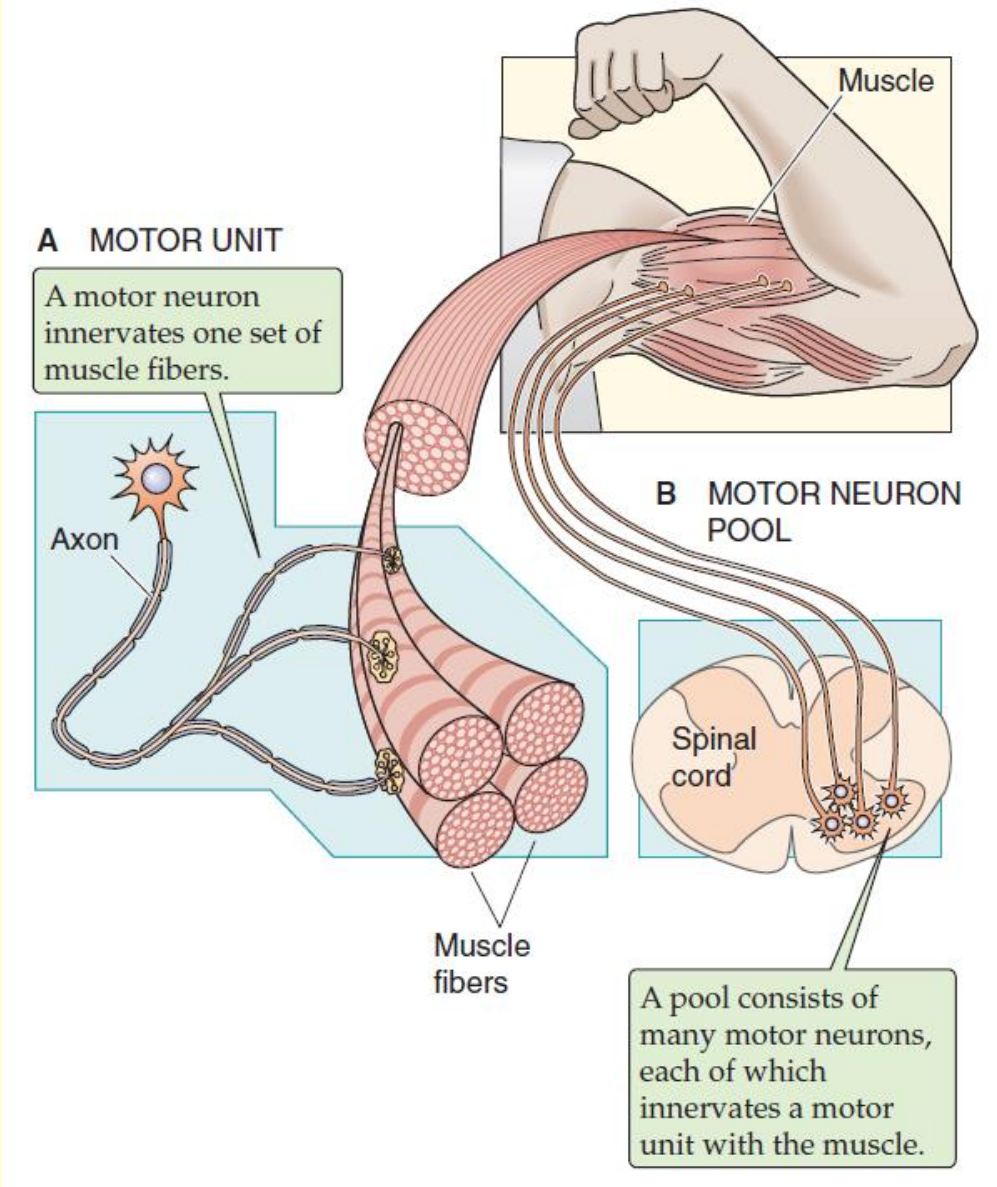
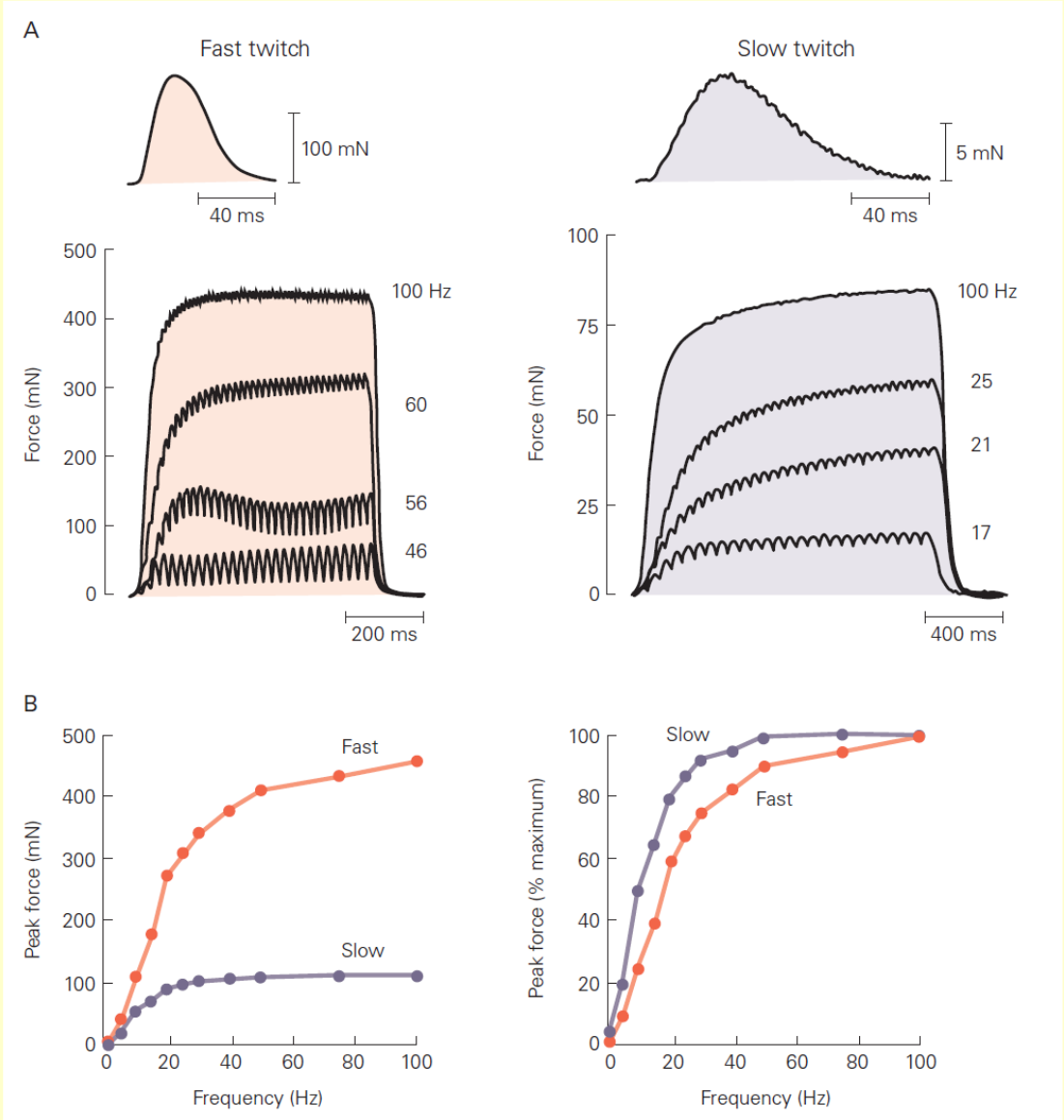
Motor unit

- Unit of muscle activity
- Few hundred motoneurons/muscle
- Innervation number

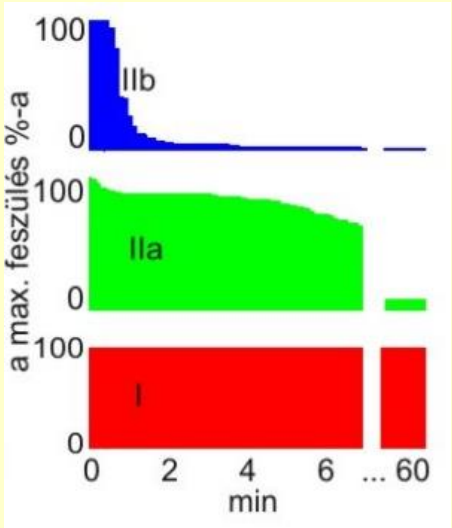
- Force depends on
  1. Recruitment
  2. AP frequency
  3. Fiber properties
  4. Muscle structure and composition



Properties of motor units

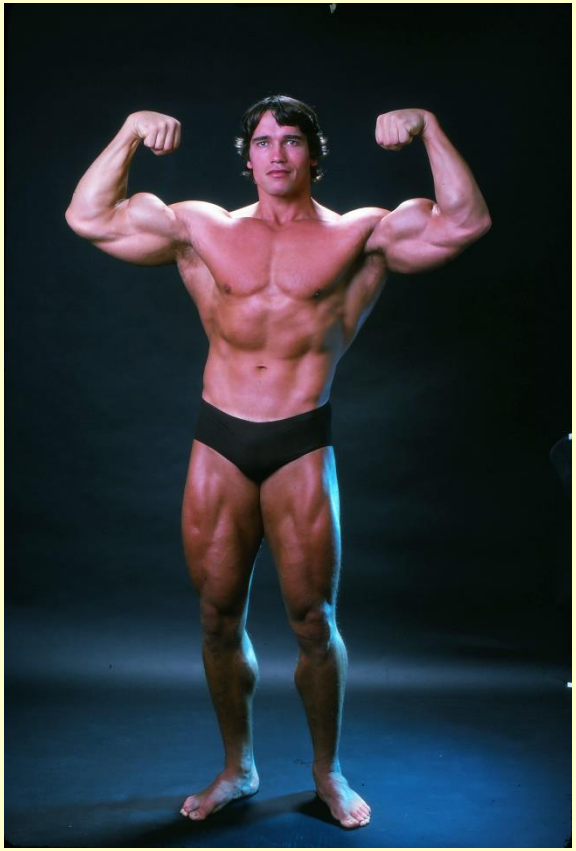


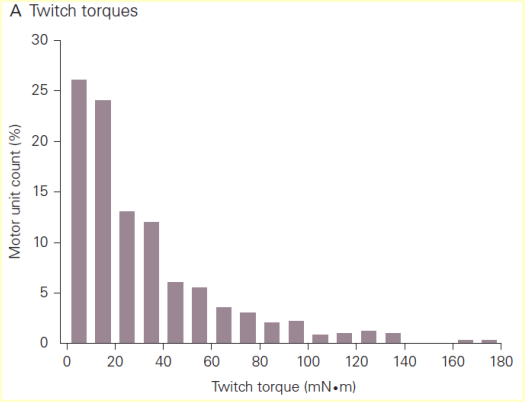
- contraction speed
- tetanic fquency
- maximal force
- fatigability

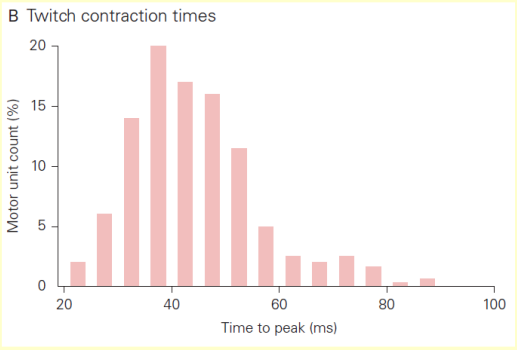


Physical activity can alter motor unit properties

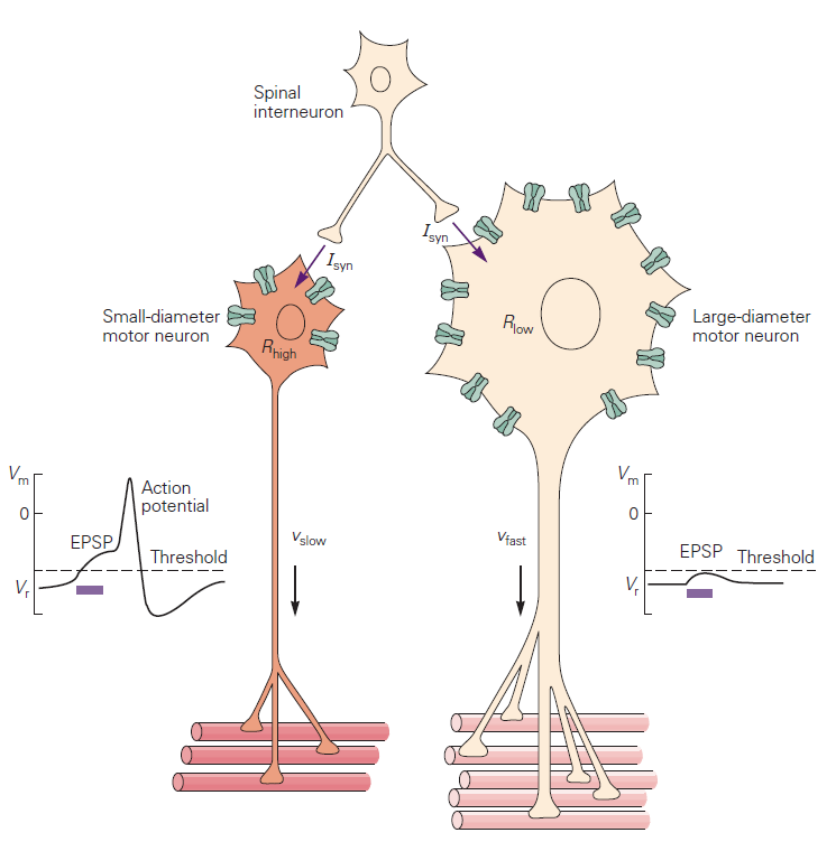
- Strength training vs Endurance training
  - faster myosin
  - more contractile proteins
  - higher capillary density
  - more mitocondria
- No change in composition!



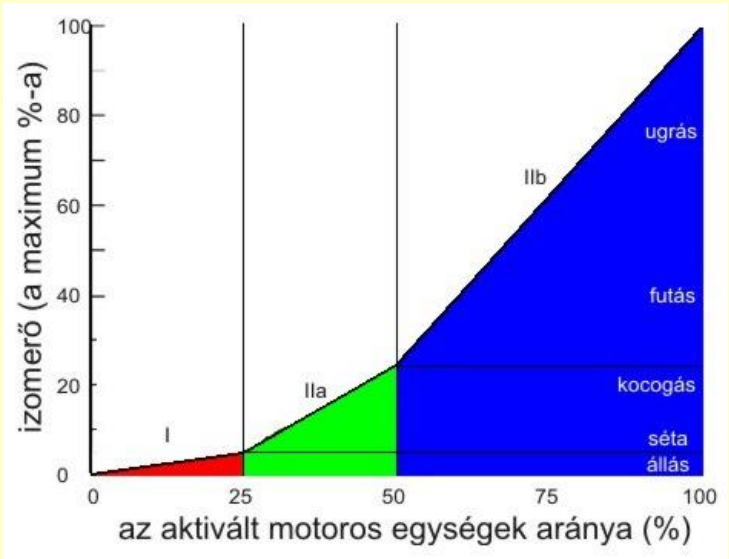




Recruitment order

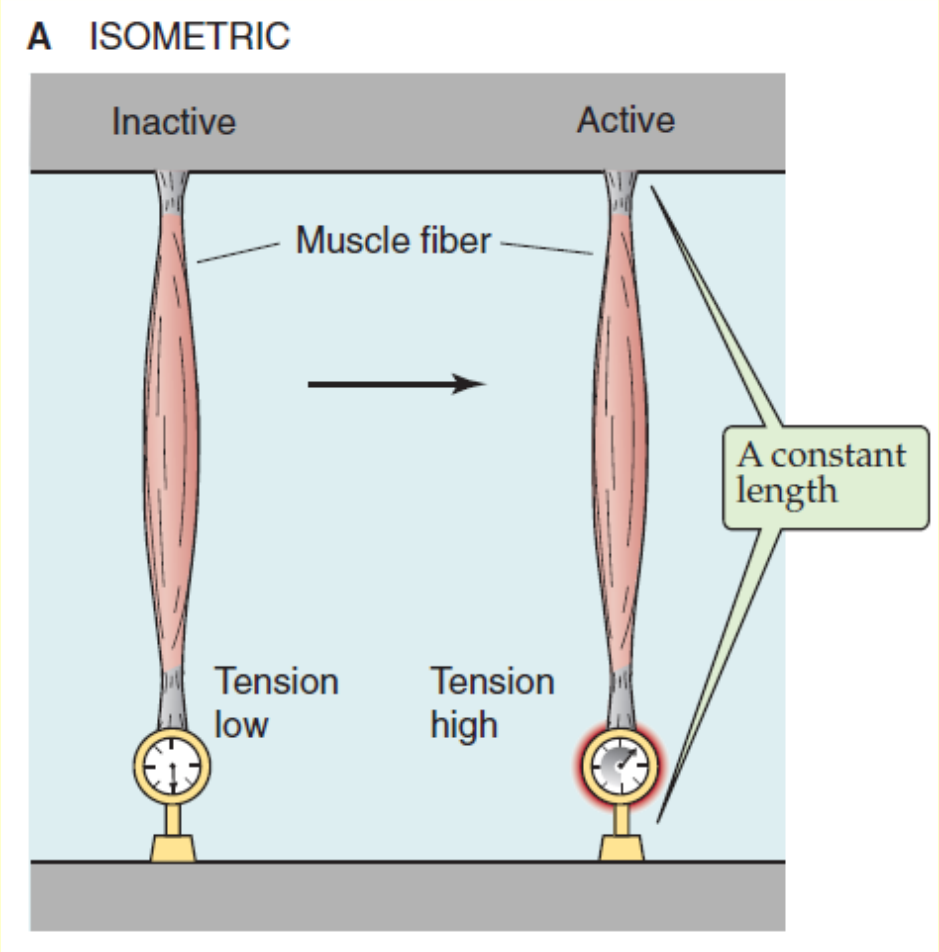


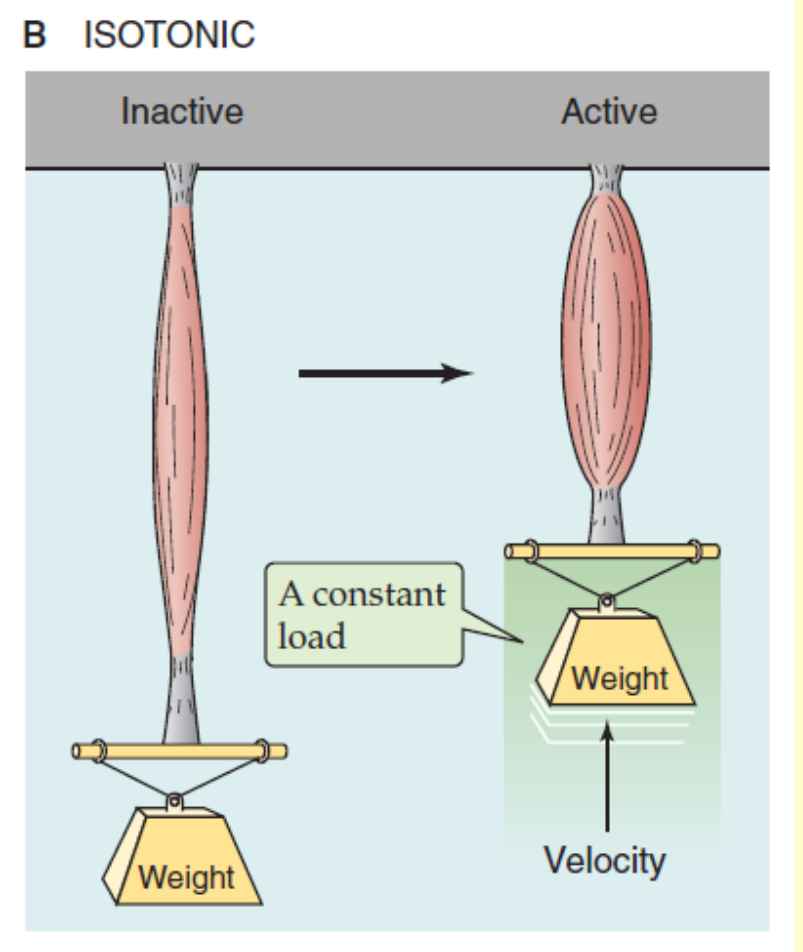
- Recruitment threshold
- Size principle



