Motor Systems
and
Motor Control

Motor Movements

Reflex Responses

Rhythmic Motor Patterns

Voluntary Movements

Muscle Control

Must convey accurately timed commands not only to one muscle group but to many groups.

Agonist and Antagonist muscle groups.

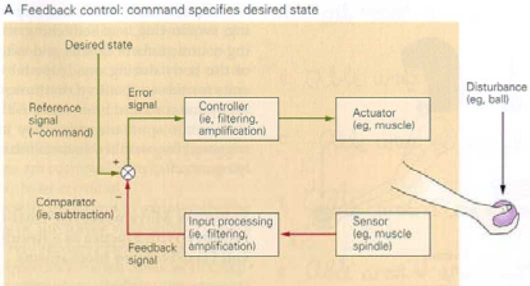
Motor Plant

Sensory Systems

Are vital to the correct functioning of motor systems

Feedback Mechanism

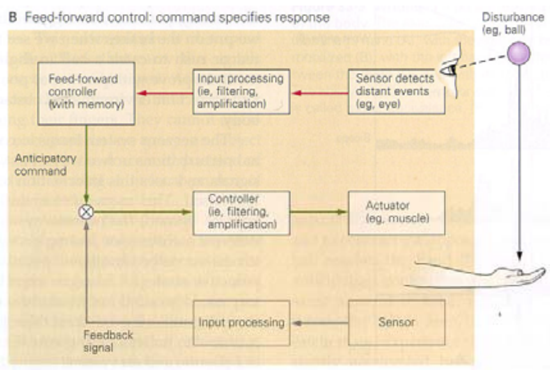
A Feedback control: command specifies desired state



- **Slow Processing**
- **Mainly limited to slow movements & sequential acts.**

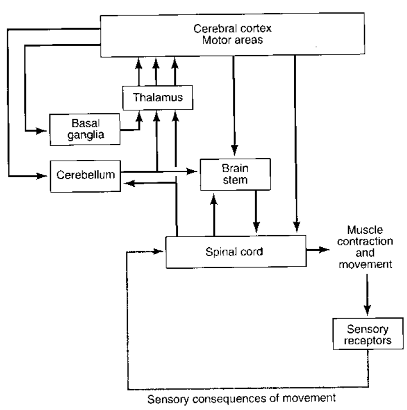
Feed Forward Mechanism

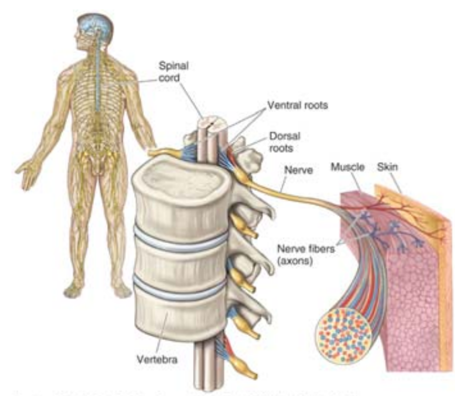
- **Predicting movements**
- **Quick dynamic movements**



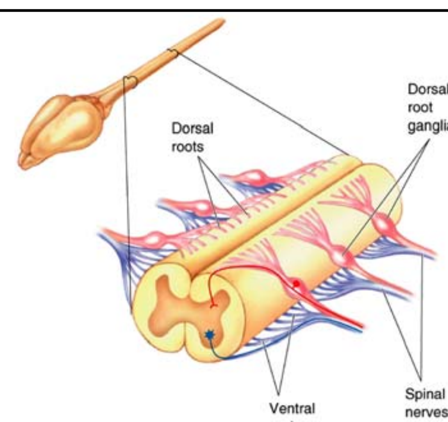
Hierarchy of Motor Control

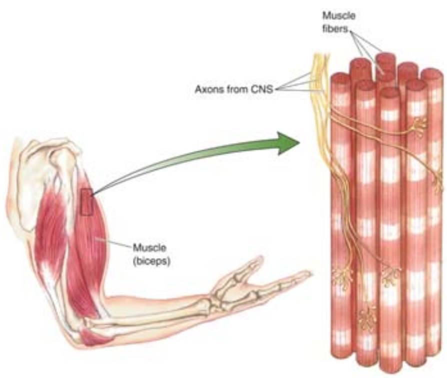
- Spinal Cord
- Brainstem
- Cortical Motor Areas

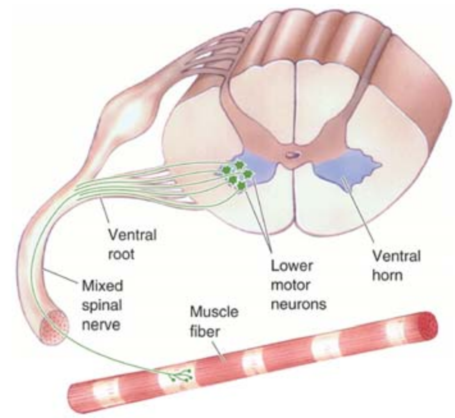


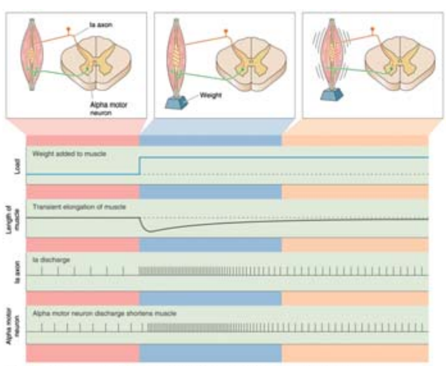


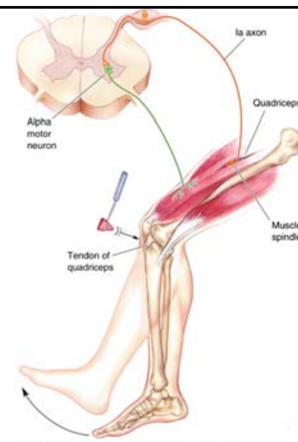
Muscle Receptors, Spinal Reflexes, and Local Control of Motor Movements





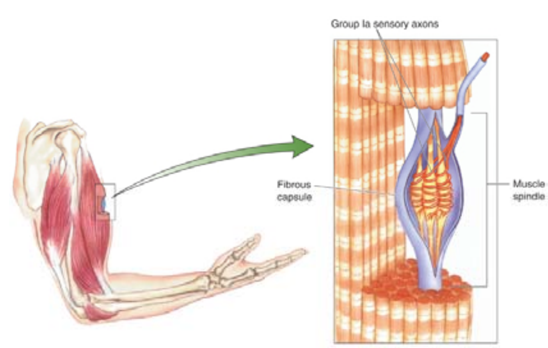






Muscle Stretch Receptors:

- **Muscle Spindles**
- **Golgi Tendon Organs**



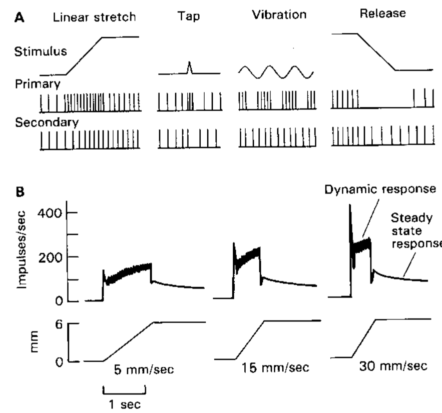
Muscle Spindle Receptors:

Specialized muscle fibers

- **Nuclear chain fibers - short, slender, ~5 in number**
- **Nuclear bag fibers - thicker, longer, 2 types**
  - **Dynamic (1)**
  - **Static (1)**

Very sensitive to the rate of change of muscle length.

