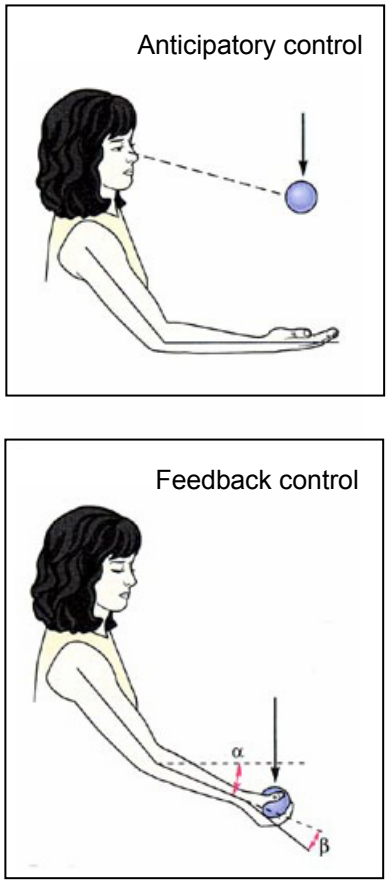
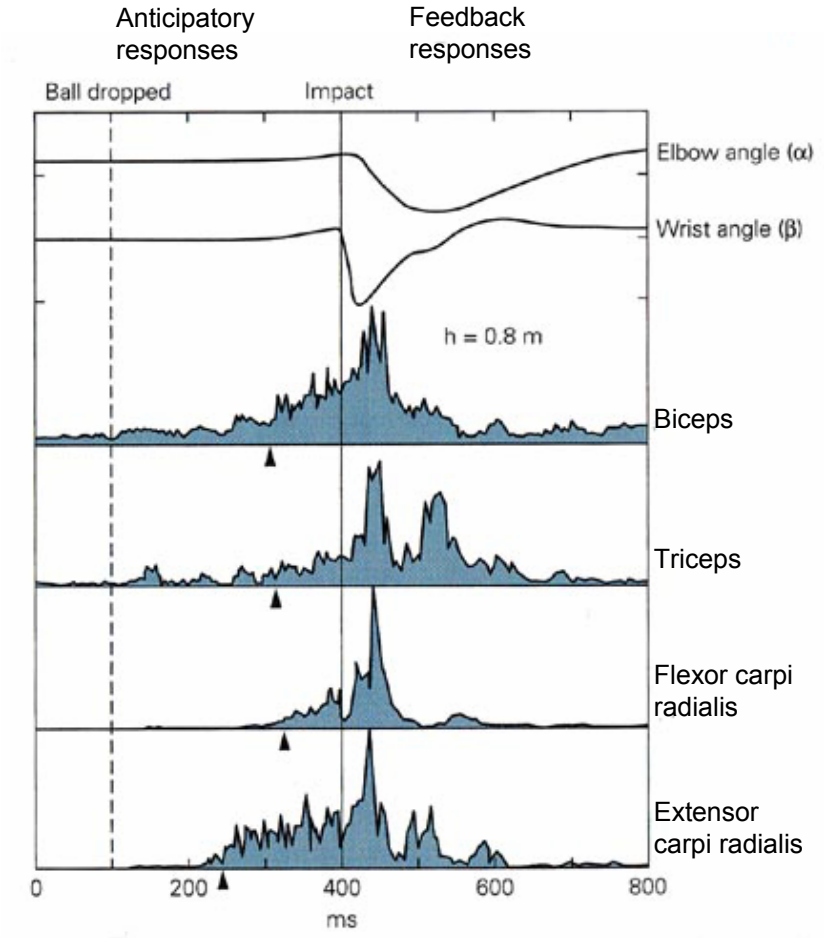
Movement and Motor systems

Movement categories:
- Reflexive and rhythmic movements
- Voluntary movements

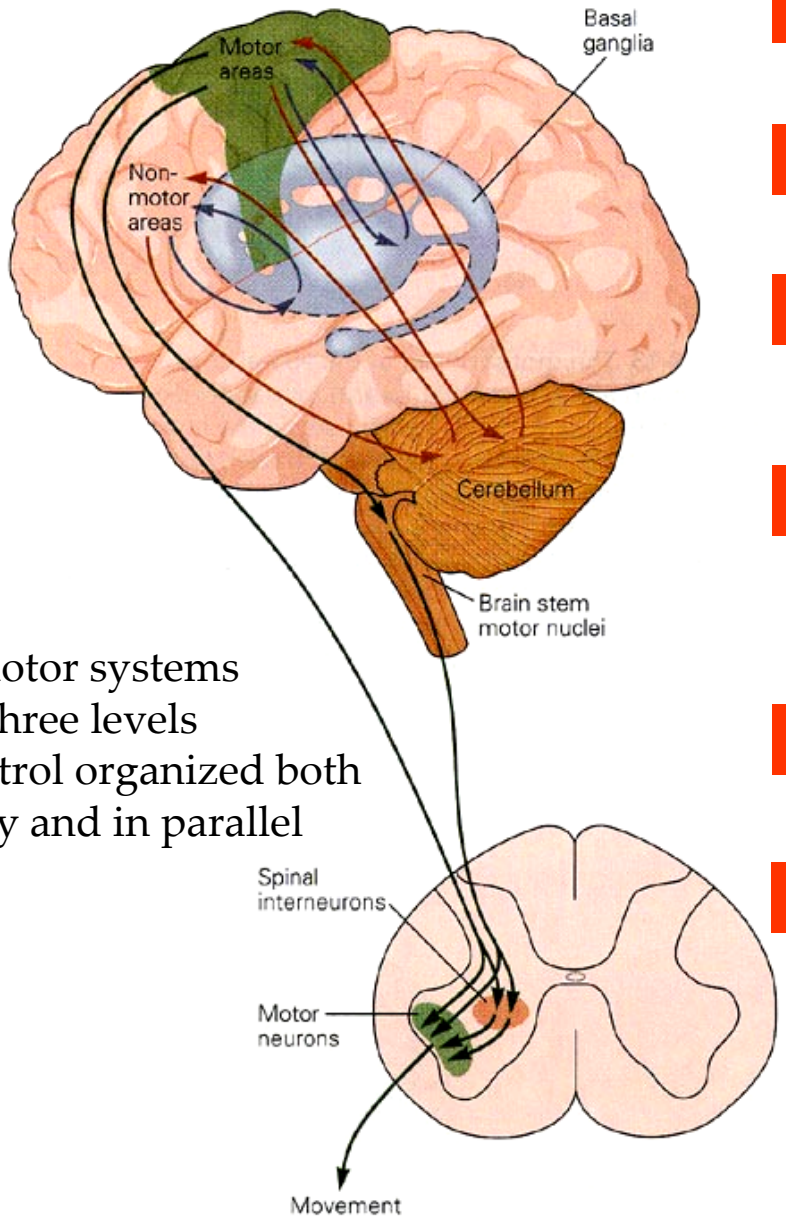
Reflexive and rhythmic movements are involuntary and produced by stereotyped patterns of muscle contraction

Voluntary movements are goal-directed and improve with practice as a result of feedback and anticipatory mechanisms





Principles of organization of motor systems



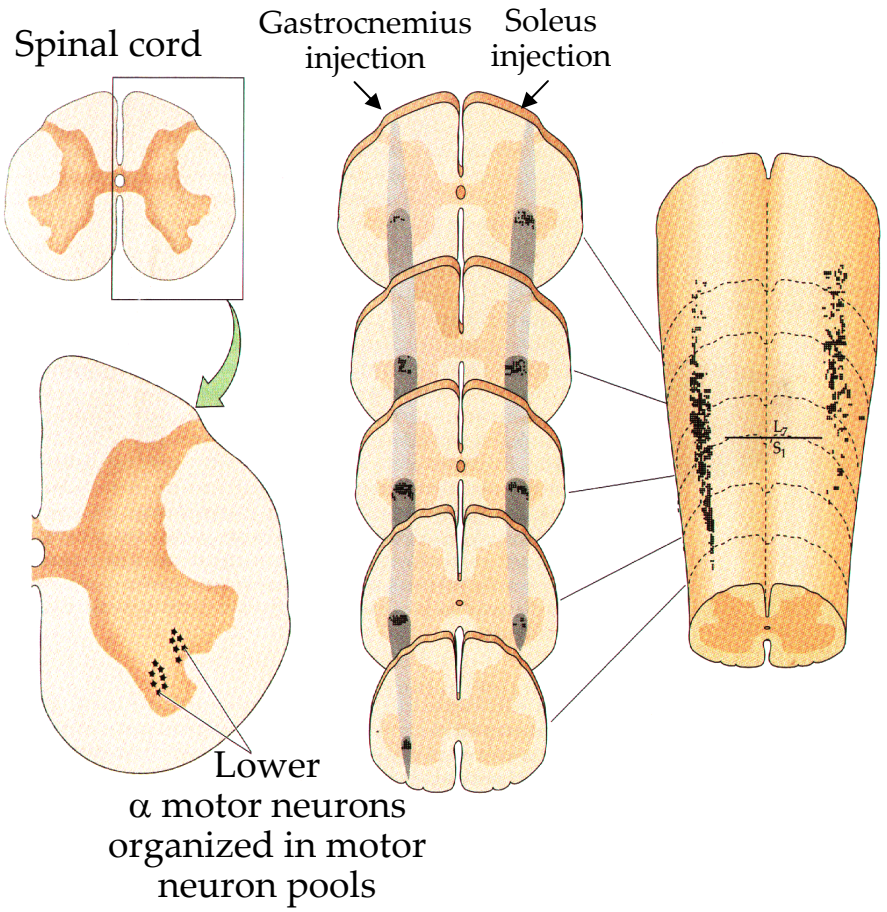
The motor systems have three levels of control organized both serially and in parallel

1. The motor systems are organized hierarchically
2. Spinal motor neurons execute movement
3. The brain stem modulates the action of spinal motor circuits
4. The cerebral cortex modulates the action of motor neurons in the brain stem and spinal cord
5. The cerebellum and basal ganglia influence cortical and brain stem motor systems
6. Sensory information related to movement is processed in different systems that operate in parallel.

Motor neuron-muscle relationships

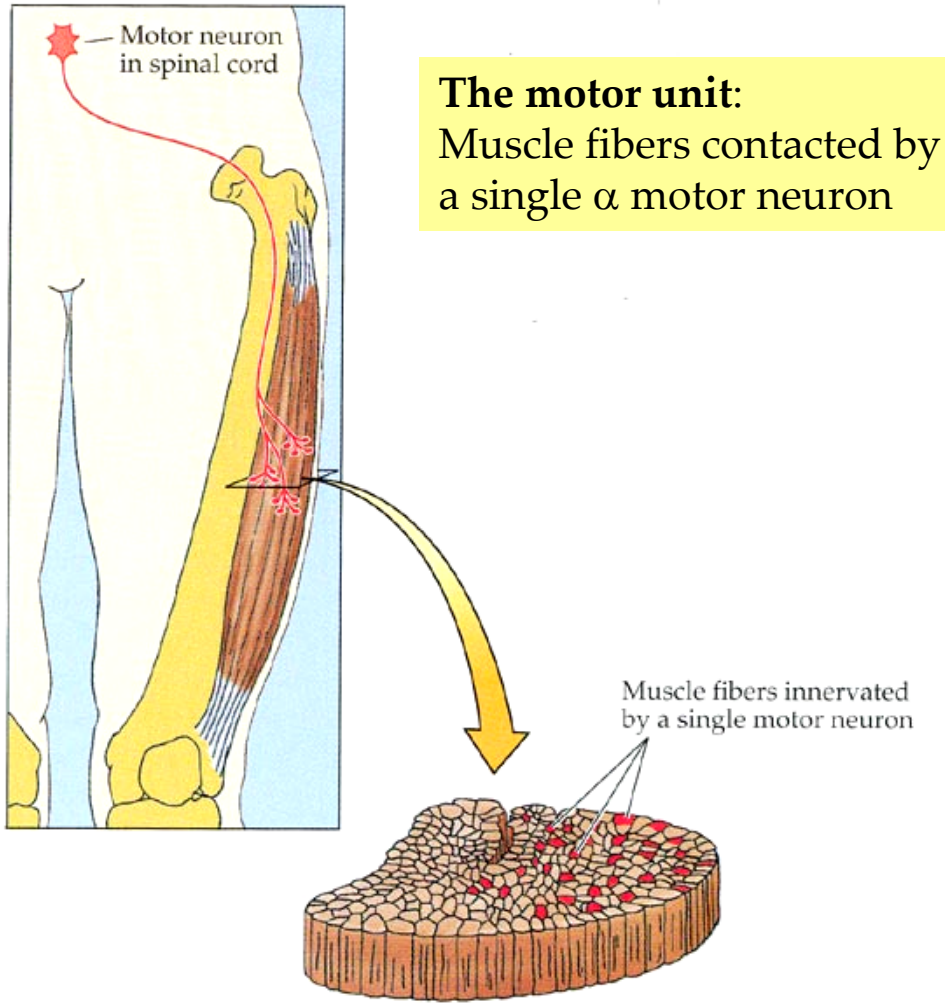
The motor neuron pools are organized in the spinal cord in a somatotopic way:

