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Kognitív idegtudomány

Introduction to neurosciences for MSs.

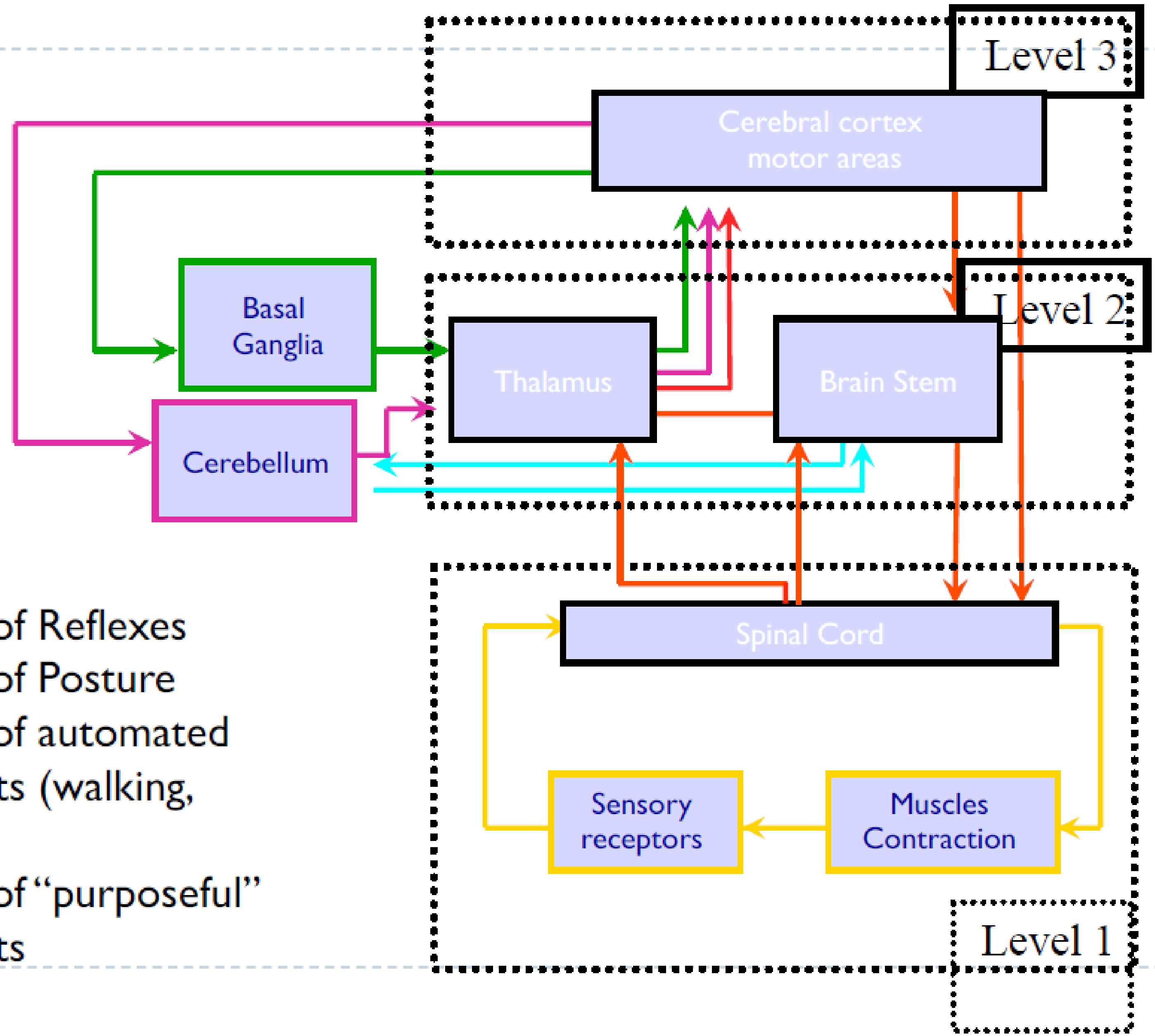
Motor system I.

