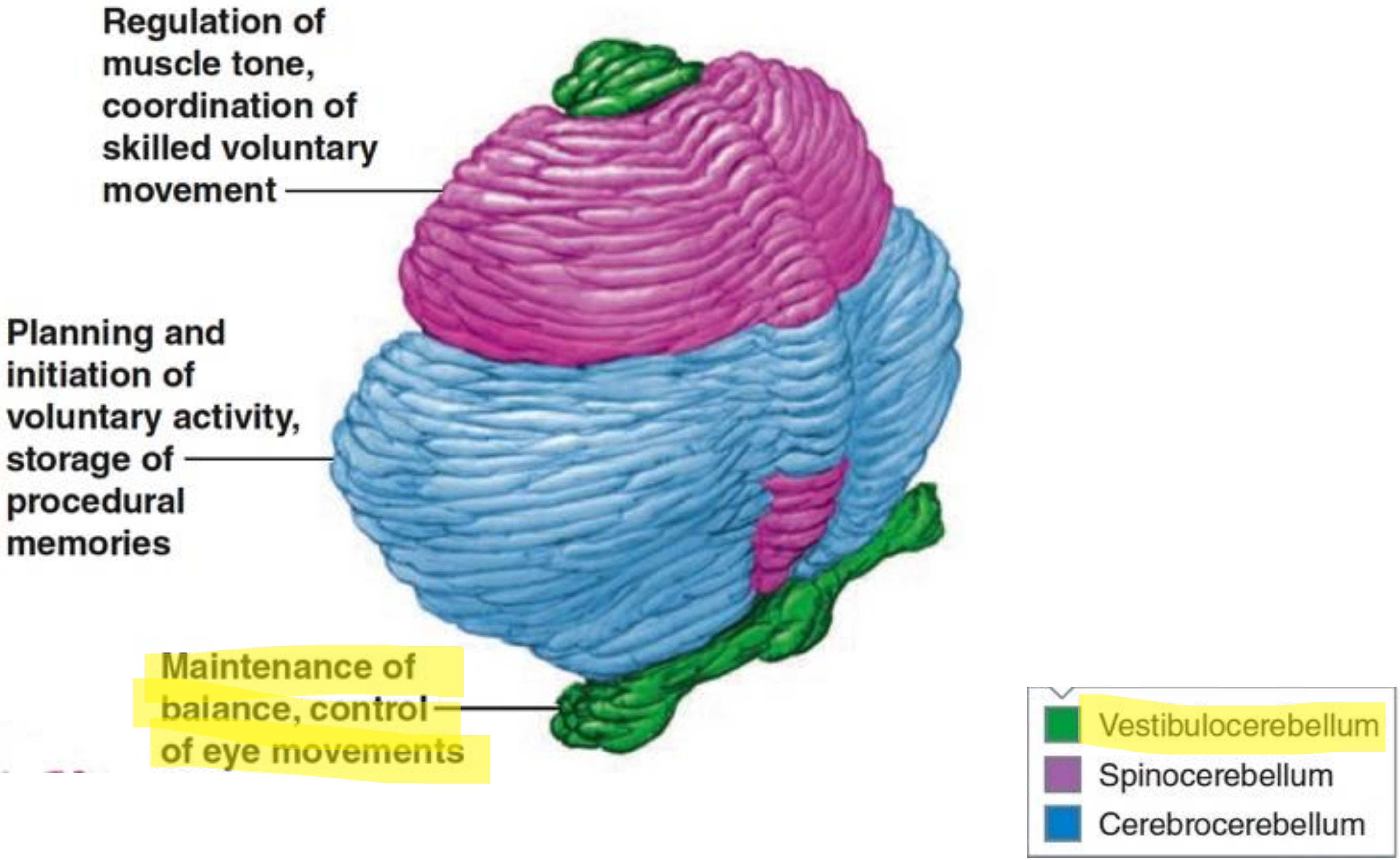
Purkinje cell
Climbing fiber
Deep nuclear cell
Inhibitory input from Purkinje cells
Excitatory afferent inputs from climbing fibers and mossy fibers
Granule cells
Mossy fiber
Input (inferior olive)
Input (all other afferents)
Output
Molecular layer
Purkinje cell layer
Granule cell layer
Cortex
Deep nuclei