- Motor neurons innervating axial musculature are located medially
- Motor neurons innervating distal musculature are located laterally

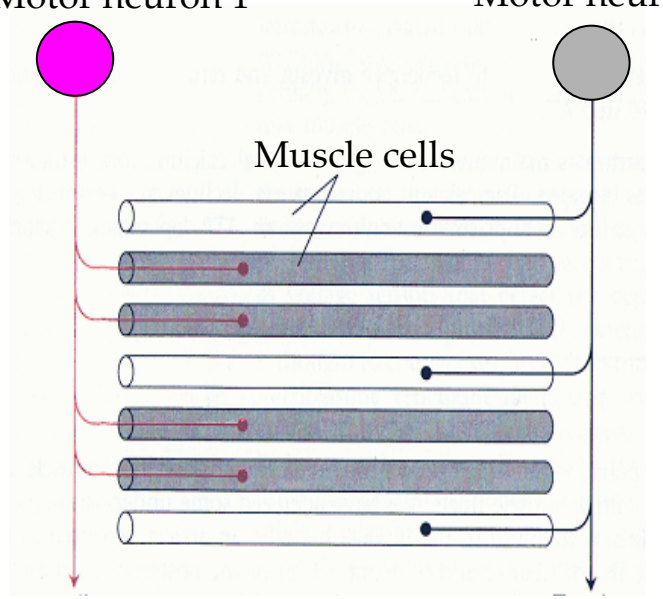


Lower motor neurons
- Fusal **γ motor neurons** (muscle spindle receptor)
- Extrafusal **α motor neurons** (fibers generating muscle force)

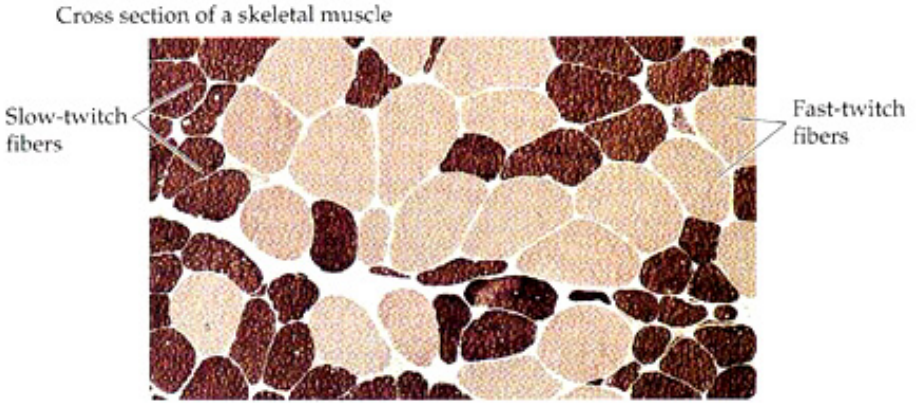
The motor unit



The motor unit:
Muscle fibers contacted by a single α motor neuron



Muscle fiber types are specialized for fast or sustained contraction



Functional characteristics of three different types of motor units

Twitch

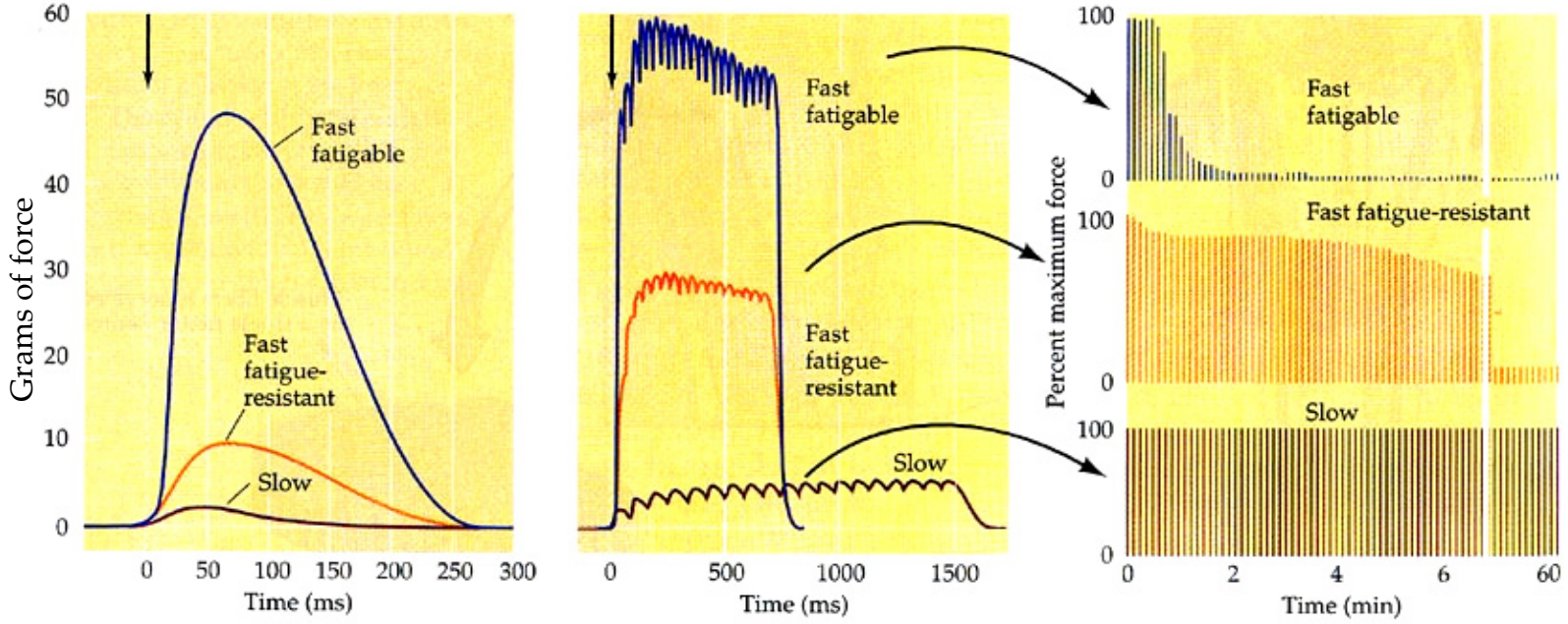
Change in muscle tension in response to a single motor neuron action potential

Unfused tetanic force

Tension in response to repetitive stimulation of the motor neurons

Fatigability

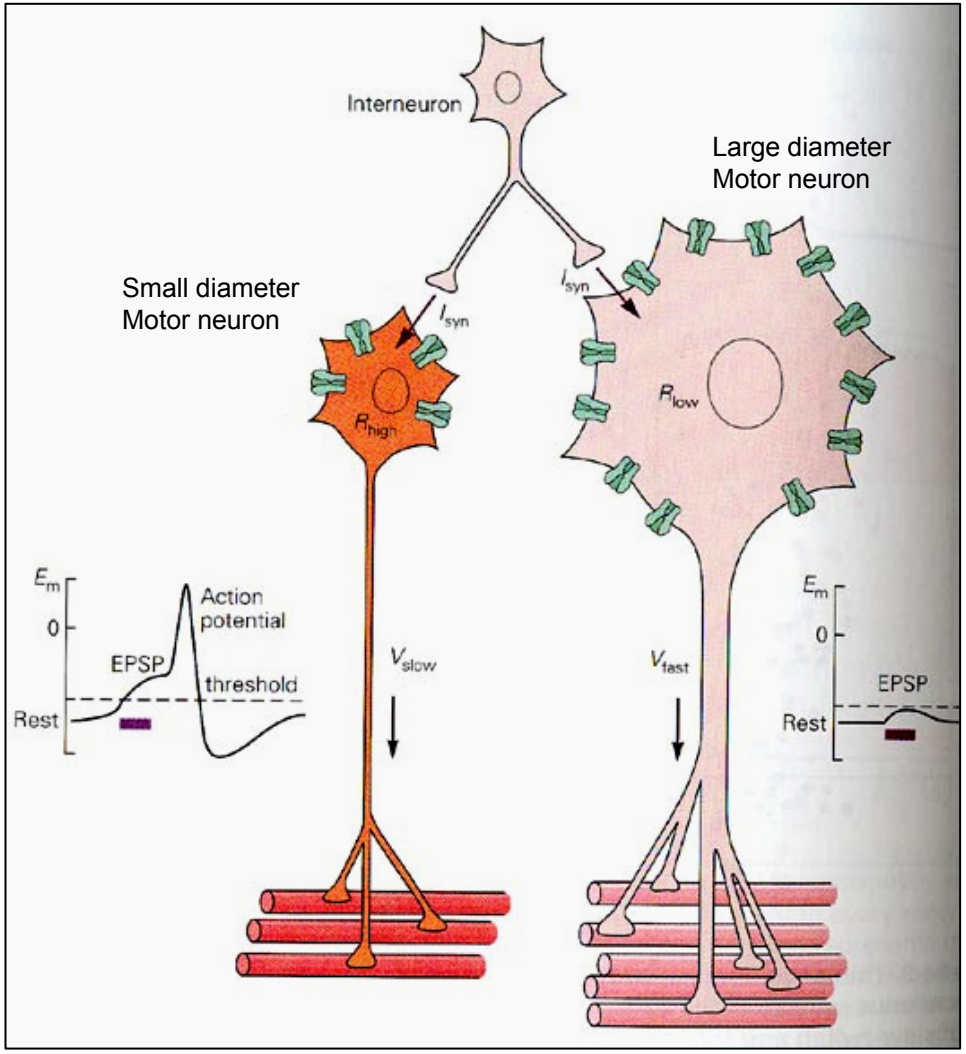
Response to repetitive stimulation that evokes maximum tension



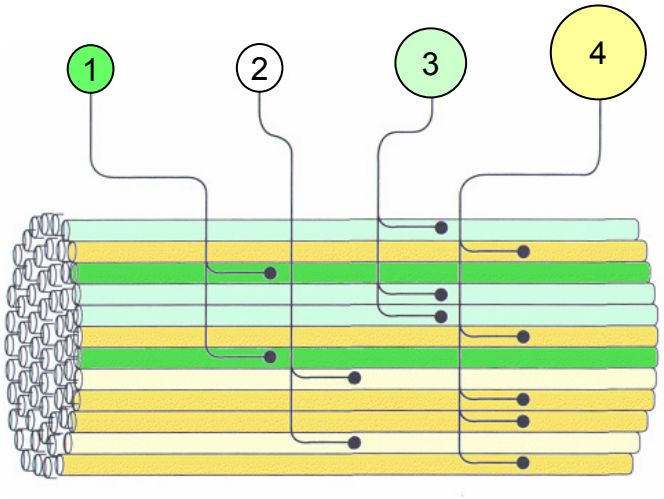
The contractile force of a motor unit depends on:

- the force-generating capabilities of fiber type
- the number of fiber muscles innervated by the motor neuron

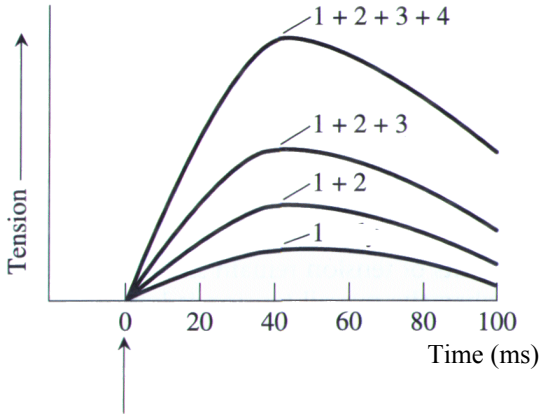
The electrical properties of motor neurons determine their responses to synaptic inputs