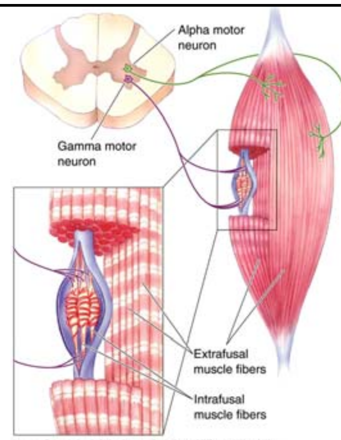
Velocity Sensitivity

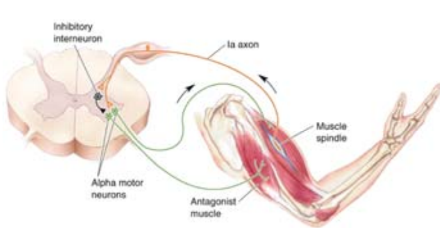


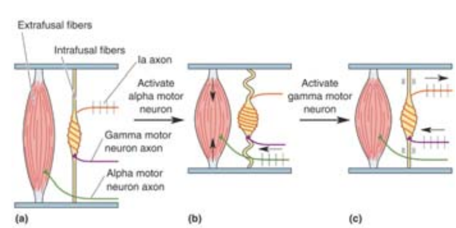
Muscle Spindle Receptors:

- **Motor neuron innervation is located on ends of intrafusal fibers.**
- **Regulate muscle length.**
- **Regulate muscle sensitivity**

Gamma Motor Neurons

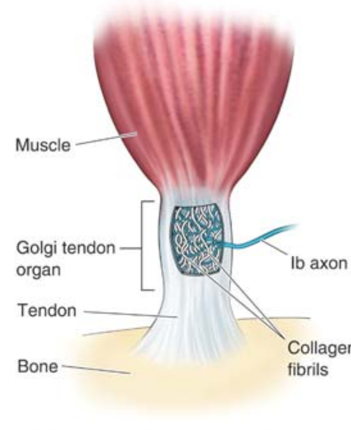






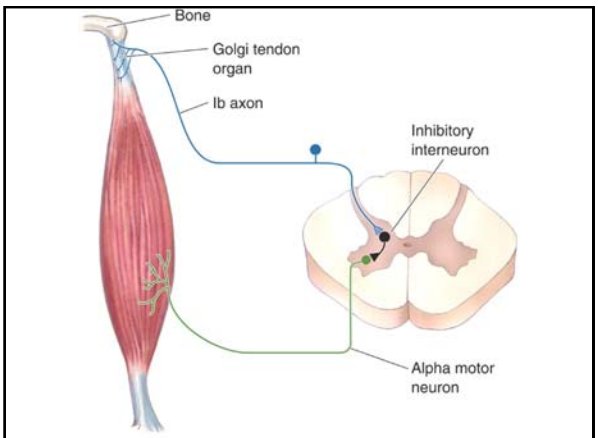
Golgi Tendon Organ:

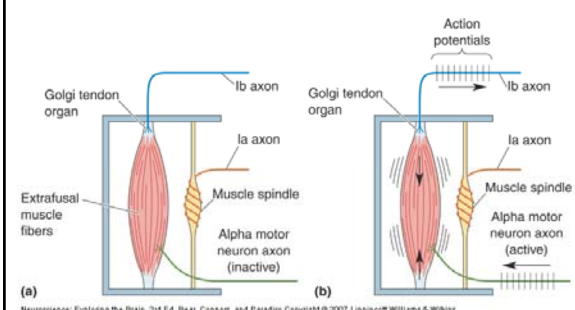
- Located at the junction of muscle and tendon.
- Looses myelination & braids itself within the collagen fibers of the tendon.



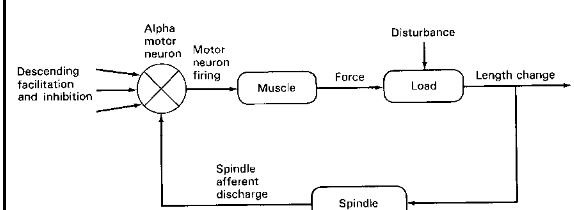
Stretching of capsule compresses nerve endings, causing the neuron to fire.

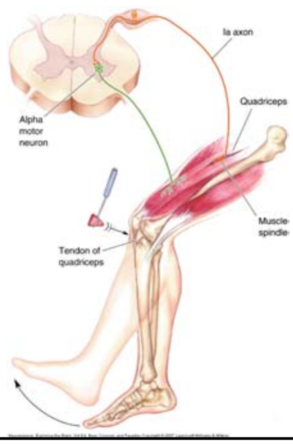
Very sensitive to changes in tension of muscle.