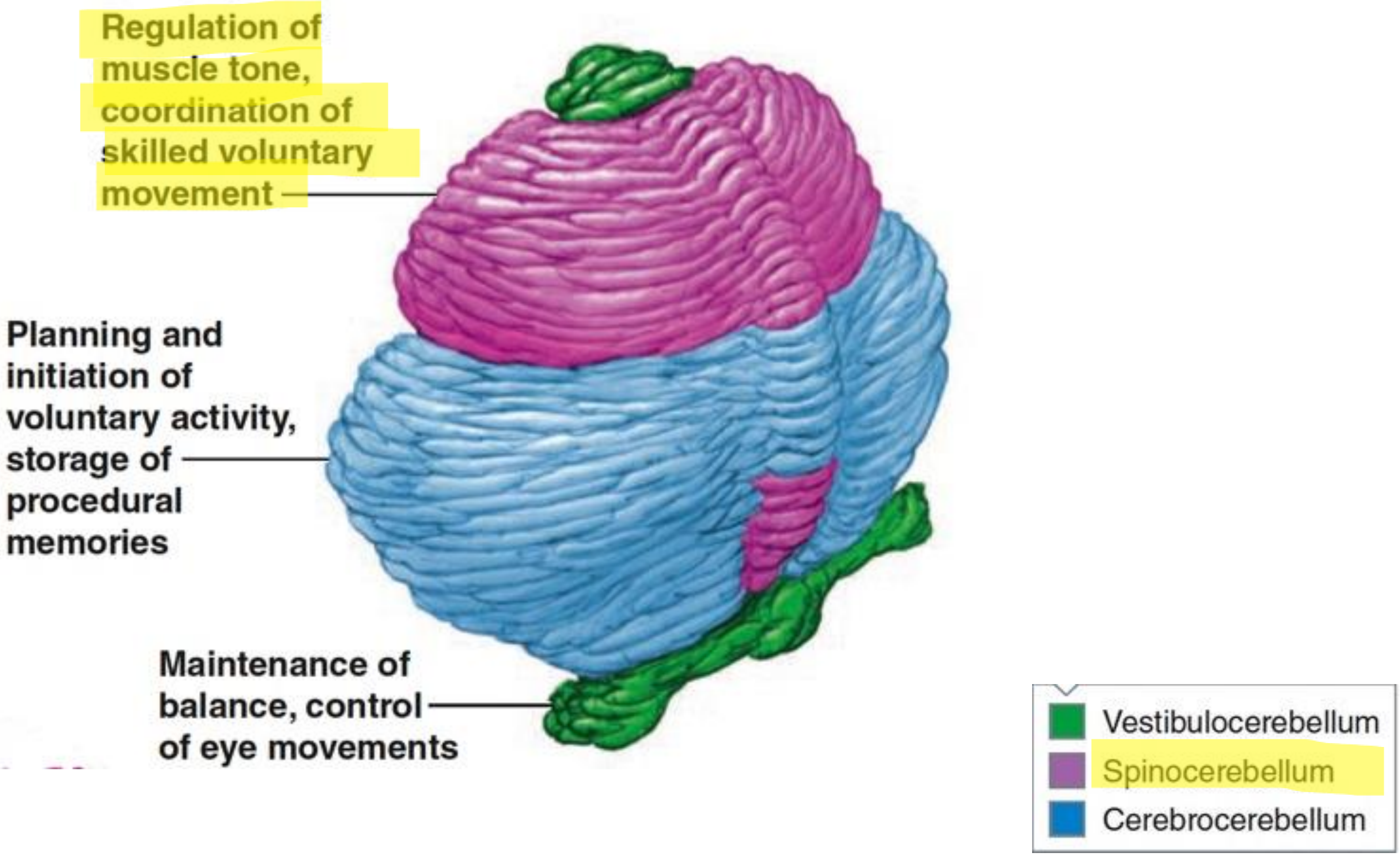


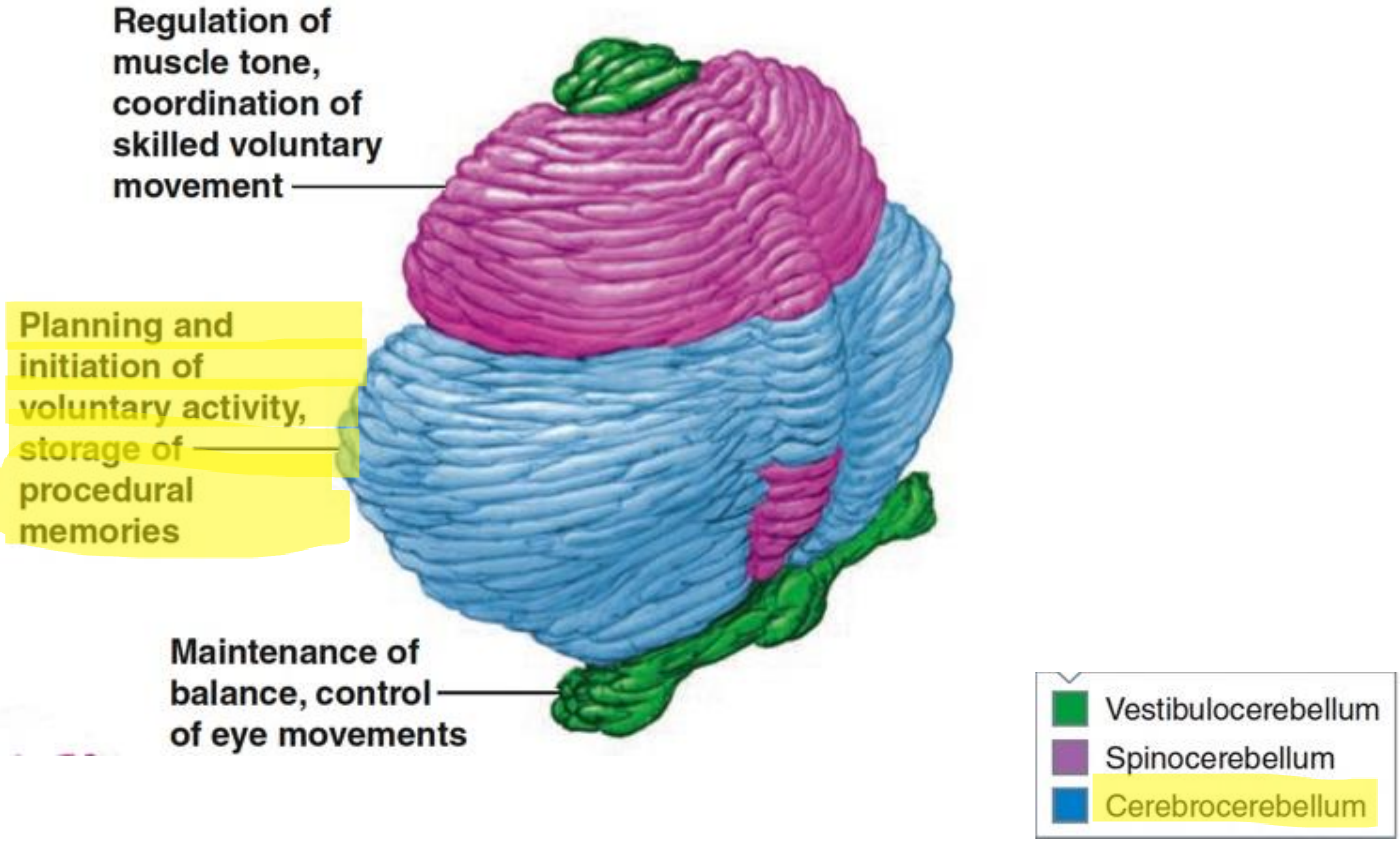
Purkinje cell
Climbing fiber
Deep nuclear cell
Input (inferior olive)
Inhibitory input from Purkinje cells
Excitatory afferent inputs from climbing fibers and mossy fibers
Output
Granule cells
Mossy fiber
Input (all other afferents)
Molecular layer
Purkinje cell layer
Granule cell layer
Cortex
Deep nuclei