From the muscle fibre to the spinal cord

Introduction: The function of the motor system

- Stabilizing body in space
- Moving body in space
- Coordinating movement of body

Organization of the motor system



•Control of Reflexes
•Control of Posture
•Control of automated movements (walking, breathing)
•Control of "purposeful" movements

Hierarchy of Motor Control

LEVEL	FUNCTION	STRUCTURES
high	strategy	association areas of neocortex, basal ganglia
middle	tactics	motor cortex, cerebellum
low	execution	brain stem, spinal cord

Principles of motor system

- **Hierarchical Organization**:
  - The higher-order areas can concern themselves with more global tasks regarding action, such as deciding when to act, devising an appropriate sequence of actions, and coordinating the activity of many limbs. (motor unit – spinal cord – brainstem - cortex)
- **Functional Segregation**:
  - The motor system is divided into a number of different areas that control different aspects of movement
- **Size Principle**: When a signal is sent to the motor neurons to execute a movement, motor neurons are not all recruited at the same time or at random.
  - with increasing strength of input onto motor neurons, smaller motor neurons are recruited and fire action potentials before larger motor neurons are recruited.

Principles of motor system

- **Reflex principle**: motor reflexes are the basic units of motor sytem (spinal cord and brain stem)

- **Final Common Pathway:** a motor pathway consisting of the motor neurons by which nerve impulses from many central sources pass to a muscle or gland in the periphery.

- **Proprioception:** In order to make a desired movement (e.g., raising your hand to ask a question), it is essential for the motor system to know the starting position of the hand.
  - Raising one's hand from a resting position on a desk, compared to a resting position on top of the head, results in the same final position of the arm, but these two movements require different patterns of muscle activation.
  - The motor system has a set of sensory inputs (called proprioceptors) that inform it of the length of muscles and the forces being applied to them; it uses this information to calculate joint position and other variables necessary to make the appropriate movement.