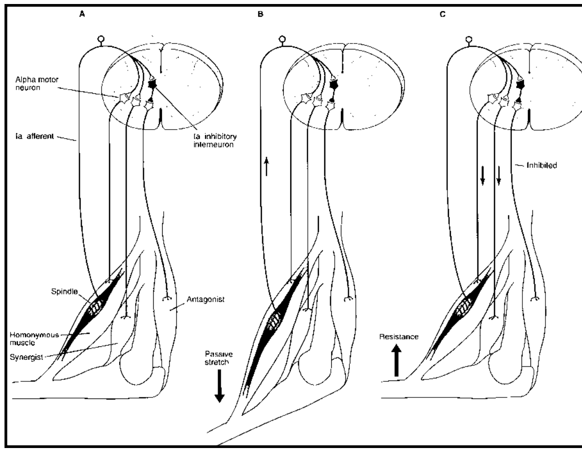


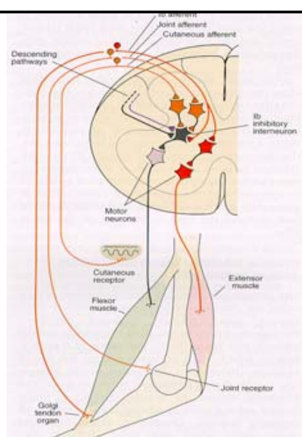
The Stretch Reflex

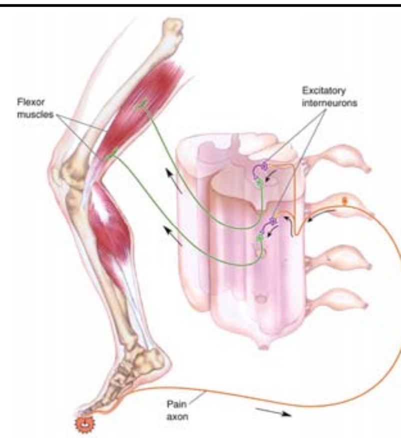


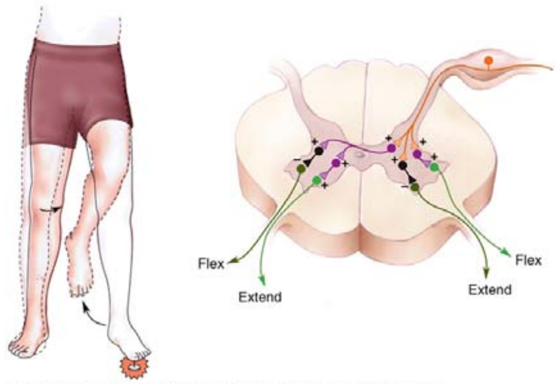


Myotatic Reflex

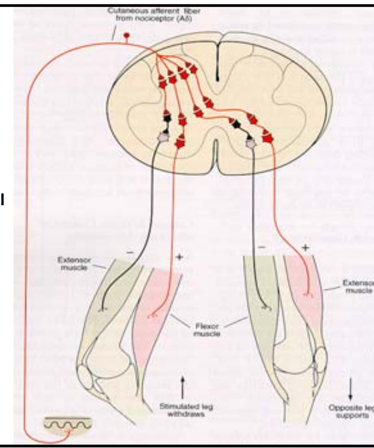


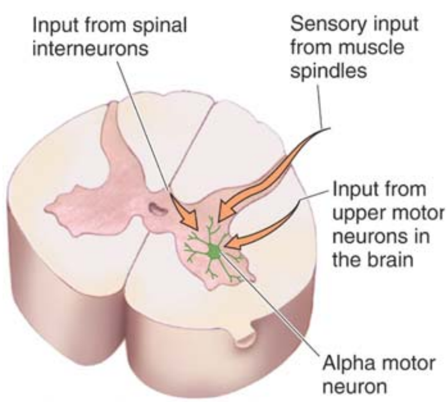






Flexion - Withdrawal Reflex





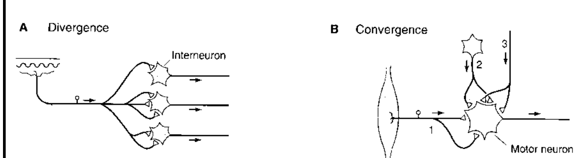
Spinal and Postural Mechanisms

Neural circuits (microcircuits) within the spinal cord play an essential role in motor coordination.

Interneurons are a vital player in these microcircuits.

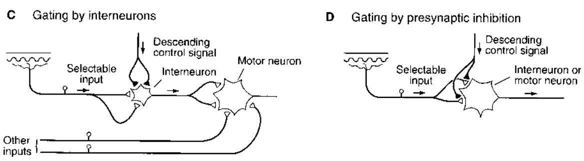
Interneurons can be either inhibitory or stimulatory within the circuits they are residing.

Divergence - the distribution of the output of a single neuron (or a group of neurons) to a number of target neurons by branching of the axon.

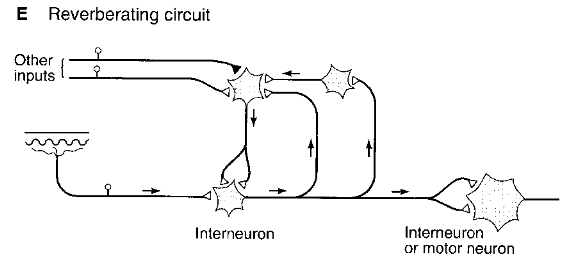


Convergence - the processing of input from several neurons (or groups of neurons) onto one neuron (or neuronal group).

Gating **- intermediate neurons (interneurons) or intermediate connections utilized by higher centers to preselect which of several possible responses will follow a stimulus.**



Spatial Organization

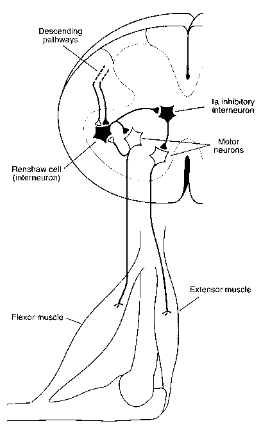


Temporal Organization

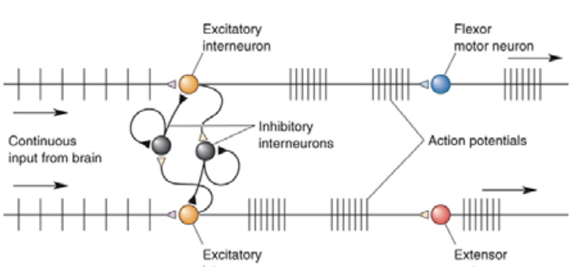
Renshaw Cell (neuron) - Inhibitory interneuron

The connections of Renshaw cells to presynaptic motor neurons form a negative feedback system, which regulates the firing rate of the motor neurons.

They not only inhibit certain motor neurons, they also disinhibit antagonist motor neurons.

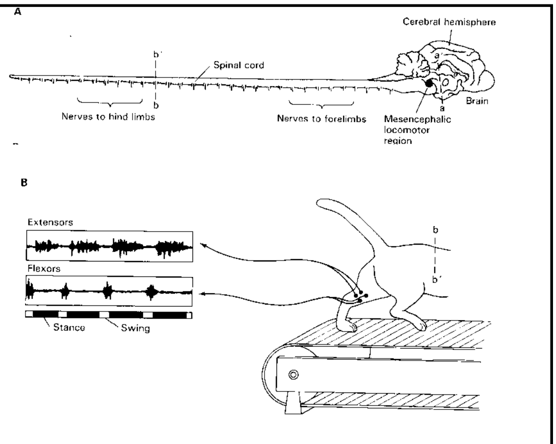


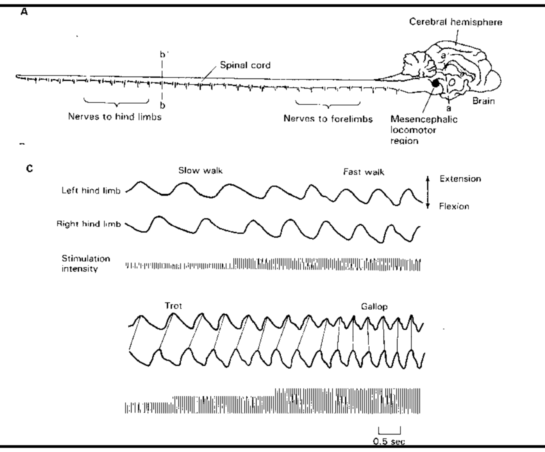
Rhythmic Movements



Spinal Circuits for Rhythmic Locomotor Patterns

- ***Normal locomotion is attributed to spinal circuits.***
- ***Decerebrate and sensory lesioned preparations both demonstrated rhythmic activity for locomotion.***
- ***Central pattern generators for locomotion are innate and specialized for each limb individually.***
- ***Mesencephalic locomotor region controls locomotor activity (Dopamine, Norepinephrine, Glutamate (NMDA))***





