

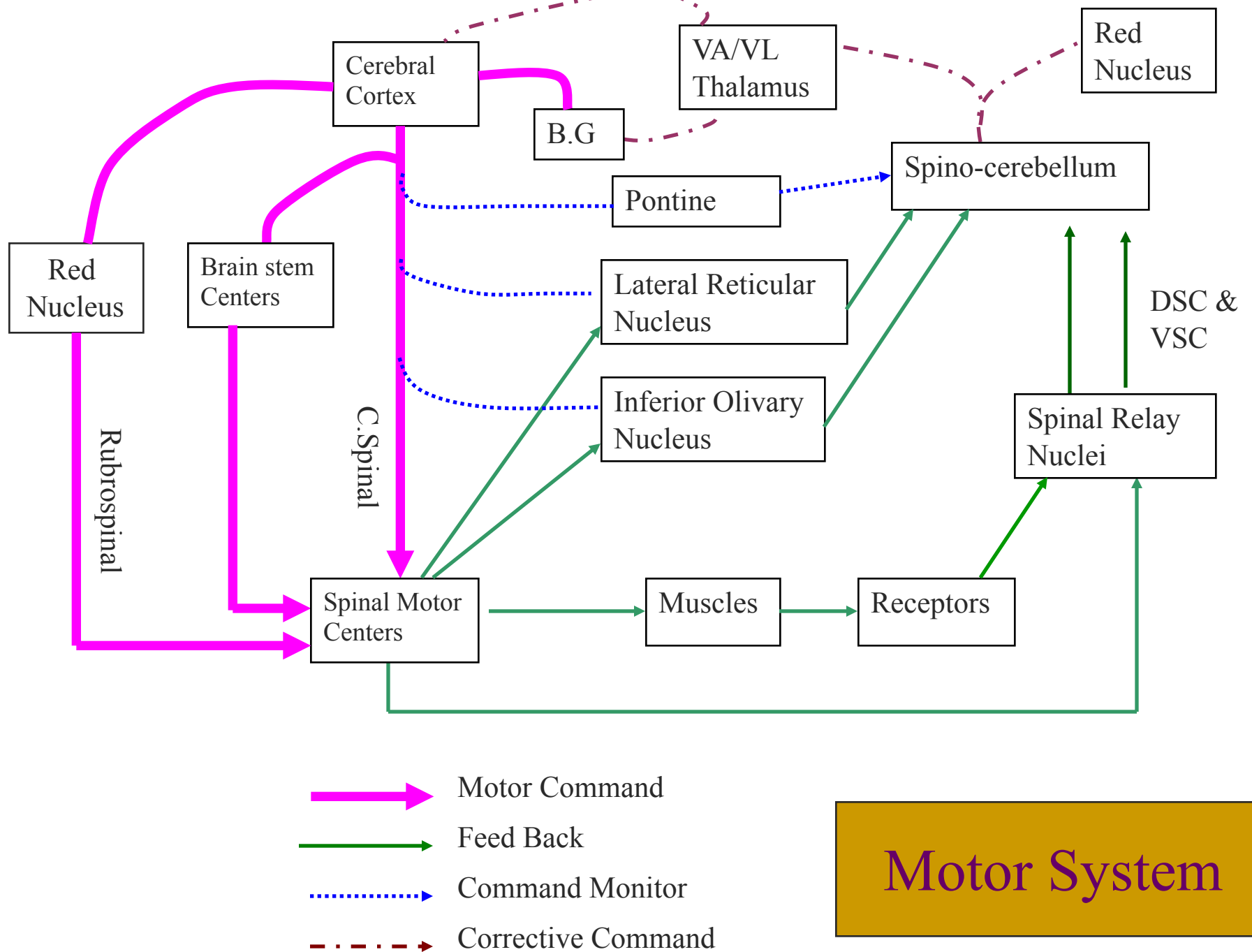
A decorative graphic consisting of a thin gold circle. A thick black left square bracket is positioned on the left side of the circle, and a thick gold right square bracket is on the right side. A horizontal gold bar with a gradient is placed across the middle of the circle, containing the title text.

# The Cerebellum

Faisal I. Mohammed, MD, PhD

# [Objectives]

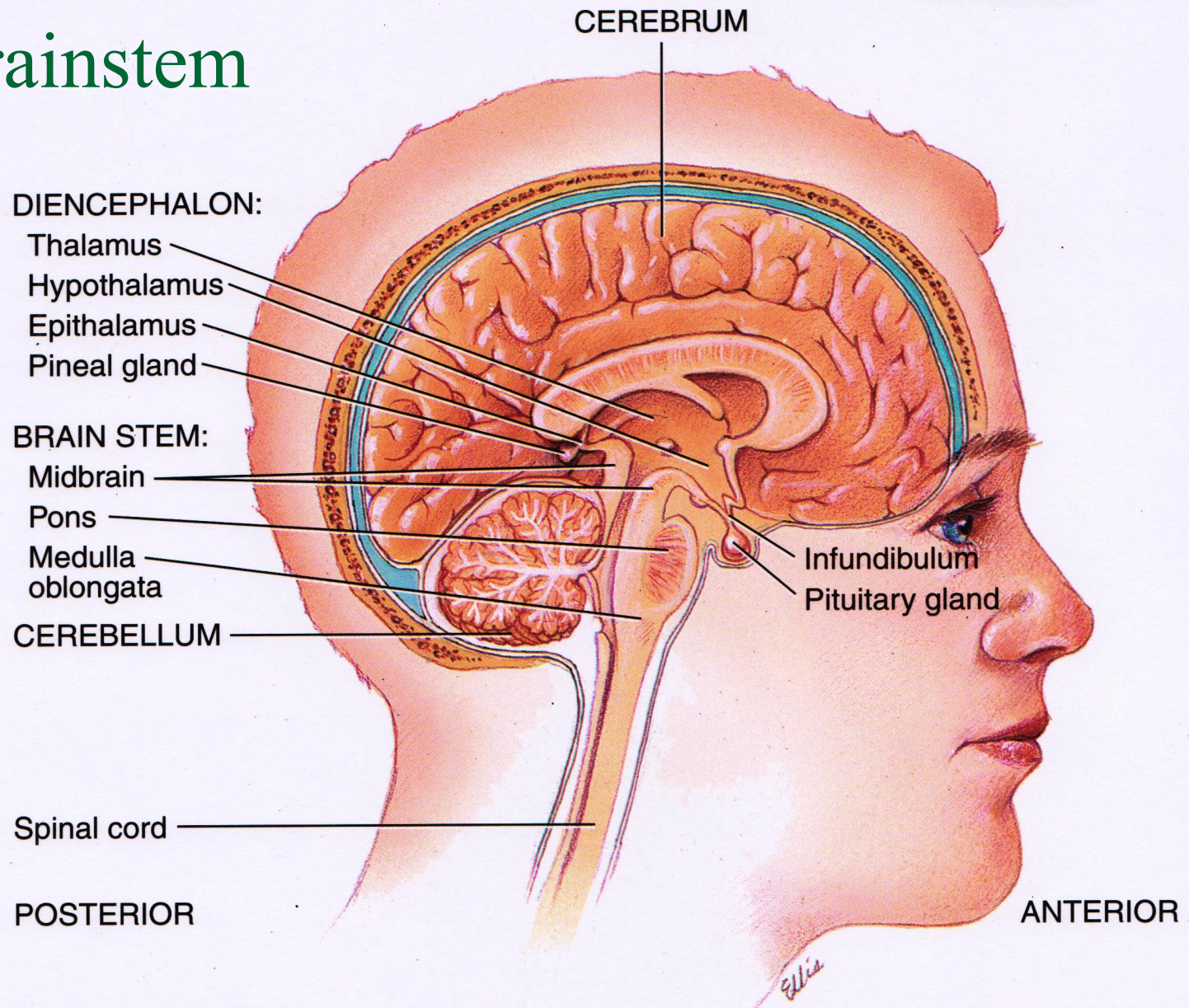
- 👁 Describe cerebellar afferents and efferents
- 👁 Describe cerebellum functions.
- 👁 Outline the functional unit of the cerebellum (circuit)
- 👁 Explain how this unit perform the cerebellar functions
- 👁 Recognize cerebellar abnormalities



# [ The Cerebellum (little brain) ]

- responsible for coordinating muscle activity
- sequences the motor activities
- monitors and makes corrective adjustments in the activities initiated by other parts of the brain
- compares the actual motor movements with the intended movements and makes corrective changes

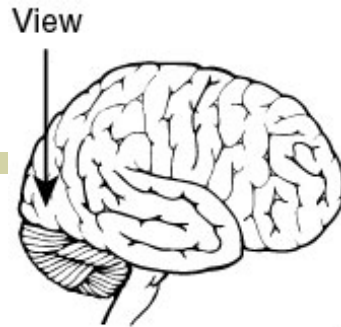
# [ Brainstem



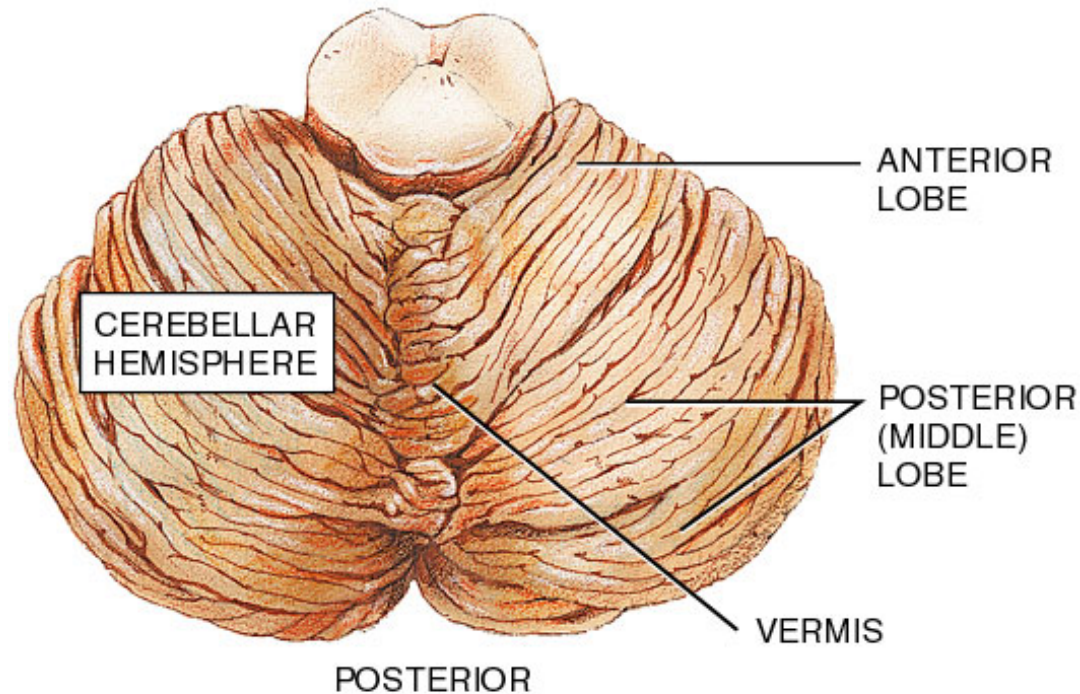
(a) Sagittal section of brain, medial view