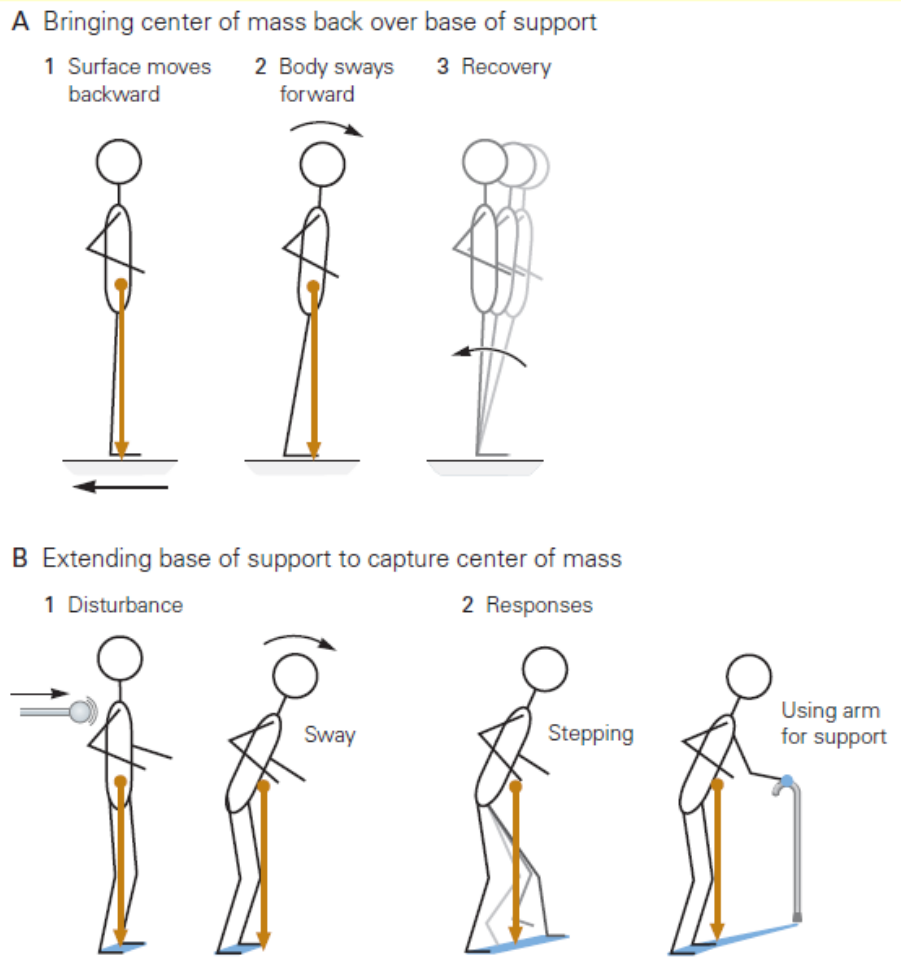
Isotonic and isometric contractions

- constant-length contractions to maintain static body postures
- stretch-shorten cycle to enhance work capacity





Posture and balance



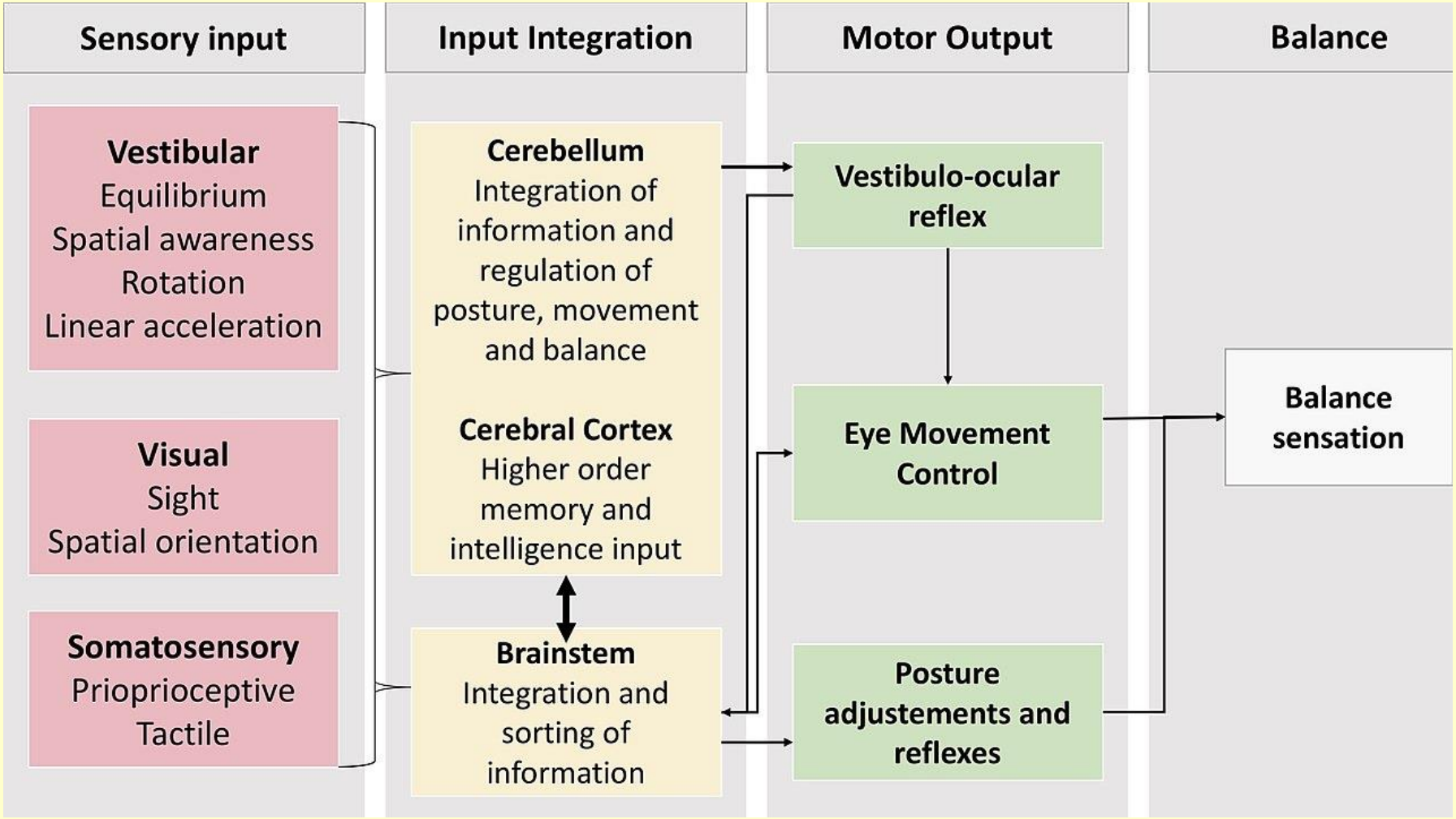
- Posture (e.g. upright stance) requires two actions:

(1) maintaining support against gravity (keeping the center of mass at some height)

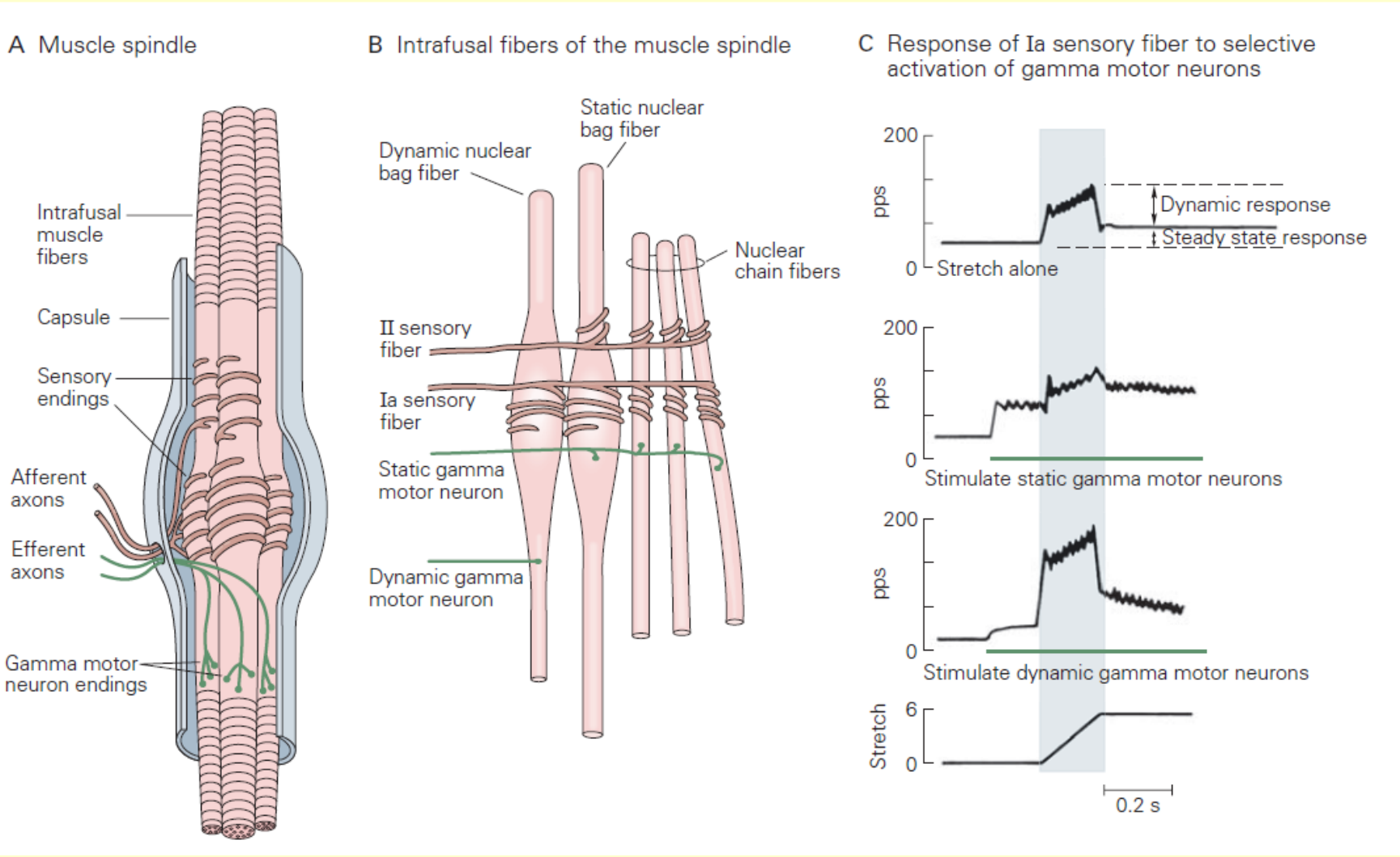
(2) maintaining balance (keeping the downward projection of the center of mass within the base of support)

- Body sway is actively counteracted by **the posture control system.**
- **anticipatory** postural adjustments during voluntary movements

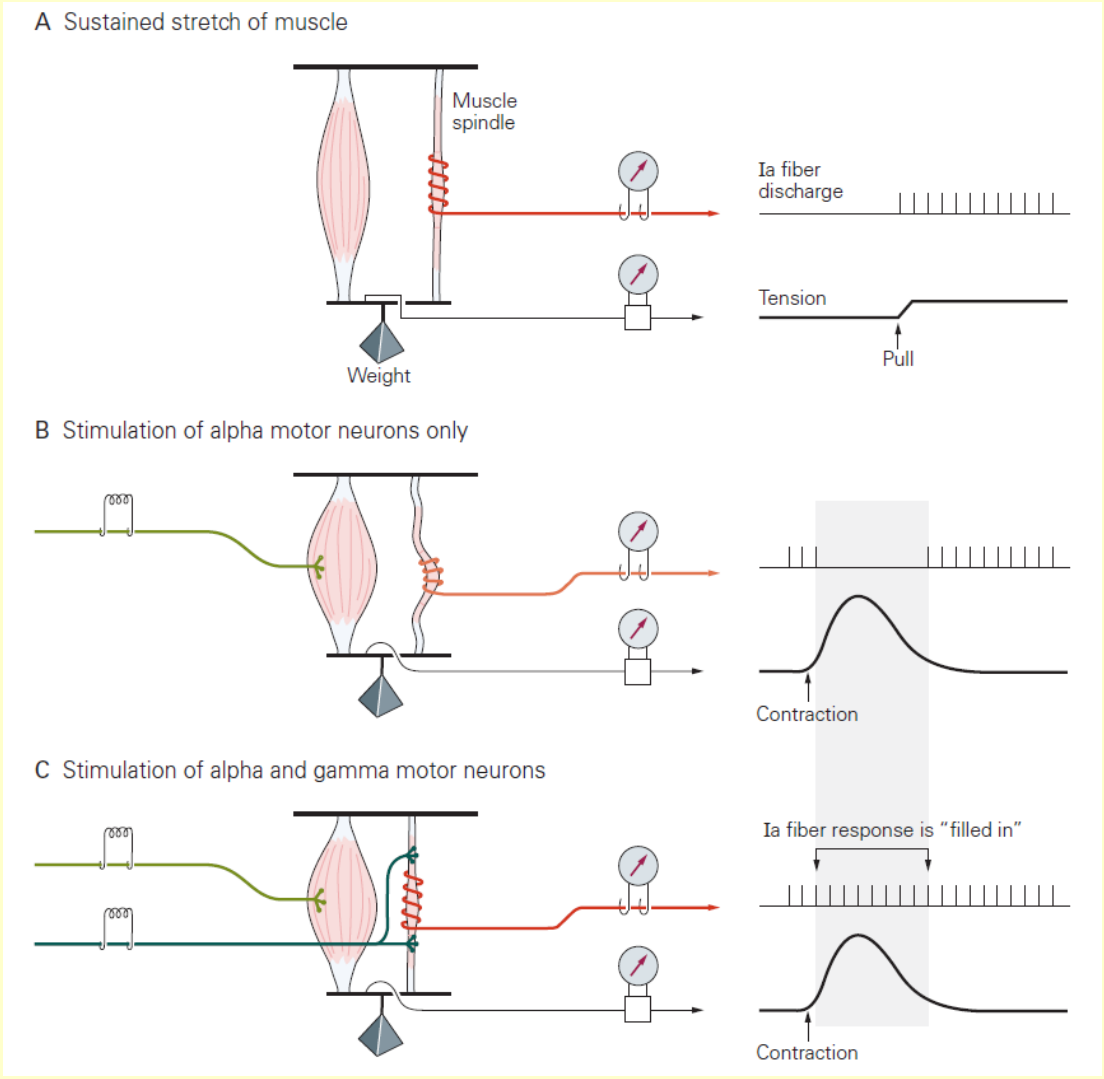
Posture control system

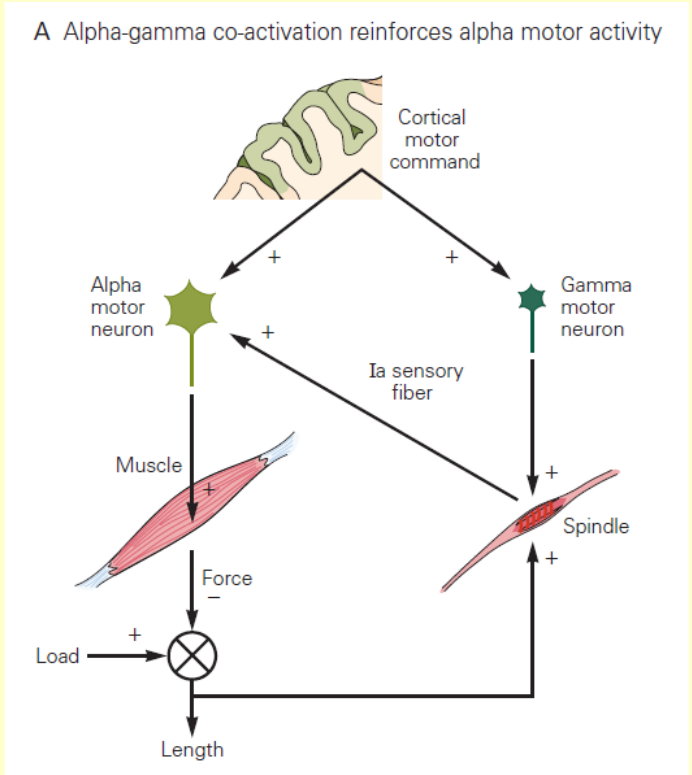


Muscle spindle



Gamma motor neurons

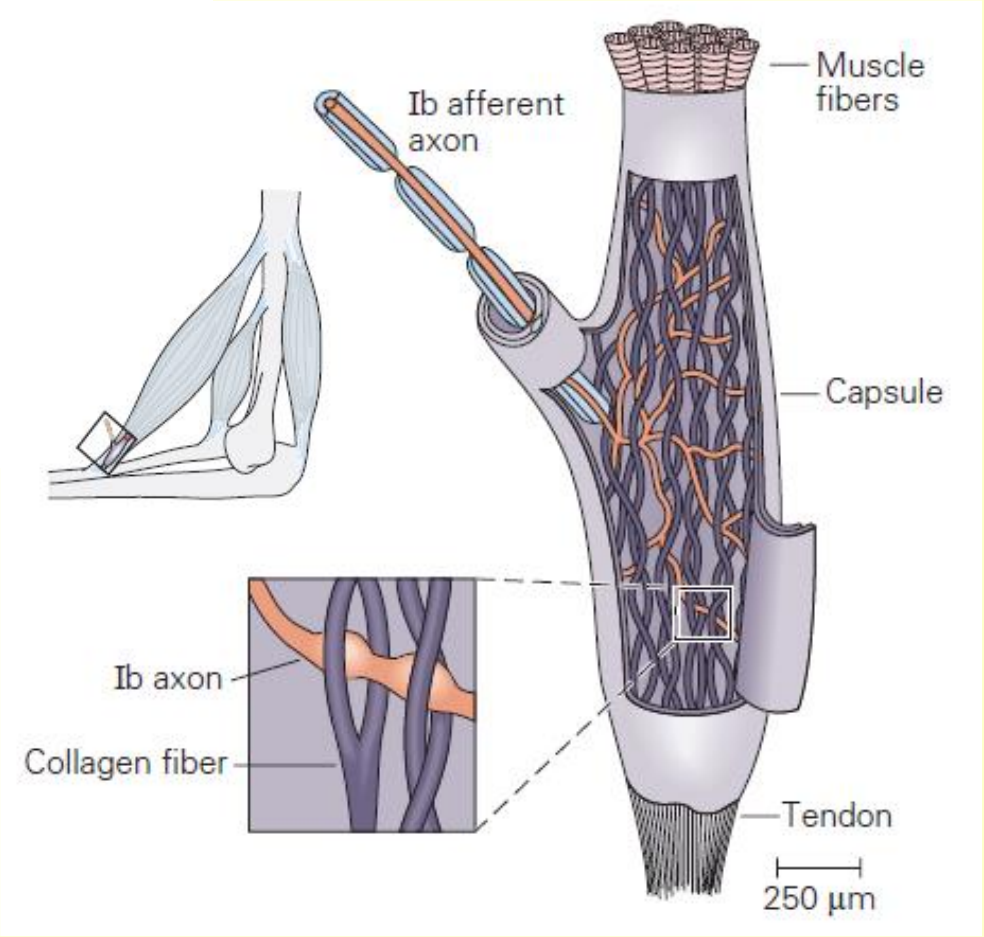




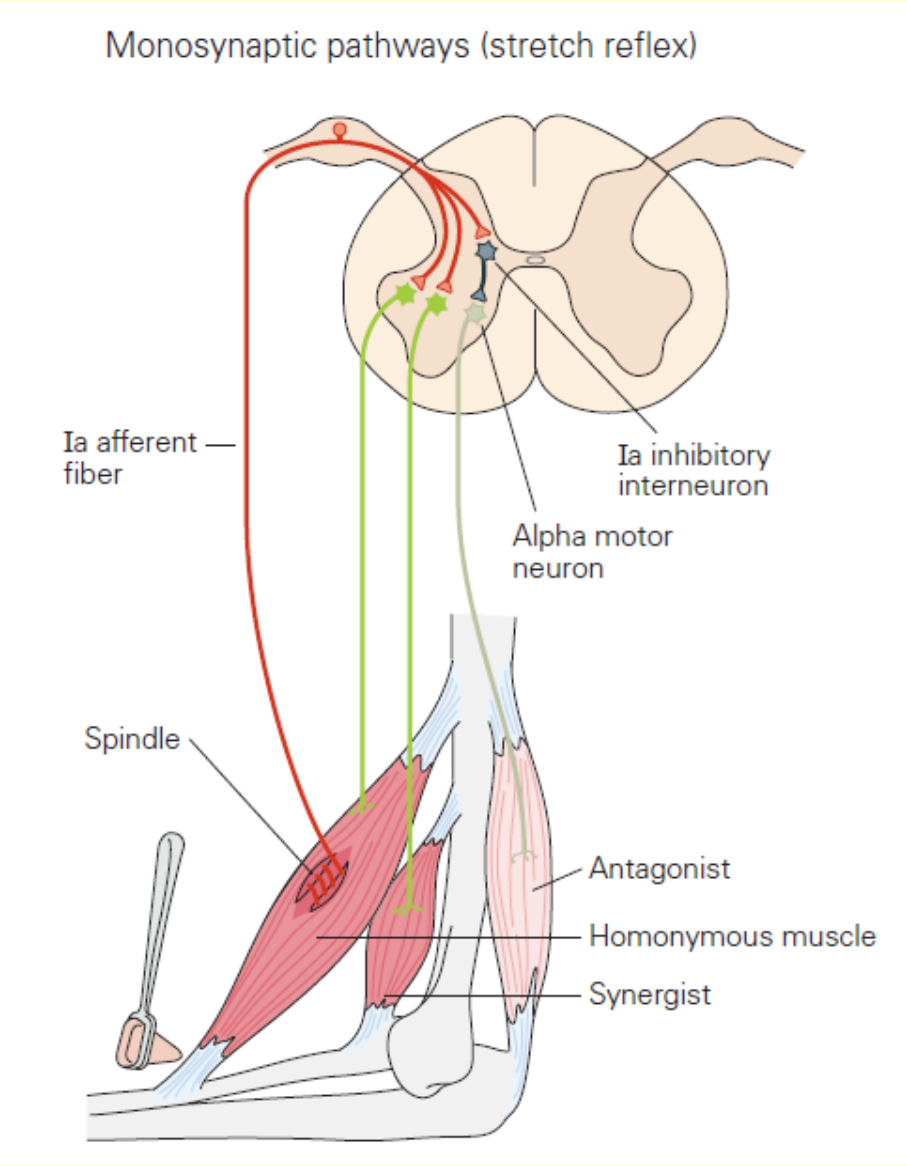
- fusimotor system

Tendon organ

- at the junction between skeletal muscle fibers and tendon
- stretching straightens the collagen fibers, thus compresses Ib nerve endings
- most sensitive to changes in muscle tension