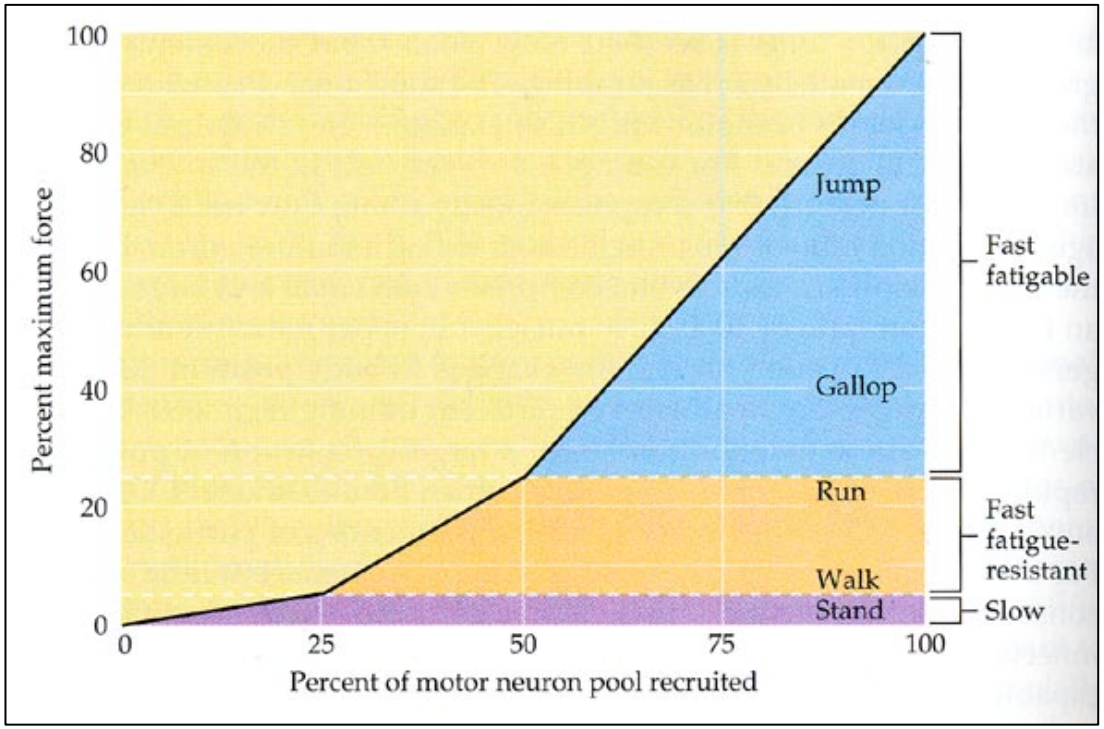
Motor units are recruited in fixed order



The size principle: Recruitment order based on the size of motor unit



The size principle and recruitment order explain the availability of motor units required to perform different motor tasks



The regulation of muscle force

1. **Recruitment of motor neurons according to the size principle**

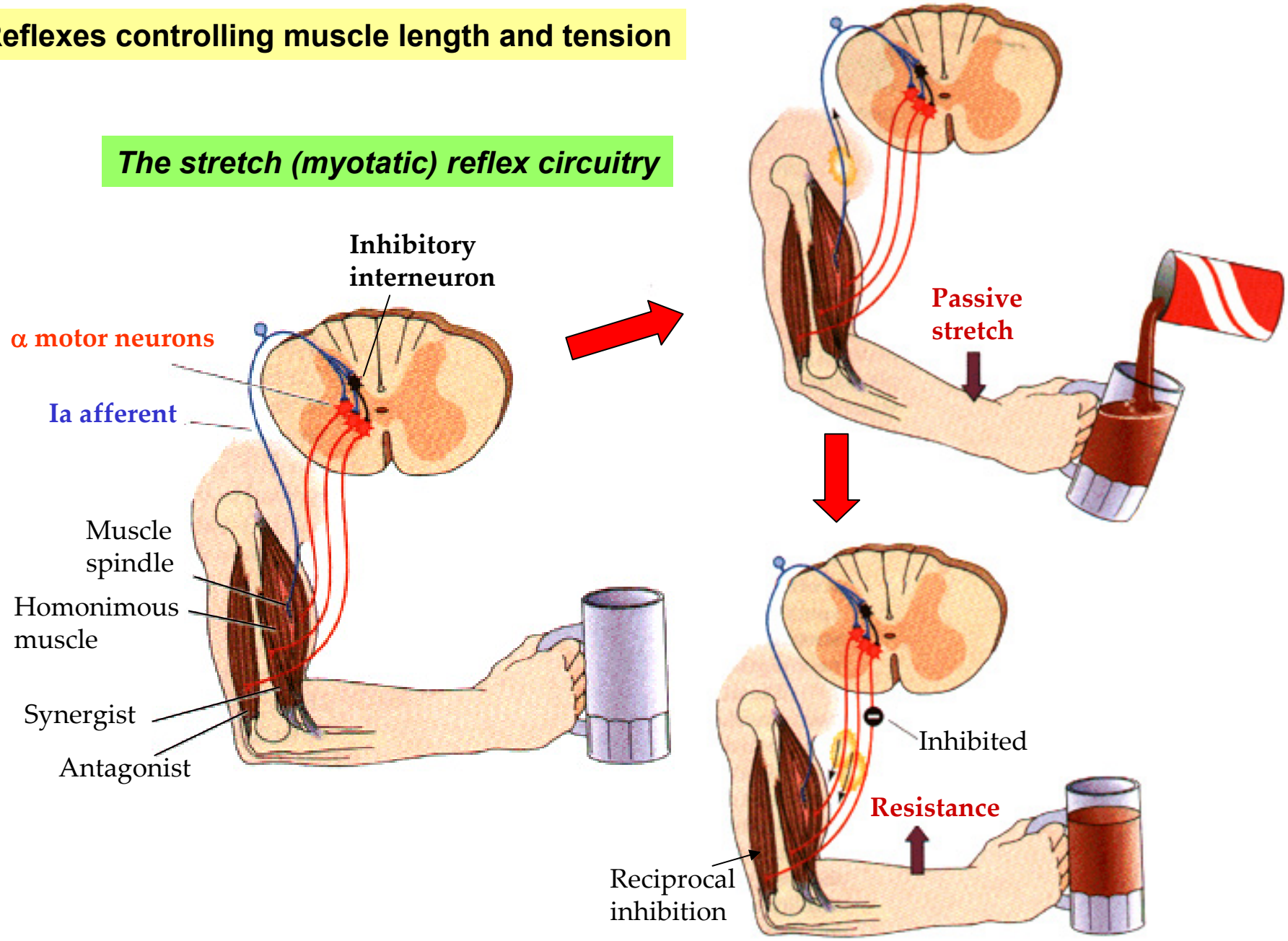
2. **Frequency of action potentials generated by motor neurons and the temporal summation of fiber muscle contractions**

3. **Asynchronous activation of motor neurons permits a maintained contraction with reduced fatigue of individual motor units**

Spinal reflexes

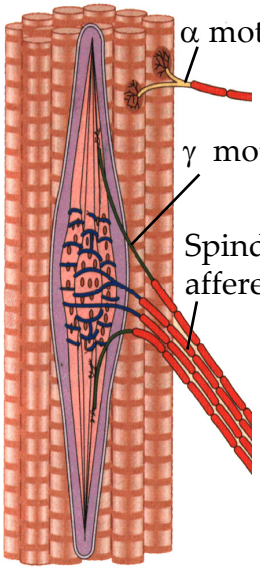
Reflexes controlling muscle length and tension

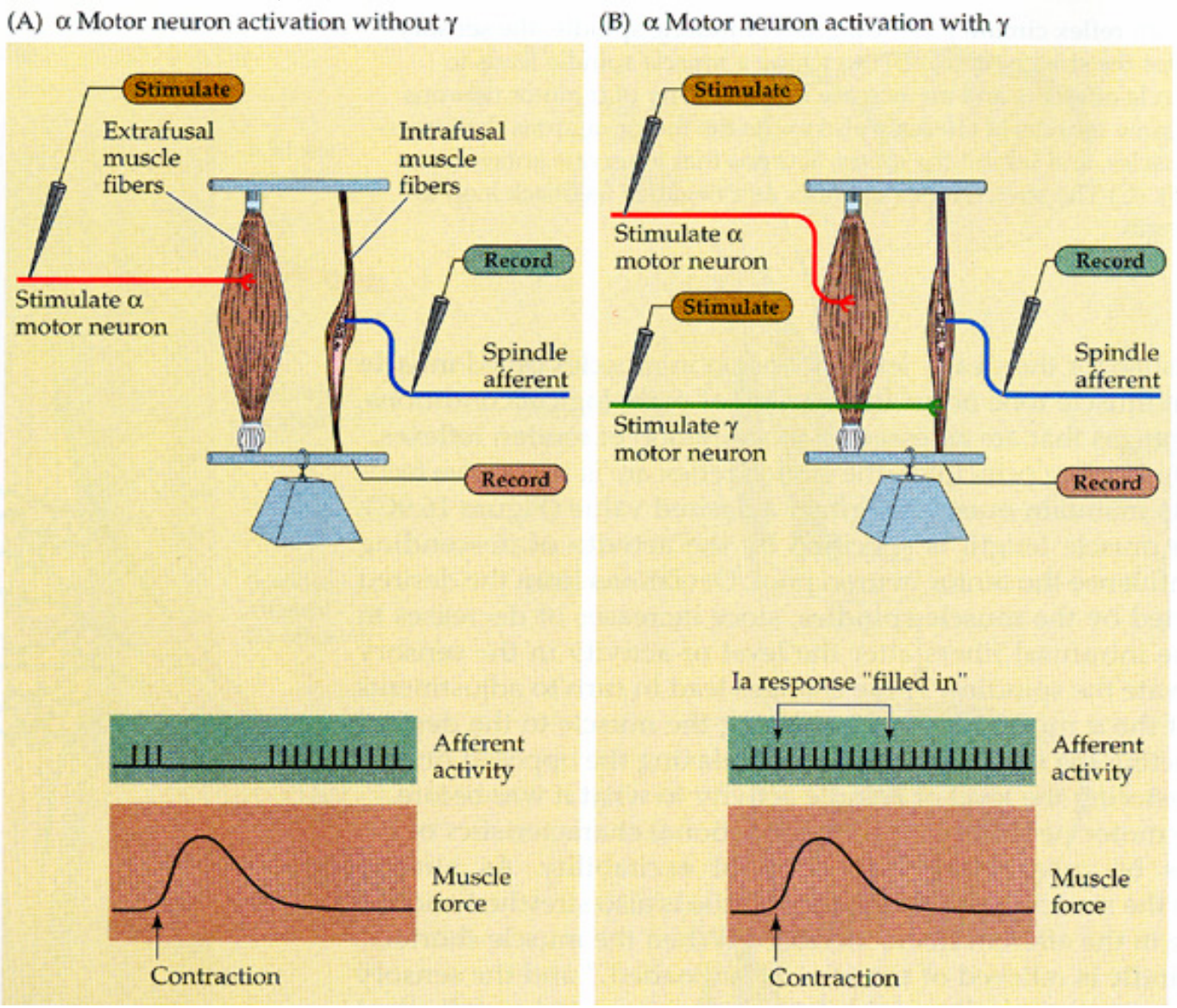
The stretch (myotatic) reflex circuitry



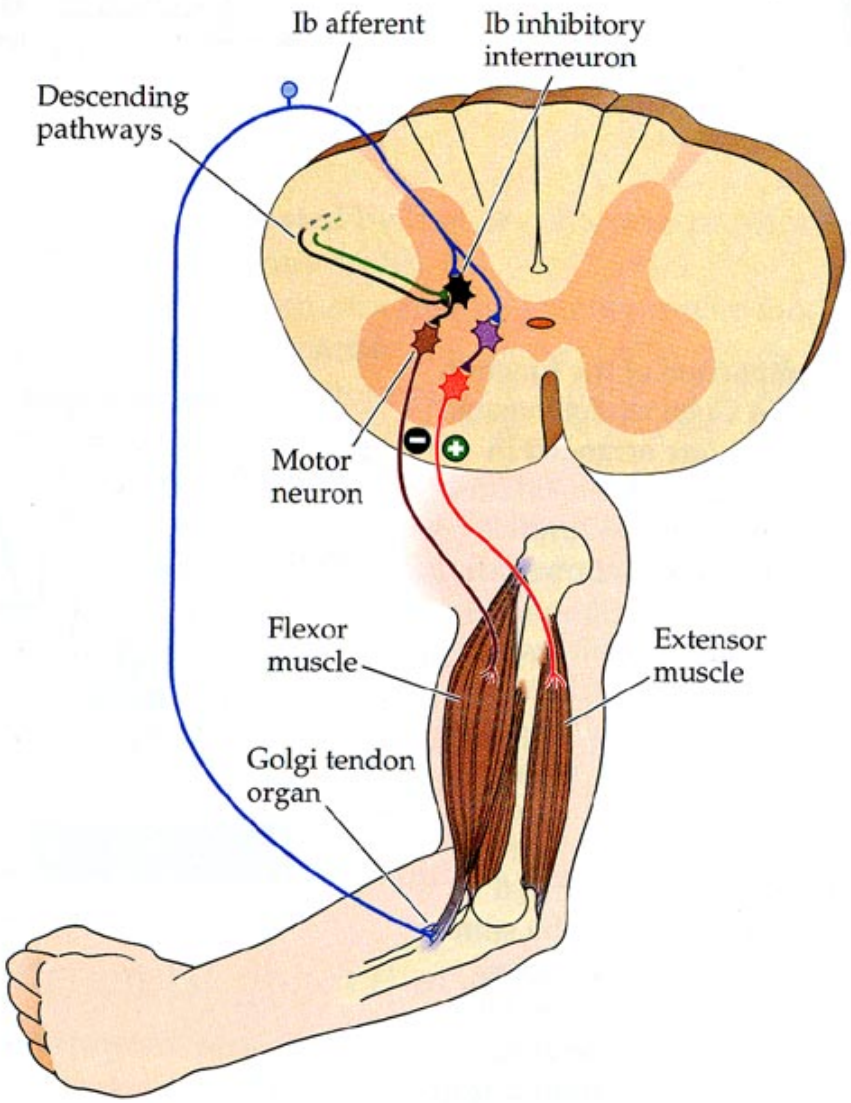
Role of γ motor neurons on muscle spindle responses