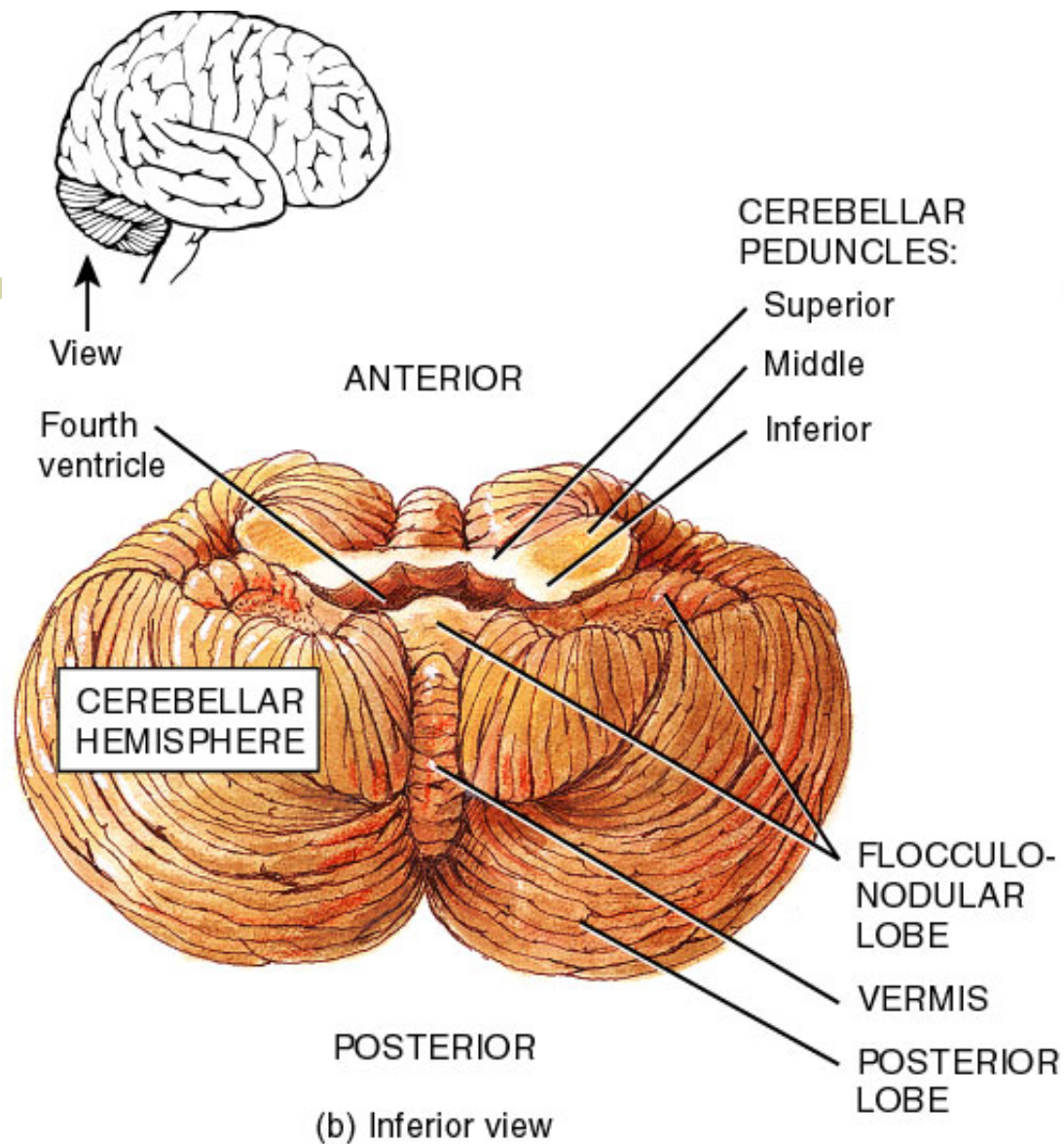
# The Cerebellum



ANTERIOR



(a) Superior view

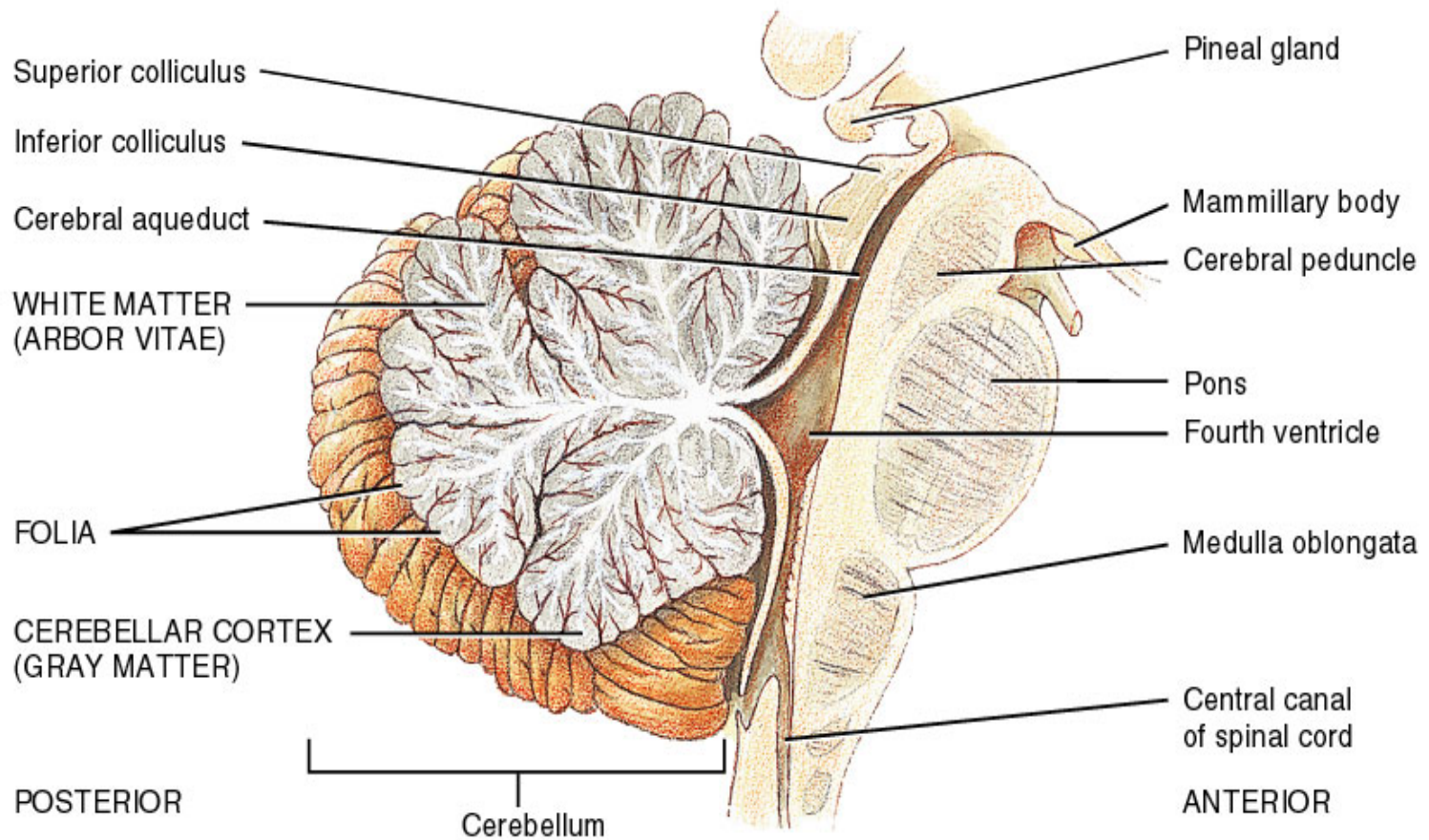
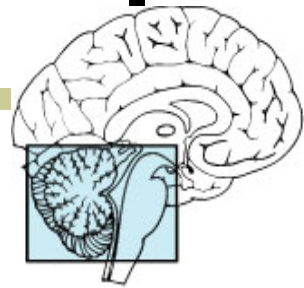


# The Cerebellum

14.08b

University of Jordan

# The Cerebellum

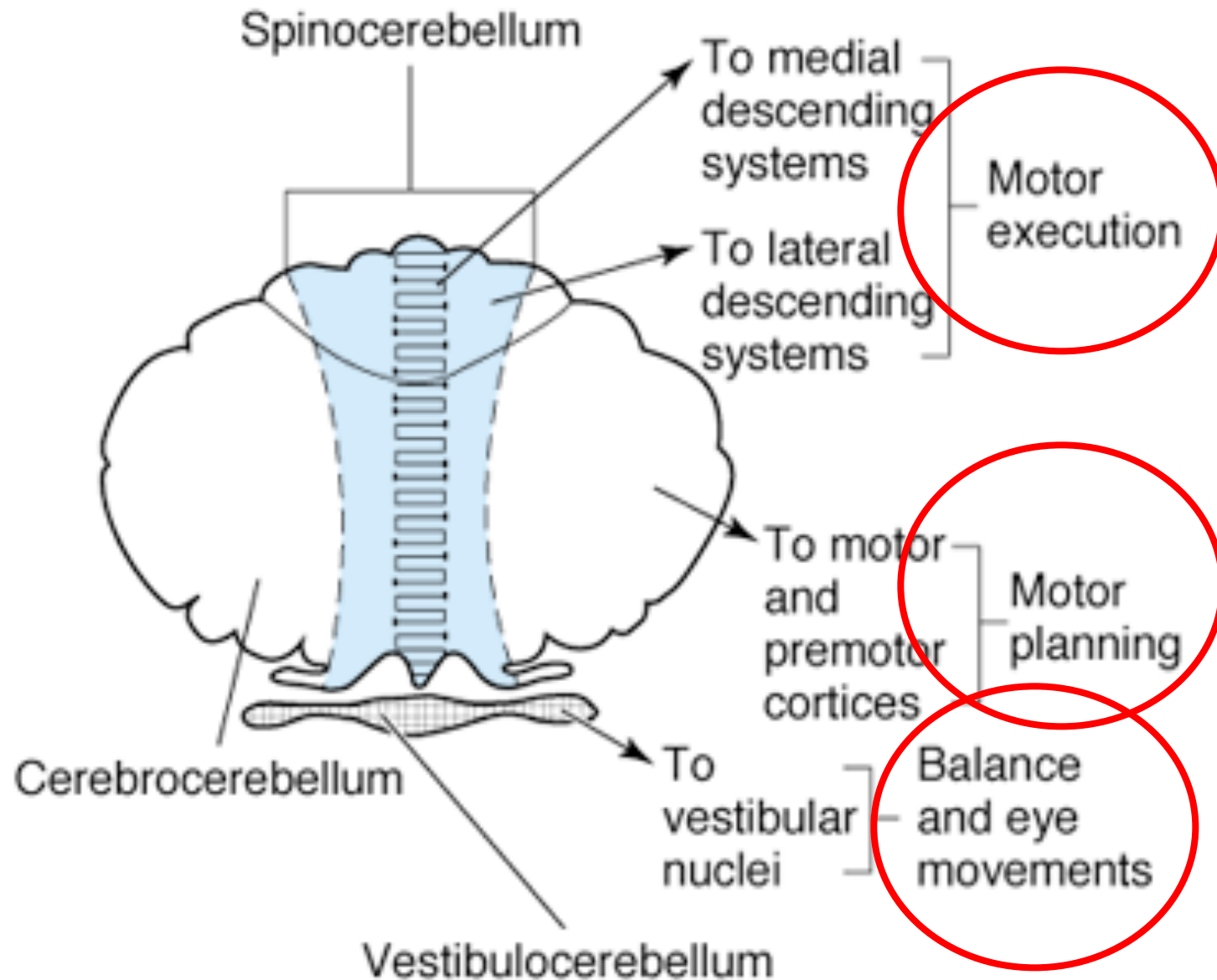


(c) Midsagittal section of cerebellum and brain stem



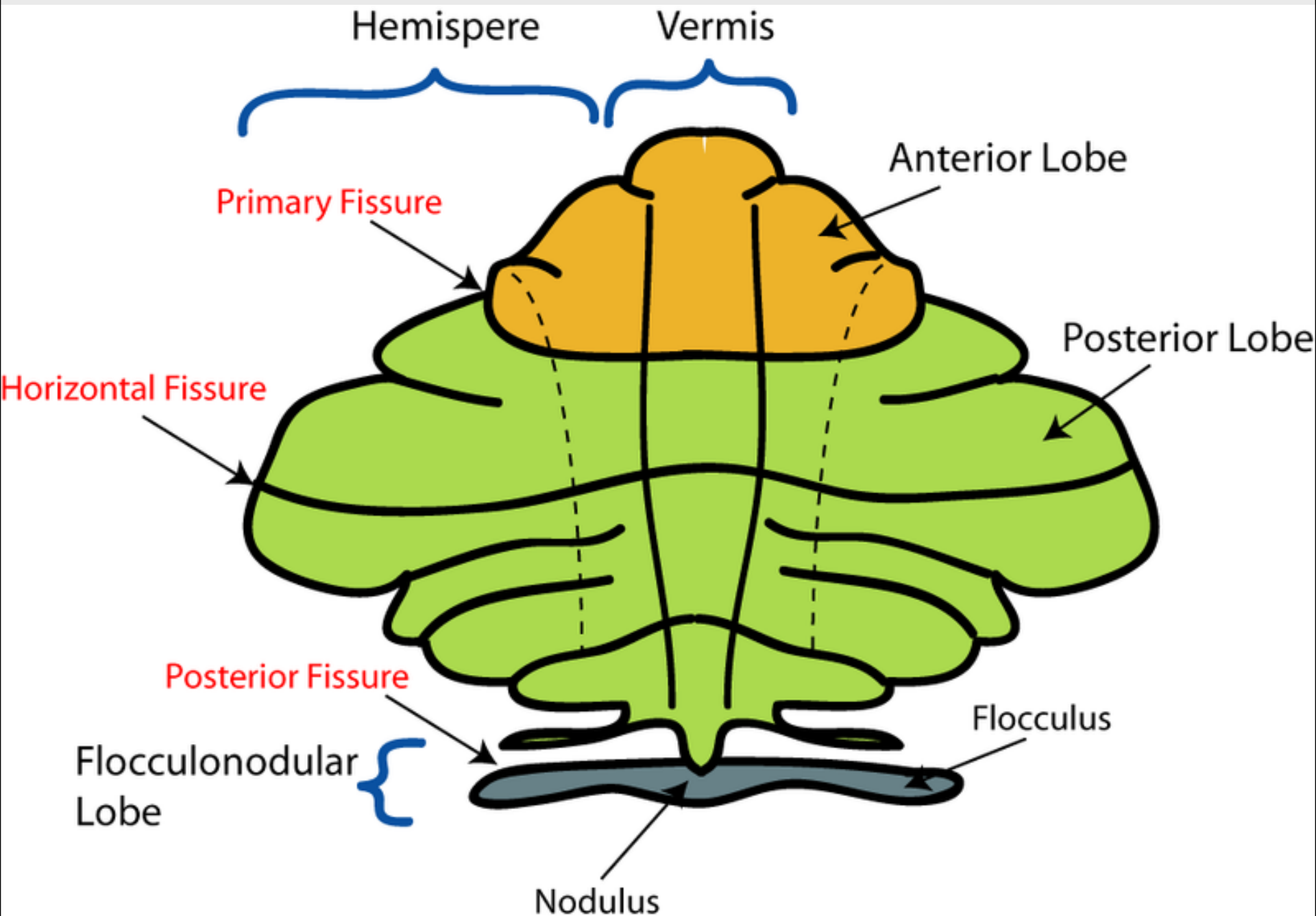
# Cerebellum

- It is divided into 3 major functional divisions;
  1. **Vestibulocerebellum**→ composed of the "flocculonodular lobe“ (Archicerebellum)
  2. **Spinocerebellum** → composed of the vermis and paravermal zone. (Paleocerebellum)
  3. **Cerebrocerebellum**→ composed of lateral zones of the cerebellar hemispheres. (Neocerebellum)