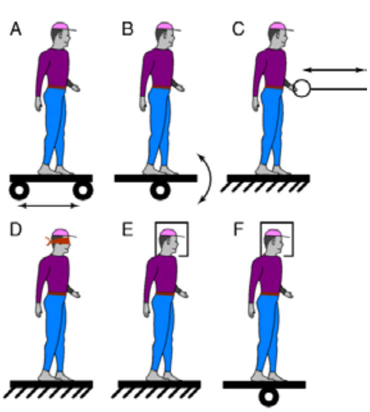
Posture

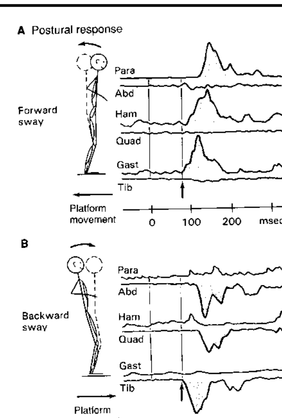
Reasons for Postural Motor Mechanisms:

- Support the head and body against gravity and other external forces.
- Maintain the center of the body's mass: aligned and balance.
- Stabalize supporting parts of the body while other muscles are being moved.

Mechanisms:

- Anticipatory or Feedforward
- Compensatory or Feedback



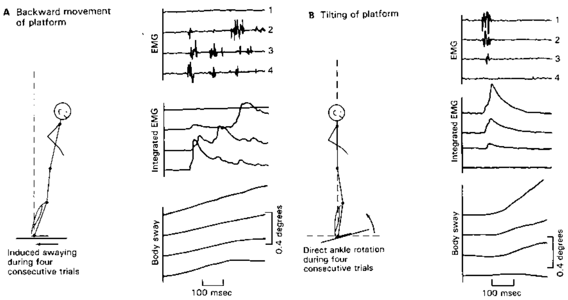


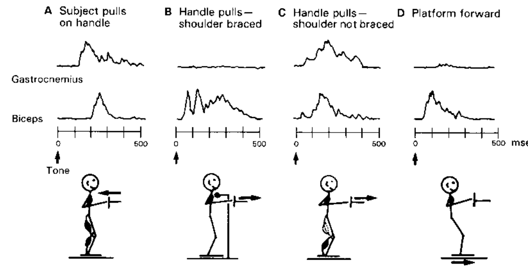
The first muscles to contract are those that are closest to the base of support." (ks&j, pg 597)

Triggering mechanism:

- **Muscle proprioception**
- **Vestibular sensation**
- **Visual sensation**

"An individual's postural response to a stimulus is shaped by experience, and the form of the response is adjusted so that balance is maintained." ks&j pg. 598





"Postural muscles contract to maintain equilibrium before destabilizing movements are executed."

Postural adjustments anticipate the occurrence of changes that would cause the loss of balance.

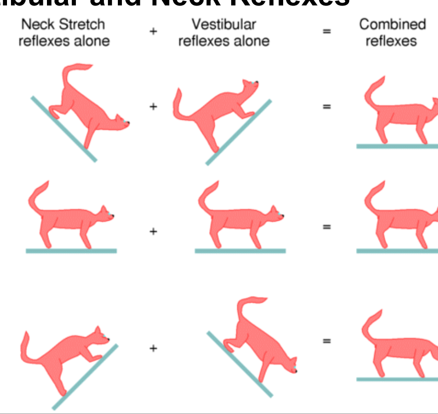
This feedforward control is essential for coordinating posture with voluntary movement.

When changes actually occur, feedback mechanisms produce rapid corrective responses. When we can predict the nature of the change, but not its exact timing, higher motor centers enhance or reduce the strength of short-latency pathways that operate automatically.

Vestibular and Neck Reflexes

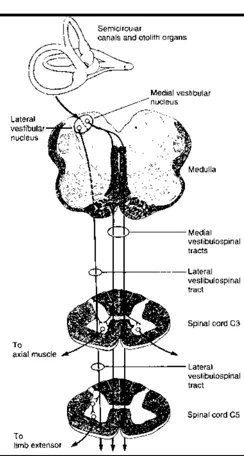
Vestibular reflexes are evoked by changes in the position of the head.

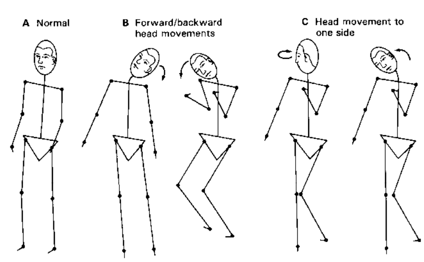
Neck reflexes are evoked by tilting/bending of the neck.



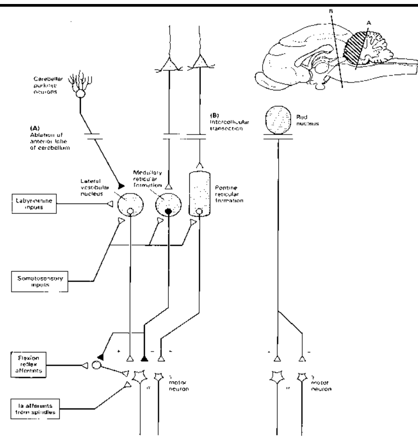
Vestibulocollic reflexes - counteract head movements keeping the head stable.

Vestibulospinal reflexes - contract the limb muscles and prepare the subject for landing during falls.





Cervicocollic reflexes contract neck muscles that are stretched. (vestibulocollic reflexes)



Control of Voluntary Motor Movement by the Brainstem Nuclei

3 Main Brainstem Motor Pathways

Ventral Pathway -

- Terminate in the ventromedial part of the spinal grey matter.
- Influence motor neurons that innervate axial and proximal muscles.