The muscle spindle:
A muscle length receptor

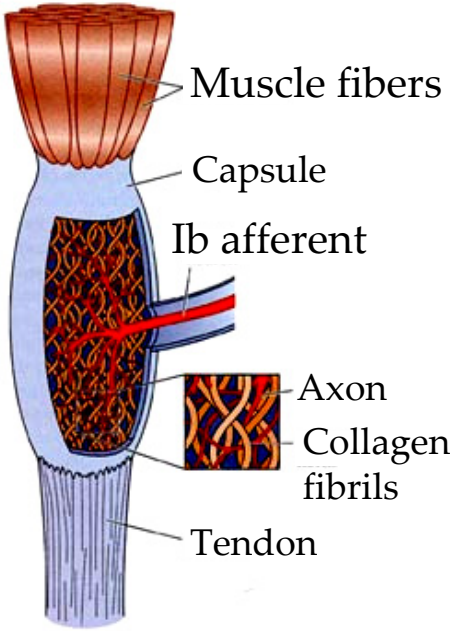


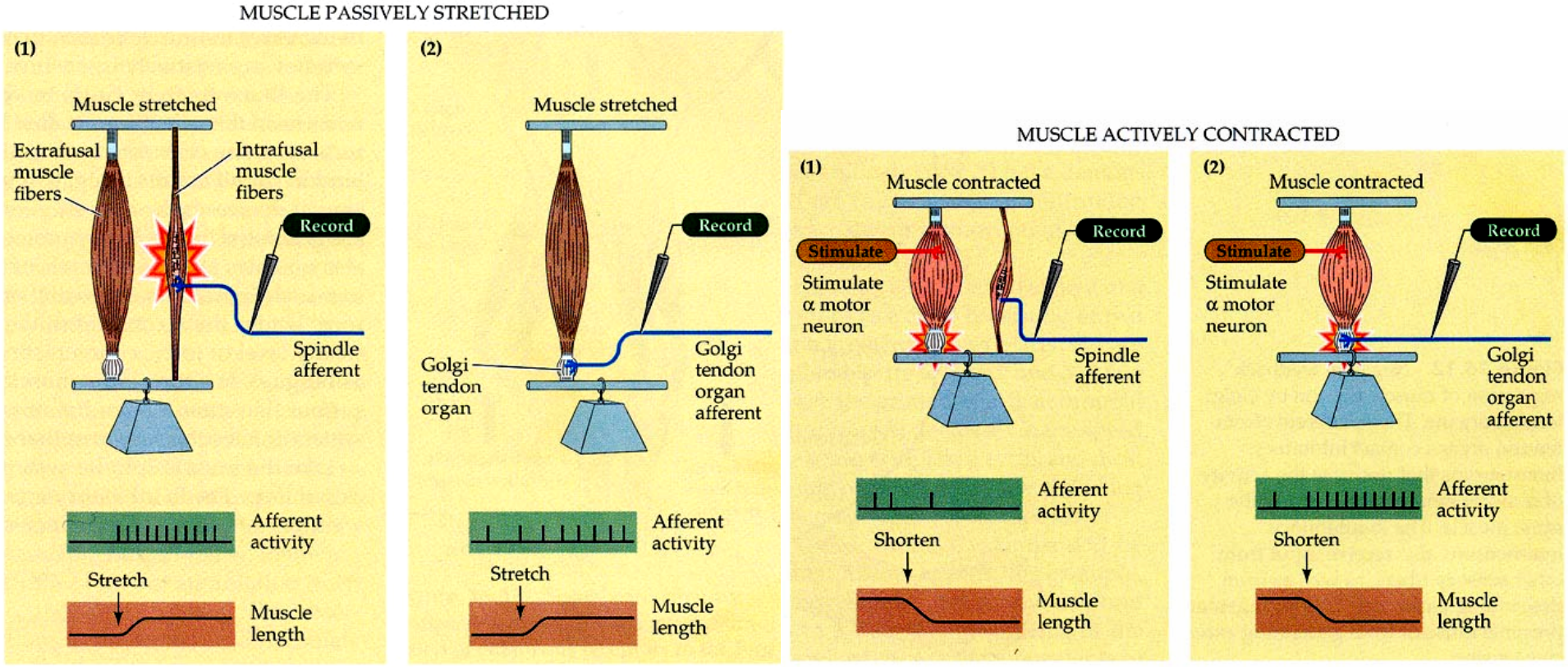


The inverse myotatic reflex circuitry



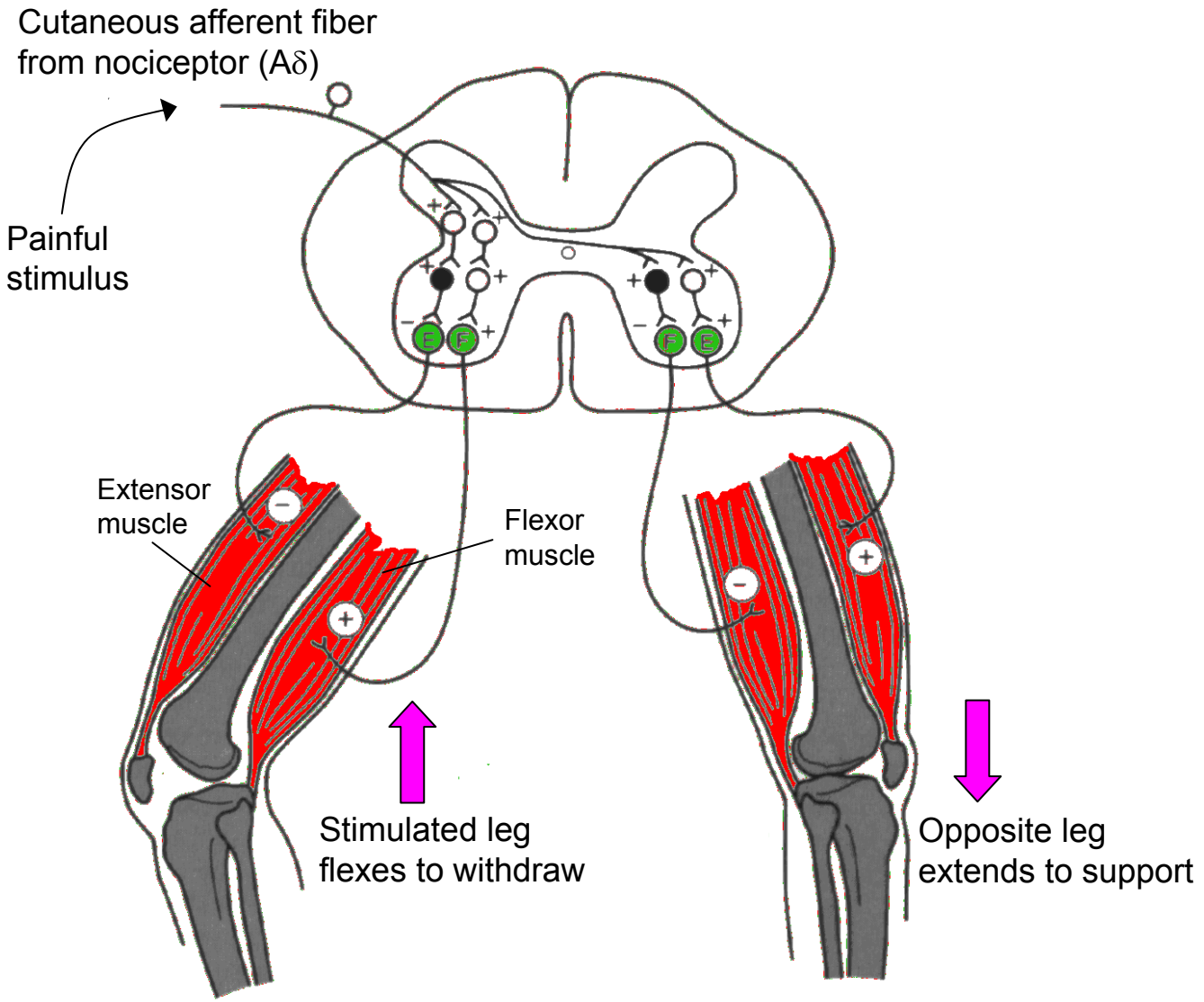
The Golgi tendon organ:
A muscle tension receptor




MUSCLE PASSIVELY STRETCHED
(1)
Muscle stretched
Extrafusal muscle fibers
Intrafusal muscle fibers
Record
Spindle afferent
Afferent activity
Stretch
Muscle length
(2)
Muscle stretched
Record
Golgi tendon organ
Golgi tendon organ afferent
Afferent activity
Stretch
Muscle length
MUSCLE ACTIVELY CONTRACTED
(1)
Muscle contracted
Stimulate
Record
Stimulate α motor neuron
Spindle afferent
Afferent activity
Shorten
Muscle length
(2)
Muscle contracted
Stimulate
Record
Stimulate α motor neuron
Golgi tendon organ afferent
Afferent activity
Shorten
Muscle length

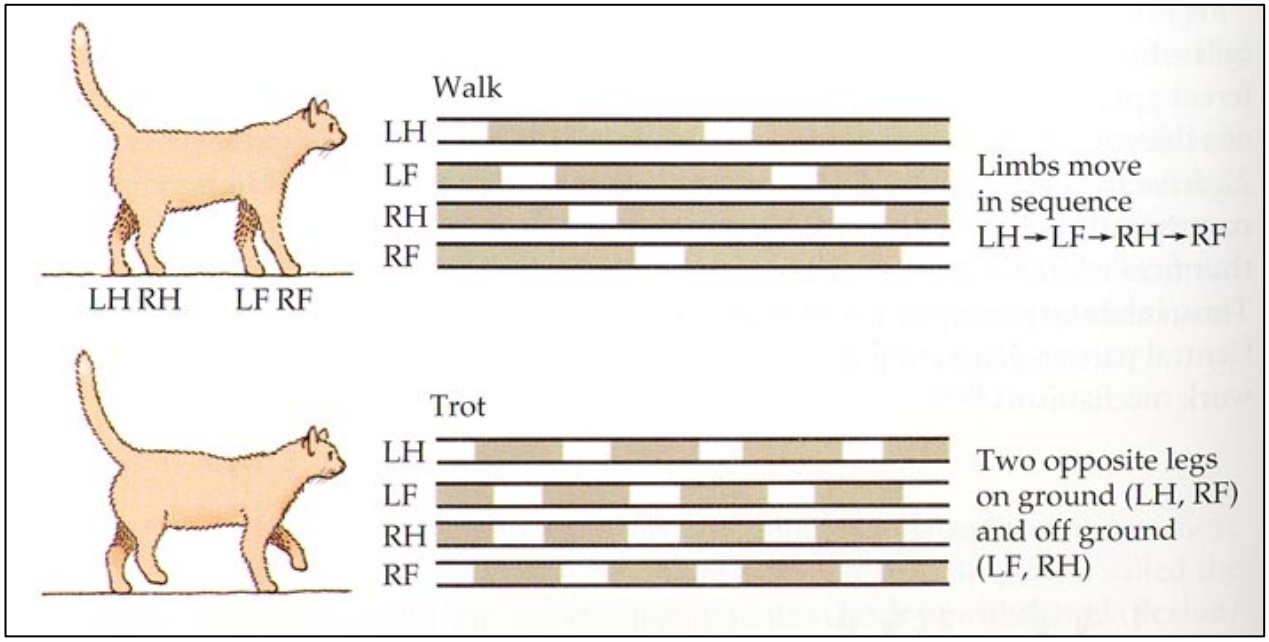
The withdrawal (flexion and crossed-extension) reflex