Output pathways




Regulation of muscle tone, coordination of skilled voluntary movement
Planning and initiation of voluntary activity, storage of procedural memories
Maintenance of balance, control of eye movements
Vestibulocerebellum
Spinocerebellum
Cerebrocerebellum


Regulation of muscle tone, coordination of skilled voluntary movement
Planning and initiation of voluntary activity, storage of procedural memories
Maintenance of balance, control of eye movements
Vestibulocerebellum
Spinocerebellum
Cerebrocerebellum



Regulation of muscle tone, coordination of skilled voluntary movement
Planning and initiation of voluntary activity, storage of procedural memories
Maintenance of balance, control of eye movements
Vestibulocerebellum
Spinocerebellum
Cerebrocerebellum

Cerebellum

- The cerebellum plays major roles in timing of motor activities and in rapid, smooth progression from one muscle movement to the next.

- It also helps control the intensity of muscle contraction when the muscle load changes and controls the necessary instantaneous interplay between agonist and antagonist muscle groups.

Functional subdivisions of the cerebellum

Vestibulocerebellum

- flocculonodular cerebellar lobes.
- Vestibular nuclei.
- Equilibrium and postural movement.

- In people with vestibulocerebellar dysfunction, equilibrium is far more disturbed during performance of rapid motions than during inactivity, especially when these movements involve changes in direction of movement.
- This phenomenon suggests that the vestibulocerebellum is important in controlling balance between agonist and antagonist muscle contractions of the spine, hips, and shoulders during rapid changes in body positions as required by the vestibular apparatus.

- during control of equilibrium, it is presumed that information from both the body periphery and the vestibular apparatus is used in a typical feedback control circuit to provide anticipatory correction of postural motor signals necessary for maintaining equilibrium even during extremely rapid motion.

Spinocerebellum

- intermediate zones.
- interposed nuclei.
- Coordinating mainly movements of the distal portions of the limbs. (compares intentions with actual movement).

- the intermediate zone of each cerebellar hemisphere receives two types of information when a movement is performed:
- (1) information from the cerebral motor cortex and red nucleus about the intended sequential plan of movement for the next few fractions of a second.
- (2) feedback information from the peripheral parts of the body, especially from the distal proprioceptors of the limbs, telling the cerebellum what actual movements result.

- After the intermediate zone of the cerebellum has compared the intended movements with the actual movements, the deep nuclear cells of the interposed nucleus send corrective output signals
- (1) back to the cerebral motor cortex through relay nuclei in the thalamus.
- (2) to the magnocellular portion of the red nucleus that gives rise to the rubrospinal tract.

Cerebrocerebellum

- Lateral zones.
- Dentate nuclei.
- plan sequential voluntary body and limb movements. (in advance).

- The large lateral zones of the cerebellar hemispheres have no direct input of information from the peripheral parts of the body.
- In addition, almost all communication between these lateral cerebellar areas and the cerebral cortex is mainly with the premotor area and primary and association somatosensory areas.

- these portions of the cerebellum are concerned with two other important but indirect aspects of motor control:
- (1) planning of sequential movements.
- (2) “timing” of the sequential movements.

Dorsal spinocerebellar tracts

- The signals transmitted in the dorsal spinocerebellar tracts come mainly from the muscle spindles and to a lesser extent from other somatic receptors throughout the body, such as Golgi tendon organs, large tactile receptors of the skin, and joint receptors.

Dorsal spinocerebellar tracts

- All these signals apprise the cerebellum of the momentary status of
- (1) muscle contraction,
- (2) degree of tension on the muscle tendons,
- (3) positions and rates of movement of the parts of the body,
- (4) forces acting on the surfaces of the body.

Ventral spinocerebellar tracts

- The ventral spinocerebellar tracts receive much less information from the peripheral receptors.
- Instead, they are excited mainly by motor signals arriving in the anterior horns of the spinal cord from
- (1) the brain through the corticospinal and rubrospinal tracts
- (2) the internal motor pattern generators in the cord itself.