Lateral Pathway -

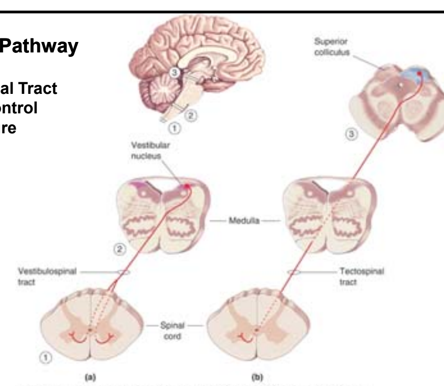
- Terminate in the dorsolateral part of the spinal grey matter.
- Influence motor neurons that control distal muscles of the extremities.

Aminergic Pathway -

- Terminate at all levels of the spinal cord.
- Modulate excitability of neurons at all levels of the cord.

Ventral Pathway

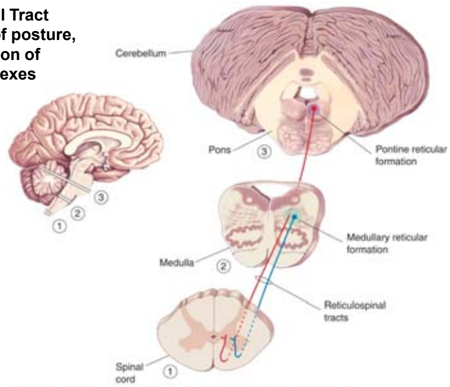
Vestibulospinal Tract
- Reflex control and posture



Tectospinal Tract
- Coordination of head and eye movements

Reticulospinal Tract

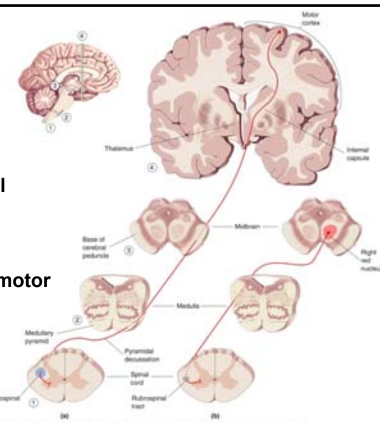
- **Control of posture, suppression of spinal reflexes**

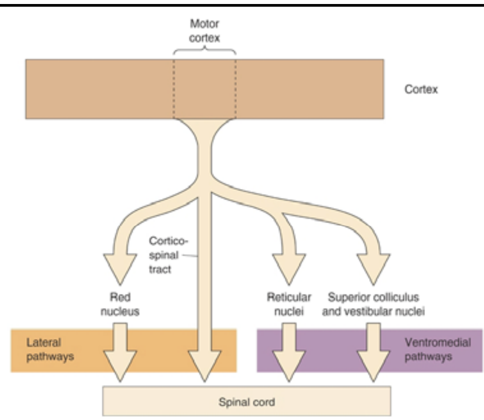


Lateral Pathway

Rubrospinal Tract

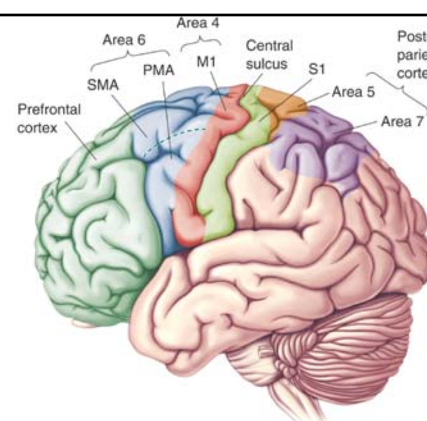
- **Medial & Lateral**
- **Red nucleus**
- **Control of fine motor movements**

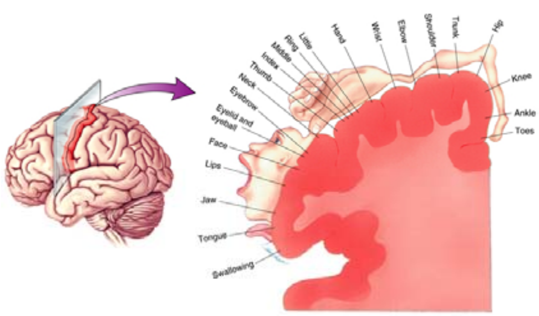




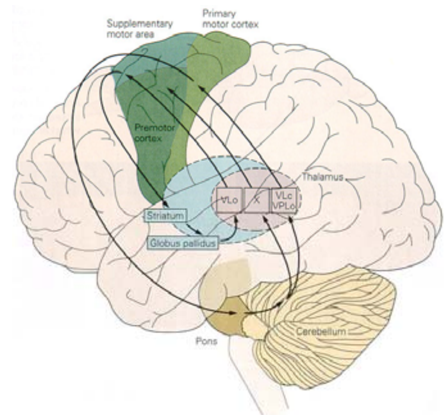
Voluntary Movement & Cortical Control of Motor Movement

- **Differs from the postural and spinal reflexes.**
- **Different strategies to achieve same goal.**
- **Improves with experience.**
- **Doesn't need to use stimuli to elicit activity.**





Neuroscience: Exploring the Brain, 3rd Ed, Bear, Connors, and Paradiso Copyright © 2007 Lippincott Williams & Wilkins



Primary Motor Cortex

Neurons encode for the force of contraction.

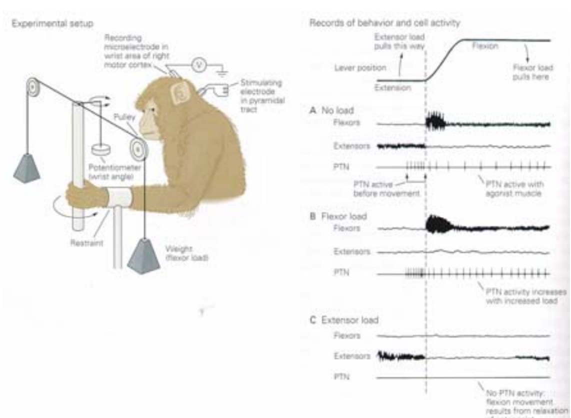
Individual neurons will control small groups of muscles.

- usually more closely associated with distal muscles.
- more than one muscle (or group of muscles) may be activated by a single cortical neuron.
- divergence of cortical neurons at the brainstem and spinal cord level.

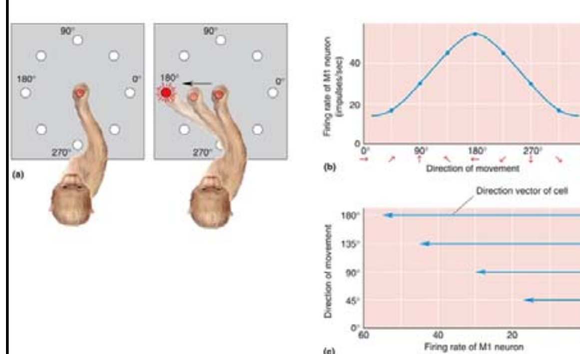
Primary Motor Cortex (Precentral Gyrus, Area 4)

Individual neurons will encode for the amount of force to be exerted and not the position of the limb.