A more complex polysynaptic reflex circuit



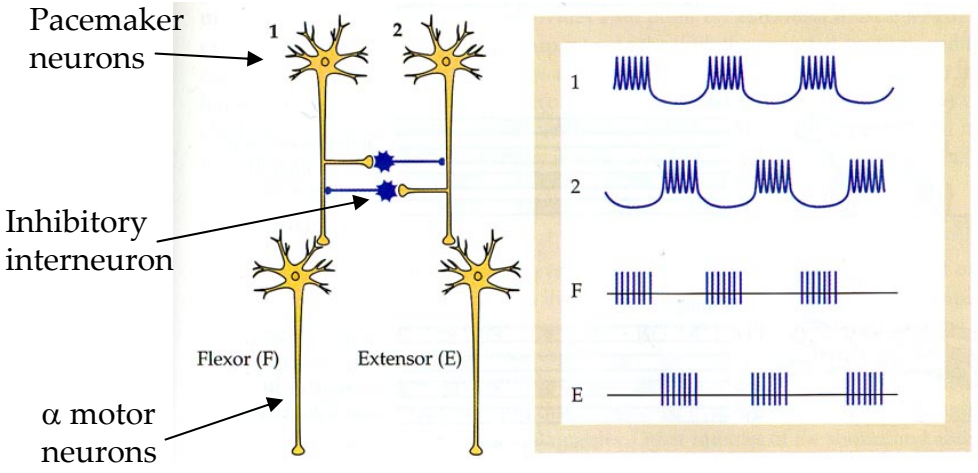
Rhythmic movements. Locomotion

The stepping pattern of a cat during walk and trot, two different locomotor cycles

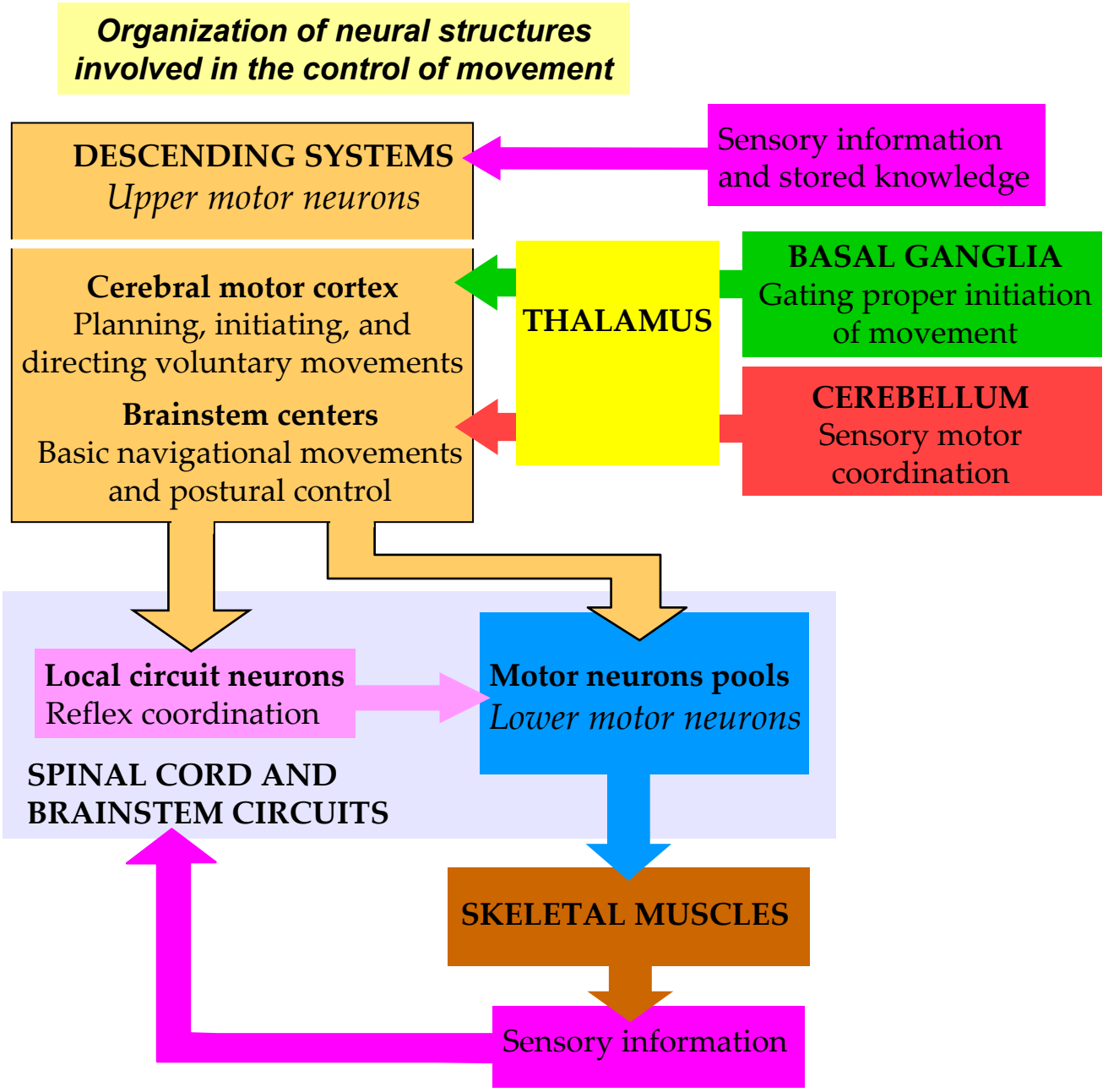


Pattern generators are local circuits in the spinal cord that coordinate rhythmic movements such as those related to locomotion

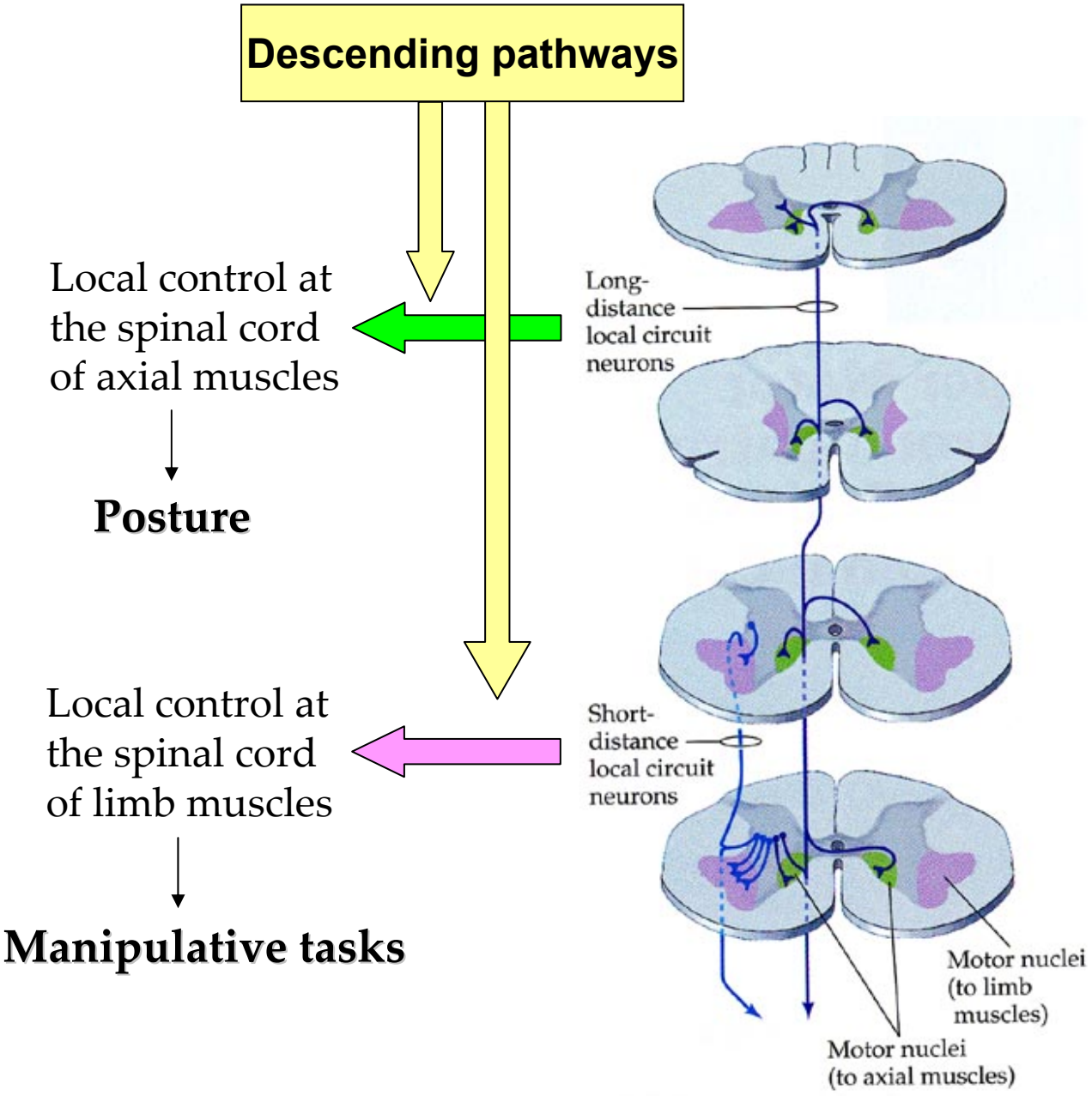
A hypothetical pattern generator circuit