Ventral spinocerebellar tracts

- Thus, this ventral fiber pathway tells the cerebellum which motor signals have arrived at the anterior horns; this feedback is called the efference copy of the anterior horn motor drive.

- The spinocerebellar pathways can transmit impulses at very high velocities.
- This speed is important for instantaneous apprisal of the cerebellum of changes in peripheral muscle actions.

Inferior olivary nucleus

- In addition to signals from the spinocerebellar tracts, signals are transmitted into the cerebellum from the body periphery through the spinal dorsal columns to the dorsal column nuclei of the medulla and are then relayed to the cerebellum.

- signals are transmitted up the spinal cord through the spinoreticular pathway and the spino-olivary pathway to the inferior olivary nucleus.

Inferior olivary nucleus

- Signals are then relayed from both of these areas to the cerebellum.

- Thus, the cerebellum continually collects information about the movements and positions of all parts of the body even though it is operating at a subconscious level.

Deep cerebellar nuclei

- on each side of the cerebellum there are three deep cerebellar nuclei: the dentate, interposed, and fastigial.

- All the deep cerebellar nuclei receive signals from two sources:
- (1) the cerebellar cortex.
- (2) the deep sensory afferent tracts to the cerebellum.

Deep cerebellar nuclei

- Each time an input signal arrives in the cerebellum, it divides and goes in two directions:
- (1) directly to one of the cerebellar deep nuclei and
- (2) to a corresponding area of the cerebellar cortex overlying the deep nucleus.
- Then, a fraction of a second later, the cerebellar cortex relays an inhibitory output signal to the deep nucleus.

Deep cerebellar nuclei

- all input signals that enter the cerebellum eventually end in the deep nuclei in the form of initial excitatory signals followed a fraction of a second later by inhibitory signals. From the deep nuclei, output signals leave the cerebellum and are distributed to other parts of the brain.

Neural circuit of the functional unit

- functional unit centers on a single, very large Purkinje cell and on a corresponding deep nuclear cell.
- The output from the functional unit is from a deep nuclear cell.
- This cell is continually under both excitatory and inhibitory influences.

Neural circuit of the functional unit

- The excitatory influences arise from direct connections with afferent fibers that enter the cerebellum from the brain or the periphery.

- The inhibitory influence arises entirely from the Purkinje cell in the cortex of the cerebellum.

- The afferent inputs to the cerebellum are mainly of two types, one called the climbing fiber type and the other called the mossy fiber type.

Climbing fibers

- The climbing fibers all originate from the inferior olives of the medulla.
- There is one climbing fiber for about 5 to 10 Purkinje cells.
- After sending branches to several deep nuclear cells, the climbing fiber continues all the way to the outer layers of the cerebellar cortex, where it makes about 300 synapses with the soma and dendrites of each Purkinje cell.

Complex spike

- This climbing fiber is distinguished by the fact that a single impulse in it will always cause a single, prolonged (up to 1 second), peculiar type of action potential in each Purkinje cell with which it connects, beginning with a strong spike and followed by a trail of weakening secondary spikes.
- This action potential is called the complex spike.

Mossy fibers

- The mossy fibers are all the other fibers that enter the cerebellum from multiple sources—the higher brain, brain stem, and spinal cord.
- These fibers also send collaterals to excite the deep nuclear cells.
- They then proceed to the granule cell layer of the cortex, where they also synapse with hundreds to thousands of granule cells.

Mossy fibers

- In turn, the granule cells send extremely small axons, less than 1 micrometer in diameter, up to the molecular layer on the outer surface of the cerebellar cortex.

- Here the axons divide into two branches that extend 1 to 2 millimeters in each direction parallel to the folia.
- It is into this molecular layer that the dendrites of the Purkinje cells project and 80,000 to 200,000 of the parallel fibers synapse with each Purkinje cell.