This activity typically occurs before the contraction of the muscle.



Individual neurons vary there activity with the direction of movement.



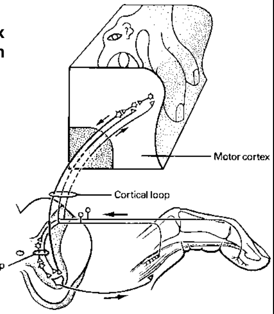
Neuroscience: Exploring the Brain, 3rd Ed, Bear, Connors, and Paradiso Copyright © 2007 Lippincott Williams & Wilkins

Voluntary behavior (movement) is determined by the activity of a rather large population of neurons and cannot be predicted from the discharge patterns of any one neuron.

Although neurons in the primary motor cortex encode for direction and force exerted during movement, their contribution is not invariant and depends on the nature of the task being performed. (ks&j, pg. 616)

Neurons in the primary motor cortex are kept informed about the position of the limb and the speed of movement through sensory input.

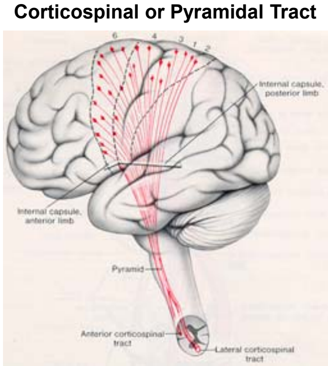
Motor cortex functions in parallel with the spinal cord stretch reflex.

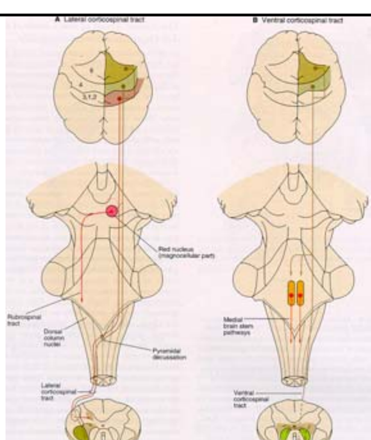


Provide assistance, supplementing the stretch reflex, when the moving limb encountered an unexpected obstacle.

Primary Motor Cortex Projections

Corticospinal or Pyramidal Tract





Primary Motor Cortex Projections

- Make direct and powerful excitatory connections with alpha motor neurons
- Although the corticospinal tract projects to motor nuclei controlling proximal and distal muscles, the corticospinal tract is the only pathway that controls the distal muscles of the fingers.

Premotor Areas of Cortex (Supplementary motor area and Premotor cortex, Area 6)

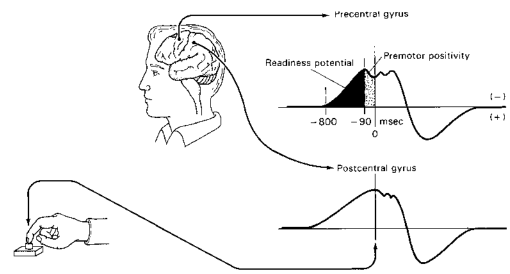
Movements are more complex in nature and require larger stimulus currents than those produced by stimulation of the primary motor cortex.

Receives Information from:

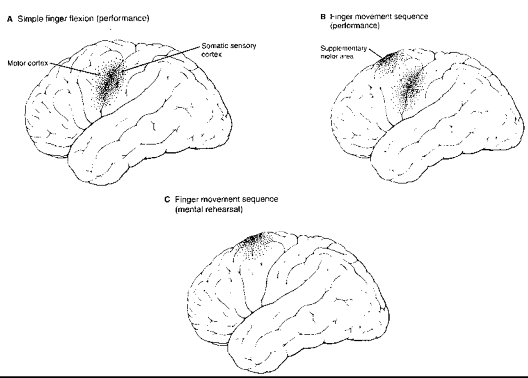
- Somatosensory cortex
- Basal Ganglia (via VL)
- Cerebellum (via VL and VPL)

Premotor Areas of Cortex (Supplementary motor area and Premotor cortex, Area 6)

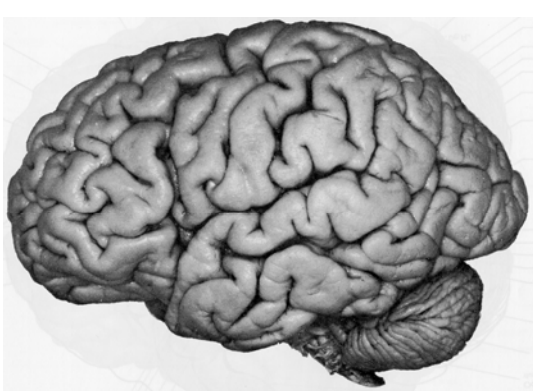
Programming and preprogramming complex sequences of movement.

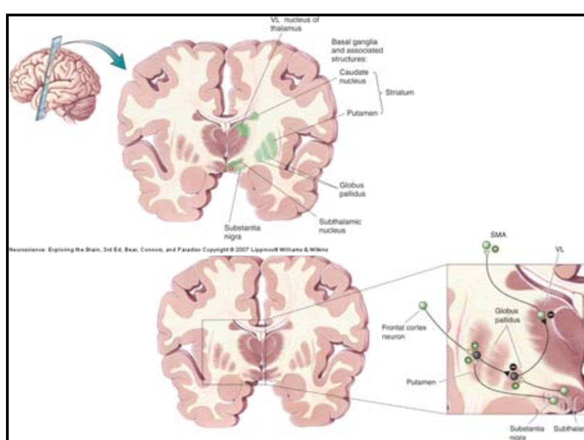


Supplementary Motor Cortex is only important in programming and planning of complex movements, not executing them.



Basal Ganglia Involvement in Motor Control





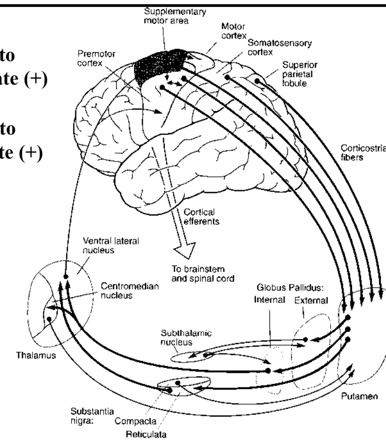
Connectivity of the Basal Ganglia

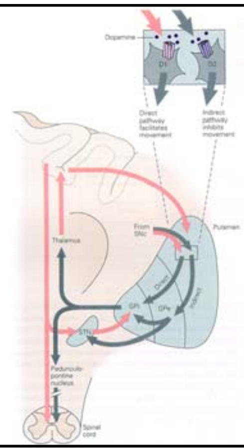
A collection of overlapping circuits responsible for higher order *<u>cognitive</u>* planning of motor control and *cognitive functioning in general*.