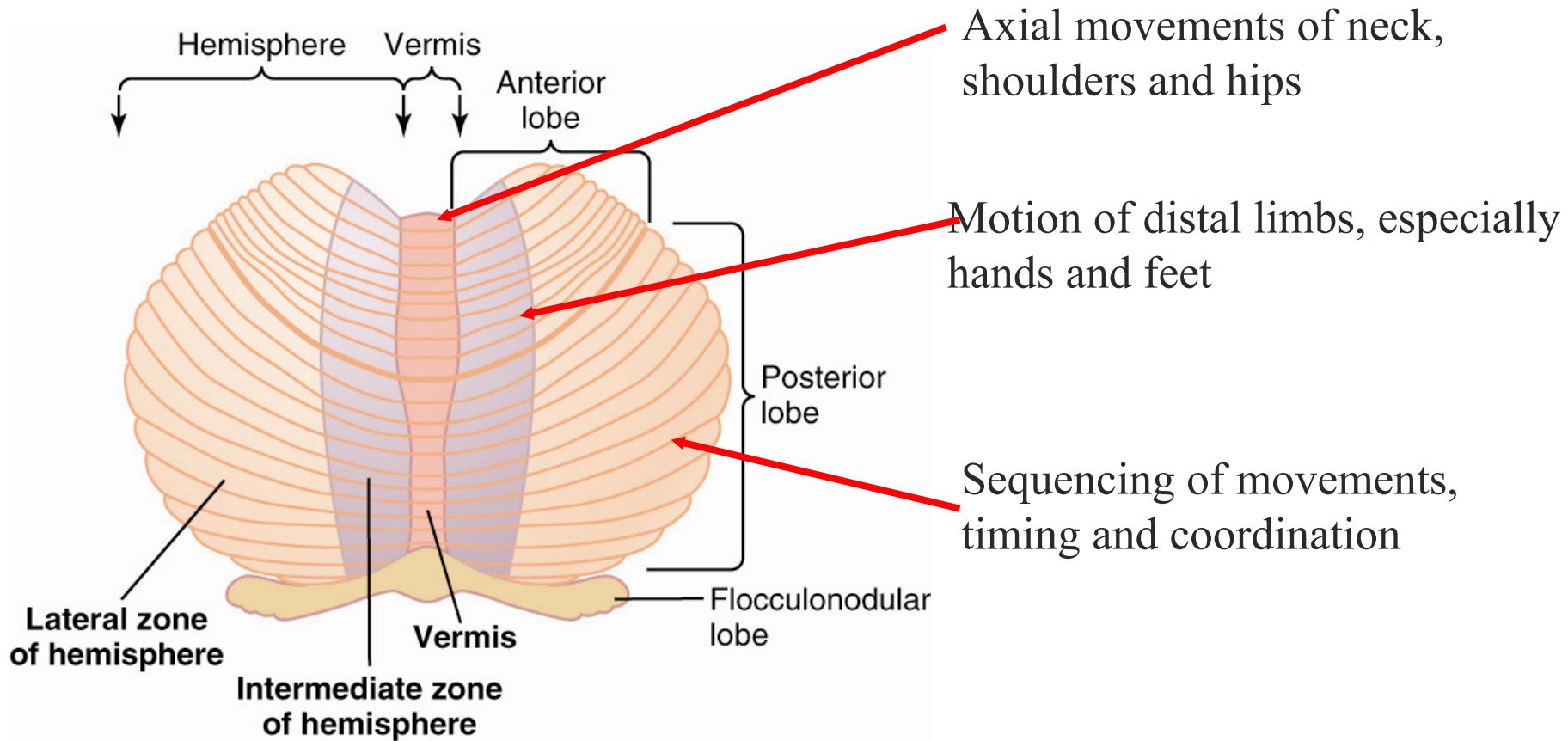


# Functional Organization of the Cerebellum

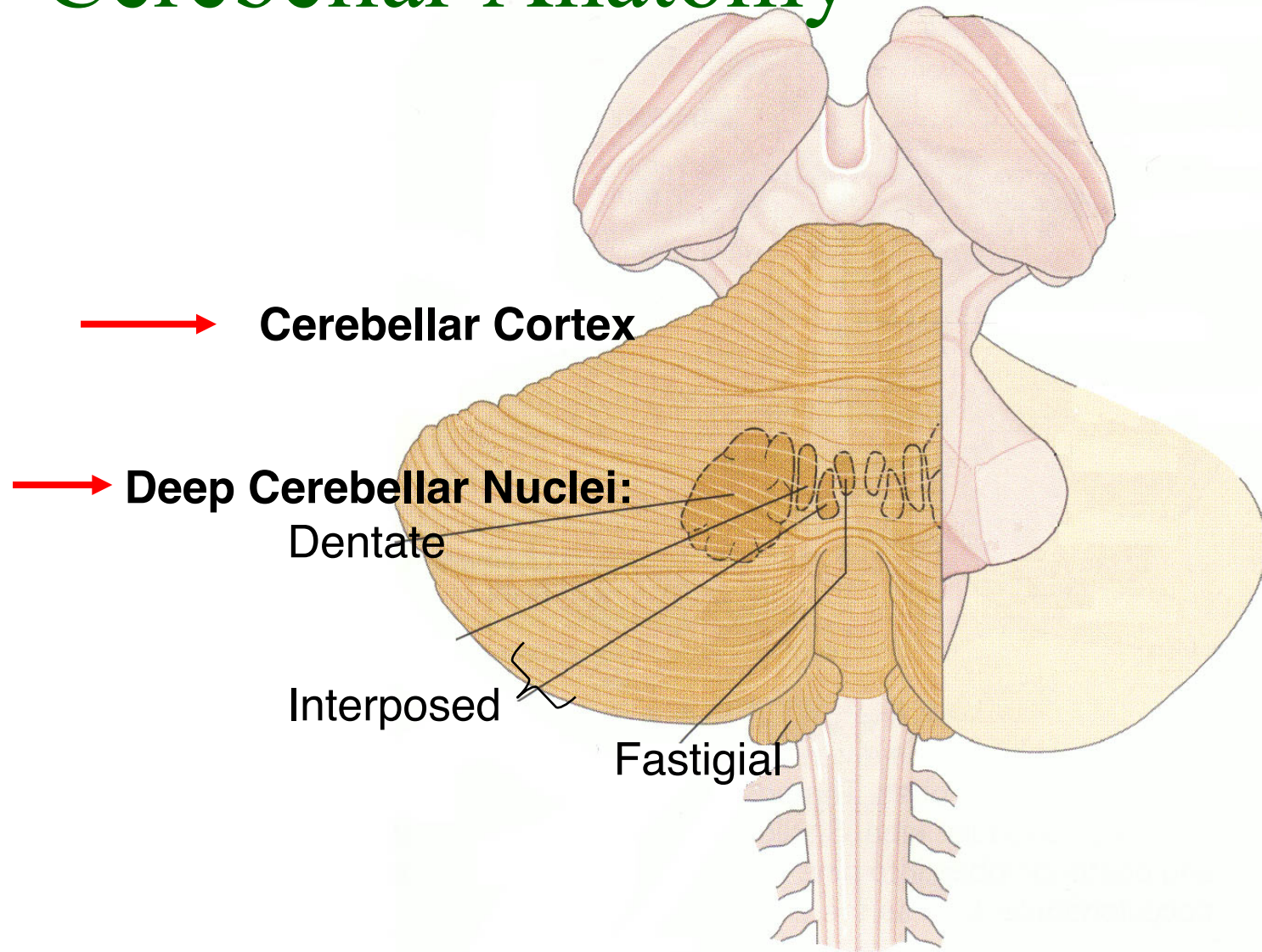
- Functionally arranged along the longitudinal axis
- *Vermis*, located at the center, controls axial movements of the neck, shoulders, and hips
- *Intermediate zone* controls motion of distal portions of upper and lower limbs especially the hands and feet
- *Lateral zone* controls sequencing movements of the muscle. Important for **timing** and **coordination** of movement.



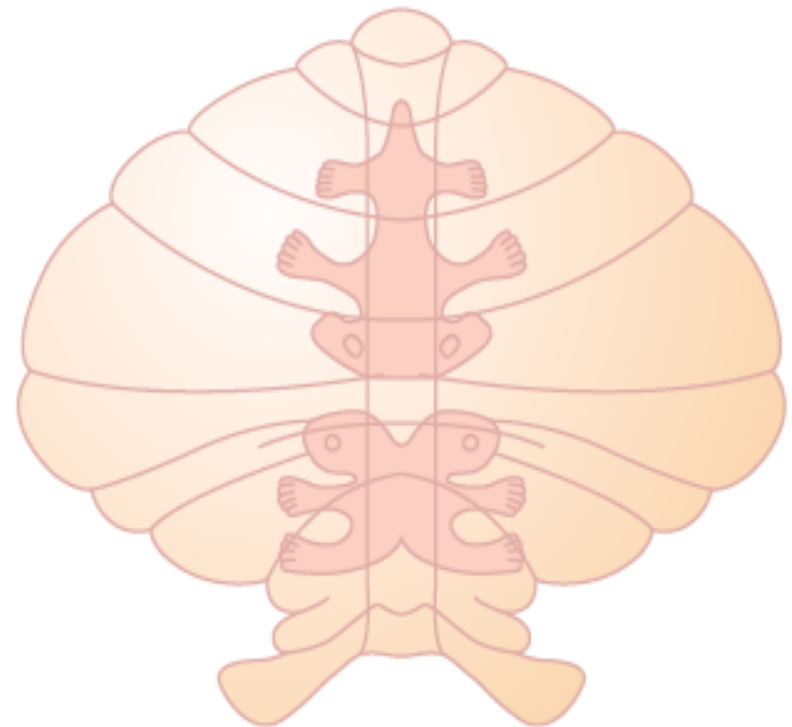
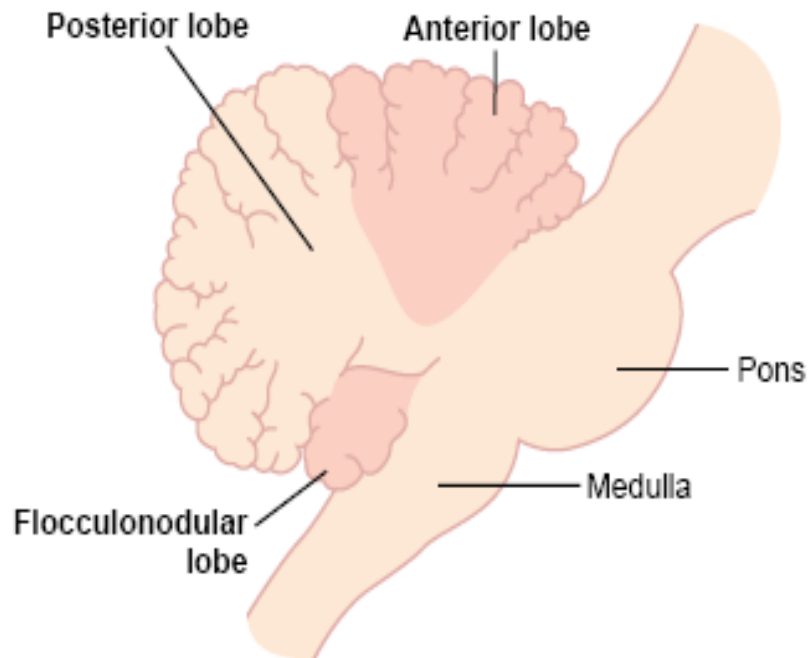




# Cerebellar Anatomy



# Cerebellar Topographical Representation



# Vestibulocerebellum

## a) Afferents:

- They arise from the vestibular system→ terminate in the flocculonodular lobe.
- They conduct vestibular signals about head position and movements.

## b) Efferents:

- From the cortex of the flocculonodular lobe to the fastigial nucleus→ leave the cerebellum through the inferior peduncle, and terminate in :-

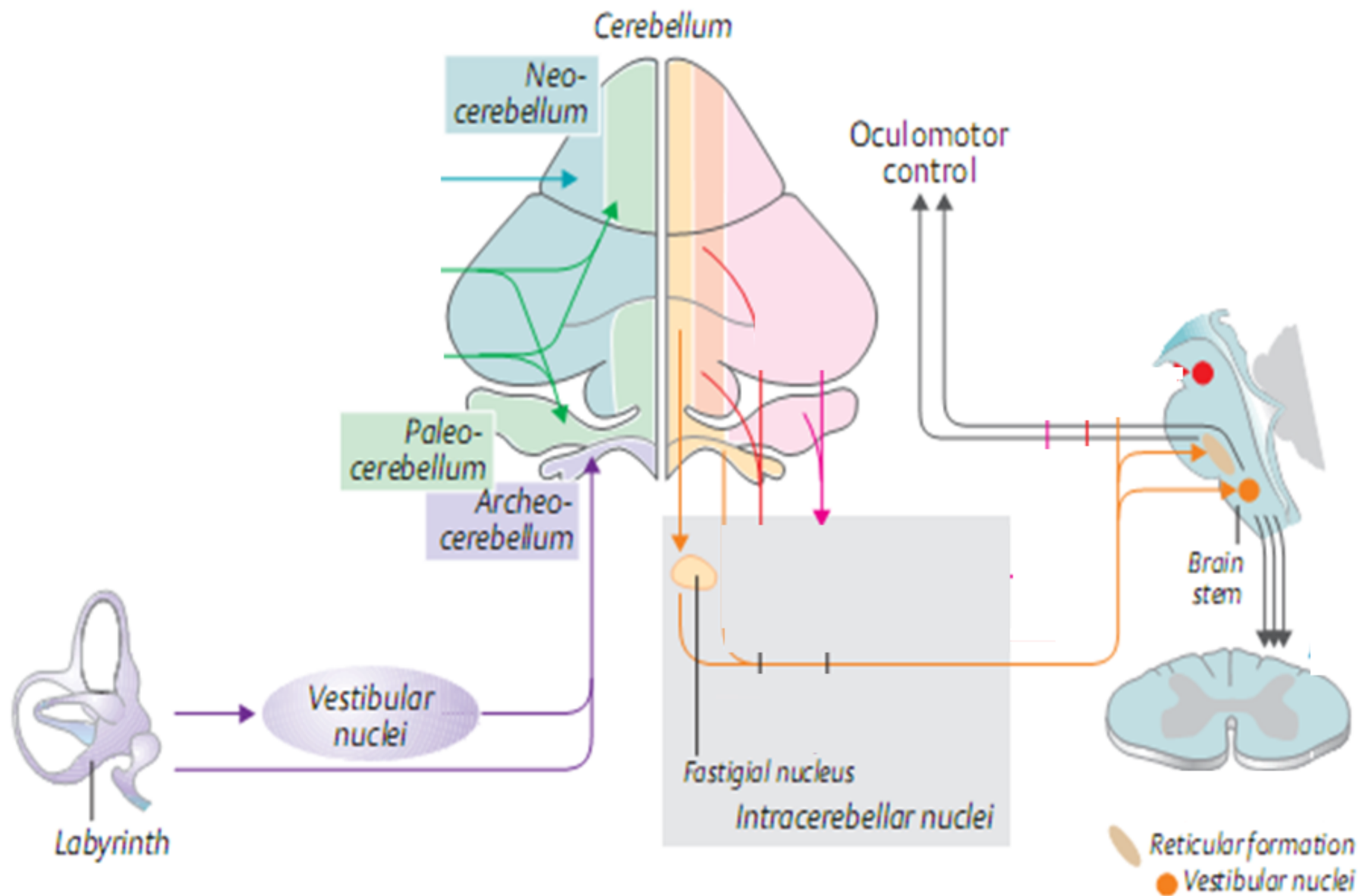


# Vestibulocerebellum

- **b) Efferents:**
  1. Vestibular nuclei → vestibulospinal tract
  2. Reticular formation (RF) in the brain stem → reticulospinal tract
  3. Motor nuclei of the cranial nerves innervating extraocular muscles (ms).
- The vestibulospinal and reticulospinal tract regulate of the tone of the antigravity ms in response to vestibular sensory signals → **regulation of equilibrium.**
- Also, it regulates movements of the eyeballs during head movements **to maintain stable vision.**