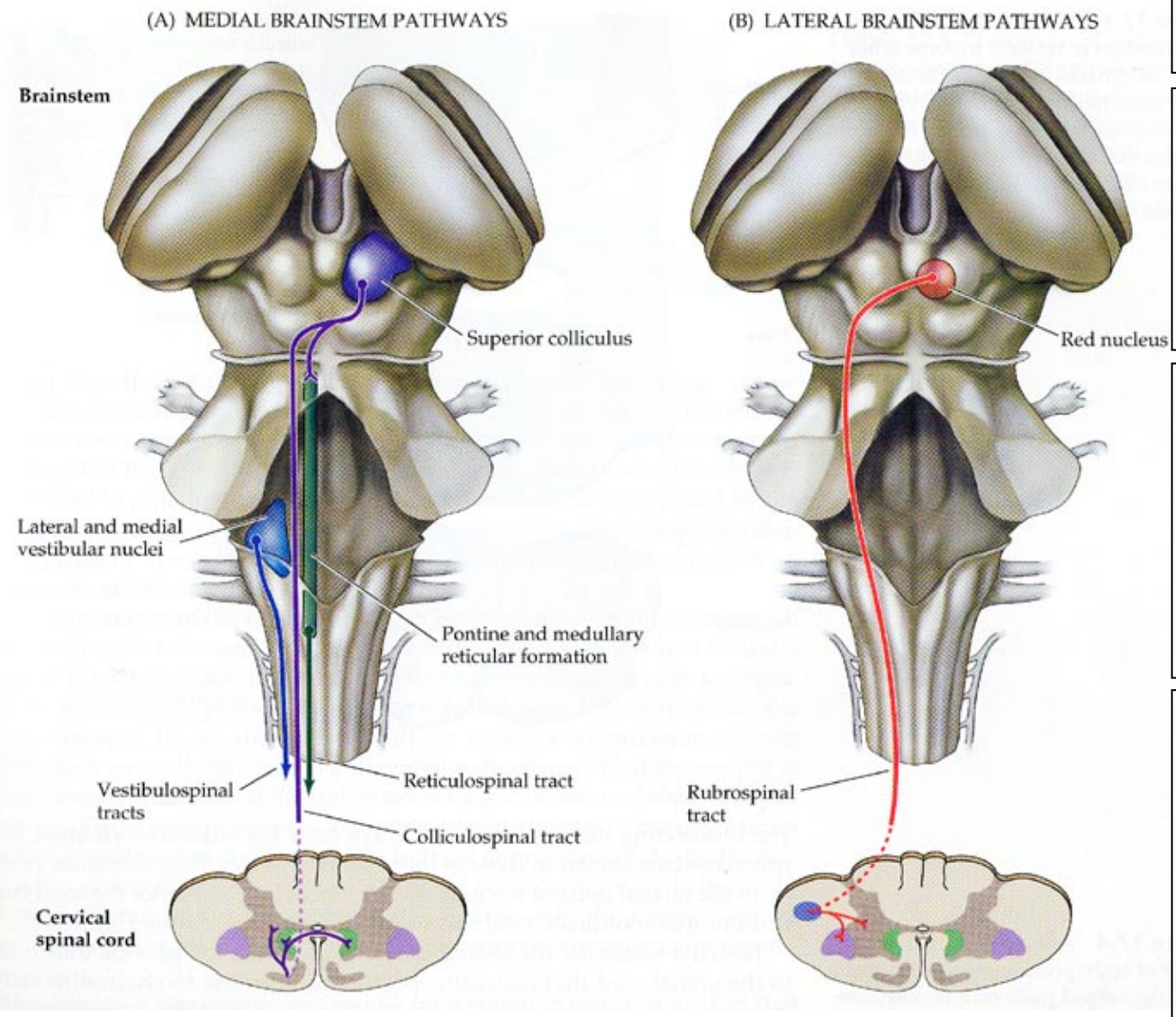
Movement and its central control



Local control circuits at the spinal cord



Motor control at the brainstem



Superior colliculus

Control of neck muscles.
Head orienting movements

Red nucleus

Control of proximal muscles of the arms.
Manipulative tasks

Vestibular nuclei

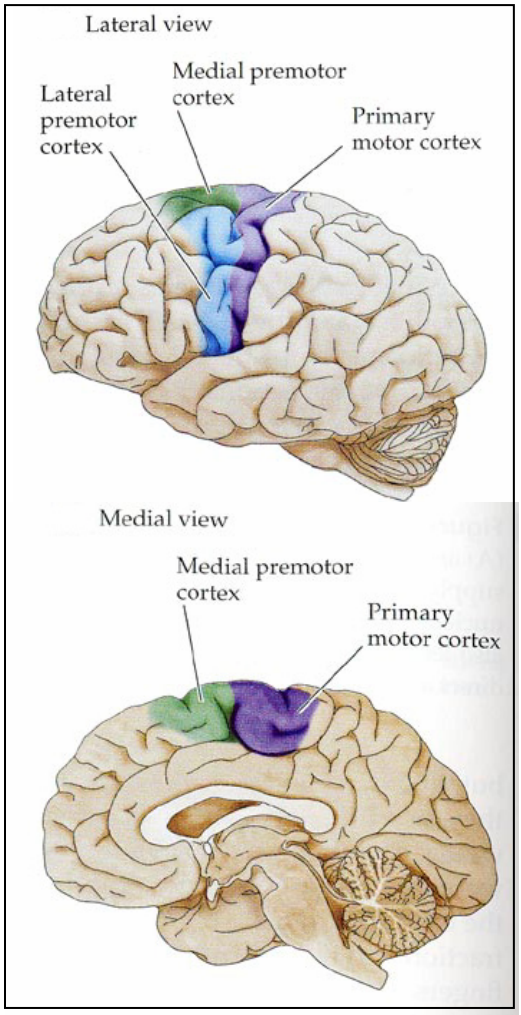
Control of axial muscles (medial tract) and proximal arm muscles (lateral tract).
Balance and posture

Reticular formation

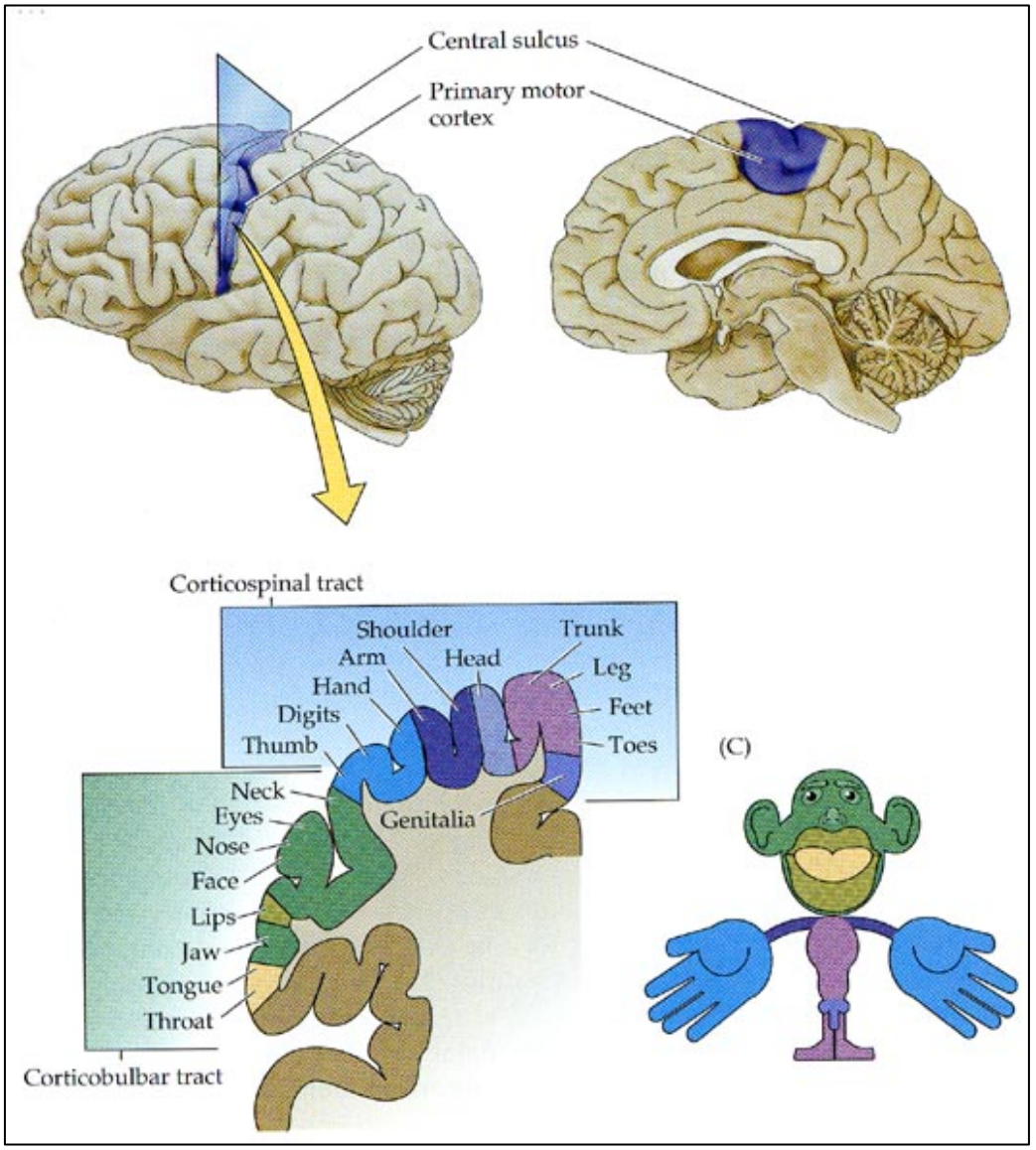
Control of axial and proximal arm muscles.
Initiate adjustments to stabilize posture during ongoing movements

Functional organization of the motor cortex

Localization of primary motor cortex and premotor area in the human brain



Somatotopic organization of motor cortex



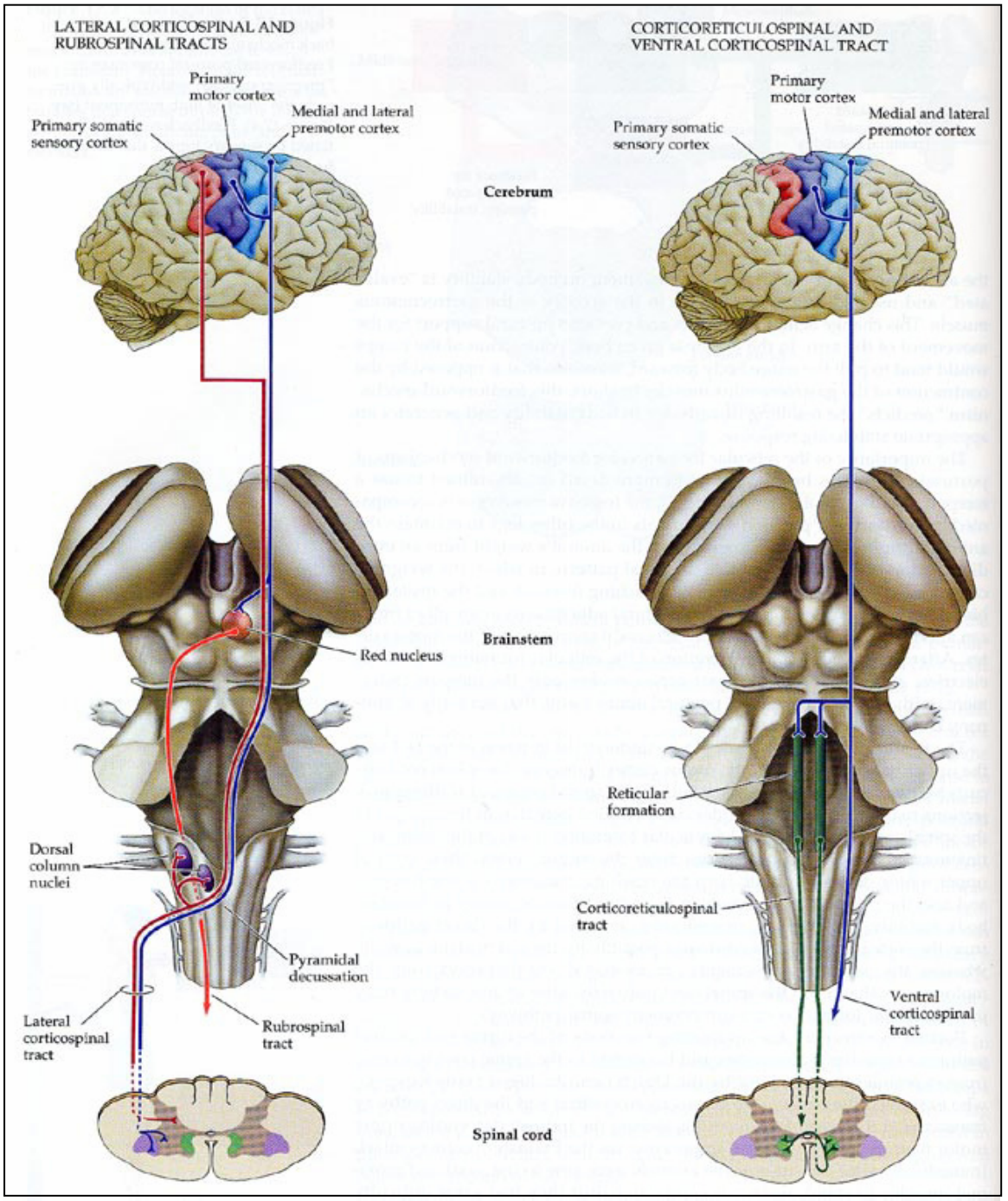
Motor control at the motor cortex

Primary motor cortex

Coding the initiation of complex voluntary movements.

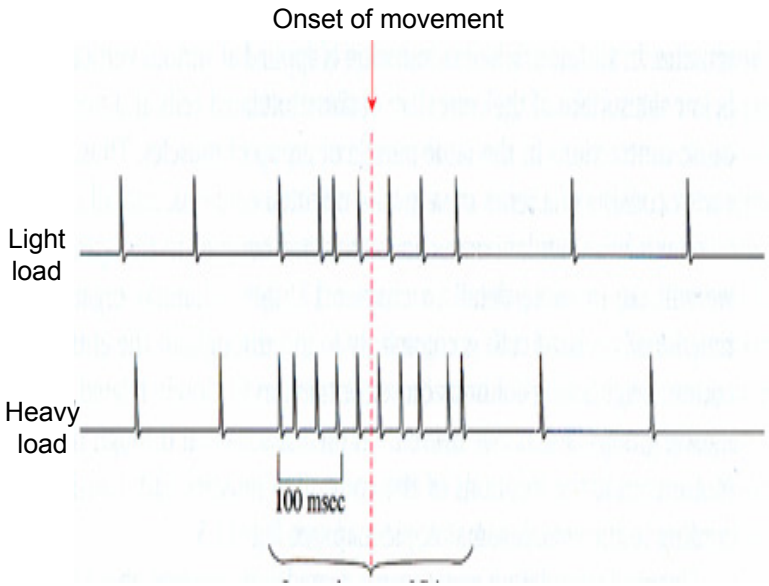
Medial and lateral premotor cortex

Coding the intention to perform a movement. Selection of movements based on external or internal events