- The mossy fiber input to the Purkinje cell is quite different from the climbing fiber input because the synaptic connections are weak, so large numbers of mossy fibers must be stimulated simultaneously to excite the Purkinje cell.
- Furthermore, activation usually takes the form of a much weaker, short-duration Purkinje cell action potential called a simple spike, rather than the prolonged complex action potential caused by climbing fiber input.

- One characteristic of both Purkinje cells and deep nuclear cells is that normally both of them fire continuously;
- the Purkinje cell fires at about 50 to 100 action potentials per second, and the deep nuclear cells fire at much higher rates.
- Furthermore, the output activity of both these cells can be modulated.

Deep nuclear cells

- the climbing and the mossy fibers excites them.
- By contrast, signals arriving from the Purkinje cells inhibit them.
- Normally, the balance between these two effects is slightly in favor of excitation so that under quiet conditions, output from the deep nuclear cell remains relatively constant at a moderate level of continuous stimulation.

- In execution of a rapid motor movement, the initiating signal from the cerebral motor cortex or brain stem at first greatly increases deep nuclear cell excitation.
- Then, another few milliseconds later, feedback inhibitory signals from the Purkinje cell circuit arrive. In this way, there is first a rapid excitatory signal sent by the deep nuclear cells into the motor output pathway to enhance the motor movement, followed within another small fraction of a second by an inhibitory signal.

Delay line

- This inhibitory signal resembles a “delay line” negative feedback signal of the type that is effective in providing damping. That is, when the motor system is excited, a negative feedback signal occurs after a short delay to stop the muscle movement from overshooting its mark. Otherwise, oscillation of the movement would occur.

Turn on/ turn off signals

- The typical function of the cerebellum is to help provide rapid turn-on signals for the agonist muscles and simultaneous reciprocal turn-off signals for the antagonist muscles at the onset of a movement.
- Then, on approaching termination of the movement, the cerebellum is mainly responsible for timing and executing the turn-off signals to the agonists and the turn-on signals to the antagonists.

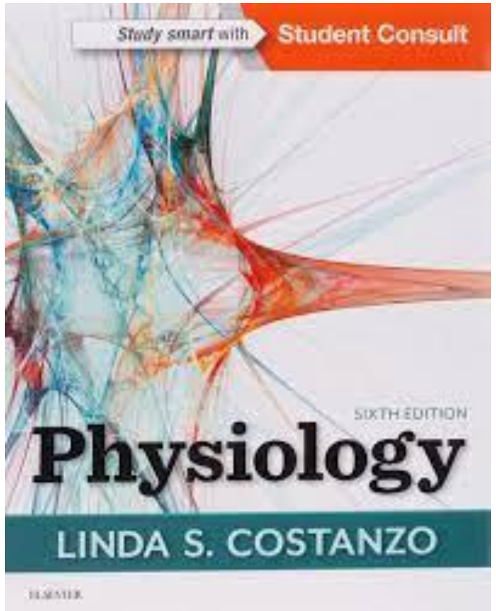
Cerebellum learns

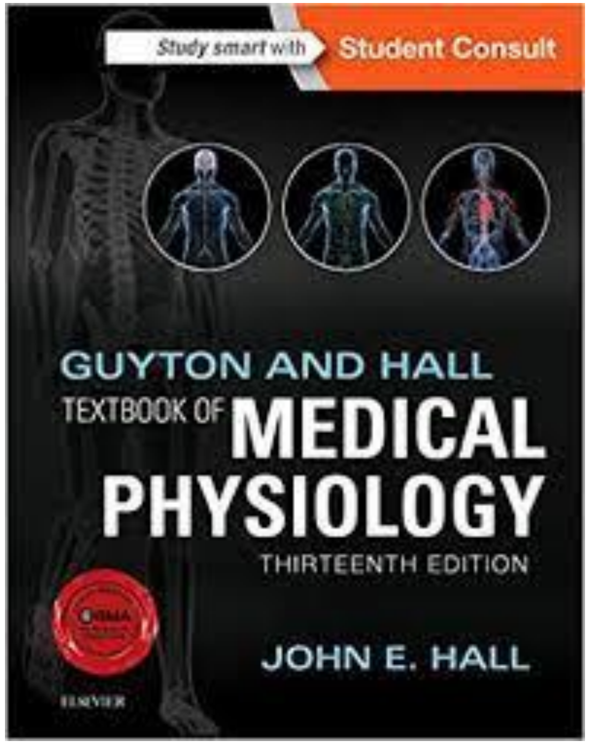
- The degree to which the cerebellum supports onset and offset of muscle contractions, as well as timing of contractions, must be learned by the cerebellum.