Afferents

Efferents



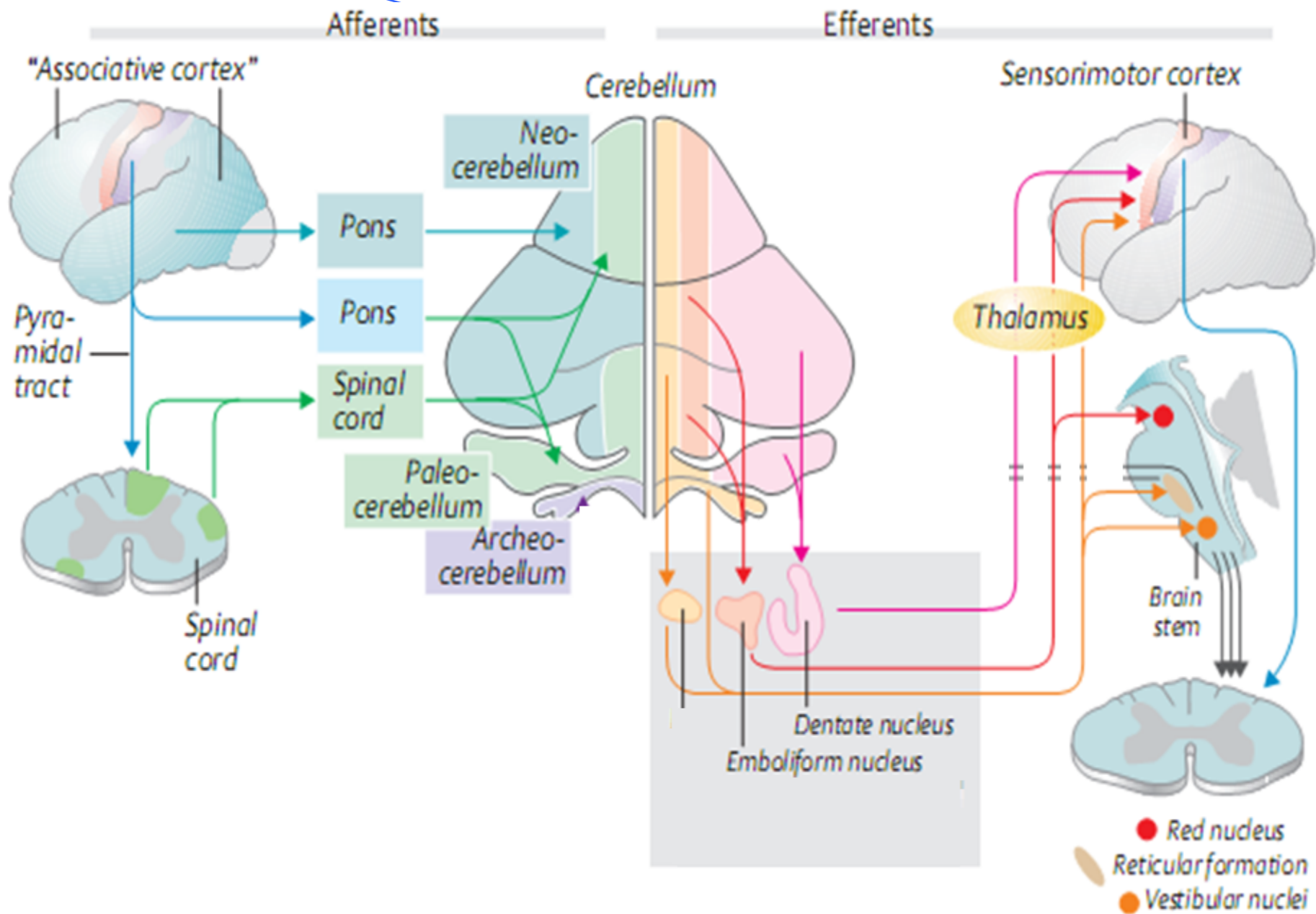
# Spinocerebellum (Paleocerebellum)

- **a) Afferents:**
  - From 2 main sources:-
  - **1) Brain and brainstem centers:** such as cerebral cortex, red nucleus, vestibular nuclei, reticular formation, and inferior olivary nucleus.
  - These afferents tell the spinocerebellum about the "**plan**" of the movement ordered by higher motor centers.
  - **2) Peripheral receptors:** via;
    - **i) Dorsal spinocerebellar tract:** from muscle spindles, Golgi tendon organ (GTOs), joint and pressure receptors → terminate ipsilaterally in the vermis and paravermal intermediate zone.
    - These signals inform the cerebellum about the position and movements of the different parts of the body.
    - **ii) Ventral spinocerebellar tract:** quickly returns to the spinocerebellum copies (efference copy) of the motor commands

# Spinocerebellum (Paleocerebellum)

- b) Efferents:
- 1) From the vermis:
- From the vermal cortex → to the "**fastigial**" nucleus → then projects to the vestibular nuclei and RF of the brain stem → to axial ms.
- 2) From the intermediate Zone:
- From the intermediate zone → to the **interposed nucleus** (composed of globose and emboliform nuclei) → via the superior peduncle, they project to:-
- (i) Contralateral thalamus → to the cerebral cortical motor areas and Basal ganglia (BG).
- (ii) Contralateral red nucleus.
- (iii) RF of the brain stem.
- They connect with the **corticospinal and rubrospinal tracts** → control of the "distal ms" of the limbs.





# Neocerebellum

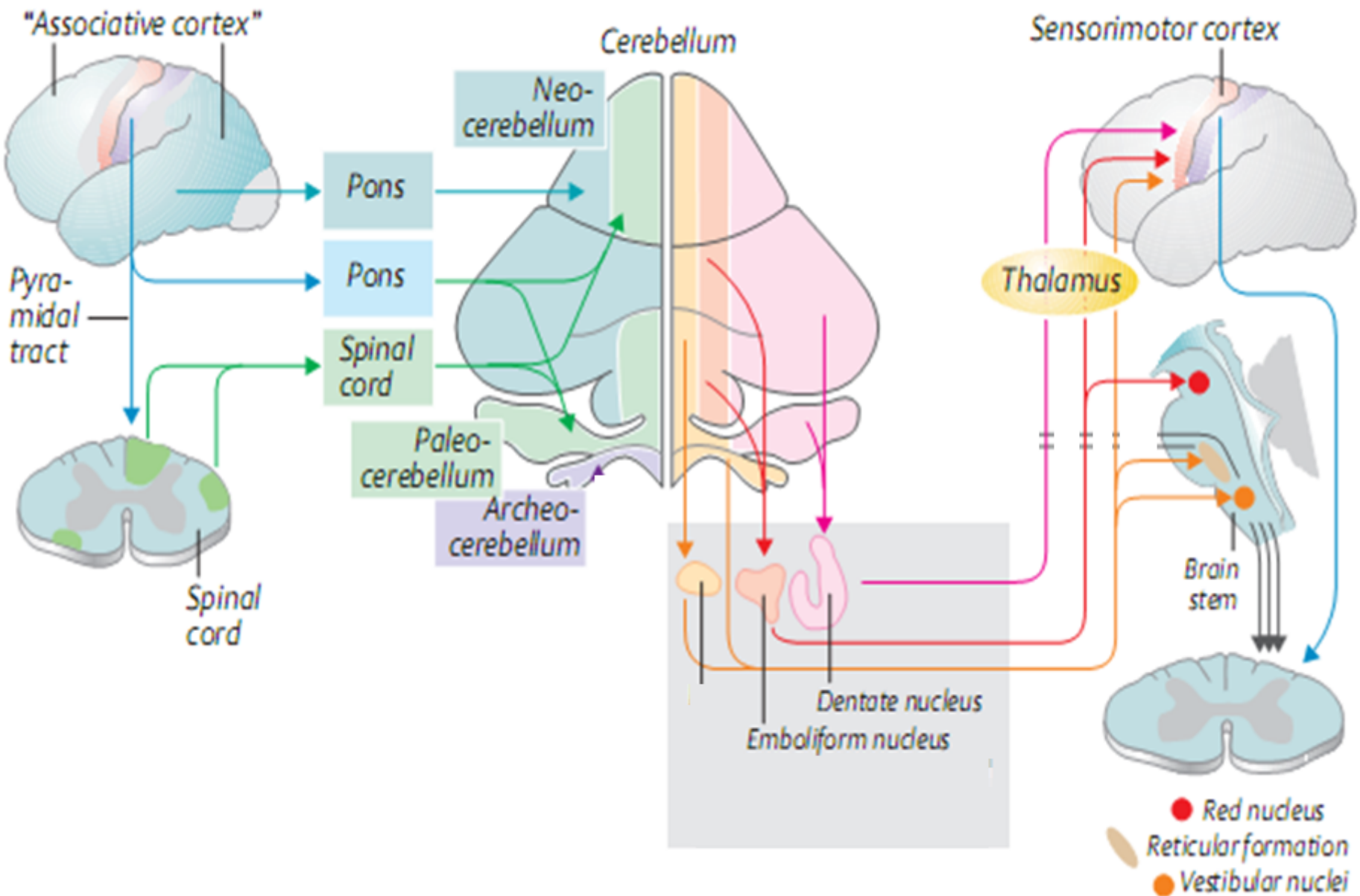
- **a) Afferents:**
- Almost all the afferents to the cerebrocerebellum originate in the cerebral cortex via the pontine nuclei.
- The cerebral cortical projections provide it with;
- **i) Motor information** → about the motor commands from motor areas (command monitor)
- **ii) Sensory information** → about the present postural state of the body, from the somatic sensory areas.

# Neocerebellum

- b) Efferents:
- -From the cortex of the cerebrocerebellum → to the **"dentate" nucleus** → through the superior peduncle to terminate mainly in the VL nucleus of the contralateral thalamus → finally projects to the motor areas of the cerebral cortex.
- -The **"cerebello - dentato - thalamo-cerebral"** pathway mediates the role of the cerebrocerebellum in adjusting the **plan** of the motor command before being discharged from the cerebral cortex motor areas to the lower motor neurons.

Afferents

Efferents





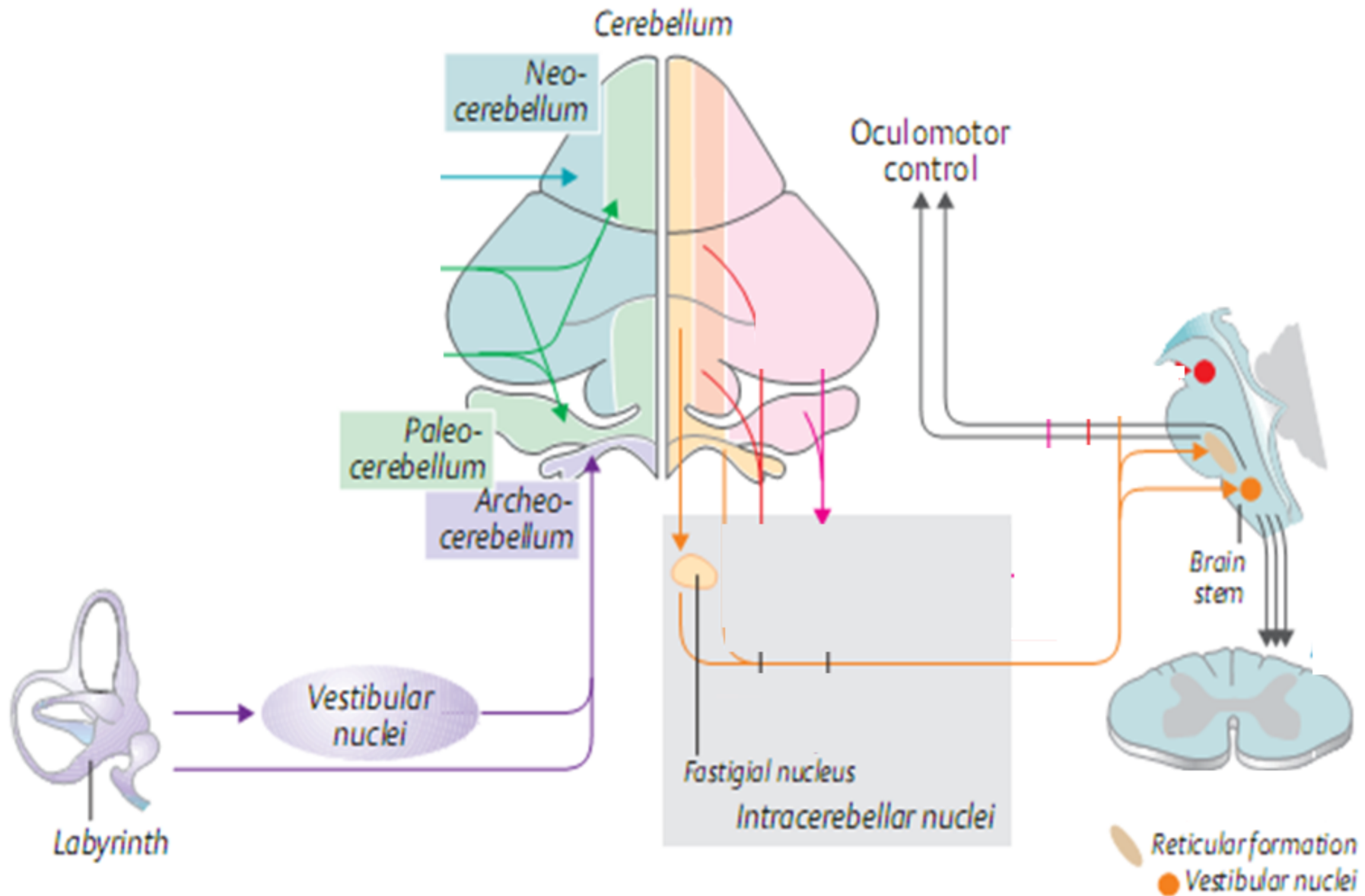
# **Functions of the Cerebellum**

# 1) Regulation of Equilibrium

- When the equilibrium is disturbed or exposed to acceleration→ ++ the vestibular receptors→ send sensory signals to Vestibulocerebellum which initiate immediate corrective signals that are sent to:-
- **i) The vestibular nuclei, and RF** → adjust the tone and contractility of the axial and proximal limb ms.
- This helps to maintain equilibrium during the change in **head position, and during exposure to acceleration or active movements of the body.**
- **ii) The superior colliculus and the medial longitudinal bundle** → to coordinate eye movements with head movements during exposure to acceleration→ **to maintain clear vision which is important for keeping equilibrium during head movements.**

Afferents

Efferents



## 2) Regulation of Posture

- The **vermis** is the principal region of the cerebellum concerned with postural adjustment.
- It receives sensory information from ms and joint proprioceptors (particularly from the axial regions), concerning "**position**" of the body.
- Its output controls the **vestibulospinal and reticulospinal tracts** that regulate the tone and contraction of the **axial and proximal limb ms** .