Cortical Inputs to Striatum = Glutamate (+)

Thalamic Inputs to Striatum = Glutamate (+) and Opioid ?

Most output connections utilize GABA (-) as their neurotransmitter.





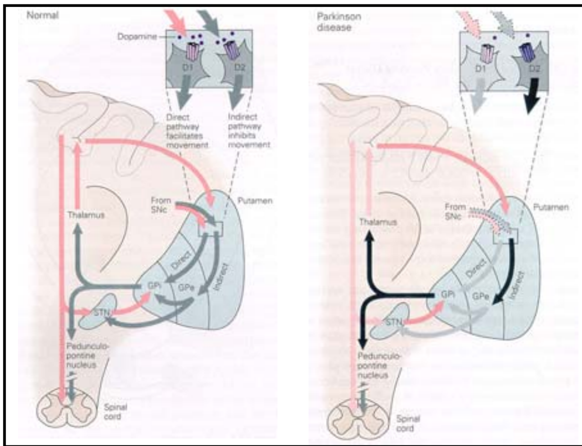
What do the Basal Ganglia do?

- **Selectively facilitate some movements and suppress others.**
- **Compare commands for movement from the precentral motor fields with proprioceptive feedback from the evolving movement.**
- **Involved in the initiation of internally generated movements.**

Movement Disorders of the Basal Ganglia

Parkinson's Disease: clinical make-up

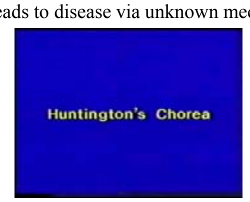
- Alternating tremor (resting tremor): "pill-rolling", oscillating
- Plastic rigidity, increase tone in all muscles
- Flexed posture
- Difficulty in moving (akinesia, hypokinesia)
- Mask like facial expression, absense of arm movements when walking
- Massive degeneration of Substantia Nigra, Striatum, and frontal cortex



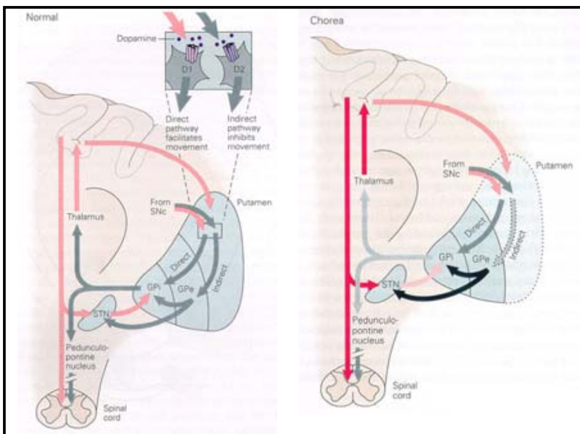
Huntington’s Disease: clinical make-up

- Severe Choreiform motor disability, random and continuous
- Decrease in muscle tone
- Reflexes and sensations are normal
- Athetosis
- Progressive, inherited, onset usually 35 - 40 yrs of age.
- Atrophy of striatum

Huntington's disease results from a gene mutation causing abnormal repetition of the DNA sequence CAG that codes for the amino acid glutamine. The resulting gene product, a large protein called huntingtin, has an expanded stretch of polyglutamine residues, which leads to disease via unknown mechanisms.



Huntington's disease affects both sexes equally. The caudate nucleus atrophies, the inhibitory medium spiny neurons in the corpus striatum degenerate, and levels of the neurotransmitters γ-aminobutyric acid (GABA) and substance P decrease.

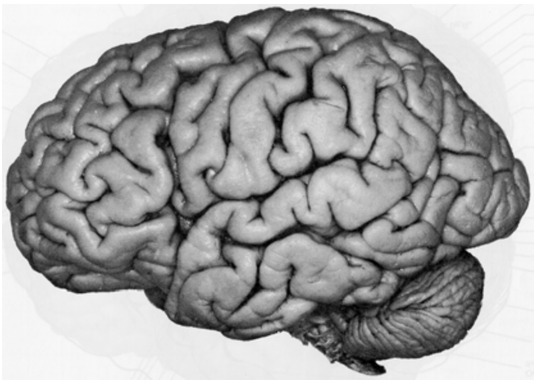


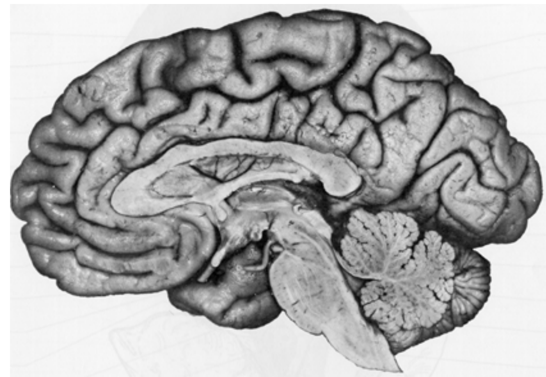
Athetosis:

Tourette’s Syndrome

Hemiballism:

The Cerebellum and the Control of Motor Movement





Cerebellar Function:

Regulates movement and posture indirectly by adjusting the output of the major descending motor systems of the brain.

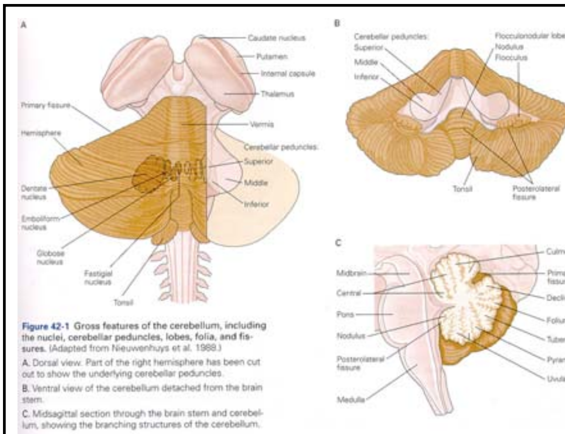


Figure 42-1 Gross features of the cerebellum, including the nuclei, cerebellar peduncles, lobes, folia, and fissures. (Adapted from Nieuwenhuys et al. 1988.)