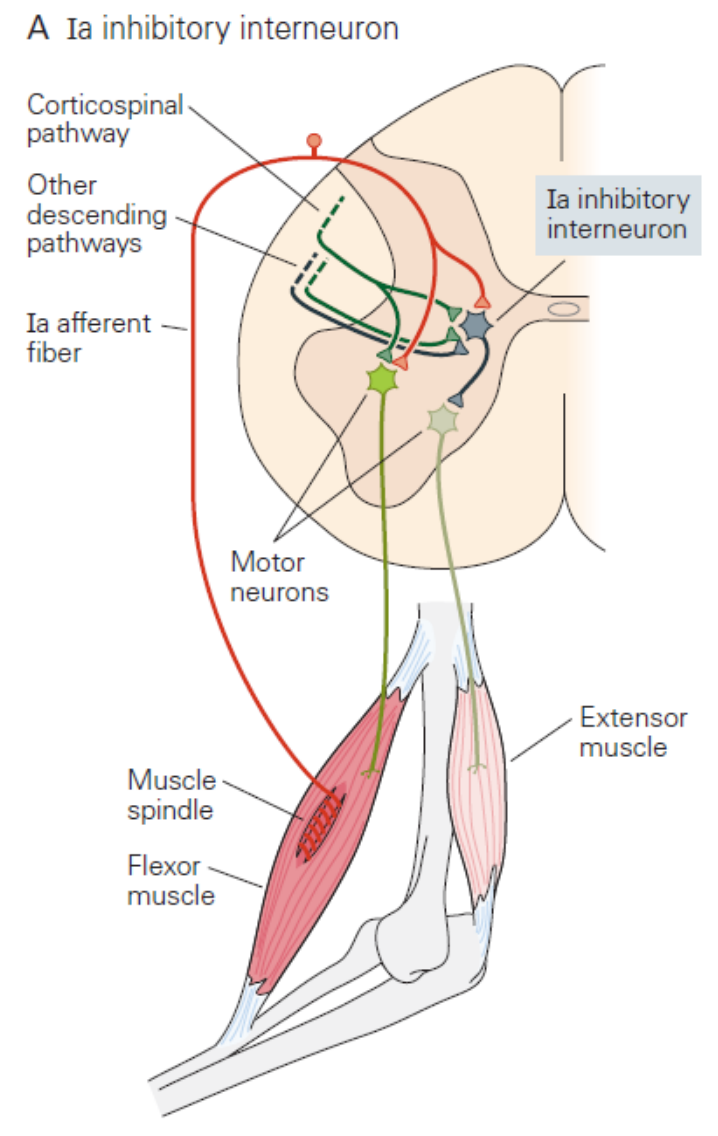


Extensor reflex



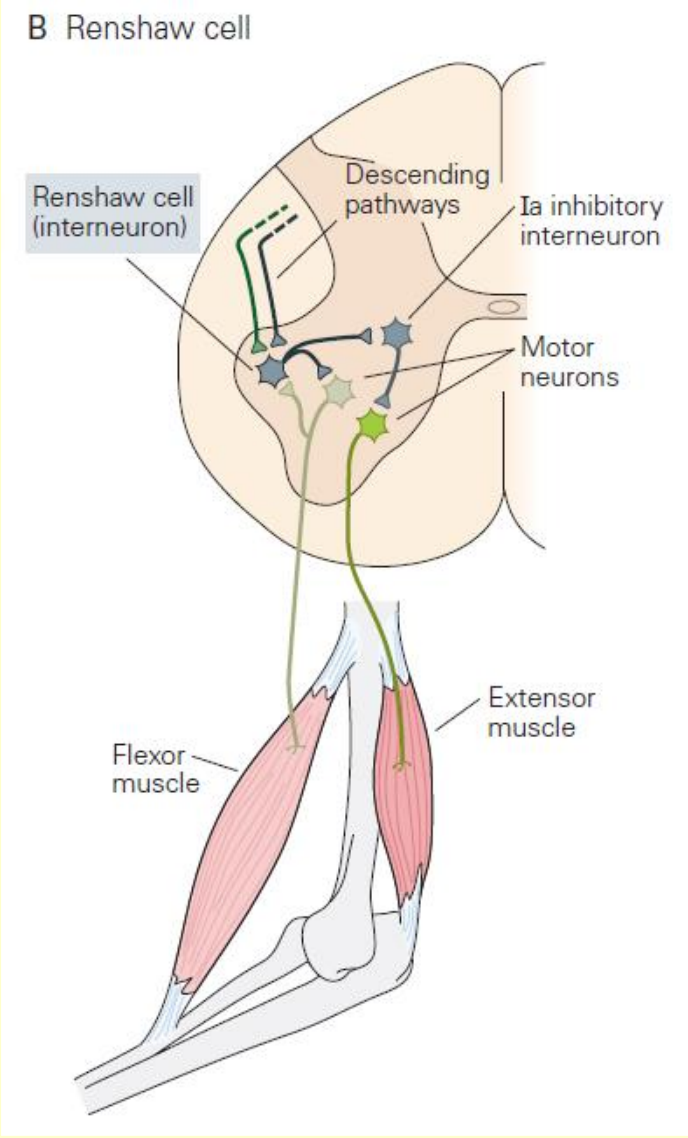
- muscle spindle
- Ia afferent
- excite synergists (monosynaptic)
- inhibit antagonists
- counteracts the stretch
- brain stem facilitates the stretch reflexes of extensor muscles
- support posture

Ia interneurons



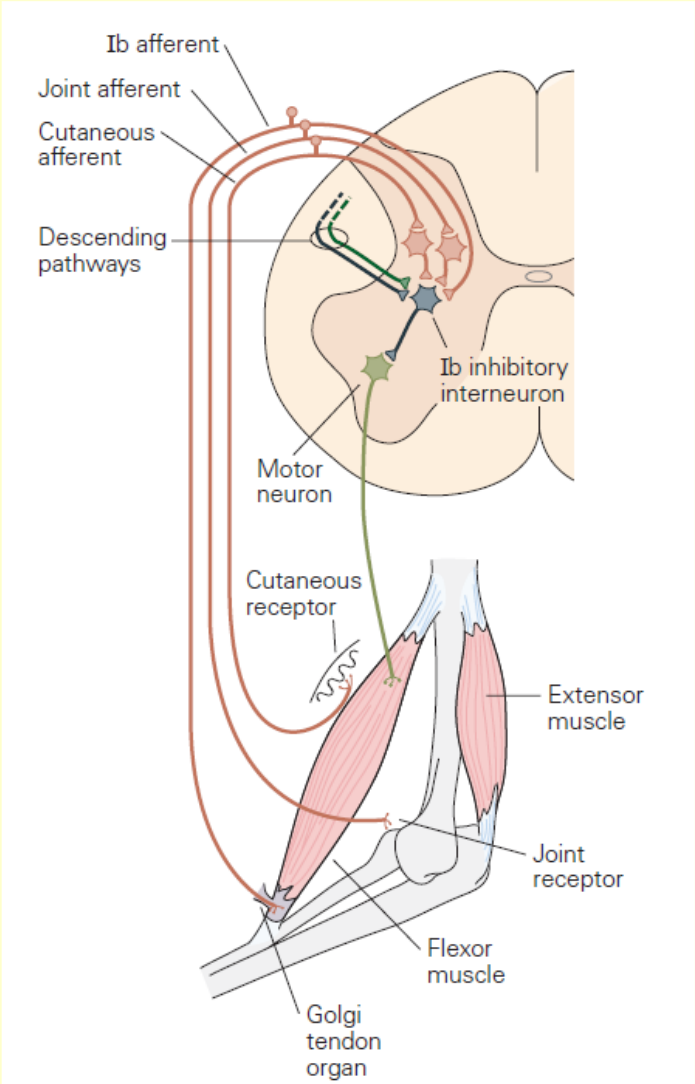
- collaterals from cortical neurons during voluntary movements
- balance of excitatory and inhibitory inputs
- supraspinal centers can reduce reciprocal inhibition
- enable co-contraction for joint stabilization

Renshaw cells

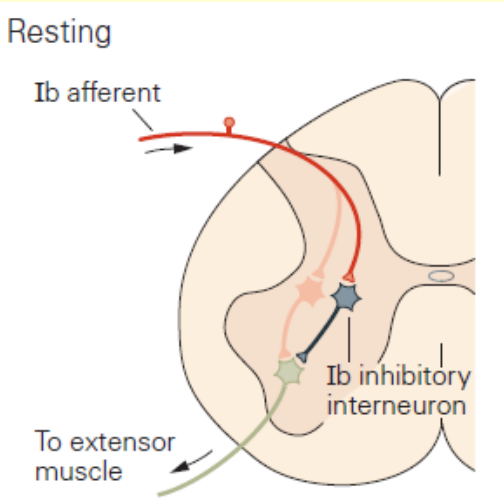


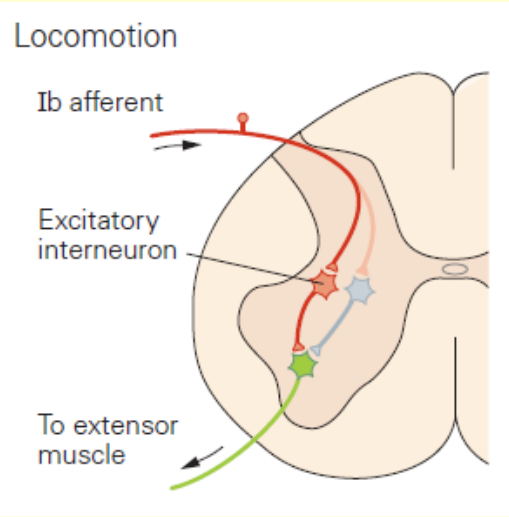
- negative feedback
- stabilize the firing rate of the motor neurons
- regulate the strength of inhibition
- synaptic input from descending pathways to distribute inhibition

Ib inhibitory interneuron

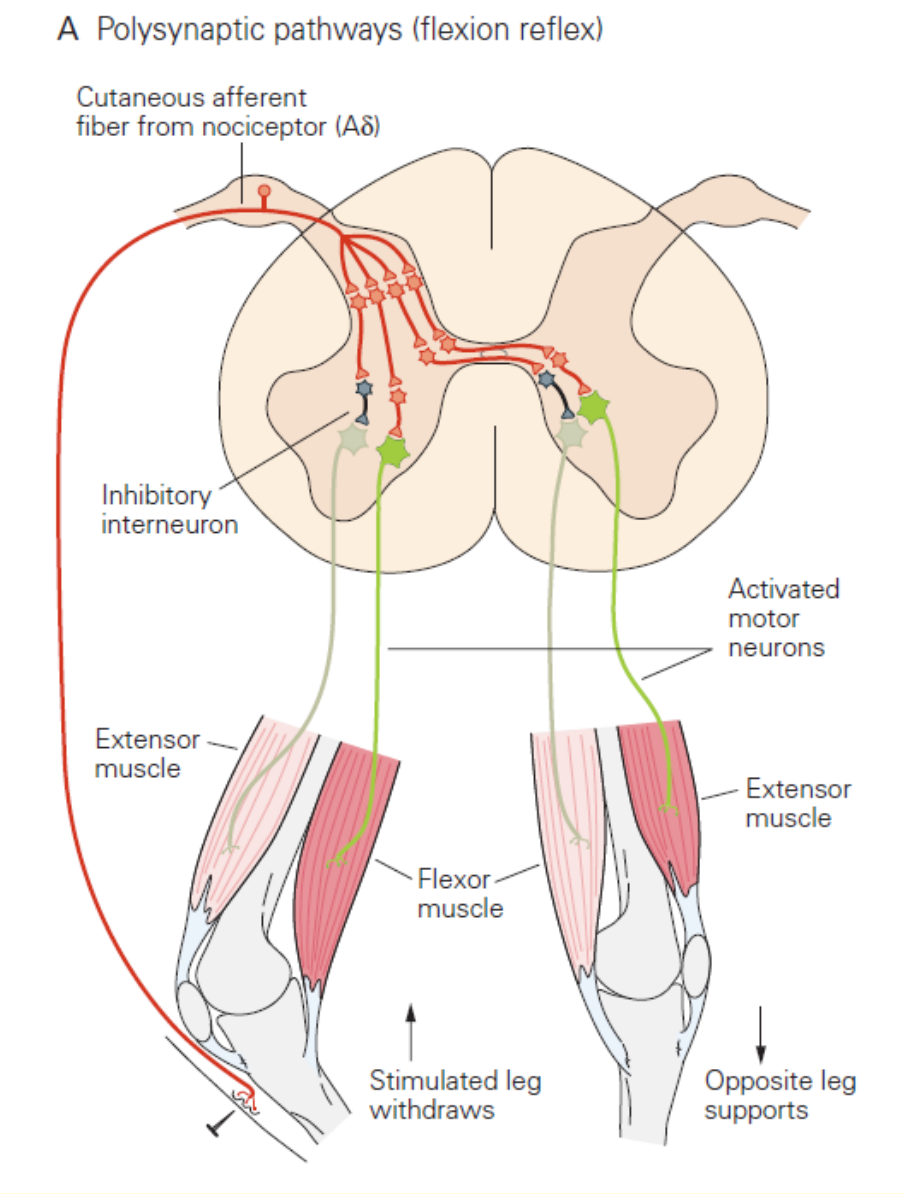


- multiple imputs
- descending control
- protective function
- precise spinal control of muscle force
- state-dependent reflex reversal



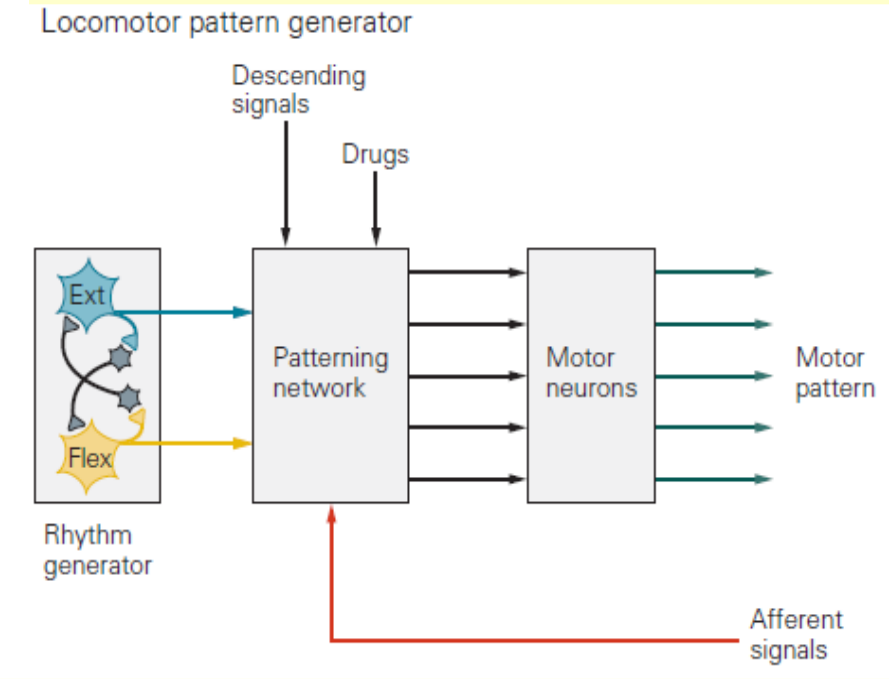


Flexion reflex

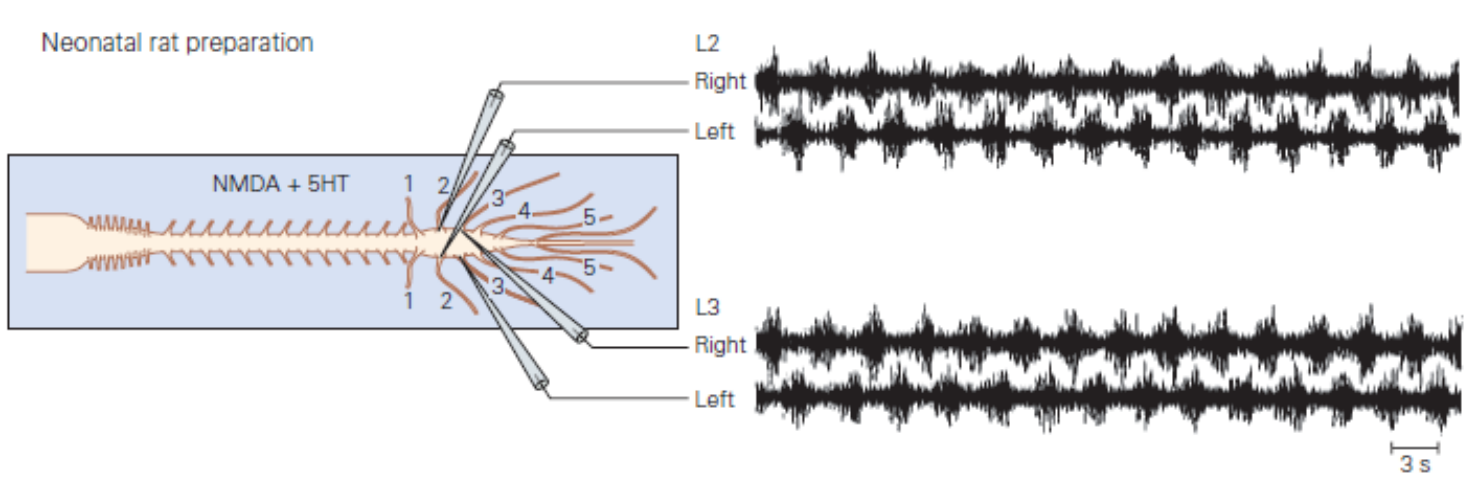


- flexion and crossed-extension
- withdraw the limb from noxious stimuli
- extensive divergence