### **3) Regulation (or Coordination) of Voluntary Movements**

- **Coordination of movements** means one's ability to proceed smoothly and precisely from one movement to the next in proper succession.
- The cerebellar role in coordination of movements is carried out by a No. of mechanisms, including:-

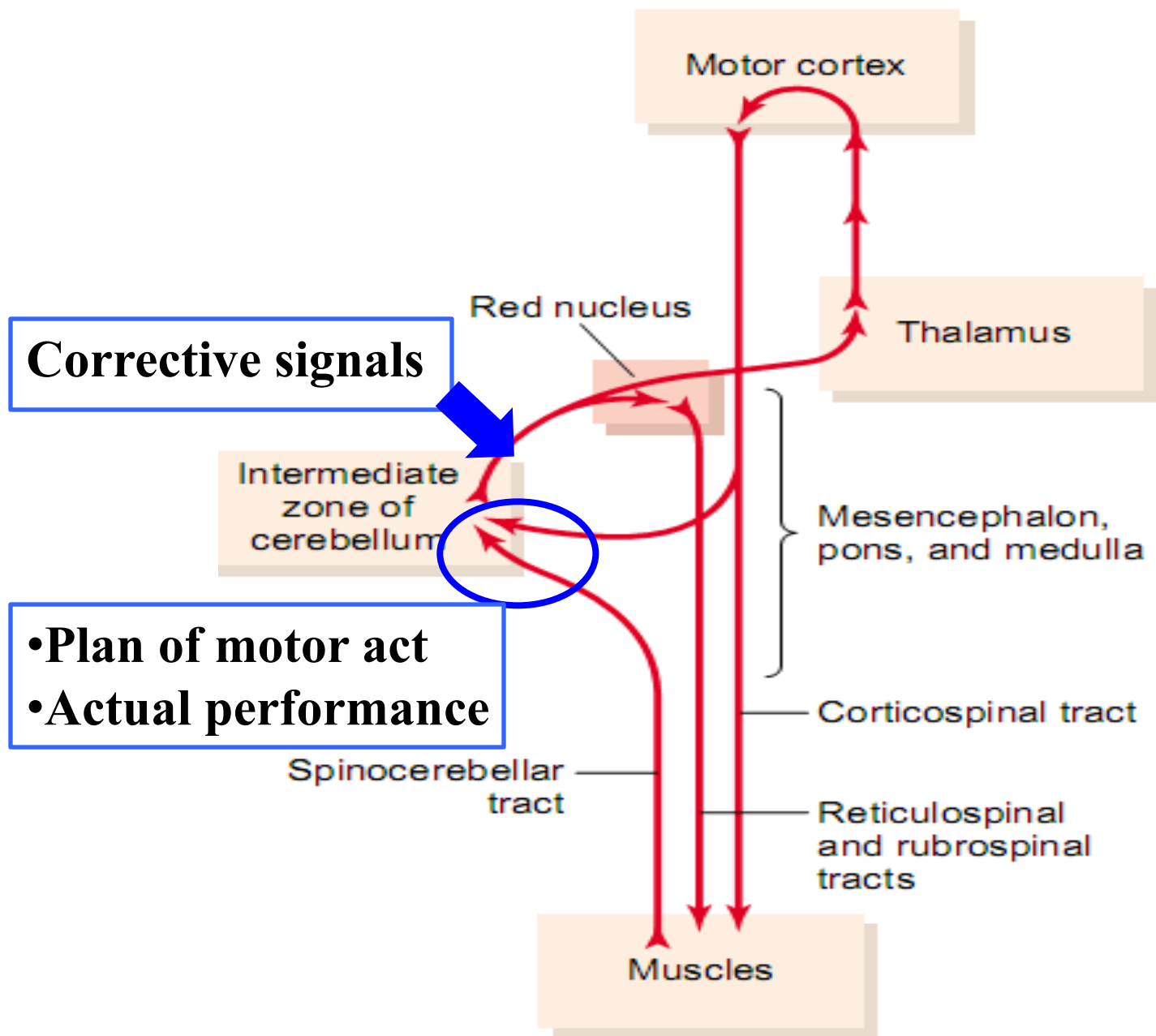
### 3) Regulation (or Coordination) of Voluntary Movements

- a) Comparator and Error- Correction Mechanism
- When the motor areas of the cerebral cortex (CC) send motor commands to ms for performance of a voluntary movement, the spinocerebellum receives immediately an **"efference copy"** of the **intended motor command** through;
  1. Cortico- ponto-cerebellar pathway
  2. Ventral spinocerebellar tract
- As the movement proceeds, the spinocerebellum receives proprioceptive signals about the **actual motor performance** via **dorsal spinocerebellar tract**



### 3) Regulation (or Coordination) of Voluntary Movements

- a) Comparator and Error- Correction Mechanism
- The intermediate **zone of the spinocerebellum** essentially acts as a "**comparator**" that compares the motor intentions of the higher centers with the actual performance of the involved ms.
- When there is any "**error**" in performance or "**deviation**" from the original plan of the intended voluntary motor act, then the intermediate zone and the interposed nucleus send '**corrective signals**' back to the motor areas of the **CC** and the **red nucleus**, which give origin to the descending motor tracts innervating mainly the lower motor neurons of the distal limb ms



### 3) Regulation (or Coordination) of Voluntary Movements

- **b) Predictive and Damping Mechanism**
- The cerebellum receives information regarding the **velocity** and **direction** of the intended movement.
- The cerebellum would **predict** from these information how far that part of the body will move in a given time, and uses this information to determine the precise time to damp the movement, and then it sends its decision to the motor cortex to stop the ongoing movement exactly at the intended position.

### 3) Regulation (or Coordination) of Voluntary Movements

- c) Planning the Sequence and Timing of Movements
- i) Planning the Sequence of Movements
- The cerebrocerebellum uses the information provided from the CC and the BG for **planning the sequence of contraction of the different ms** involved in the voluntary motor act, to achieve the goal of the movement.
- Then, the "**plan**" of the movement sequence is transmitted from the cerebrocerebellum to the motor areas of the CC, where it is used to adjust the final motor command before it is discharged to the lower motor centers.

# 3) Regulation (or Coordination) of Voluntary Movements

- c) Planning the Sequence and Timing of Movements
- ii) Timing of Movements
- Also the cerebrocerebellum is to **provide perfect timing of voluntary movements.**
- This is established by computing (calculating) the appropriate timing for the "**onset**" and "**termination**" of contraction of each of the ms involved in the performance of the successive movements during voluntary motor acts → **assures the smooth progression of the whole movement.**

## 4) Role of the Cerebellum in Motor learning

- When a person first performs a complex motor act, the degree of cerebellar adjustment of the "**onset**" and "**termination**" of the successive ms contractions involved in the movements is almost always inaccurate, then **cerebellar neuronal circuits learn to make more accurate movement the next time.**
- Thus, after the motor act has been repeated many times (*motor training*), the successive steps of the motor act become gradually more precise.
- Once the cerebellum has perfectly learned its role in different patterns of movements, it establishes a specific "***stored program***" for each of the learned movements.



## **5) Role of the Cerebellum in Rapid and Ballistic Movements**

- These movements include writing, typing, talking, running, and many other athletic and professional motor skills.
- These movements occur so rapidly that it is almost impossible to depend for their control on the sensory feedback information from the periphery, because the movement would be over before such information reaches the cerebellum and the cerebral cortex.
- These movements are referred to as "ballistic" movements (ballistic is a word meaning "thrown"), because once the movement goes on there is no way to modify its present course by any sensory feed-back control mechanism.

# Afferent Pathways to the Cerebellum

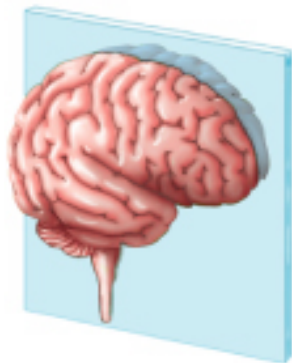
## ■ From the brain

- *corticopontocerebellar* pathway from **motor** and **premotor** area, **somatosensory** cortex as well as some pontine nuclei which join this tract. Projects mostly to the **lateral hemispheric** areas.
  - *olivocerebellar* tract, *vestibulocerebellar* tract, *reticulocerebellar* tract
- These pathways transmit information about intended motion.

# Afferent Pathways to the Cerebellum

## ■ from the periphery

- *dorsal spinocerebellar tract* - transmits information mostly from **muscles spindle** but also from **Golgi tendon organs, large tactile, and joint receptors**. It is **uncrossed tract**
  - apprises the brain of the momentary status of muscle contraction, **muscle tension** and **limb position** and **forces** acting on the body surface
- *ventral spinocerebellar tract* - signals from anterior horn, and interneurons (**efference copy**) the integrated signal from the final common pathway before it goes to the muscle. It is **bilateral tract**
  - transmits information on which signals have arrived at the cord