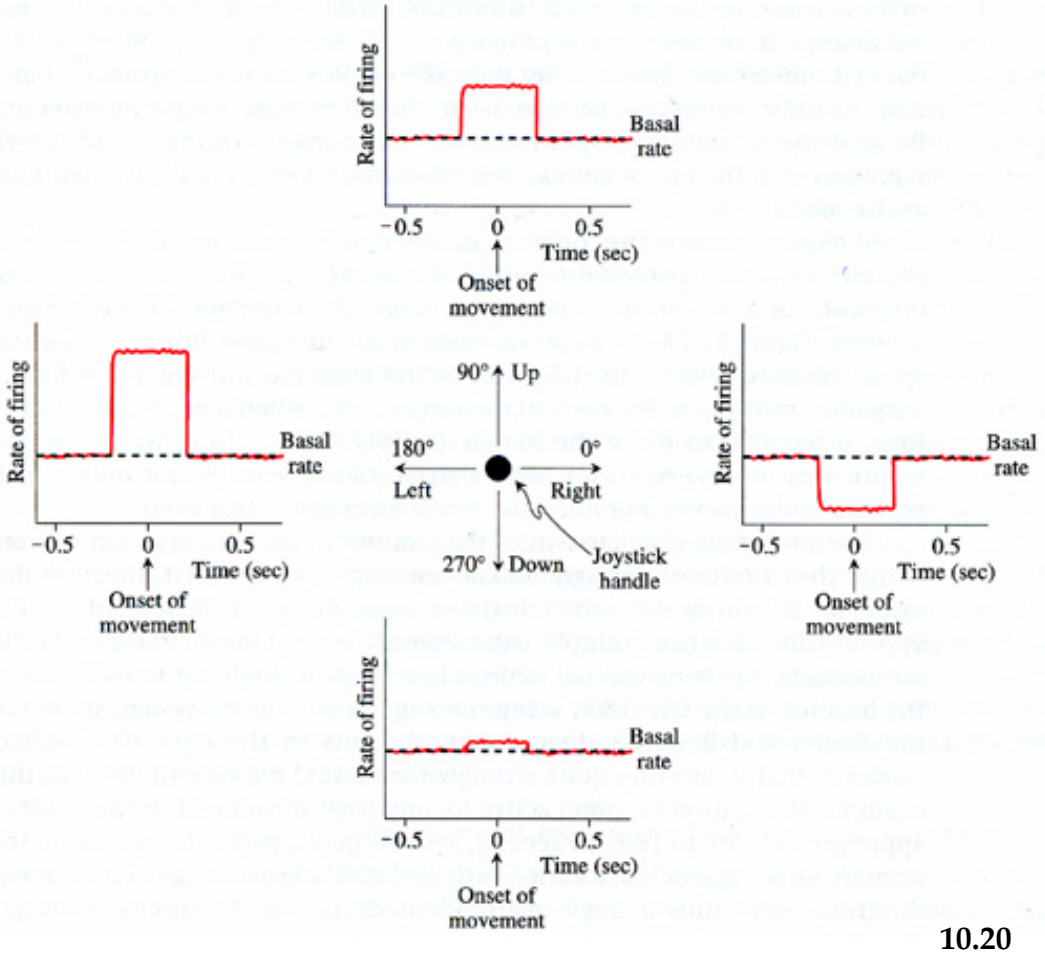


An example of how cortical neurons can code for the initiation of a movement.

The rate of action potential firing increase before the onset of contraction in the relevant muscles



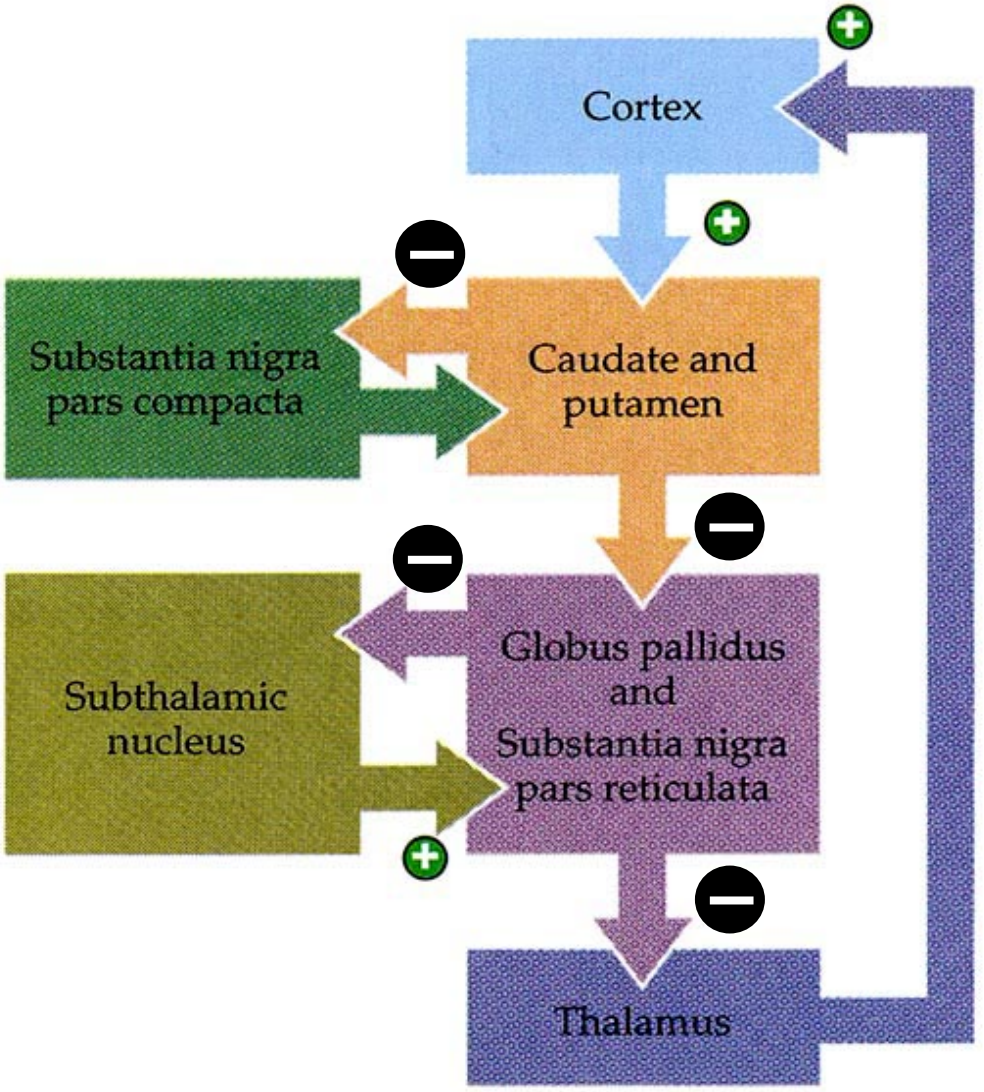
Neurons in the primary motor cortex fire most strongly for movements in a particular direction.



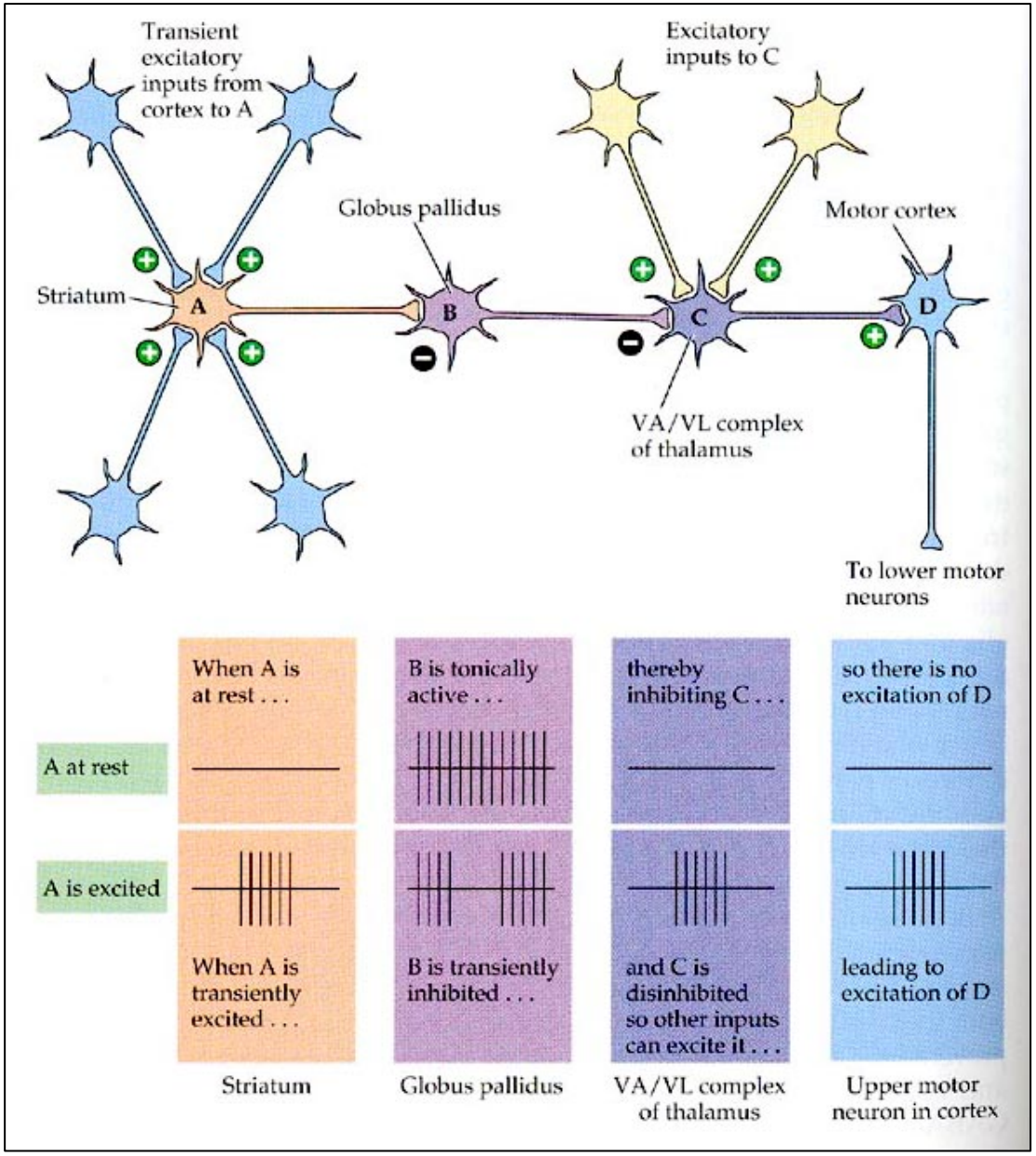
Functional circuits in the basal ganglia