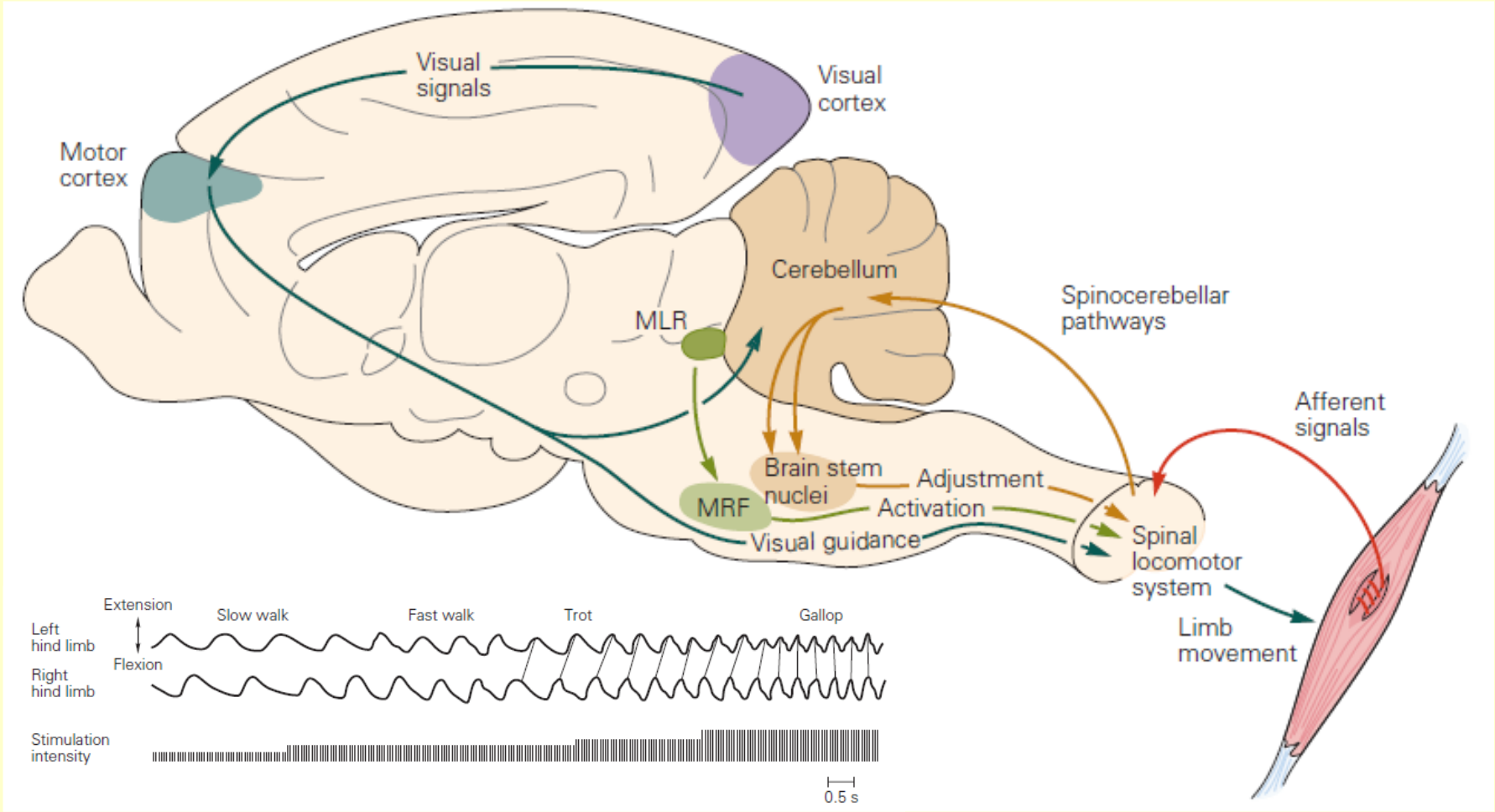
Basic motor patterns



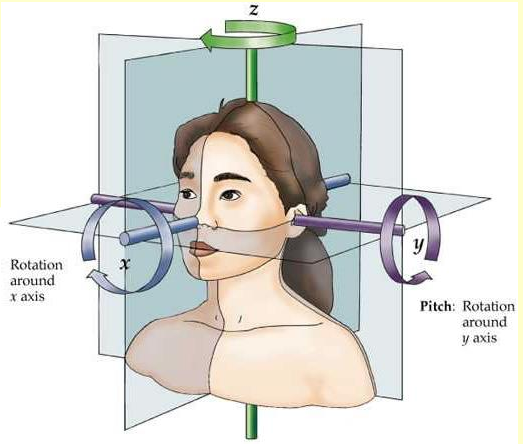
- locomotion is repetitive and stereotyped
- basic motor pattern for stepping is generated in the spinal cord
- central pattern generators



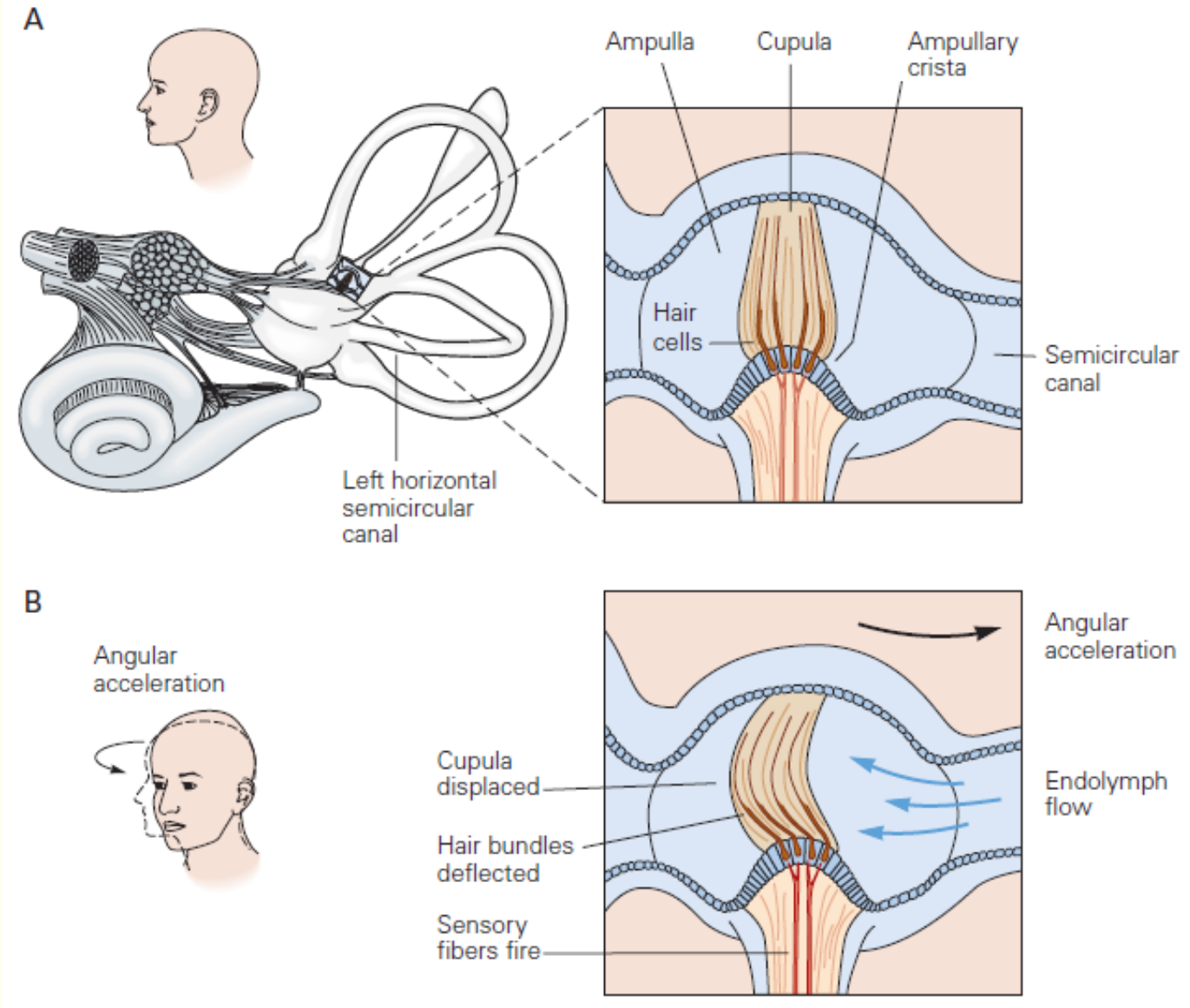
The brain stem and motor cortex control locomotion



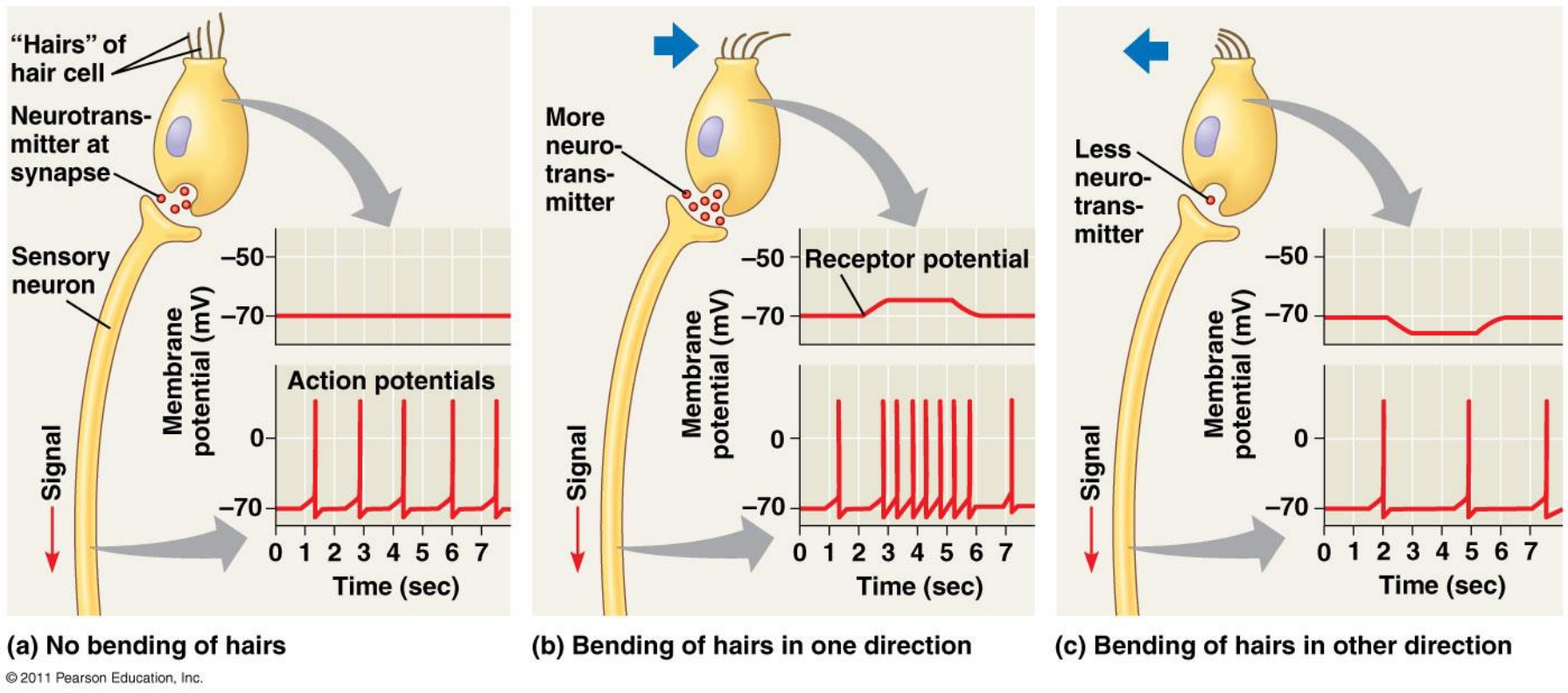
The vestibular apparatus



The ampulla of a semicircular canal



Hair cells in the vestibular labyrinth

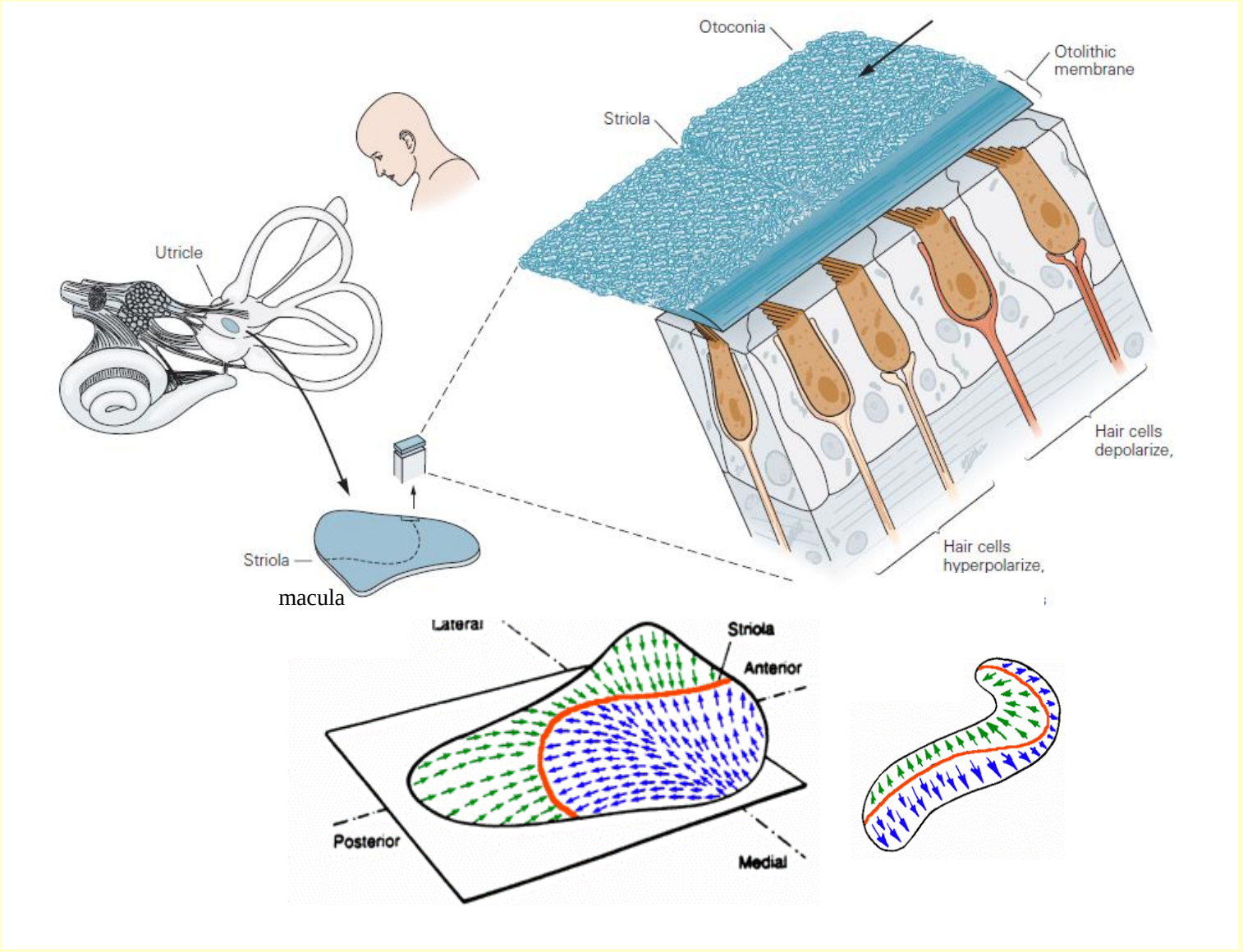


(a) No bending of hairs

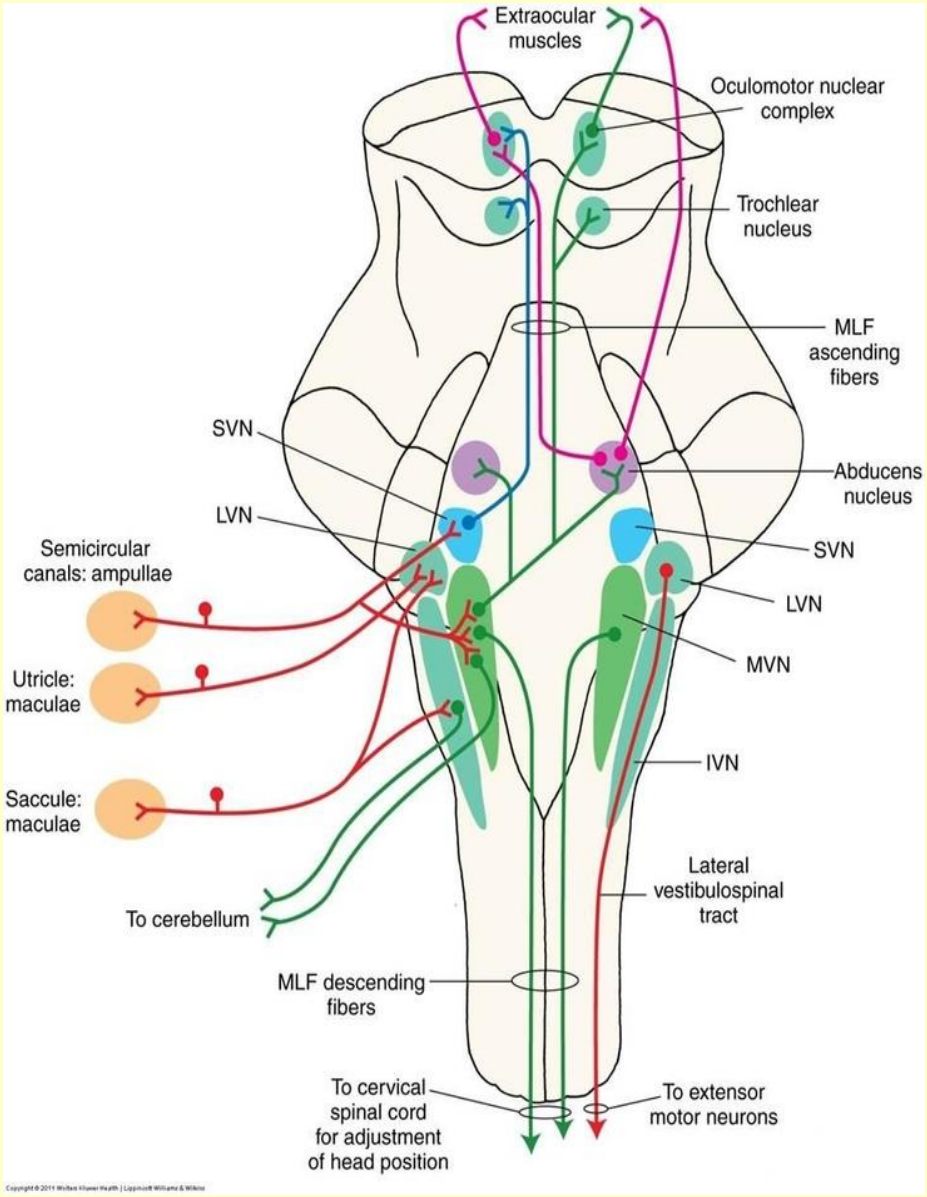
(b) Bending of hairs in one direction

(c) Bending of hairs in other direction

Az Otolith Organs



Vestibular nuclei



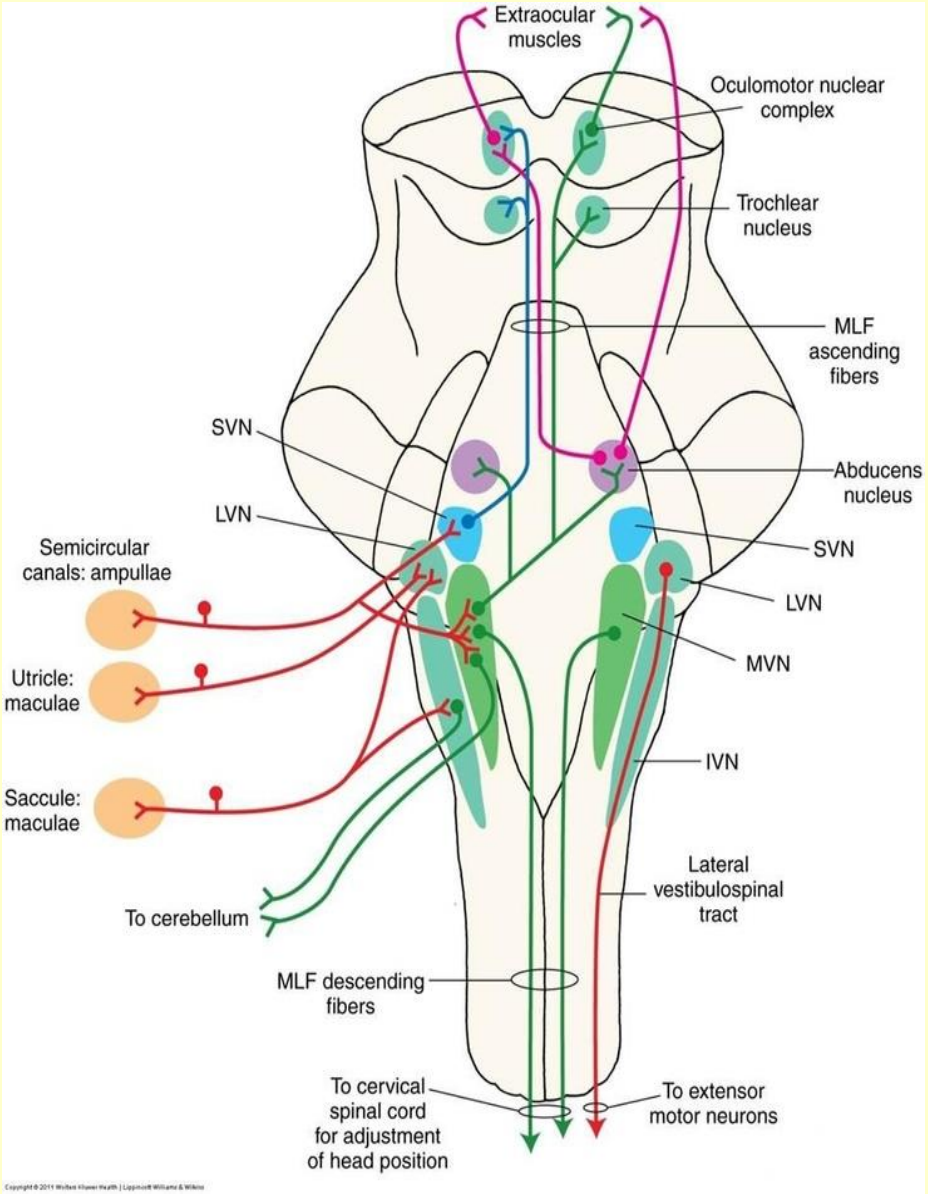
- Gaze control:

semicircular canals → superior and medial vestibular nuclei → oculomotor centers / spinal cord