Sagittal  
plane

Corrective  
feedback

Motor areas of  
cerebral cortex

Thalamus

Cortex of  
cerebellum

Motor centers in  
brainstem

Pons

Pontine nuclei

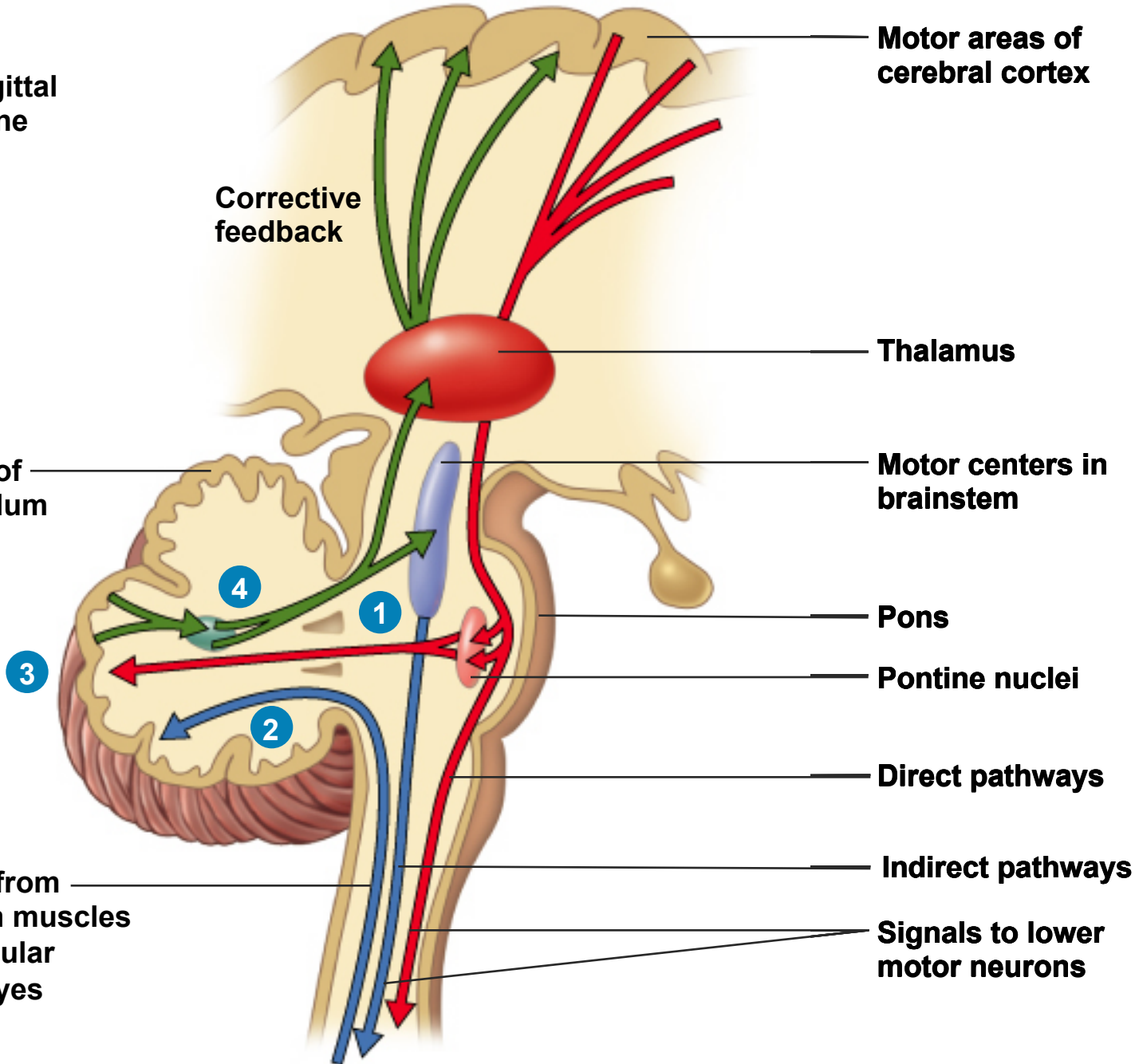
Direct pathways

Indirect pathways

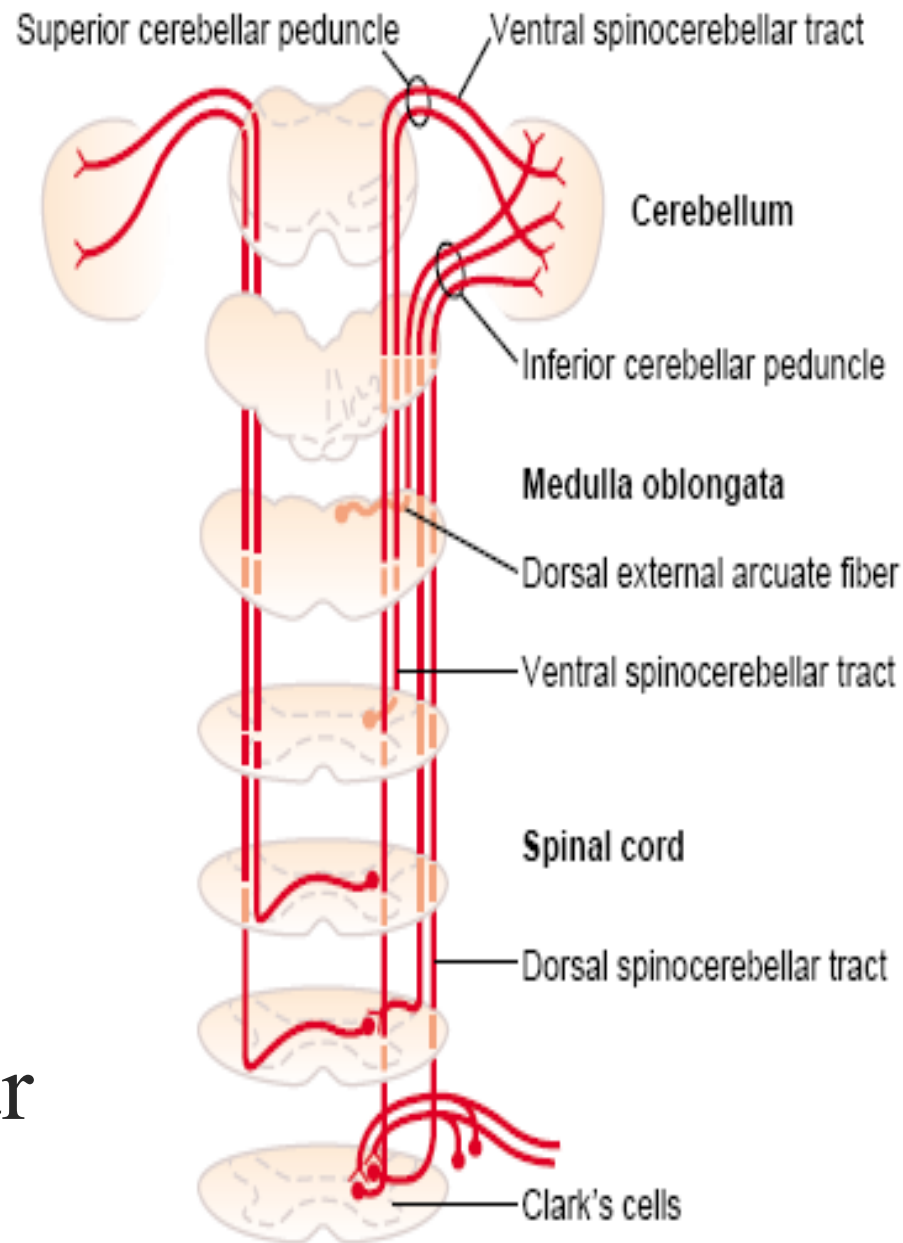
Signals to lower  
motor neurons

Sensory signals from  
proprioceptors in muscles  
and joints, vestibular  
apparatus, and eyes

Sagittal section through brain and spinal cord



# Spinocerebellar tracts

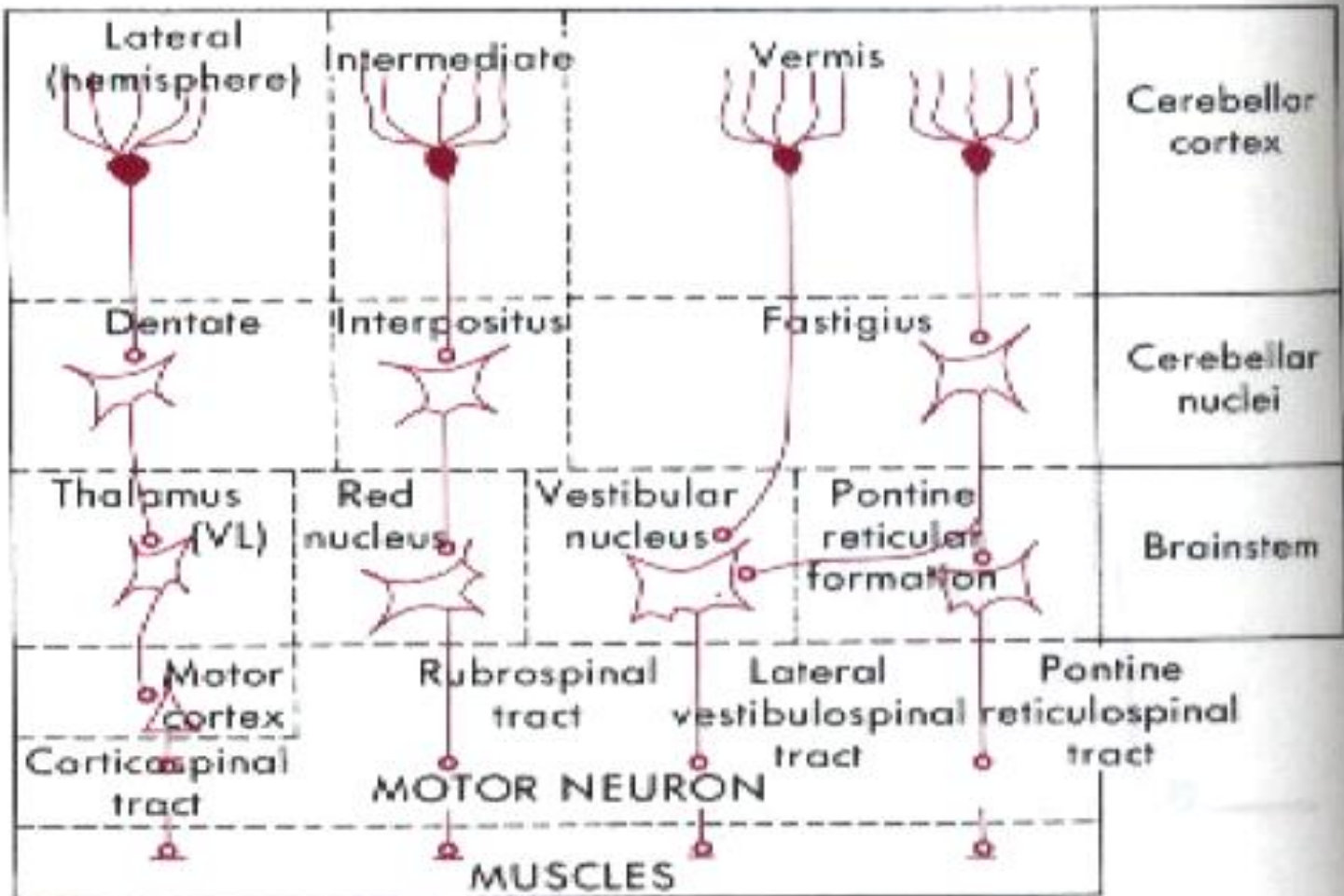


# Efferent Pathways from the Cerebellum

- All efferents go out from deep cerebellar nuclei
- **Vermis**--fastigioreticular tract and from cerebellar cortex **directly to lateral vestibular nuclei**. (i.e. vestibular nuclei are functionally deep cerebellar nuclei)
  - **equilibrium control**
- Intermediate zone—Interpositus (Globose and Emboliform) fine voluntary movements of distal muscles
- Lateral hemisphere-- dentatohalamocortical tract
  - **coordinates agonist and antagonist muscle contractions**



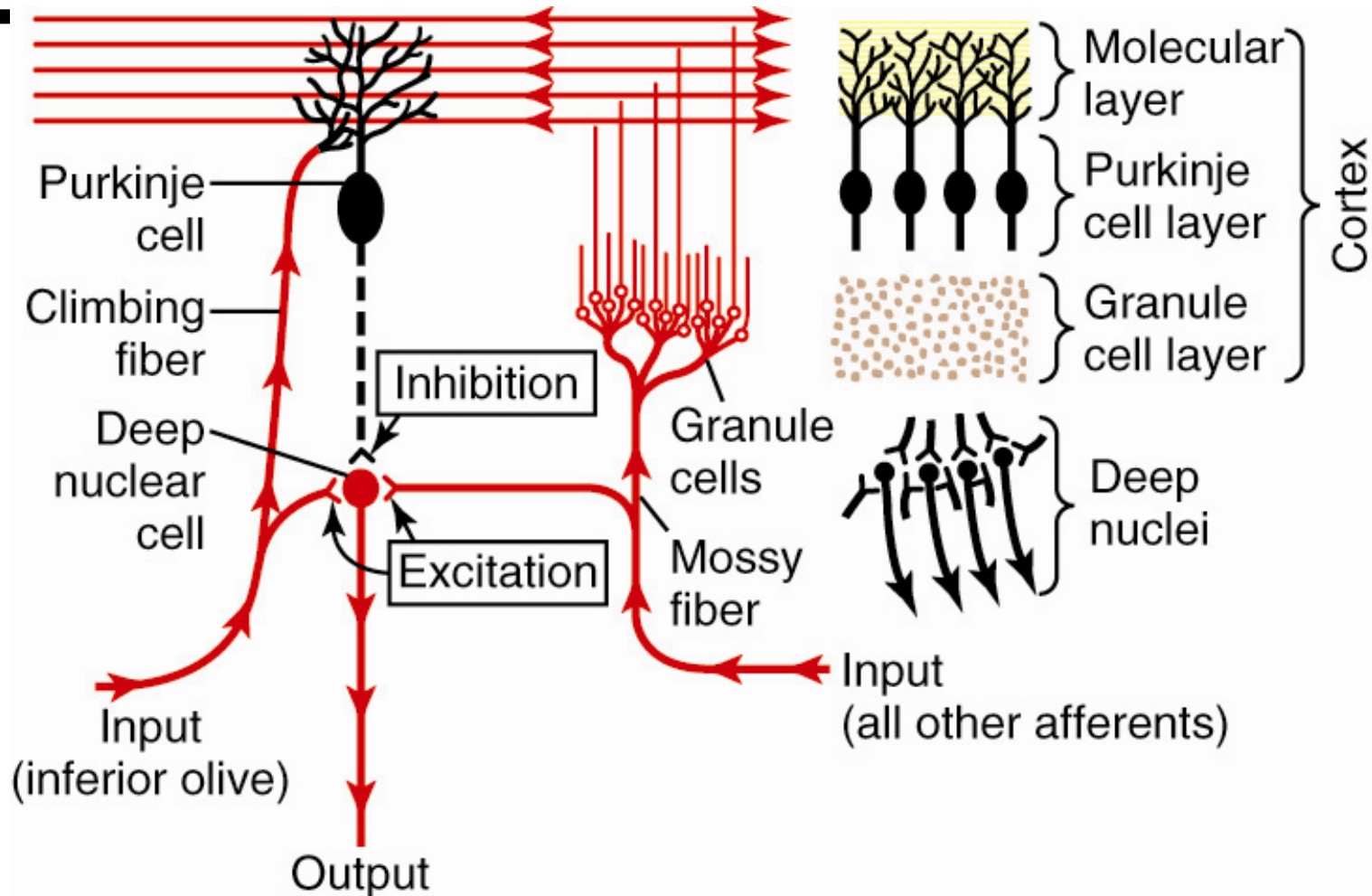
# Efferents of the cerebellum



# Neuronal Organization of the Cerebellar Cortex

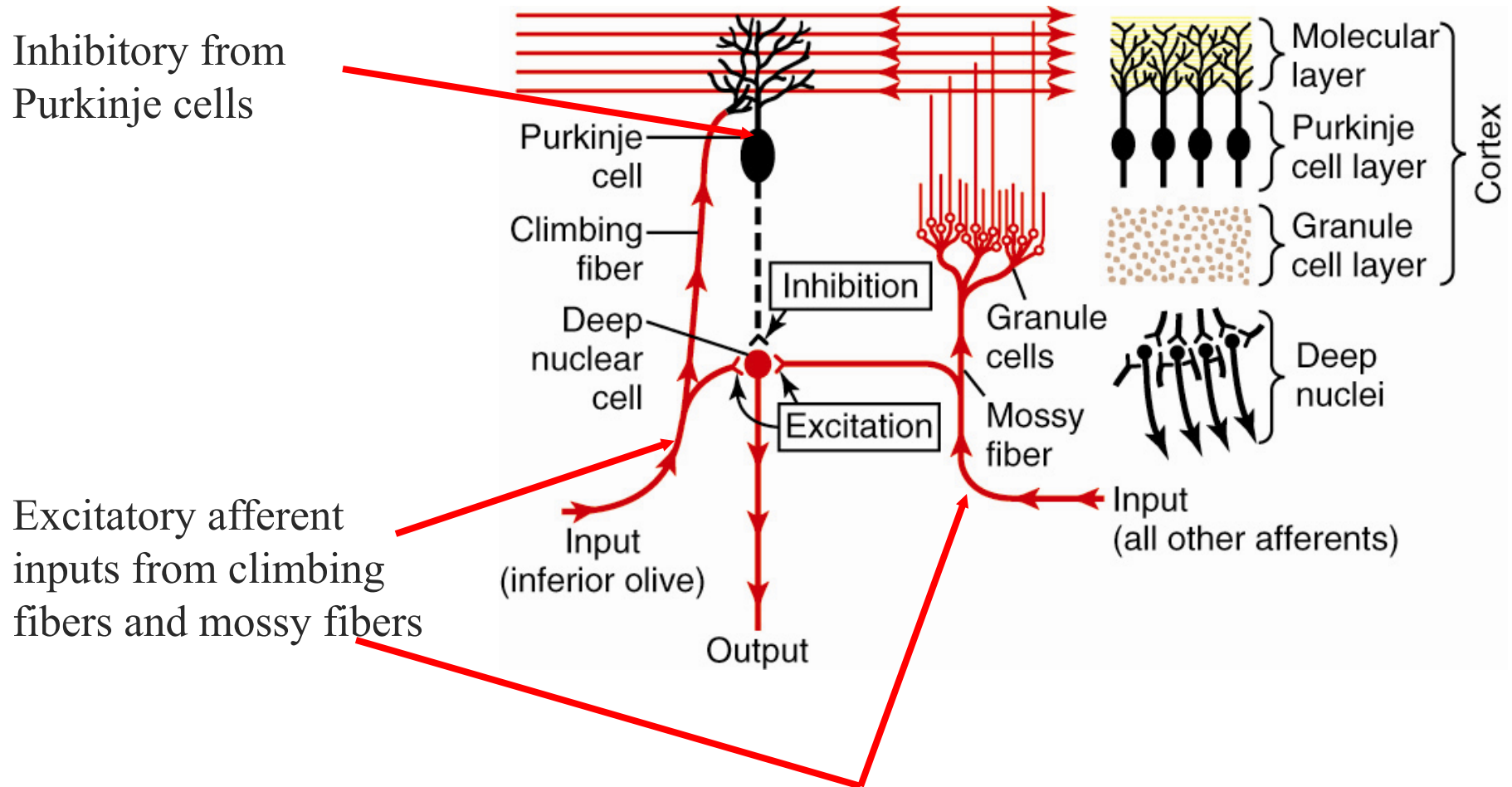
- organized in three layers
  - molecular cell layer
  - Purkinje cell layer
  - granular cell layer
- output from the cerebellum comes from a deep nuclear cell layer located below these layers of cortex