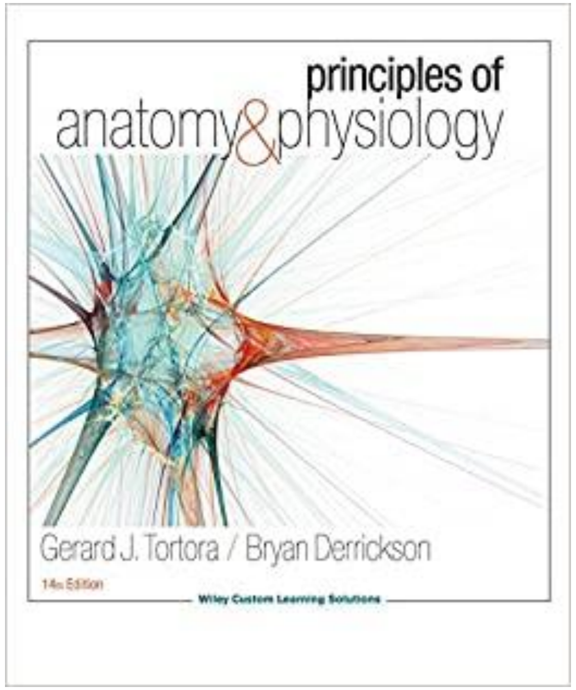
Basket and Stellate cells

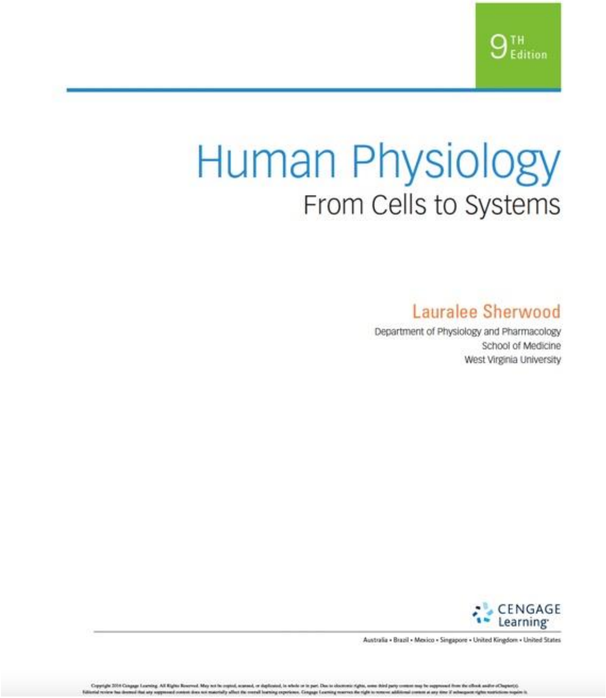
- basket cells and stellate cells are inhibitory cells with short axons.
- Both are located in the molecular layer of the cerebellar cortex.
- These cells send their axons at right angles across the parallel fibers and cause lateral inhibition of adjacent Purkinje cells, thus sharpening the signal.

References


Study smart with Student Consult
SIXTH EDITION
Physiology
LINDA S. COSTANZO
ELSEVIER


Study smart with Student Consult
GUYTON AND HALL
TEXTBOOK OF MEDICAL PHYSIOLOGY
THIRTEENTH EDITION
JOHN E. HALL
ELSEVIER


principles of
anatomy&physiology
Gerard J. Tortora / Bryan Derrickson
14th Edition
Wiley Custom Learning Solutions


9TH Edition
Human Physiology
From Cells to Systems
Lauralee Sherwood
Department of Physiology and Pharmacology
School of Medicine
West Virginia University
CENGAGE Learning

Thank you