- Postural reflexes

semicircular canals / otolith organs → lateral vestibular nucleus (Dieters) → spinal cord

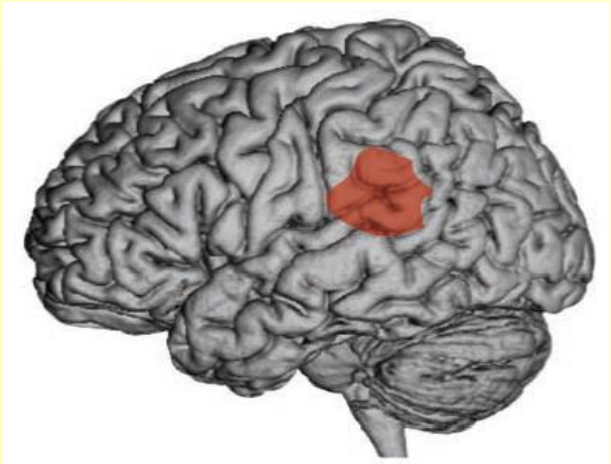
Vestibular nuclei



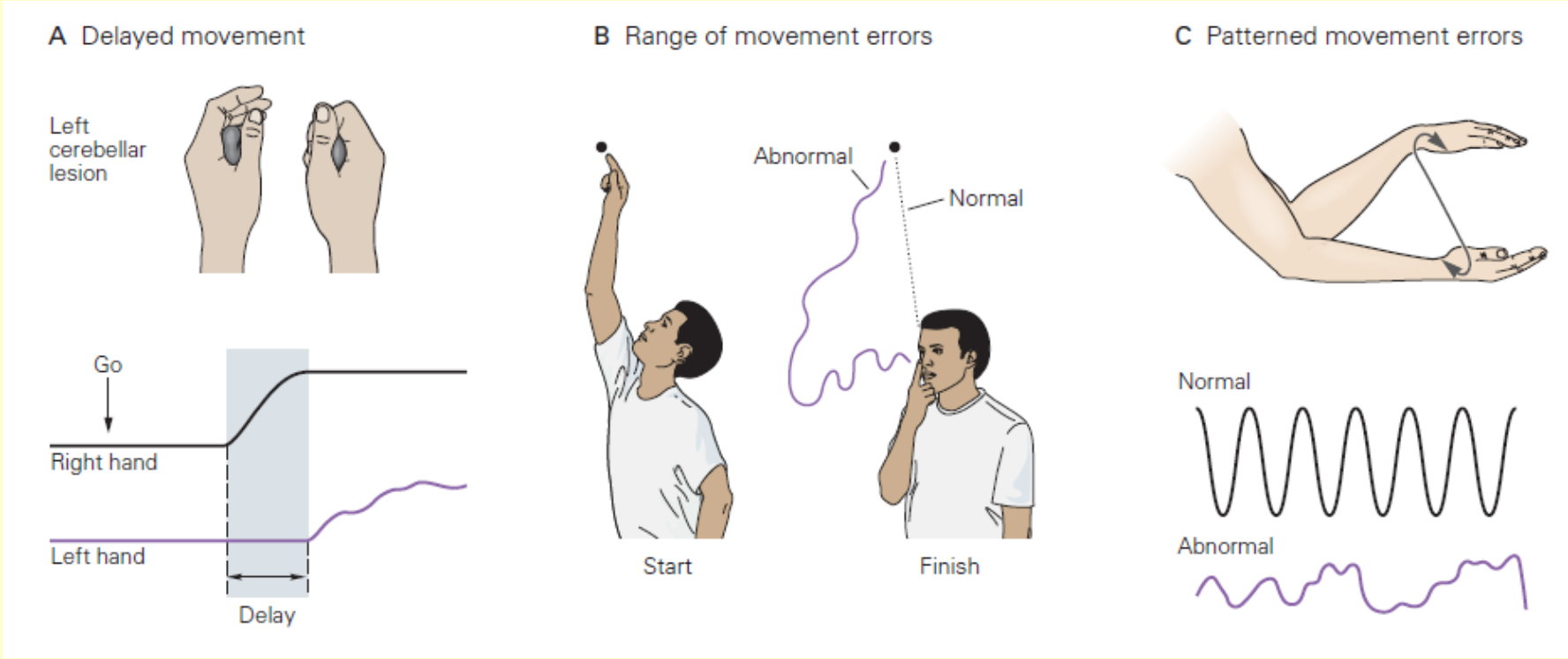
- Complex balance control

otolith organs → descending (inferior) vestibular nucleus → cerebellum / reticular formation / contralateral vestibular nuclei / spinal cord

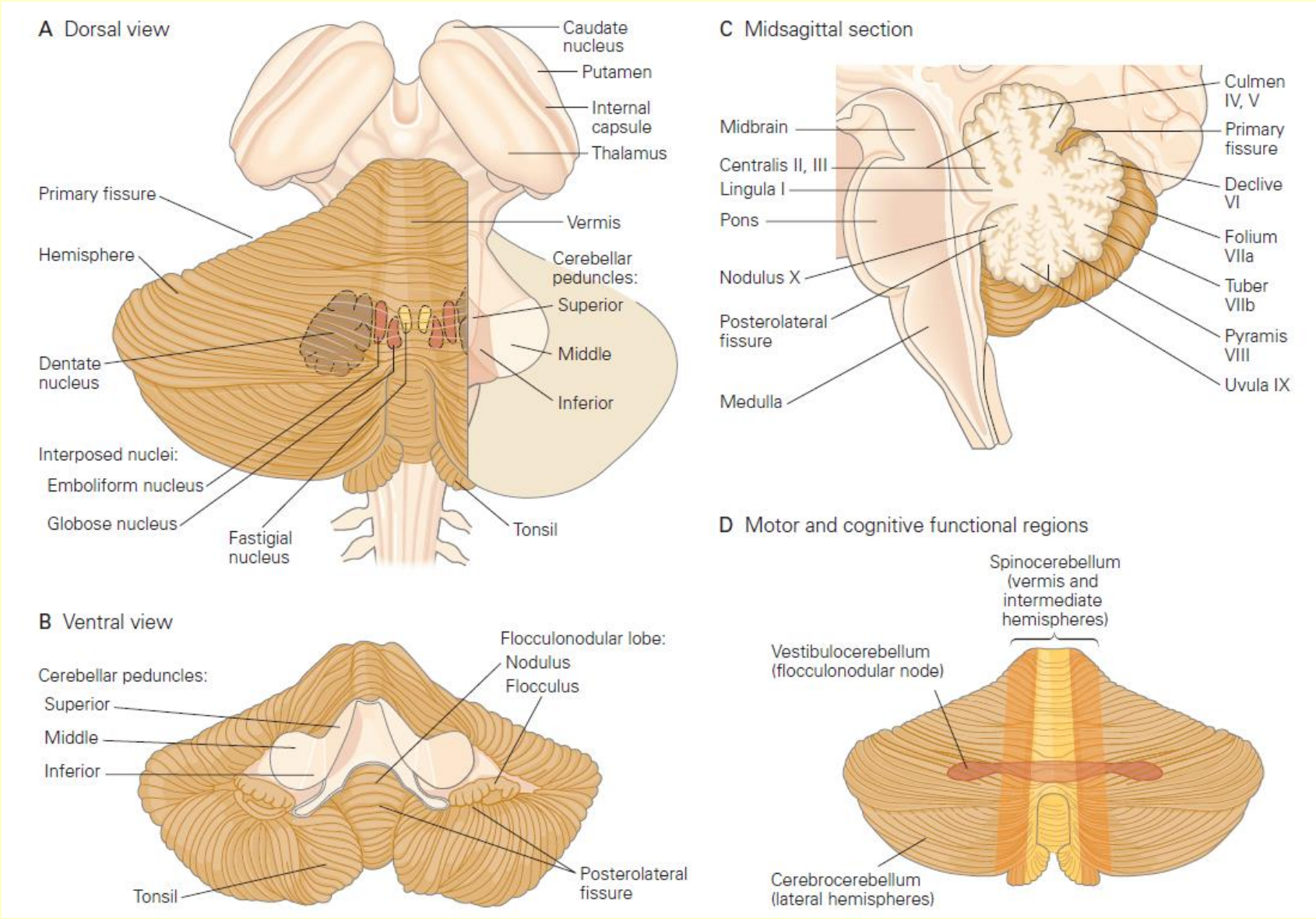
- All vestibular nuclei project to the thalamus, then to the vestibular somatosensory cortex: areas 2 and 3a



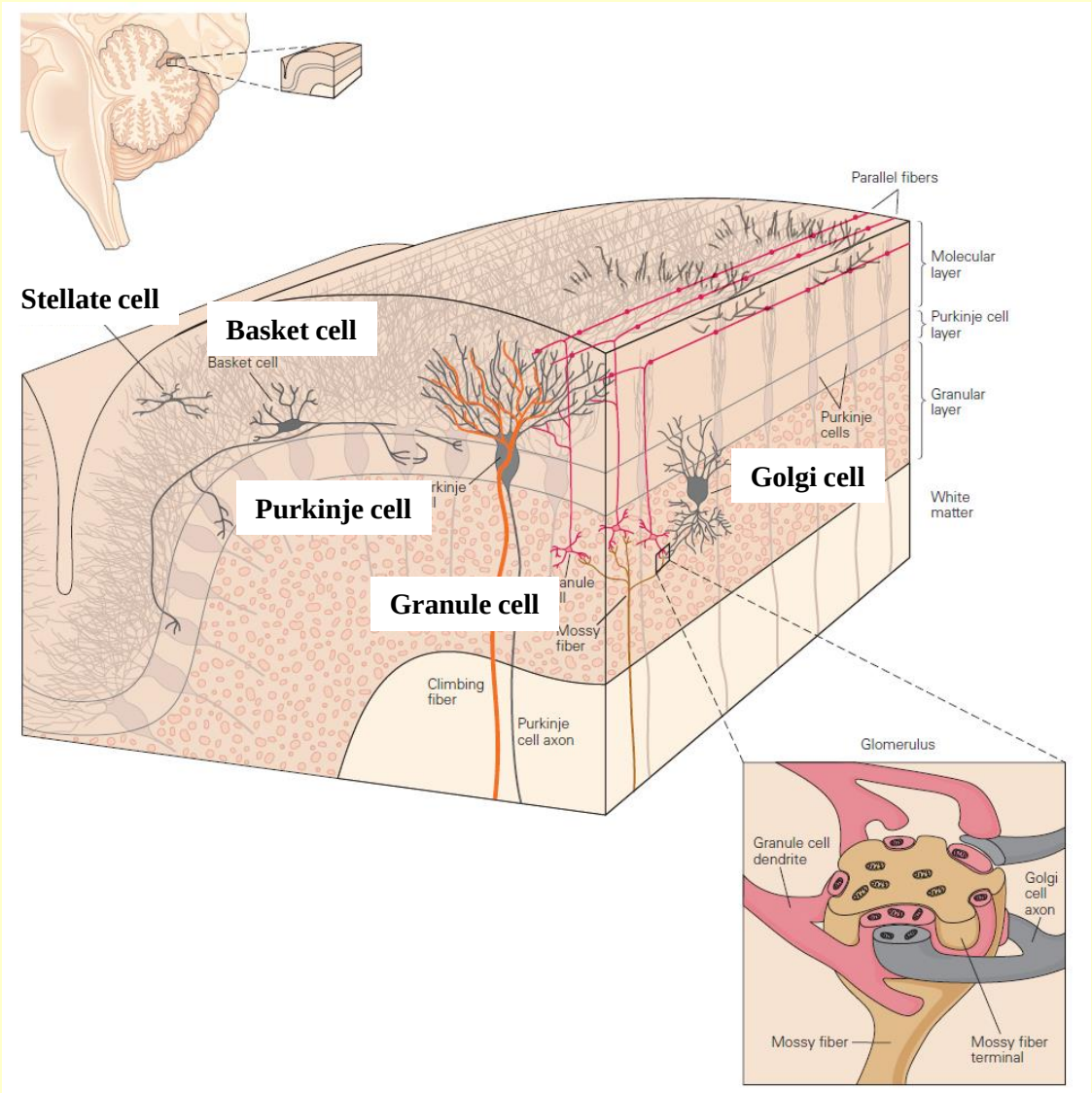
Typical defects observed in cerebellar diseases



Gross features of the cerebellum

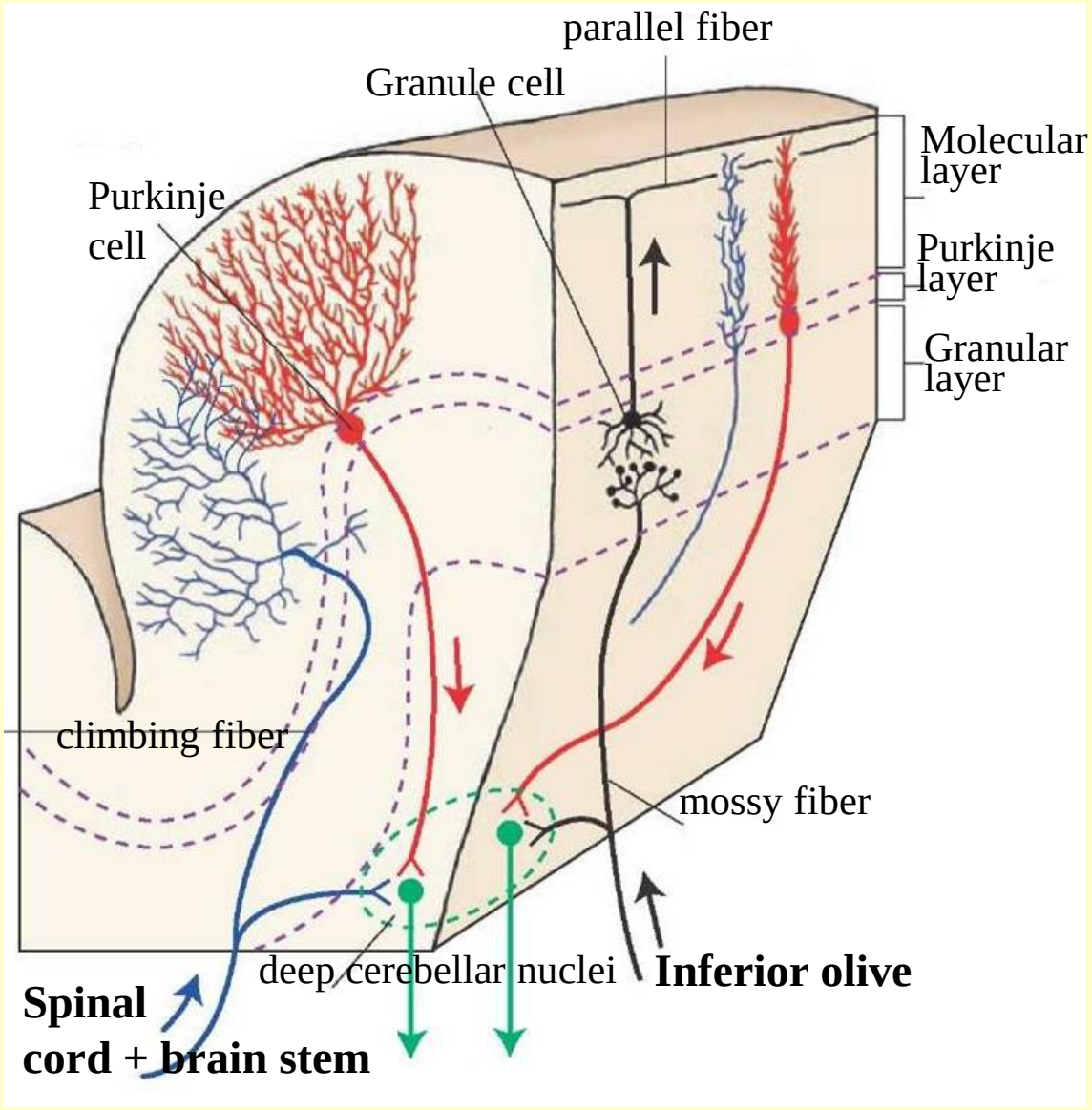


Cerebellar cortex anatomy



- granular layer
  - *cerebellar glomeruli:*
  - granule cells
  - Golgi interneurons
  - mossy fibers
- Purkinje cell layer
  - Purkinje cells
- molecular layer
  - fan-like dendrites of Purkinje cells
  - climbing fibers
  - stellate and basket cells
  - parallel fibers

Cerebellar cortex imputs



climbing fiber:

Event detection

Low rate

Powerful influence

- 1 climbing fiber to 1-10 Purkinje cell
- 1 Purkinje from 1 climbing fiber

mossy/parallel fiber:

Stimulus information

High rate

Weak influence

- 1 granule cell from few mossy fiber to many Purkinje cell

Parallel Pathways

Comparation of excitatory and inhibitory signals

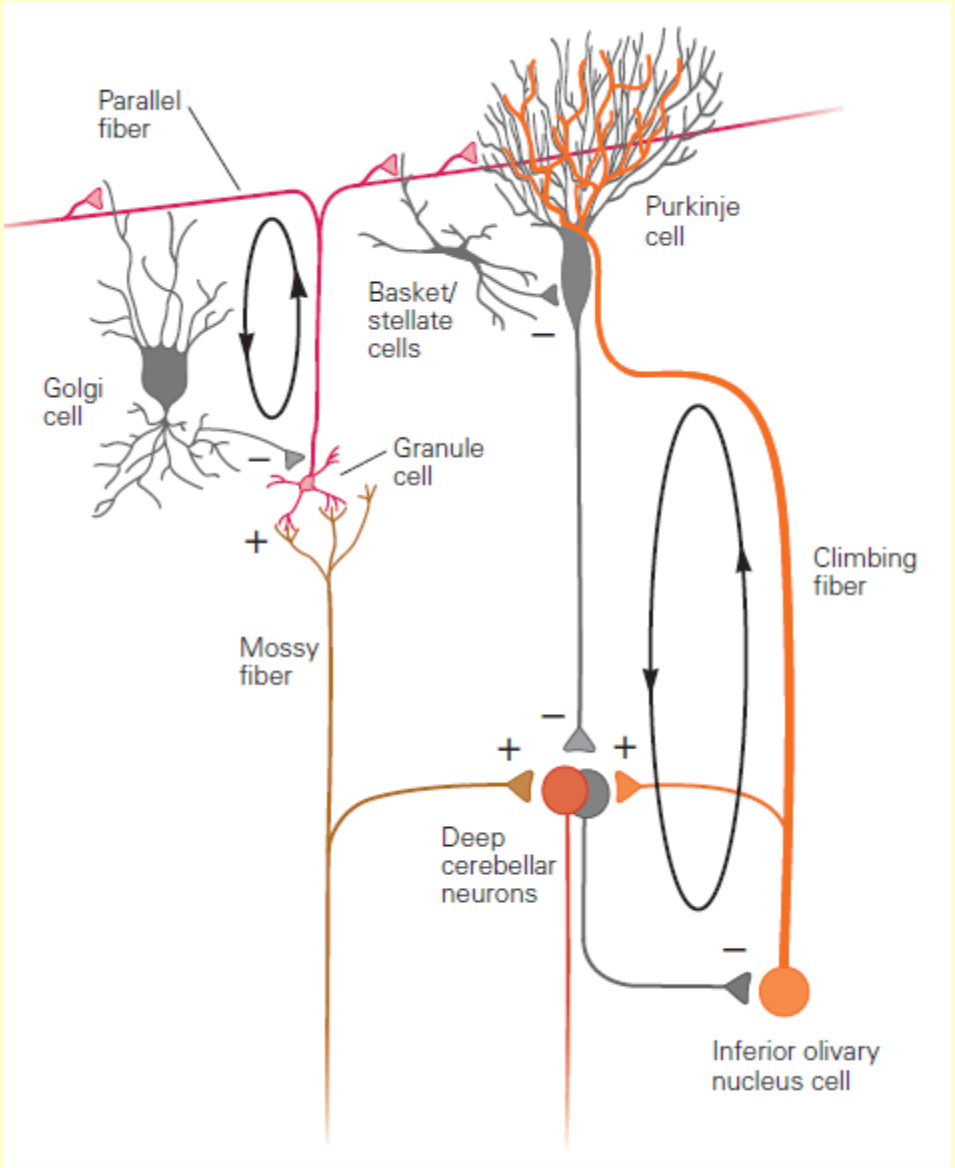
- mossy fiber → deep nuclei
- mossy fiber → granule cell → Purkinje cell → deep nuclei