# Organization of the Cerebellum

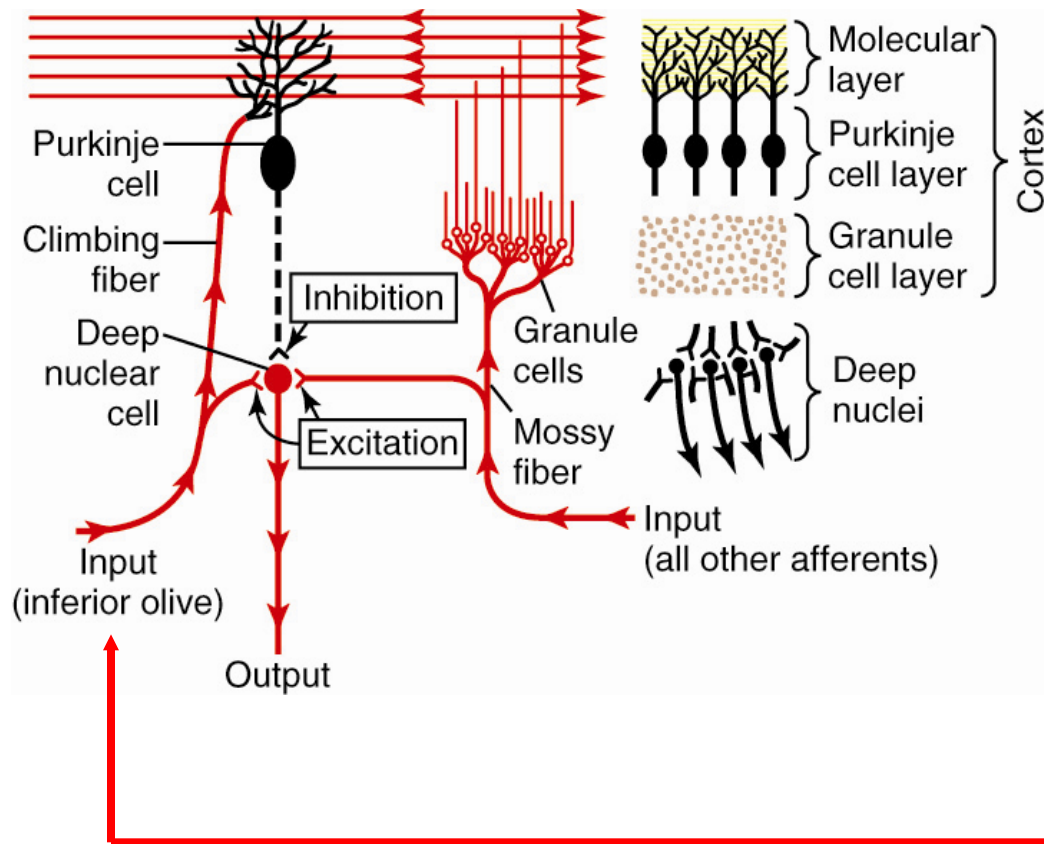


# Neuronal Circuit of the Cerebellum

Deep nuclear cells receive excitatory and inhibitory inputs

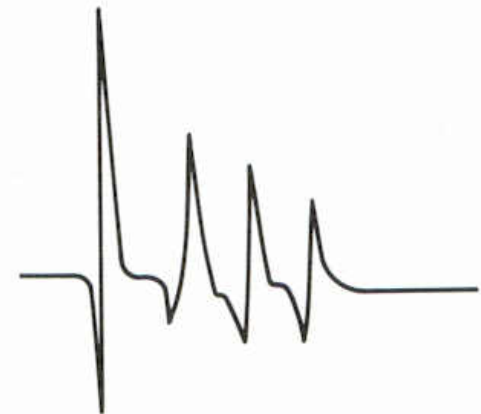


# Neuronal Circuit of the Cerebellum



climbing fibers send branches to the deep nuclear cells before they make extensive connections with the dendrites of the Purkinje cell. Causes **complex spike** output from Purkinje cell.

Complex spike



all **climbing fibers** originate from the inferior olive

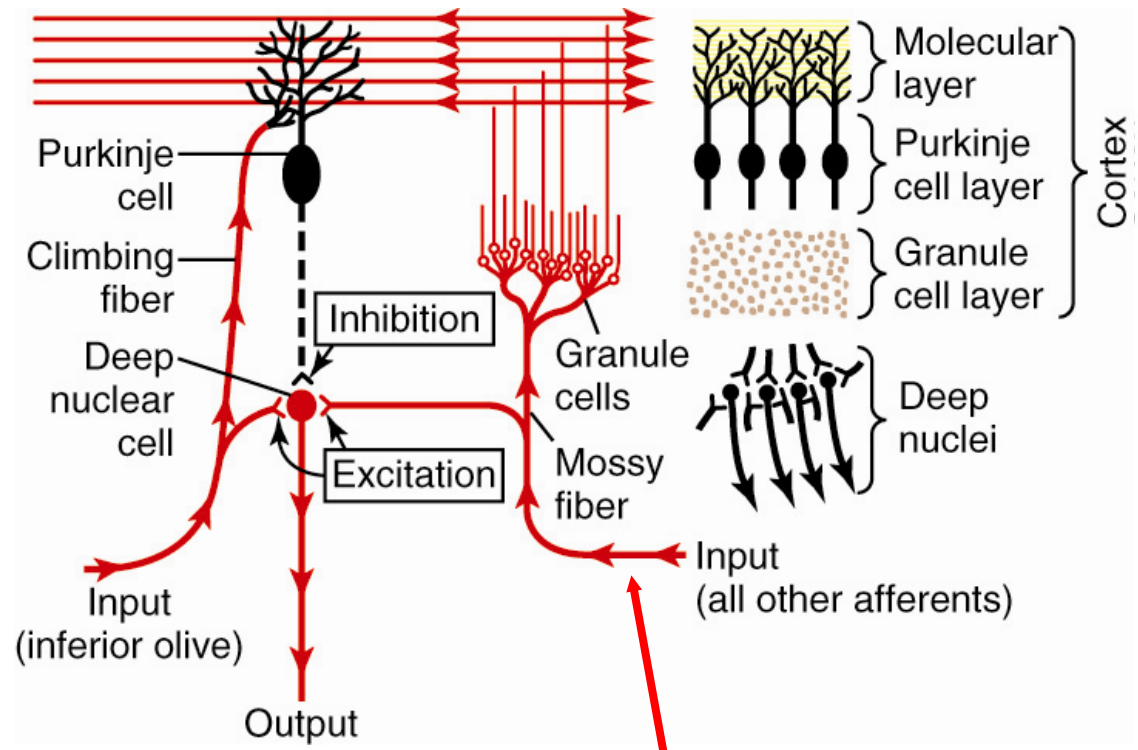
# Neuronal Circuit of the Cerebellum

**mossy fibers** relay all other afferent input into the cerebellum, also send branches to the deep nuclear cell

Simple spike



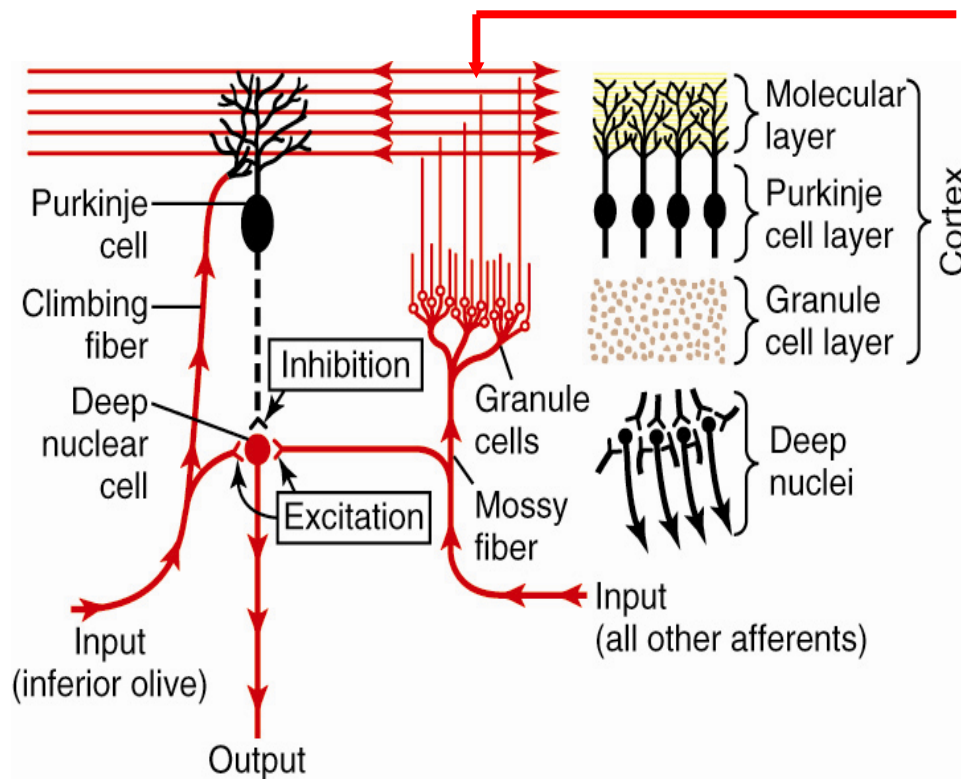
**mossy fiber** stimulation causes a simple spike output



**mossy fibers** terminate in the granular cell layer.



# Neuronal Circuit of the Cerebellum



**granular cells** send axons to the molecular cell layer where they divide and go a few mm in opposite directions to become parallel fibers in the molecular layer

500 - 1000 granule cells for every Purkinje cell, anywhere from 80,000 to 200,000 parallel fibers synapse with each Purkinje cell

# Deep Nuclear Cell Activity

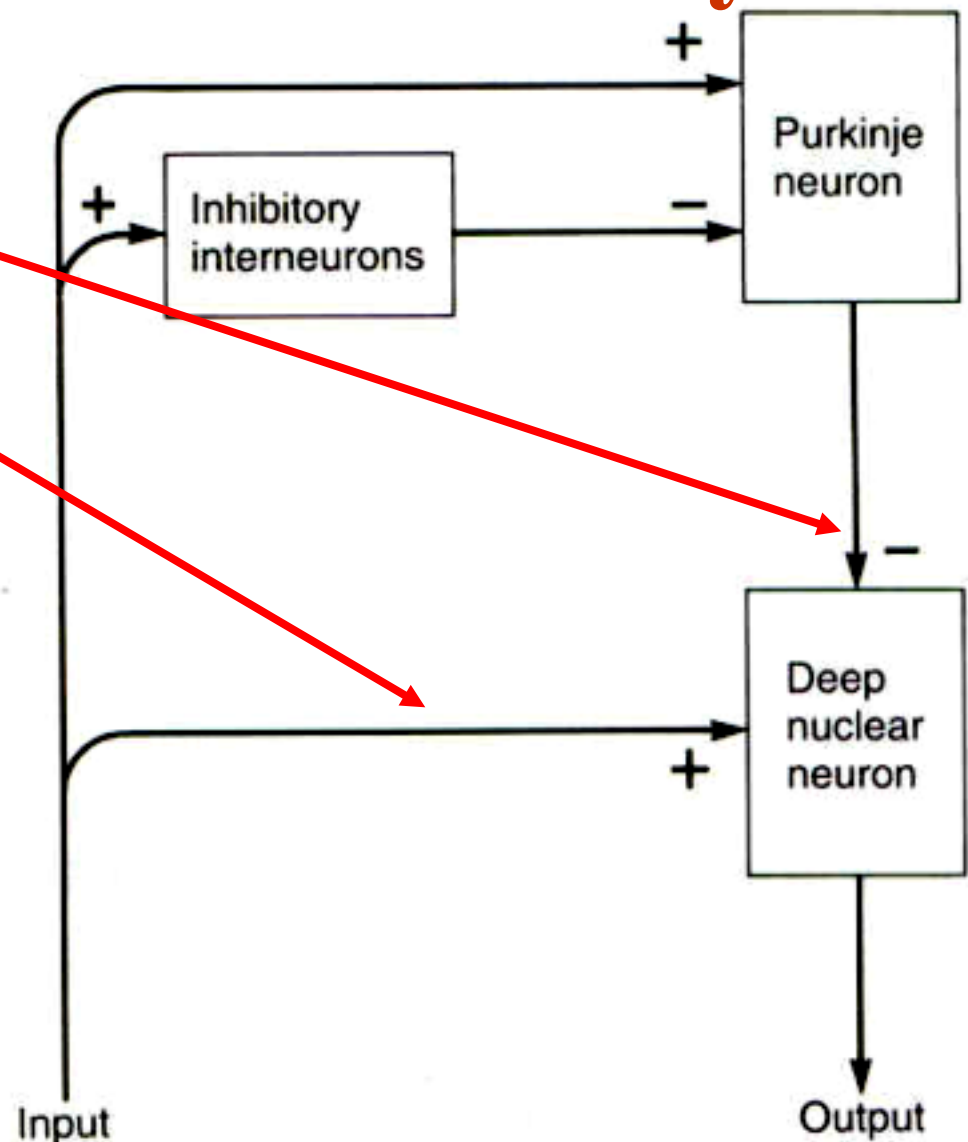
Inhibited by Purkinje cell input

Stimulated by both climbing and mossy fiber input

Normally the balance is in favor of excitation

Deep nuclear cell at first receives an excitatory input from both the climbing fibers and mossy fibers.