A. Dorsal view. Part of the right hemisphere has been cut out to show the underlying cerebellar peduncles.

B. Ventral view of the cerebellum detached from the brain stem.

C. Midsagittal section through the brain stem and cerebellum, showing the branching structures of the cerebellum.

Anterior Lobe ← **Muscle spindles, stretch receptors, golgi tendon organs, Spinocerebellar tract**

muscle tone

Posterior Lobe ← **Neocortex, Pontine Nuclei**

free motor movement and planning

Flocculo-nodular Lobe ← **Vestibular Nuclei**

Equilibrium and posture

Cellular Circuitry of the Cerebellum

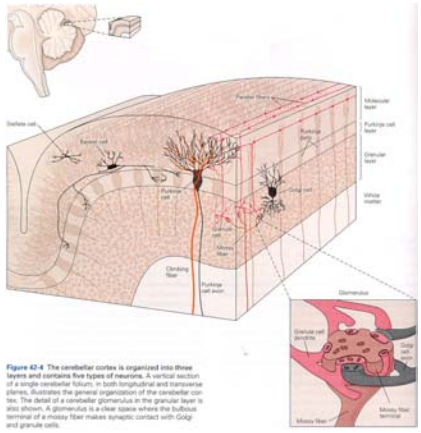


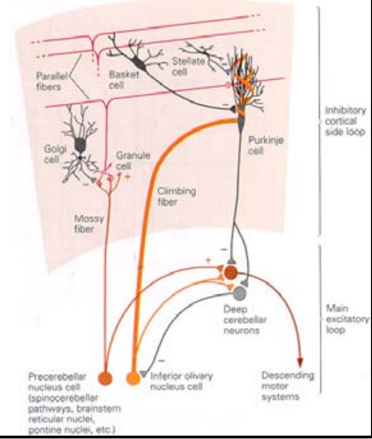
Figure 42-4 The cerebellar cortex is organized into three layers and contains five types of neurons. A vertical section of a single cerebellar folium, in both longitudinal and transverse planes, illustrates the general organization of the cerebellar cortex. The detail of a cerebellar glomerulus in the granular layer is also shown. A glomerulus is a clear space where the bulbous terminal of a mossy fiber makes synaptic contact with Golgi and granule cells.

Cells of the Molecular Layer

- **Stellate**
  - receive stimulatory input from parallel fibers
  - deliver inh. Input from Purkinje Cells
- **Basket Cells**
  - receive stim. input from parallel fibers
  - deliver inh. Input to Purkinje Cells

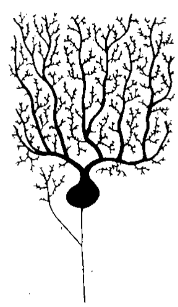
Cells of Granule Layer

- **Granule Cells**
  - receive stim. input from mossy fiber pathway
  - deliver powerful stim. Input to Purkinje Cells by parallel fibers
- **Golgi Cells**
  - receive stim. input from parallel fibers and adjacent granule cells
  - deliver inh. Input to granule cells



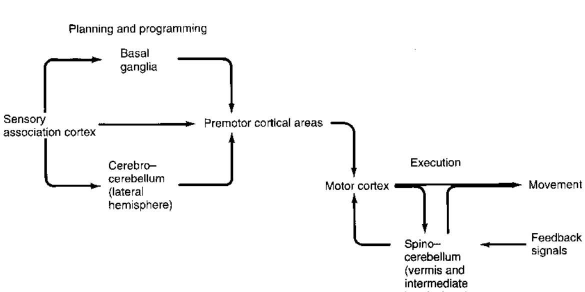
Purkinje Cells - The most important cell in the cerebellum.

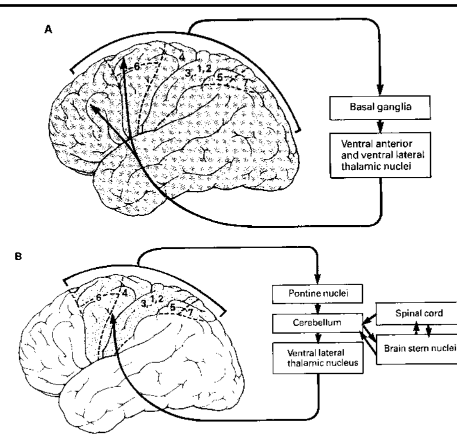
- **Inhibitory**
- **Only output neuron of the cerebellum**
- **Large dendritic tree receiving both stimulatory and inhibitory information**

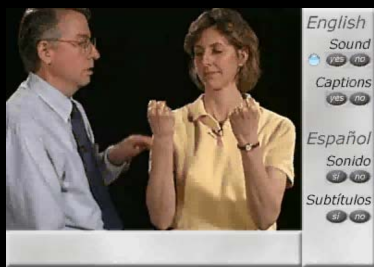


Cerebellum acts as a comparator that compensates for errors in movement by comparing intention with performance.

- **Receiving information about plans for movement from structures concerned with programming and execution (*Corollary Discharge*).**
- **Receiving information about motor performance from sensory systems during movement (*Reafferance Feedback*).**
- **Sends information to descending motor systems.**





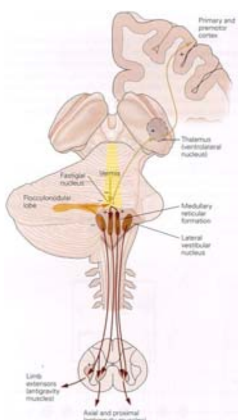


Control of Motor Circuitry

Vestibulocerebellum

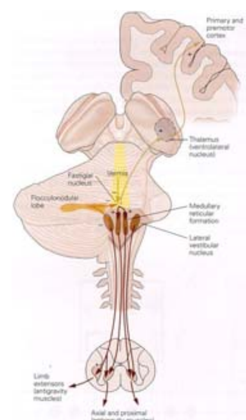
Governs eye movements and body equilibrium

Control of axial and proximal limb muscles that are used to maintain balance.



Spinocerebellum (2 parts)

- **Originates from Vermal region of cerebellum**
- **Inputs from special senses, vestibular apparatus, and spinocerebellar tracts.**
- **Axial and proximal motor control of ongoing execution of movement.**



Spinocerebellum

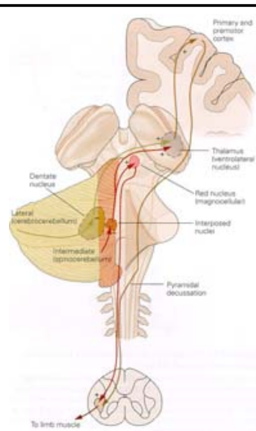
Two (2) sections

Originates from Intermediate region of cerebellum

Inputs from spinocerebellar tracts (distal body parts).

Distal motor control of ongoing execution

.



Sensory Input

↓

Intermediate region

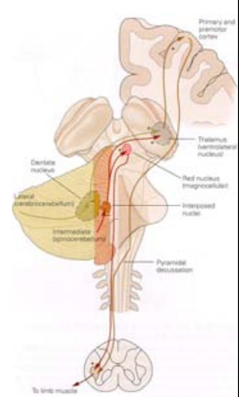
↓

Interpositus Nuclei

↓ ↓

Red Nucleus (Bilaterally) → **Rubrospinal pathway**

Thalamic Nuclei (Bilaterally) → **Motor Cortex**



Cerebrocerebellum
Two (2) sections

Originates from Lateral posterior lobe of cerebellum

Inputs from Sensory/motor cortex, premotor, and parietal cortex by way of the pontine nuclei.

Achieving precision in control of rapid limb movements and in tasks requiring fine dexterity.