- climbing fiber → deep nuclei
- climbing fiber → Purkinje cell → deep nuclei

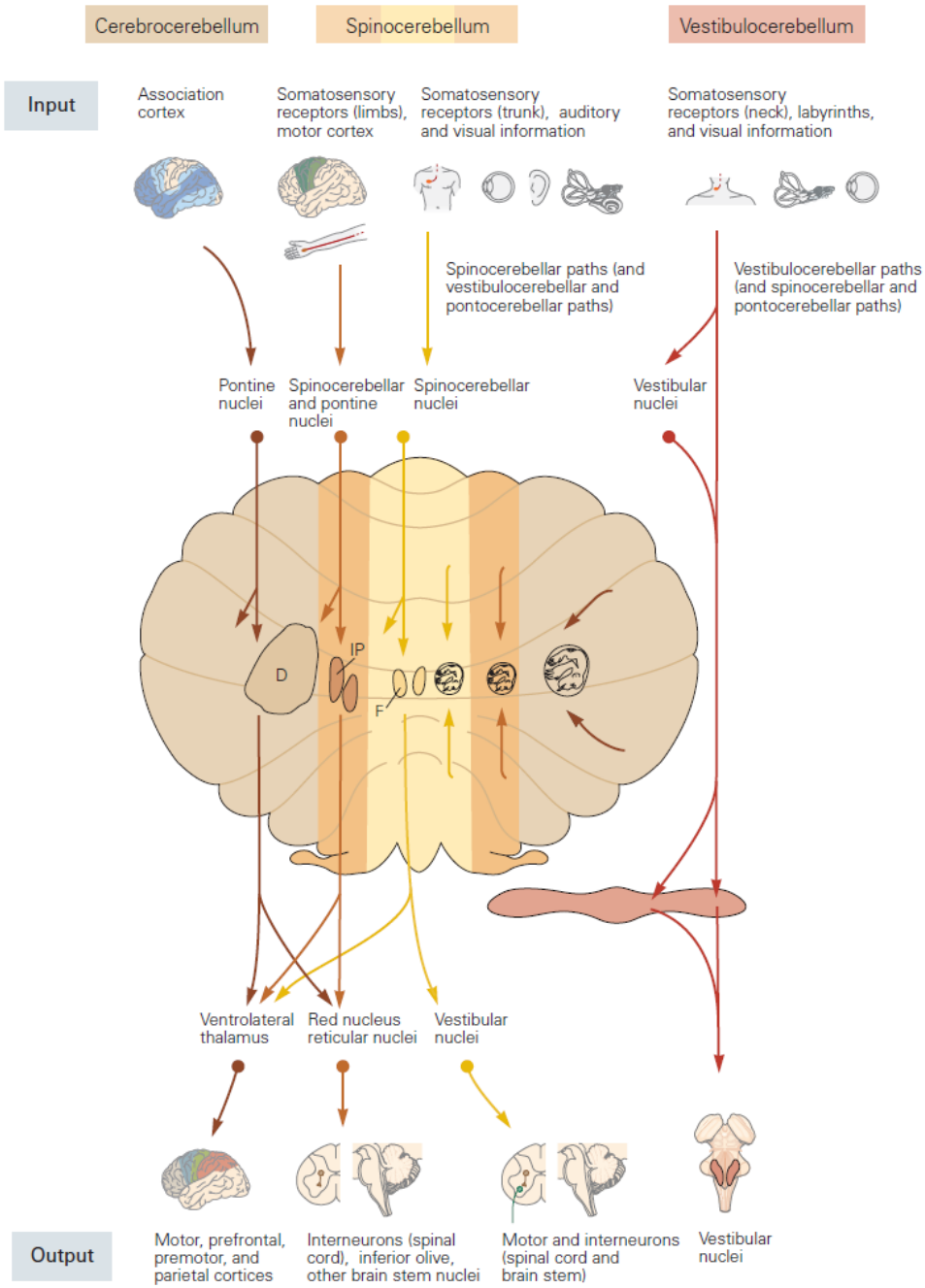
- granule cell → Purkinje cell
- granule cell → basket/stellate cell → Purkinje cell

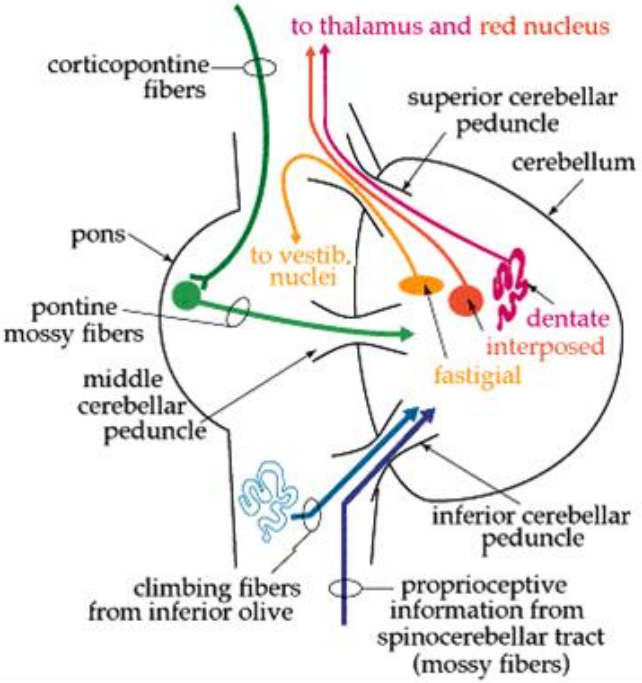
Inhibitory loops

- granule cell → Golgi cell → granule cell
- Inferior olive → deep nuclei → inferior olive



Functional regions of the cerebellum

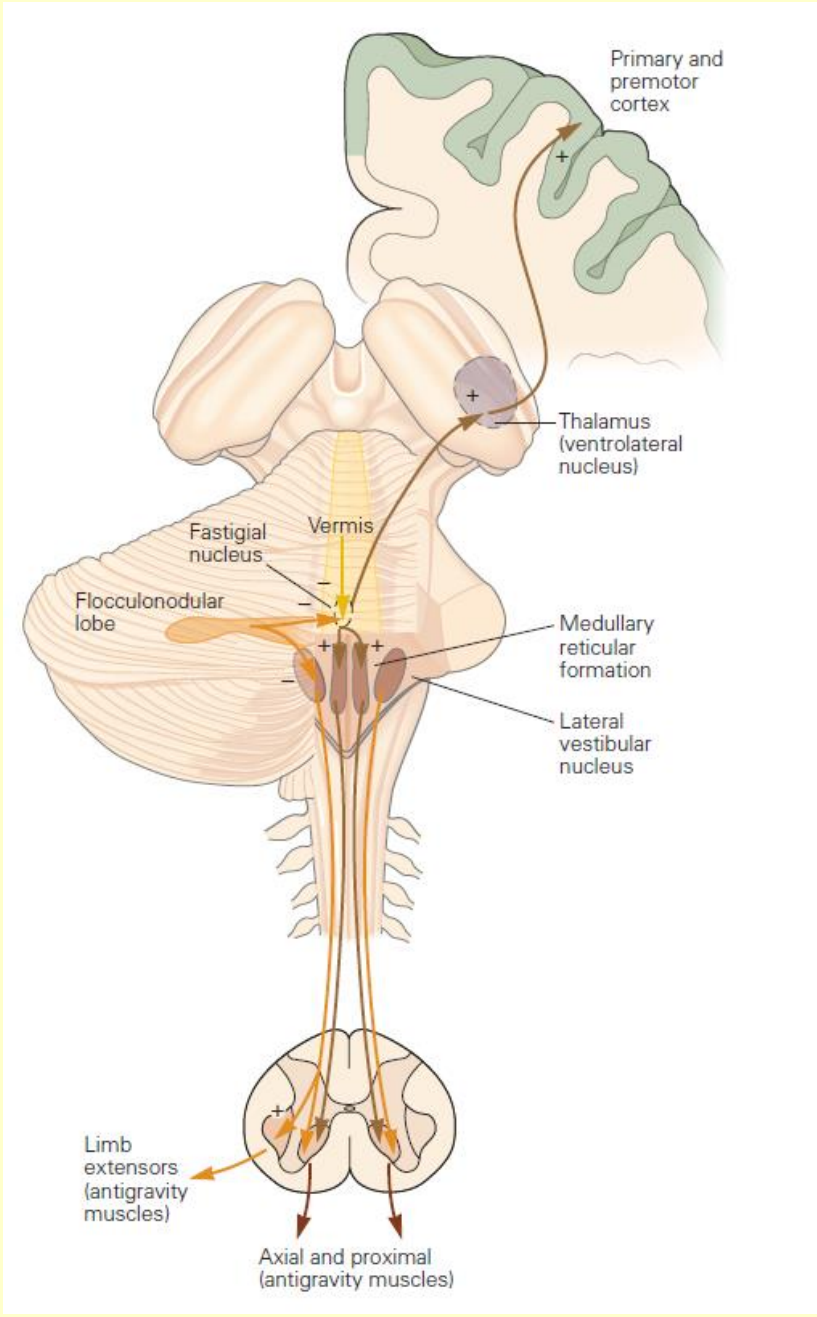




Cerebral control of balance

Vestibulocerebellum

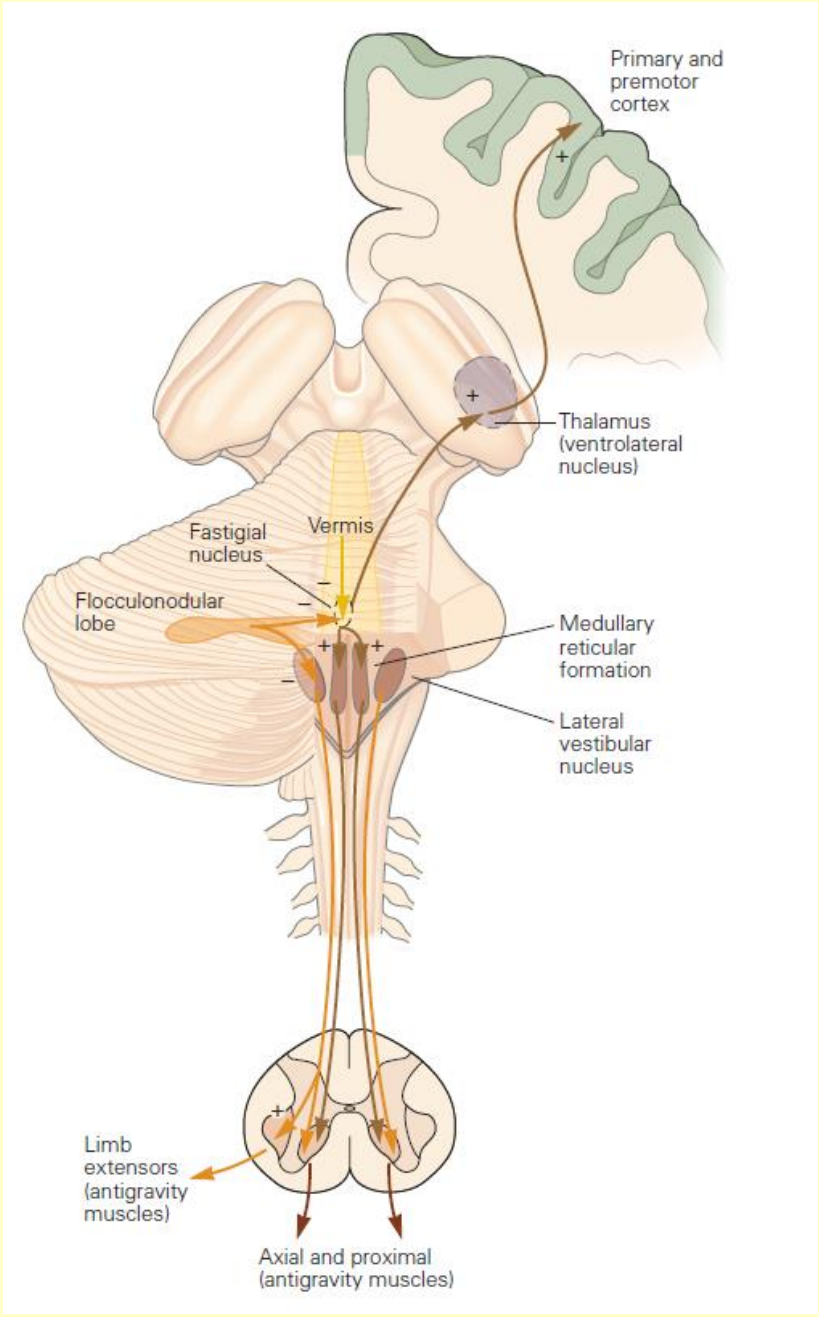
- Input: **vestibular organ/nuclei**, visual, somatosensory/proprioceptive
- Output:
  - n.vest.med → n.III.IV.VI.
  - n.vest.lat → spinal cord (axial muscles and limb extensors)



Cerebral control of balance

Spinocerebellum – vermis

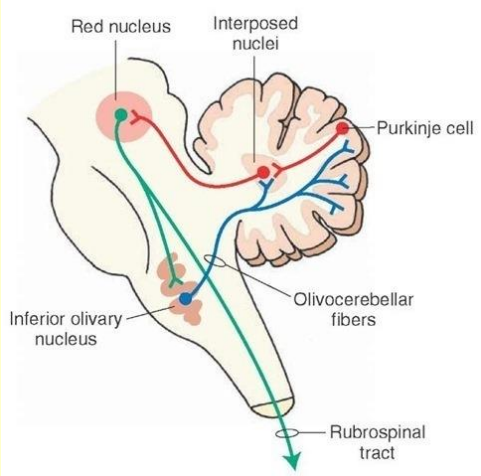
- Input: **vestibular**, visual, auditory, somatosensory/proprioceptive
- Deep nucleus: n. fastigii
- Output:
  - MRF/n.vest.lat → spinal cord (axial muscles and limb extensors)
  - n.vest.med → n.III.IV.VI.
  - Thalamus → motor ctx
- Loop: cerebellum → IO → cerebellum

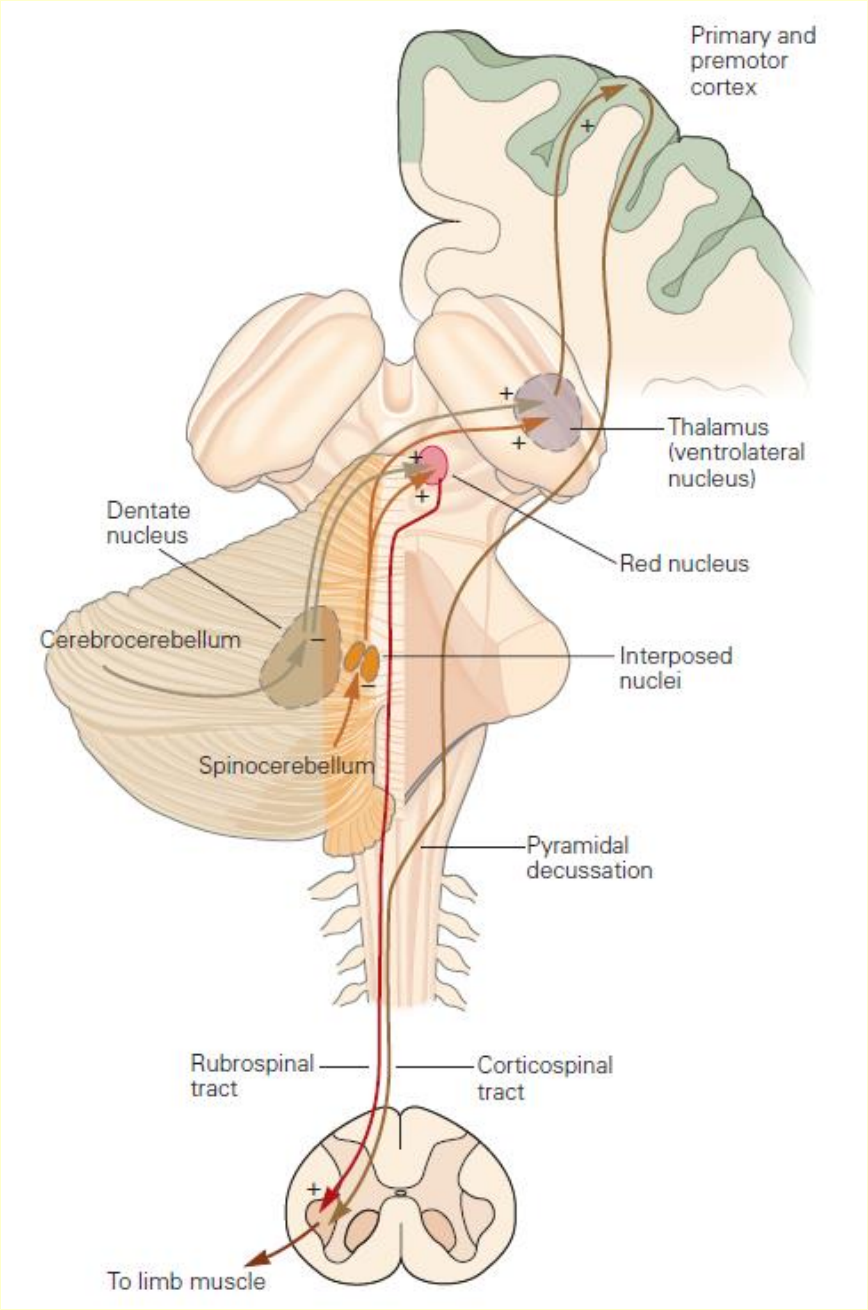


Cerebellar control of limb and axial muscles

Spinocerebellum – intermediate hemispheres

- Input: somatosensory/proprioceptive
- (and motor ctx)
- Deep nucleus: n. interpositus
- Output: MRF/n.ruber → spinal cord (distal muscles of the limbs and digits)
- Loop: cerebellum → n.ruber → IO → cerebellum