This is followed by an inhibitory signal from the Purkinje cells



# [ Deep Nuclear Cell Activity ]

- At beginning of motion there are excitatory signals sent into motor pathways by deep nuclear cells to enhance movement, followed by inhibitory signals milliseconds later.
  - Provides a damping function to stop movement from overshooting its mark
  - Resembles a delay-line type of electronic circuit for negative feedback

# [ The Turn-On / Turn-Off Function ]

- cerebellum contributes to the rapid turn-on signals for agonist muscles and turn-off of antagonist muscles at beginning of a motion
- then it times the opposite sequence at the end of the intended motion
- direct motor pathway via corticospinal tract is enhanced by cerebellum by additional signals to the tract or by signals back to the cortex

# [ The Turn-On / Turn-Off Function ]

- mossy fiber input also to Purkinje cells which activates them after a few millisec., this results in an inhibitory signal to the deep nuclear cell
- this inhibits the agonist muscle which stops its activity

# Purkinje Cells Function to Correct Motor Errors

- precise motor movement must be learned
- **climbing fiber** input adjusts the **sensitivity of the Purkinje cells to stimulation by parallel fibers**
- this **changes the long-term sensitivity of the Purkinje cell to mossy fiber input (i.e., from muscle spindle, golgi tendon, proprioceptor)**
- this **adjusts the feedback control of muscle movement**

# Correction of Motor Errors

- **inferior olivary complex** receives input from:
  - corticospinal tract and motor centers of the brain stem
  - sensory information from muscles and surrounding tissue detailing the movement that actually occurs
- **inferior olivary complex** compares intent with actual function, if a mismatch occurs output to cerebellum through climbing fibers is altered to correct mismatch



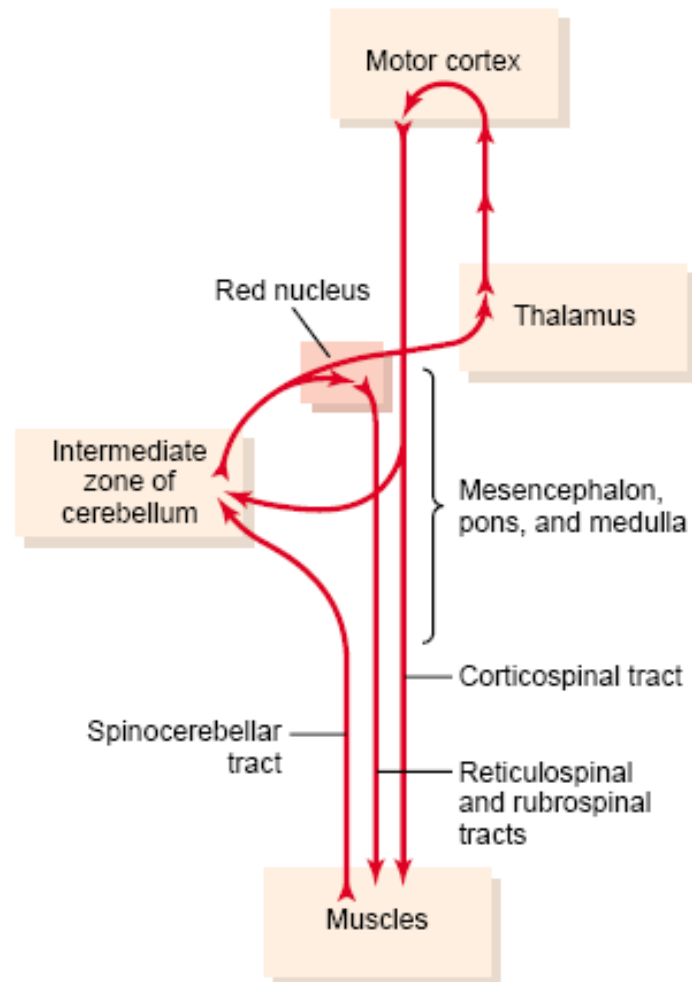
# Motion Control by the Cerebellum

- most cerebral cortical motions are **pendular**, therefore, there is **inertia and momentum**
- to move a limb accurately it must be **accelerated and decelerated** in the right sequence
- cerebellum **calculates momentum and inertia and initiates acceleration and braking activity**

# Predictive and Timing Function of the Cerebellum

- motion is a series of discrete sequential movement
- the **planning and timing** of sequential movements is the function of the **lateral cerebellar hemisphere**
- this area communicates with **premotor** and **sensory cortex** and corresponding area of the **basal ganglia** where the **plan originates**
- the lateral hemisphere **receives the plan and times the sequential events to carry out the planned movement**

# Cerebellar Voluntary Control



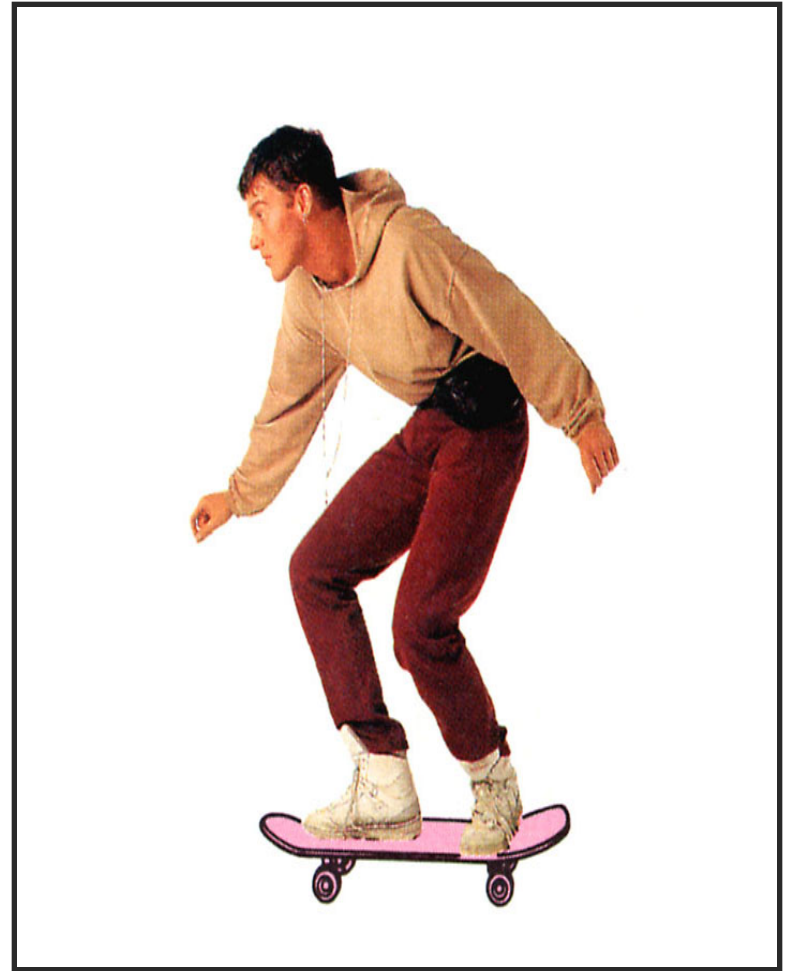
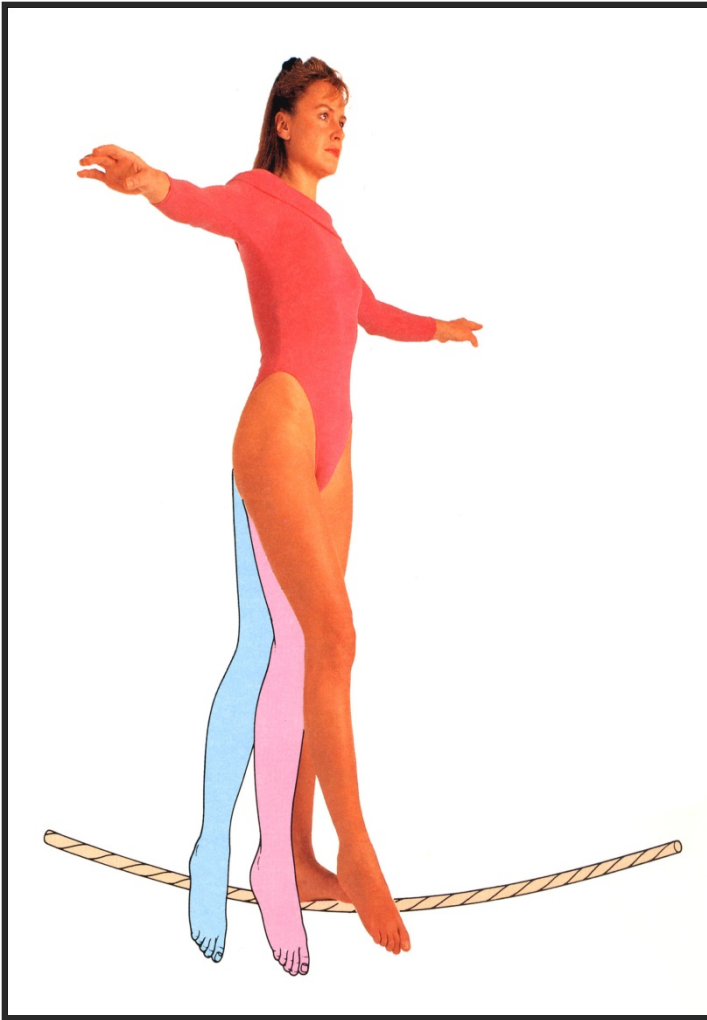
# Cerebellar Disorders

# [ *1) Flocculonodular Lobe Disorders* ]

- It is manifested by:-
- **1) Swaying** during standing, with a tendency to fall down.
- **2) Unsteady (staggering) gait** → wide-based (drunken gait) in order to provide better equilibrium during walking.
- **Tandem gait: walk heel-to-toe in a straight line**

## [ 2) *Vermal Disorders* ]

- It is manifested by:-
- inability to **maintain the upright standing posture** due to **failure to adjust the tone and contractility of antigravity ms.**





### *3) Neocerebellar syndrome*

- *Causes*

- It results from vascular strokes, degenerative disorders, or tumours.

- *Manifestations*

- It is manifested by:
  1. Hypotonia,
  2. Asthenia
  3. Ataxia.

# [ *A) Hypotonia* ]

- - Hypotonia → ↓ ms tone in skeletal ms of the affected side of the body → due to ↓ed facilitation of the  $\gamma$ -MNs, as a result of ↓ed supraspinal facilitation.
- - Hyporeflexia → ↓ somatic reflexes.
- - Pendular knee jerk.

## [ *B) Asthenia* ]

- There is weakness of movements and the involved ms fatigue more readily than do normal ms, resulting from interruption of the activating effect of the cerebellum on the cerebral cortical motor areas.

## *C) Ataxia (or Asynergia)*

- Ataxia means incoordination of voluntary movements.
- Cerebellar ataxia can manifest itself in a number of ways:-

# [ *C) Ataxia (or Asynergia)* ]

## ■ I) Dysmetria

- There are errors in the range and direction of the movement.
- The moving limb more often overshoots the intended point (hypermetria or past -pointing), but sometimes the limb undershoots the intended point (hypometria).
- These errors result from failure of the "comparator" and "damping" functions of the cerebellum that normally adjust the course of the movement and bring it smoothly to the desired position.

## ***(C) Ataxia (or Asynergia)***

### **2) Intention Tremors (Kinetic Tremors)**

■ They appear when the patient performs a voluntary motor act, not seen when the ms are at rest.

### **3) Decomposition of Complex Movements**

■ The motor act is carried out as several fragmented steps rather than a smoothly progressing movement.

■ For instance, in reaching for an object by the hand, the cerebellar patient may first move the shoulder joint, then the elbow, followed by the wrist and fingers → simulate movements of a "robot".



## [ *C) Ataxia (or Asynergia)* ]

- **4) Rebound Phenomenon**
- The cerebellar patient is unable to stop the ongoing movement rapidly due to failure of the predictive and damping functions of the cerebellum. This can be observed in what is called "rebound phenomenon".
- When there is a flexion of the forearm against resistance (provided by the examiner's hand), the cerebellar patient cannot stop the resultant inward movement of his limb in due time following its release, and the forearm flexes forcibly and may strike his body with considerable violence.





## [ *C) Ataxia (or Asynergia)* ]

### ■ 5) Dysdiadochokinesia

- • Dysdiadochokinesia → inability of the patient to perform rapid alternating opposite movements e.g. rapid repetitive pronation and supination of forearm.
- The movements are slow and irregular.
- • It results from failure to adjust precisely the proper timing for the onset and termination of the successive alternating contractions of the opposing ms groups.

# [ *C) Ataxia (or Asynergia)* ]

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- **6) Nystagmus**
- Nystagmus of cerebellar disorders is a tremor of the eye balls as a result of "dysmetria" of the "saccadic movements" of the eyes.

# [C) Ataxia (or Asynergia)]

- 7) Scanning Speech (Dysarthria)
- Speech becomes slow and decomposed.
- Each word is fragmented into several separate syllables, producing "scanning" or "staccato" speech, like someone trying to speak an obscure foreign language for the first time.
- Decomposition of words is due to failure to adjust the precise timing of contraction of the different ms of speech.

## *C) Ataxia (or Asynergia)*

- **8) Unsteady Gait**
- The gait is unsteady and broad-based due to dysmetria and kinetic tremors of the lower limb ms.

[

]





# Clinical Abnormalities of the Cerebellum

- All signs of cerebellar diseases are ipsilateral since there is double crossing- from cortex to pons and back to cortex
- Ataxia and intention tremor
  - failure to predict motor movement, patients will overshoot intended target, **past pointing**.
  - Dysequilibrium- ataxic (staggering) gait (drunken gait)
- Dysdiadochokinesia (Adiadochokinesia)
  - failure of orderly progression of movement
- Dysarthria
  - failure of orderly progression in vocalization
- Cerebellar nystagmus
  - intention tremor of the eyes when trying to fix on object.





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