Basal ganglia:
Striate: caudate nucleus + putamen
Globus pallidus

Related areas: Subthalamic nuclei and substantia nigra

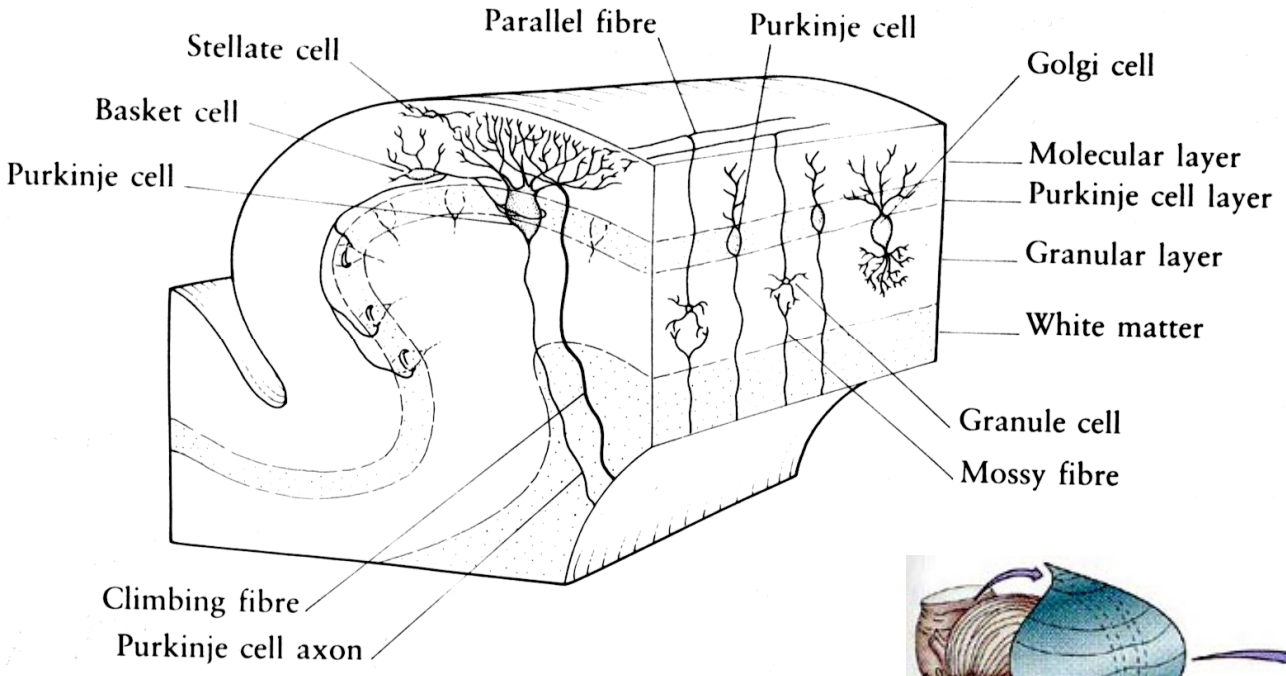


Disinhibitory circuit in the basal ganglia

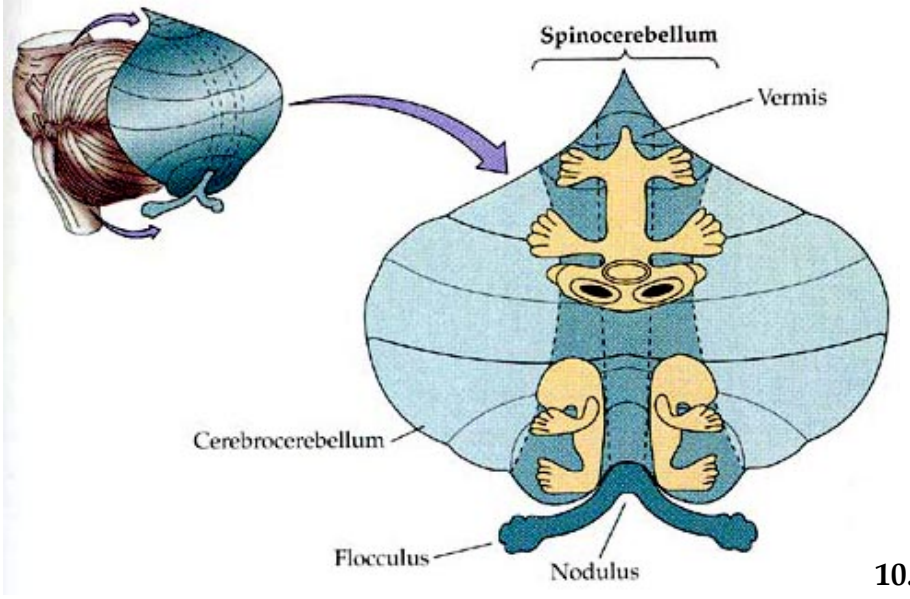


Modulation of movement by the cerebellum

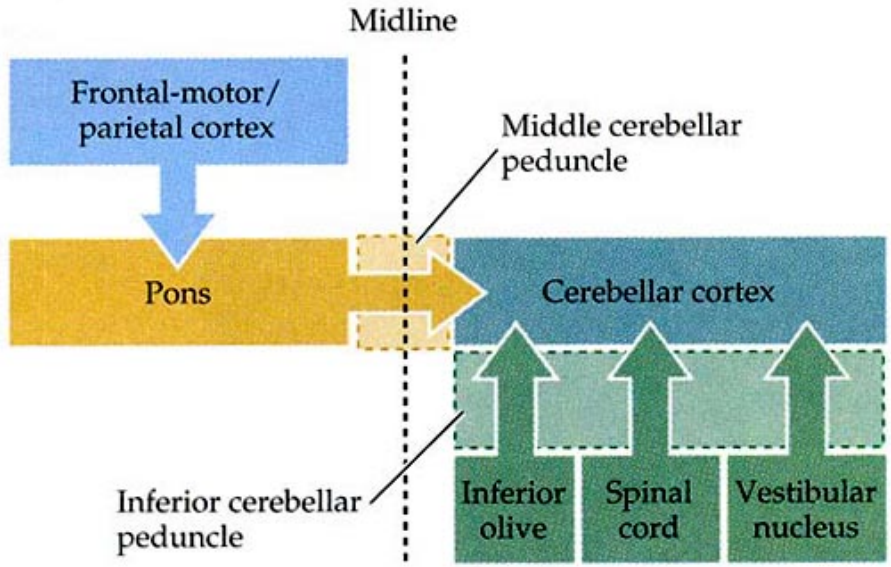
Neurons and circuits of the cerebellum

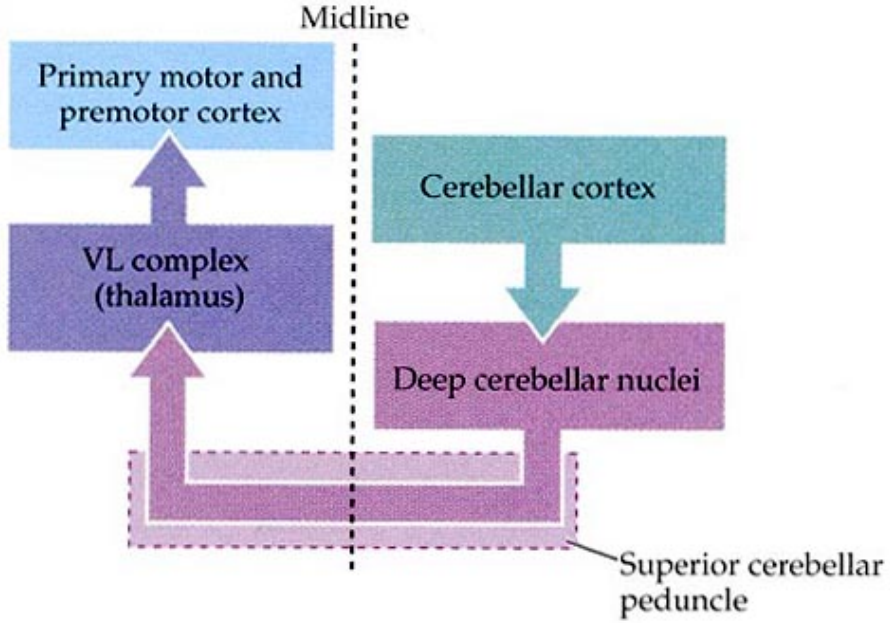


Somatotopic maps of body surface in the cerebellum

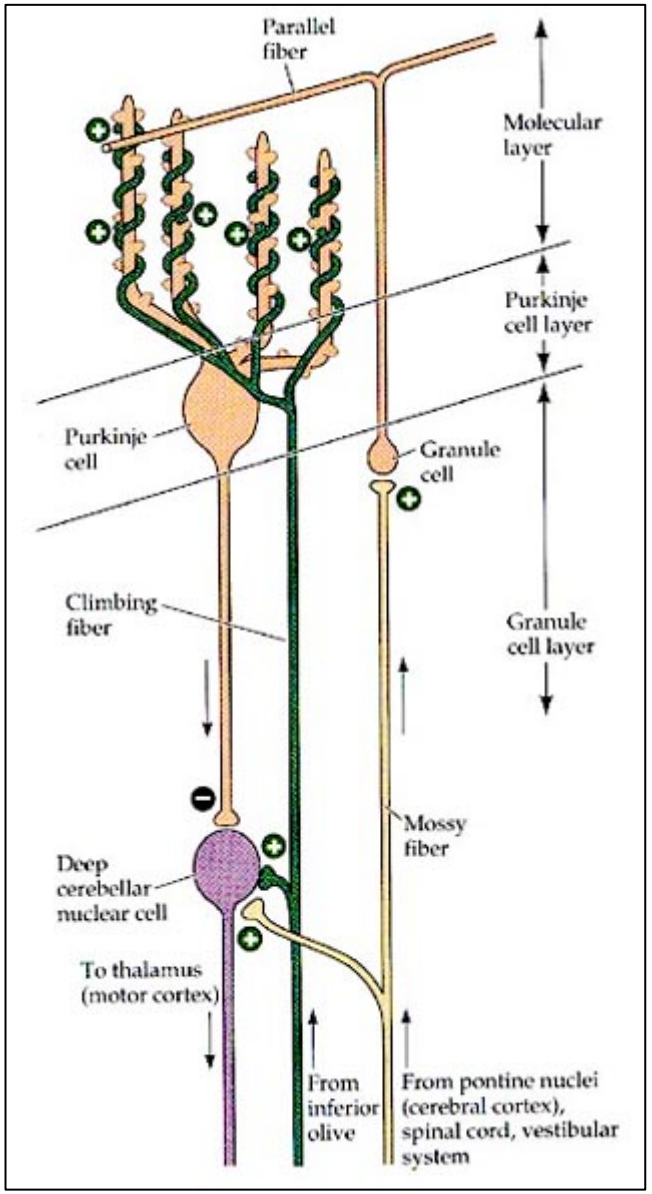


Diagrams of inputs and outputs of the cerebellum

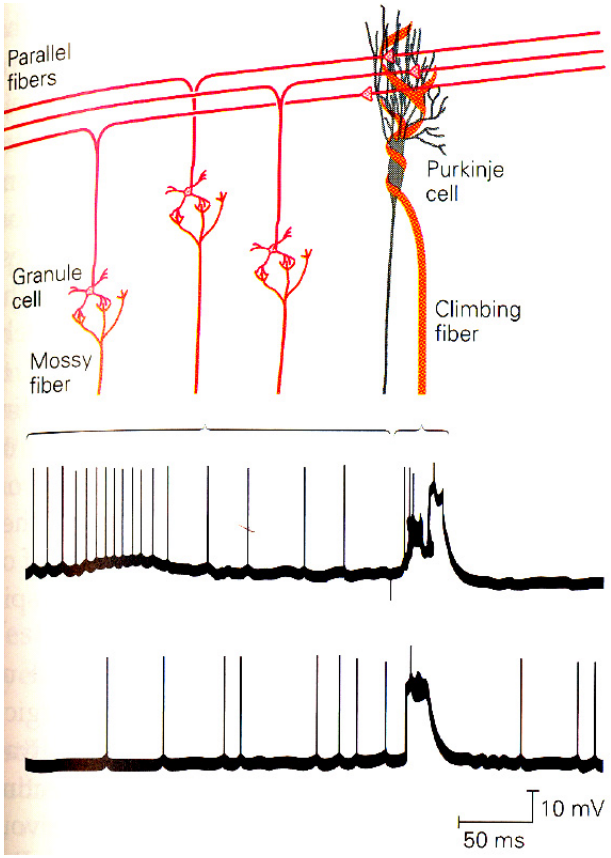


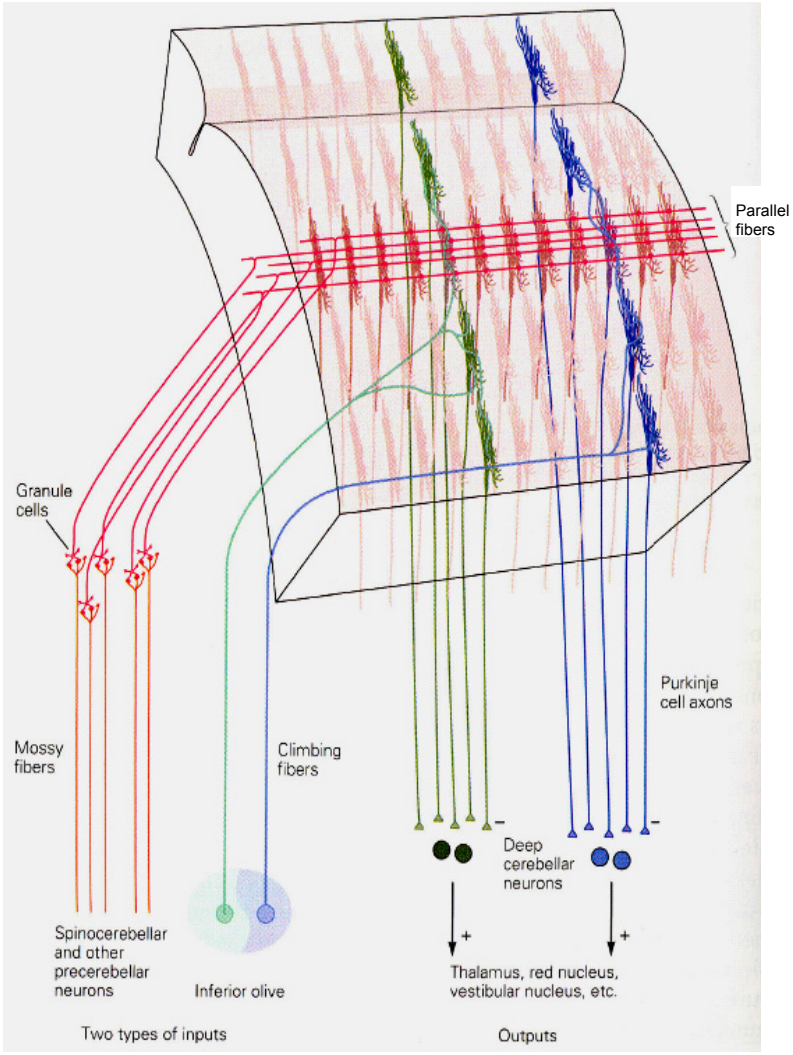


Functional circuits in the cerebellum



Modulation of movement by the cerebellum





Modulation of movement by the cerebellum