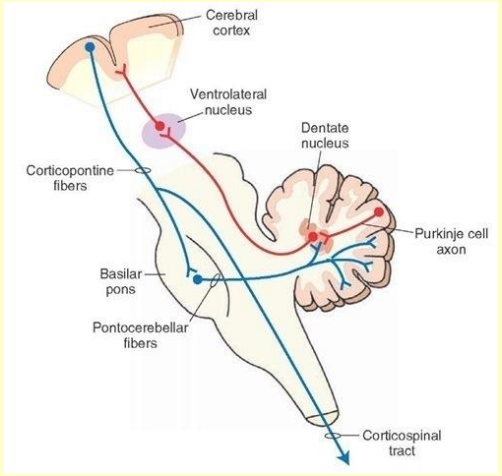


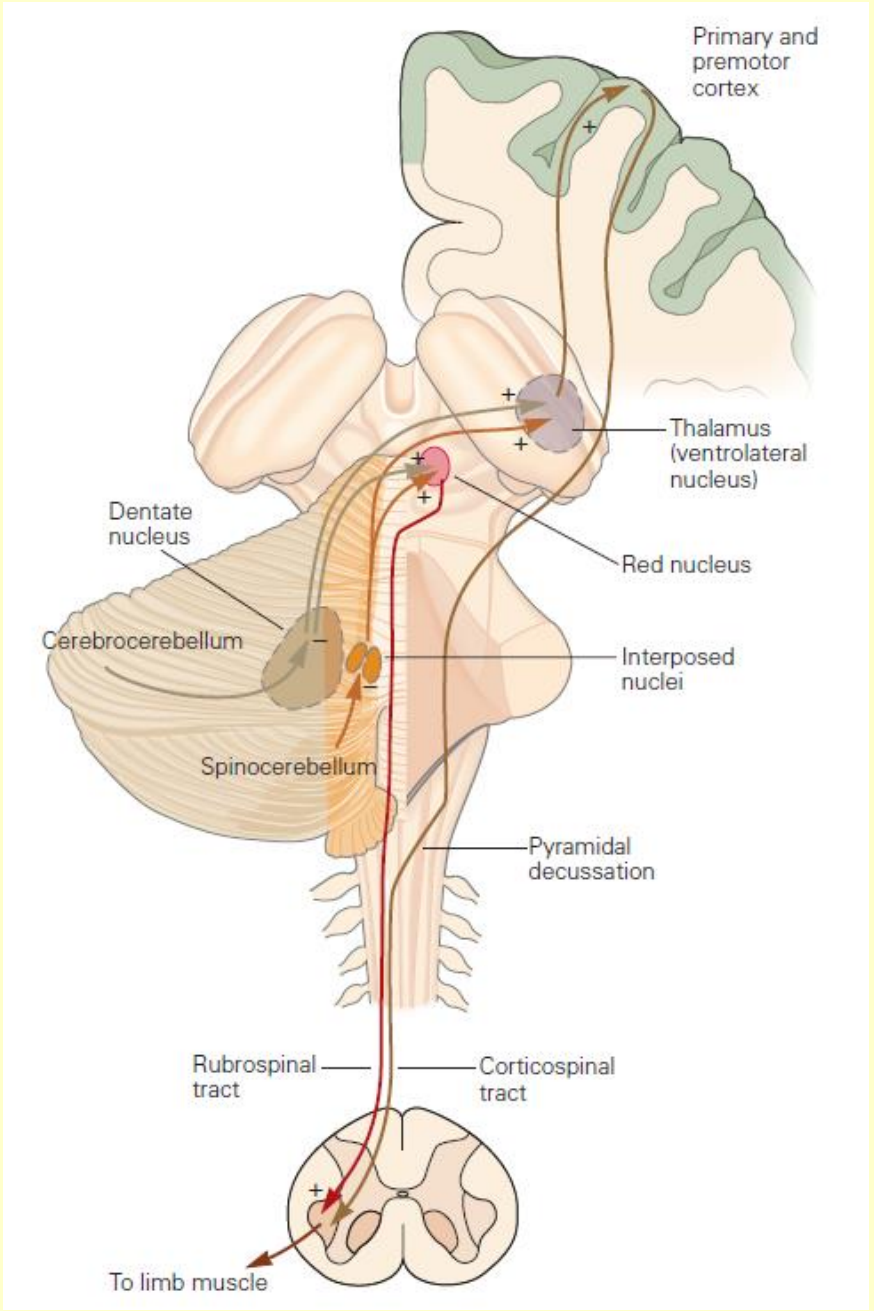


Cerebellar control of limb and axial muscles

Cerebrocerebellum – lateral hemispheres

- Input: motor and associative ctx → pontine nuclei
- Deep nucleus: n. dentatus
- Output: thalamus → motor ctx
- Loop: cerebellum → ctx → IO → cerebellum

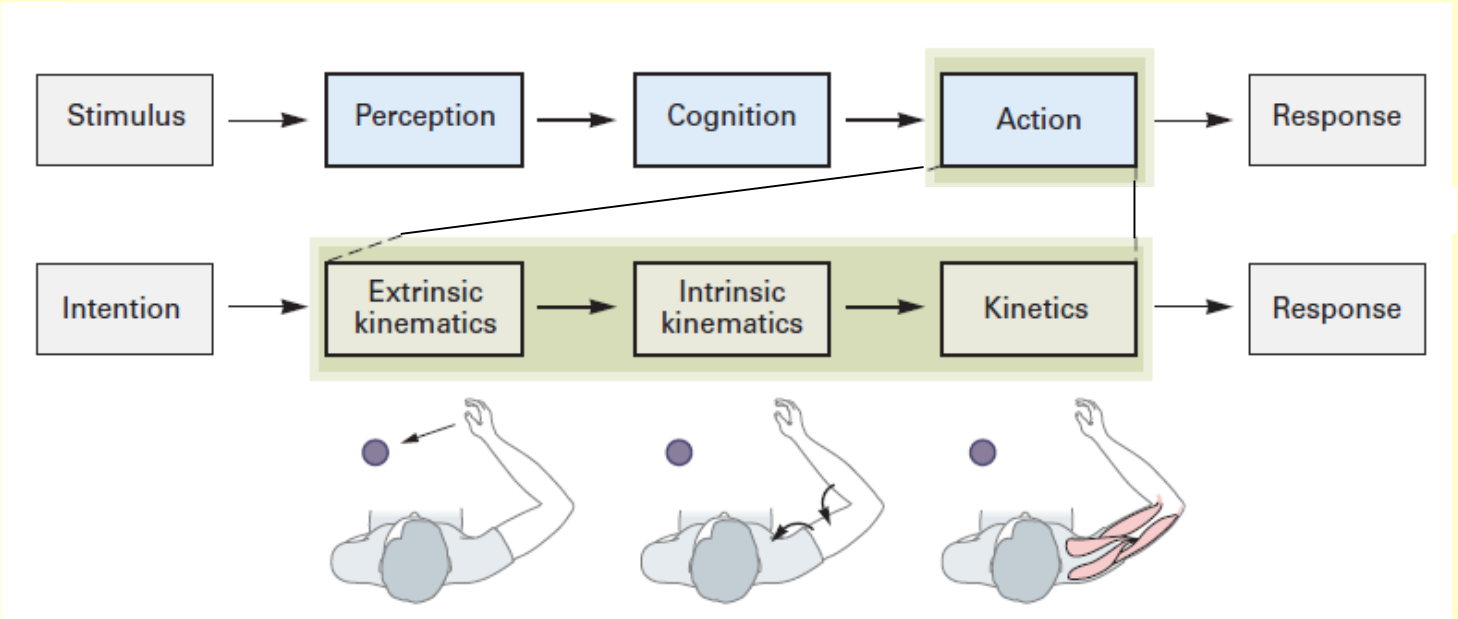




Voluntary behavior

- initiated **internally**
- involve choices between **alternatives**, including the choice not to act
- organized to achieve some **goal**
- improve with experience (learning)

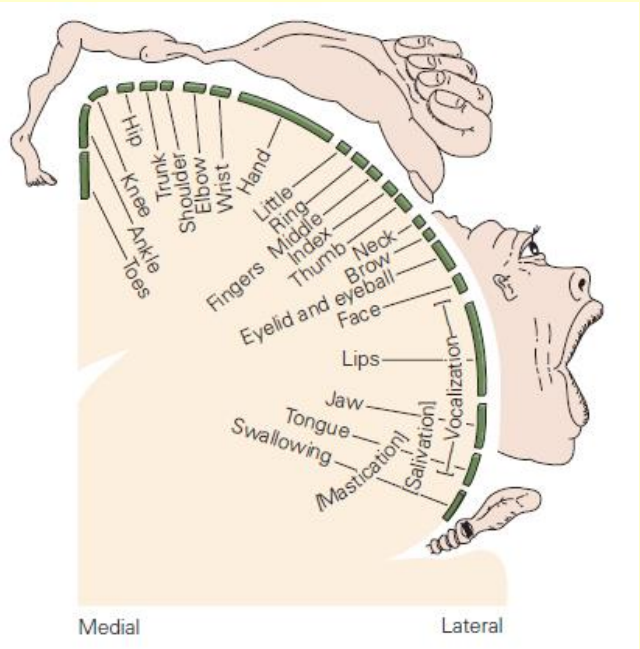
Organized in a hierarchical series of operations:



The execution itself is serial in nature (sensorymotor transformation)

1. general description of the movement
2. calculation of specific details
3. patterns of motor neuron activity

Motor cortex



M1, primary motor cortex; (F1)

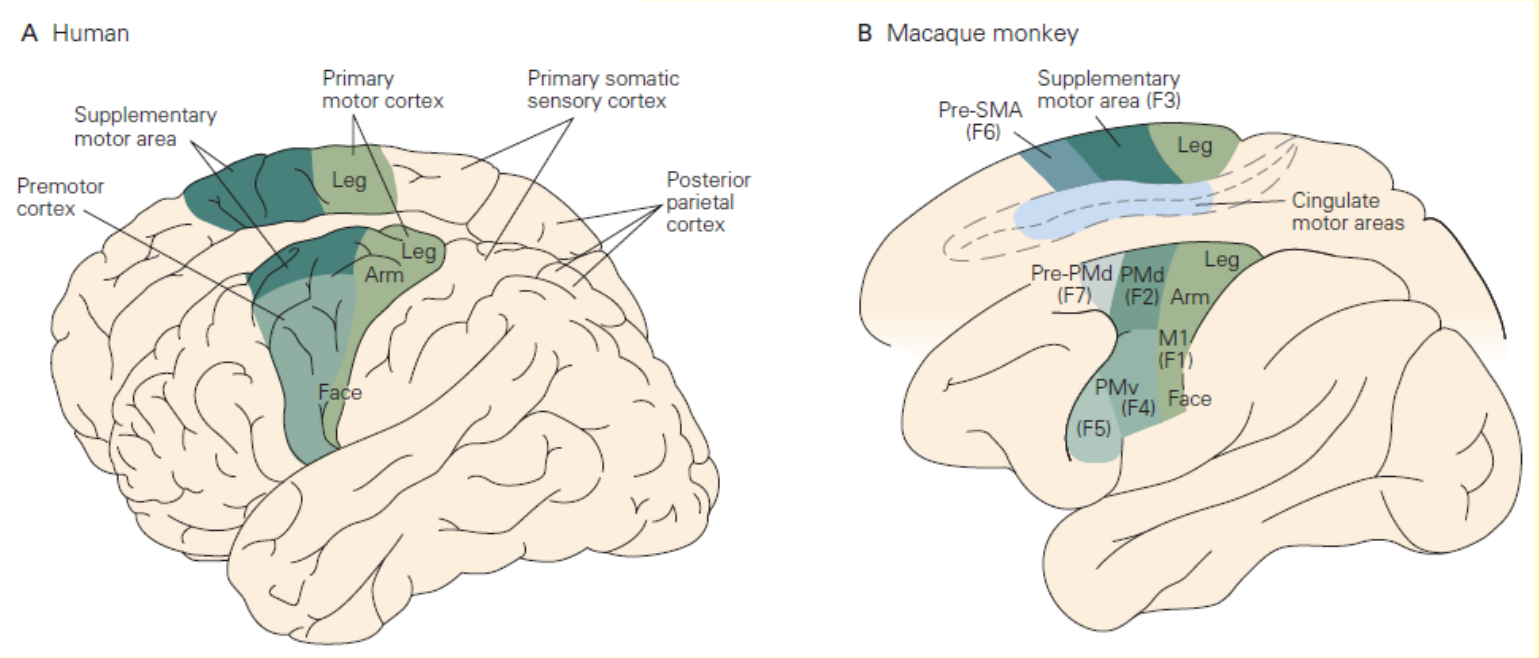
PMd, dorsal premotor cortex; (F2)

SMA, supplementary motor area; (F3)

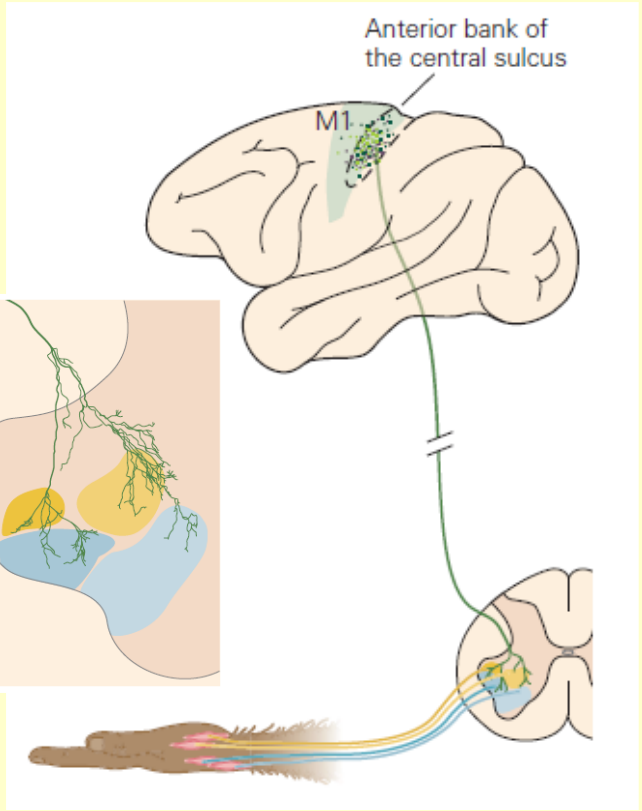
PMv, ventral premotor cortex. (F4-5)

Pre-SMA, pre-supplementary motor area; (F6)

Pre-PMd, pre-dorsal premotor cortex; (F7)



The pyramidal tract



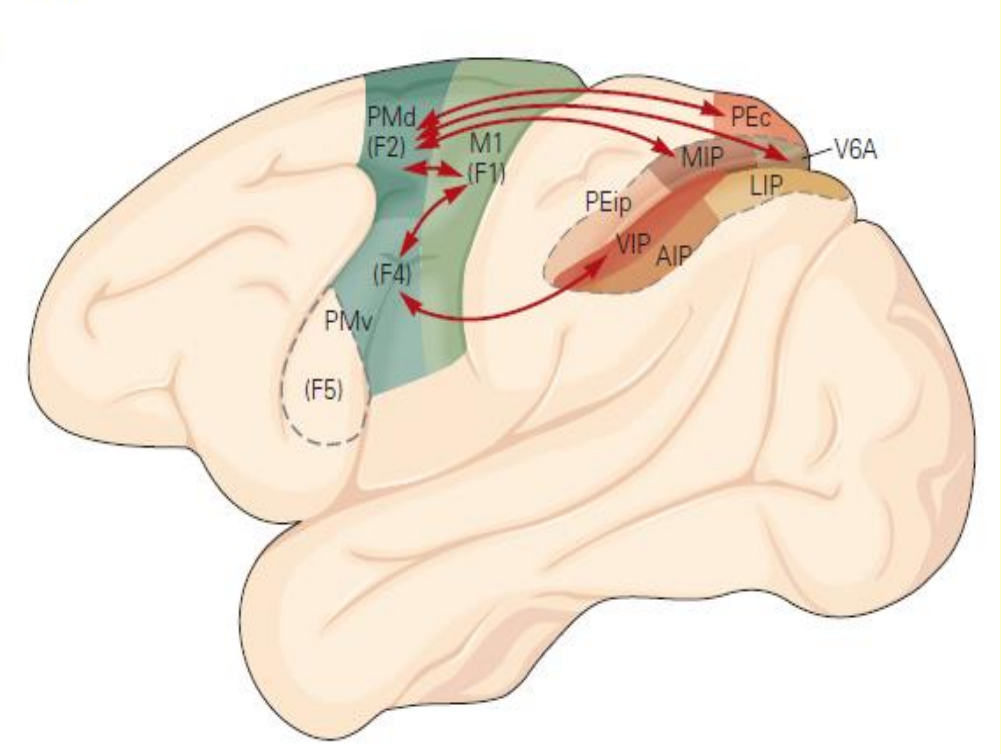
Pyramidal tract

- Pyramidal cells from
  - primary motor cortex (80%)
  - supplementary motor and dorsal and ventral premotor areas
    - pre-supplementary motor and pre-dorsal premotor areas only indirectly
  - primary somatosensory cortex
  - rostral parts of the superior and inferior parietal lobules
- Axon endings on
  - spinal interneurons (many in primates, and all in other mammals)
  - spinal motor neurons (only in primates, mainly distal muscles, only from primary motor ctx) =*corticomotoneurons*

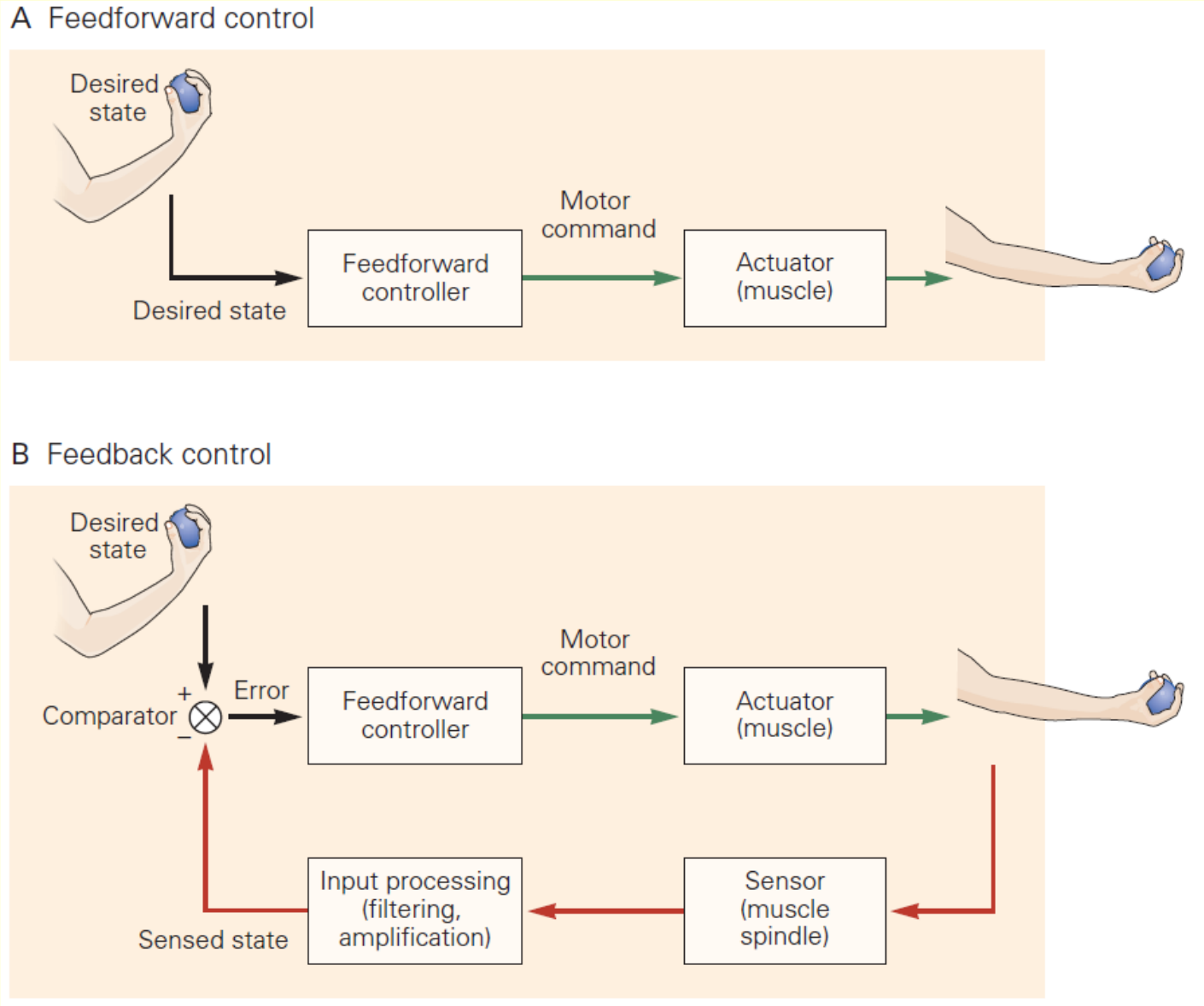
rubrospinal, reticulospinal, and vestibulospinal tracts

Motor planning

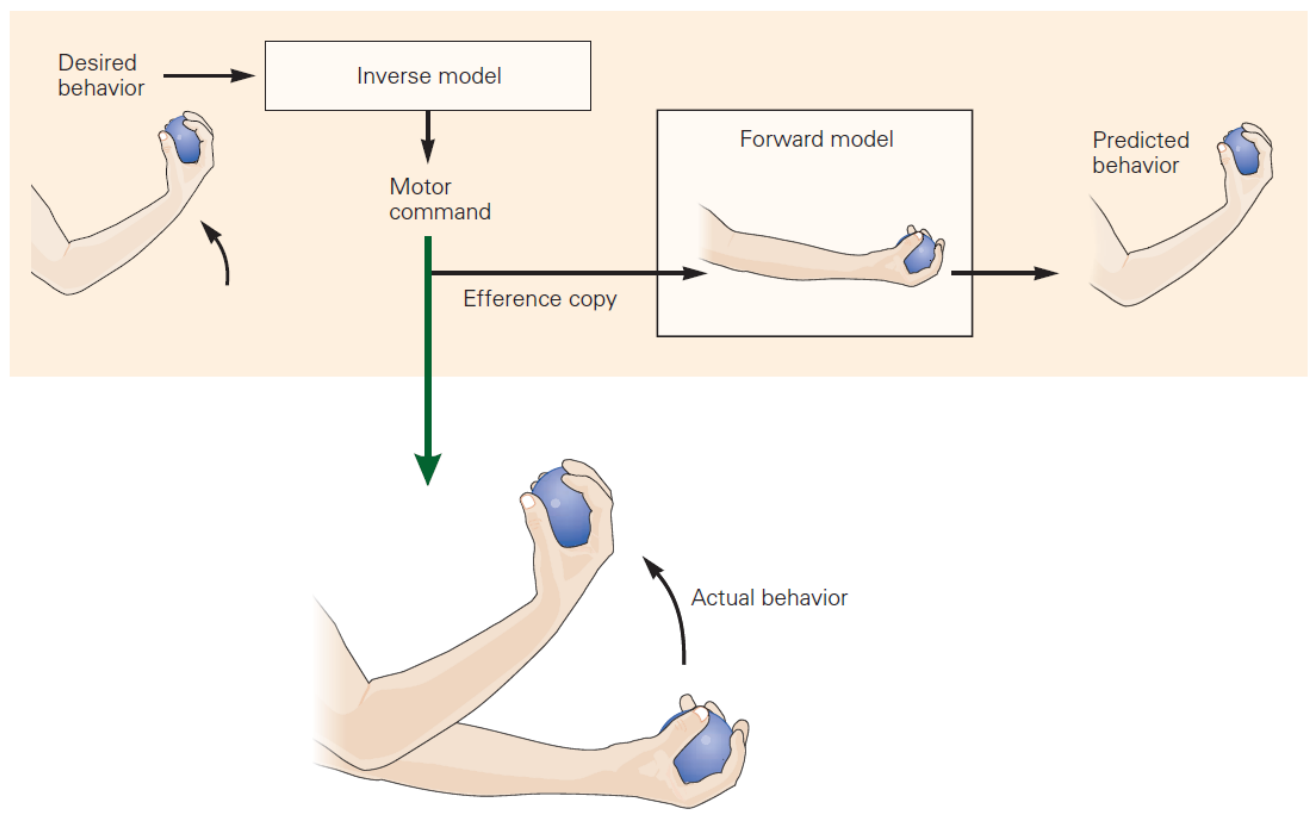
- parietal cortex: representations of peripersonal space (and motion) based on sensory information
- Premotor/primary motor ctx: formulate specific motor plans
- pre-SMA may controls (initiates) the execution



Feedforfard and feedback control

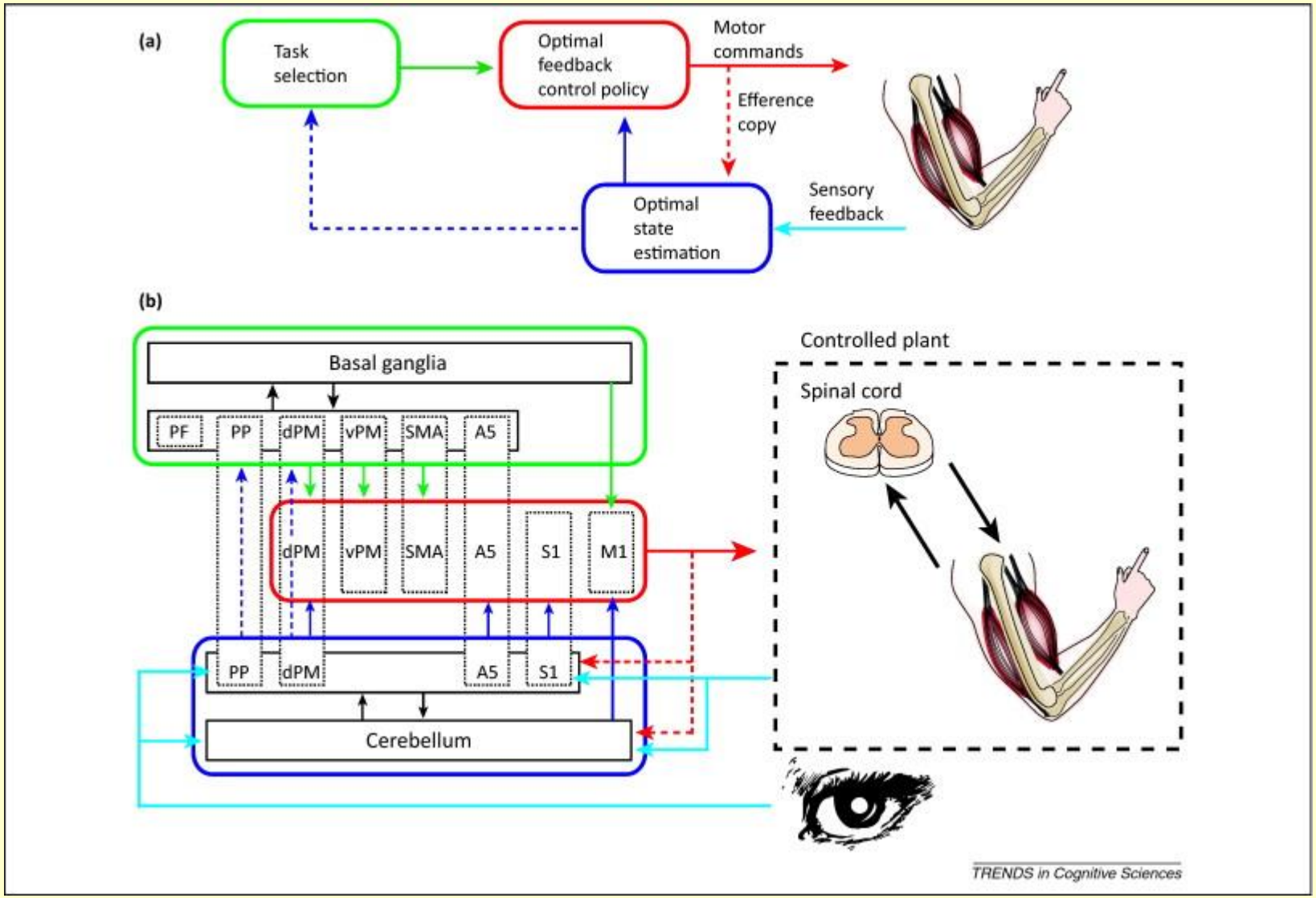


Internal models

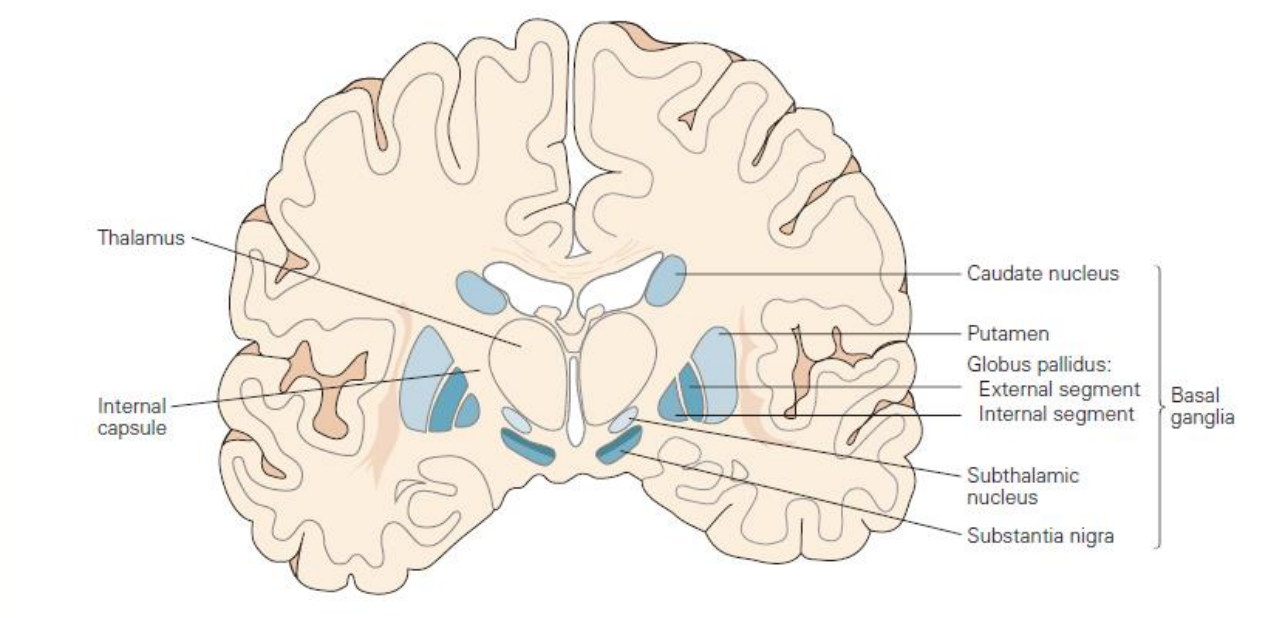


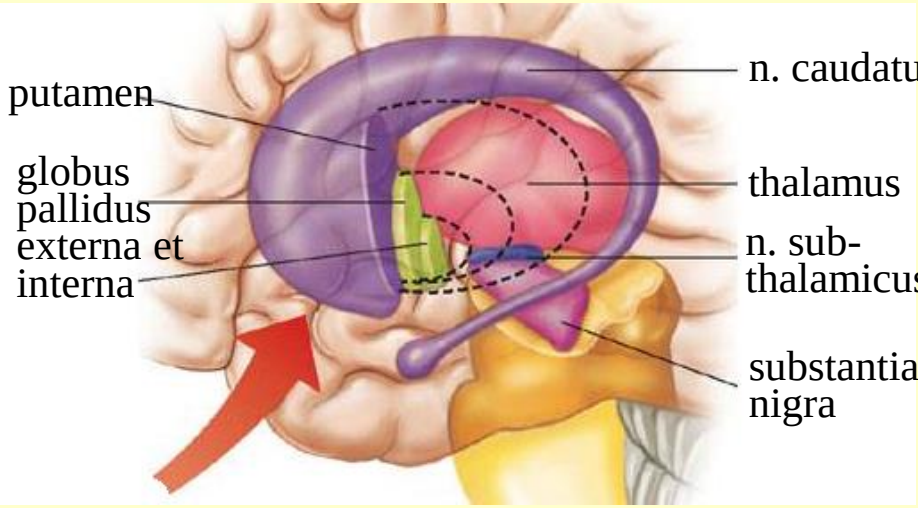
- The **inverse model** determines the motor commands that will produce a behavioral goal
- The **forward model** simulates the interaction of the motor system and the world predict behaviors.

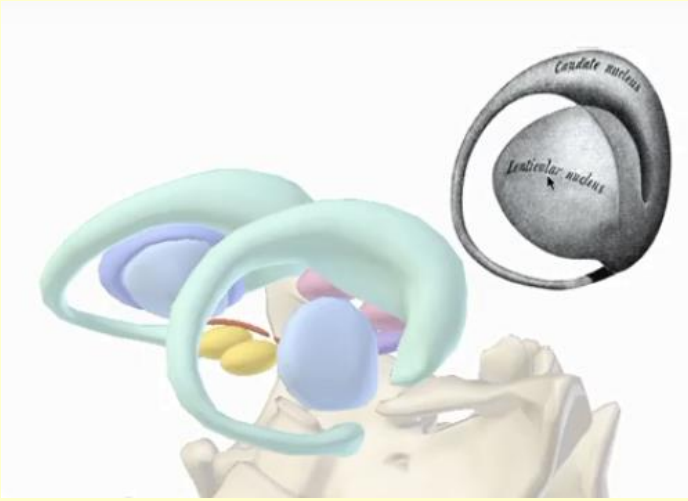
Motor control of voluntary movements



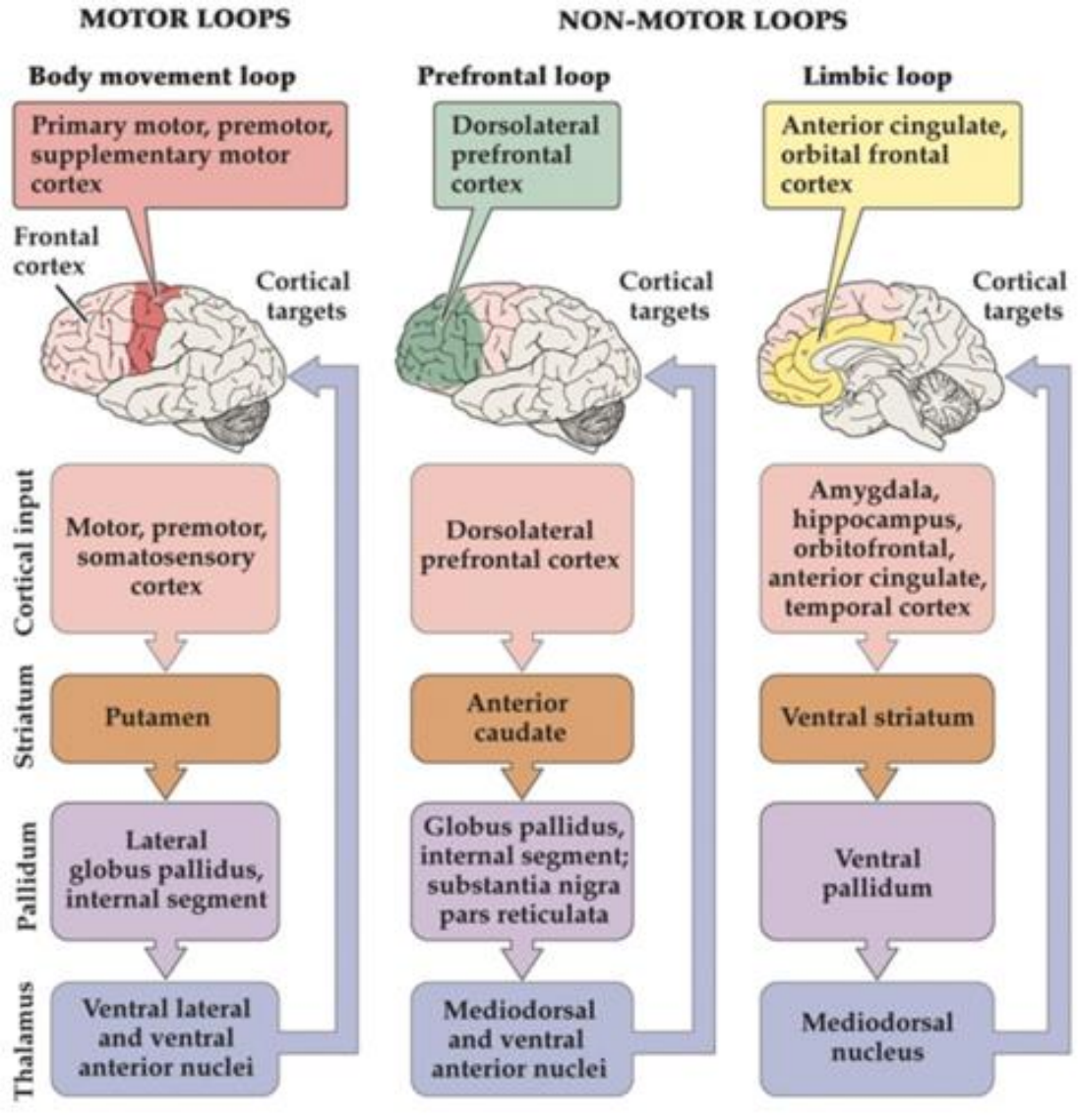
Basal ganglia





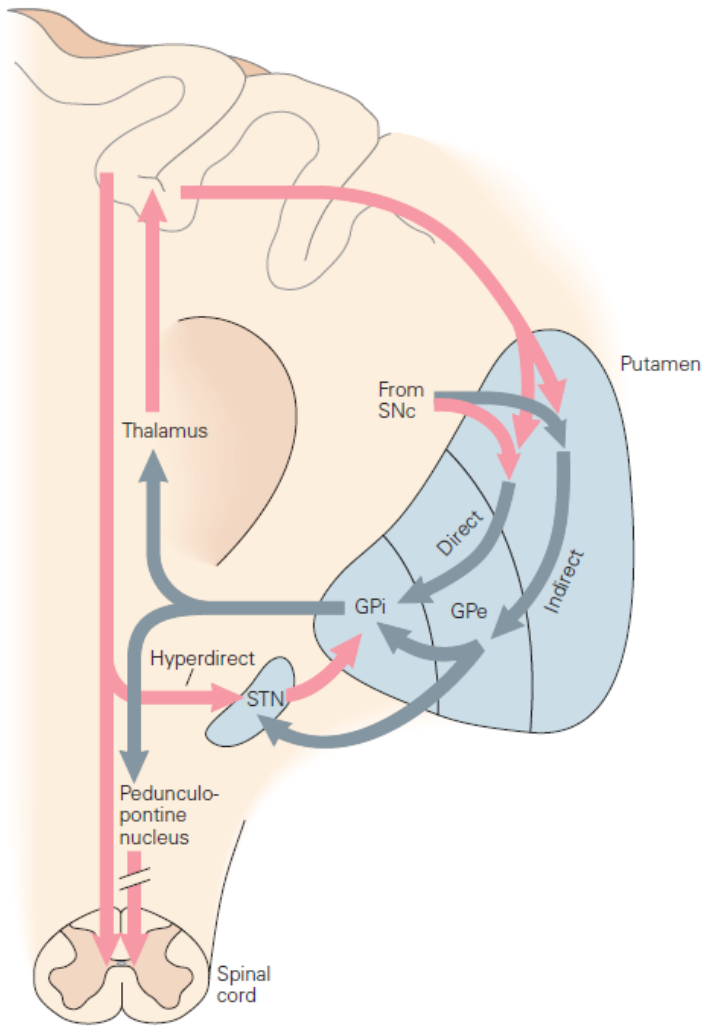


Basal ganglia functional domains



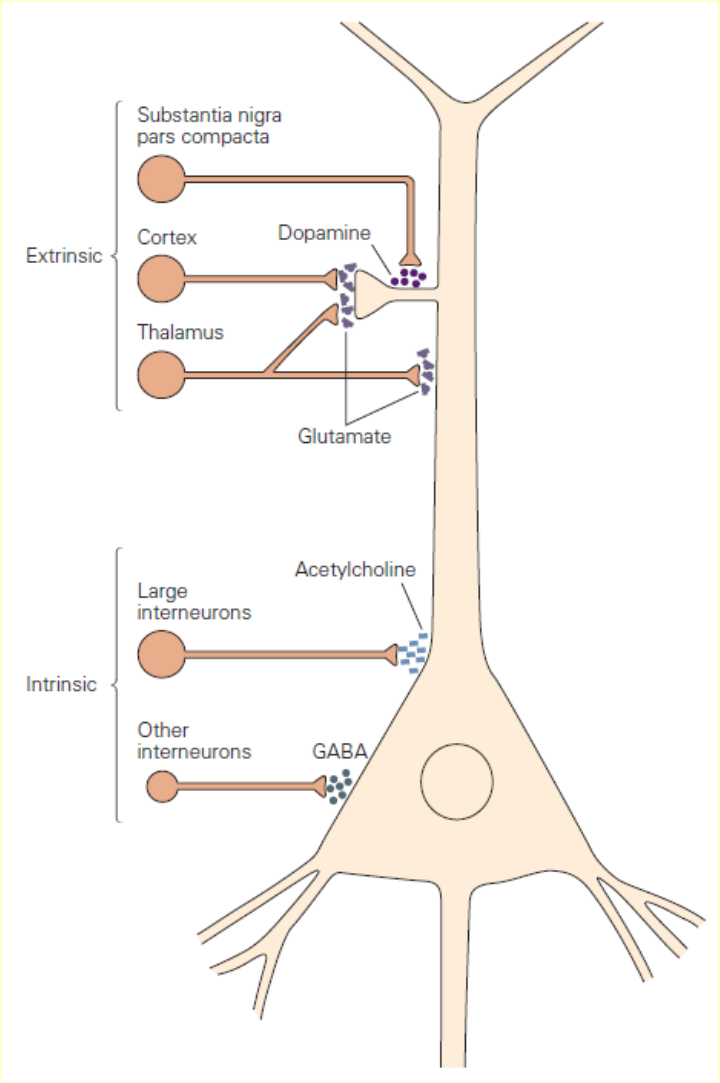
- Prefrontal
  - problem solving using verbal skills
  - mediation of empathic and socially appropriate behaviour
- Limbic
  - also receives input from the hippocampus, amygdala, and entorhinal cortices
  - motivated behaviour
- Motor
  - action selection
  - reinforcement learning

The basal ganglia–thalamocortical circuitry



- Imput: striatum
- Output: GP pars interna + SN pars reticulata

- Direct loop: Ctx → Put → GBi → Thal → Ctx
- Indirect loop: Ctx → Put → GBe → STN → GBi → Thal → Ctx
- Hyperdirect loop: Ctx → STN → GBi → Thal → Ctx
- Dopamine!



The medium spiny neurons in the striatum have extrinsic and intrinsic inputs.