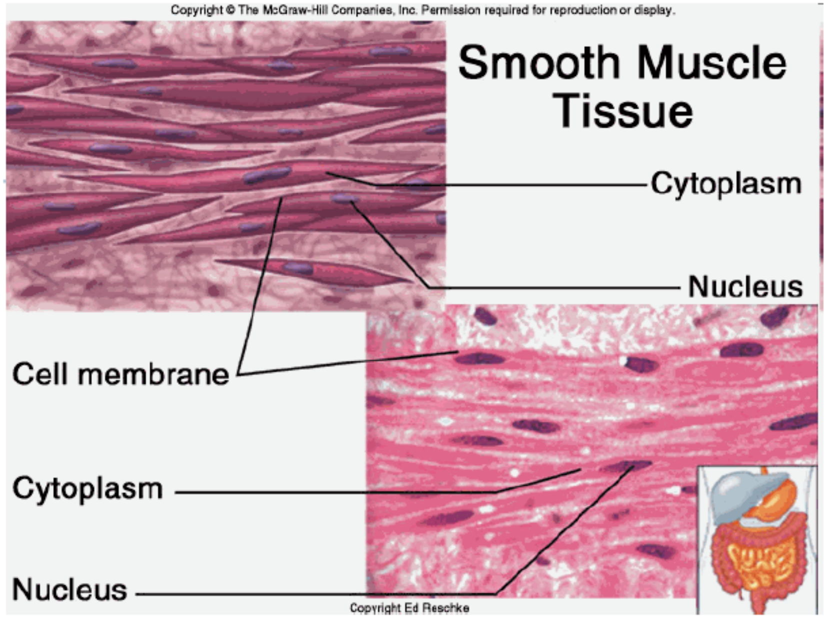
Principles of motor system

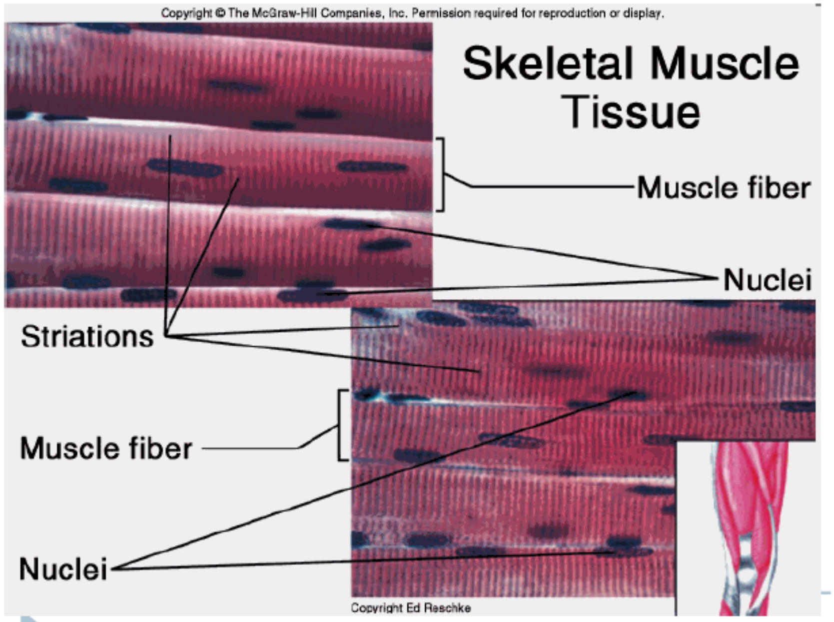
- **Postural adjustments**:
  - to compensate for changes in the body's center of mass as we move our limbs, head, and torso.
  - Without these automatic adjustments, the simple act of reaching for a cup would cause us to fall, as the body's center of mass shifts to a location in front of the body axis.

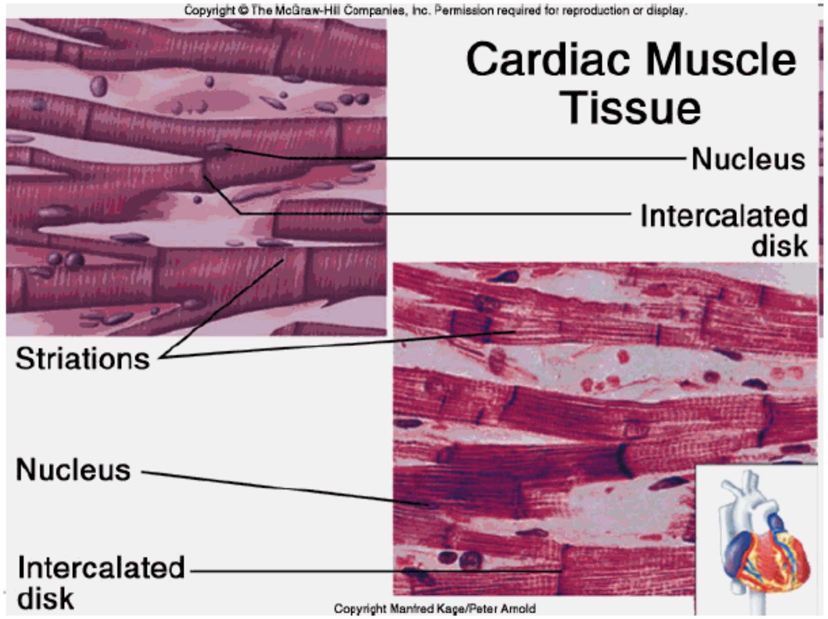
- **Sensory feedback**:
  - the motor system must use other sensory information in order to perform the movement accurately.
  - By comparing desired activity with actual activity, sensory feedback allows for corrections in movements as they take place, and it also allows modifications to motor programs so that future movements are performed more accurately.

Types of muscles:

- Smooth muscles
- Cardiac muscles
- Skeletal muscle

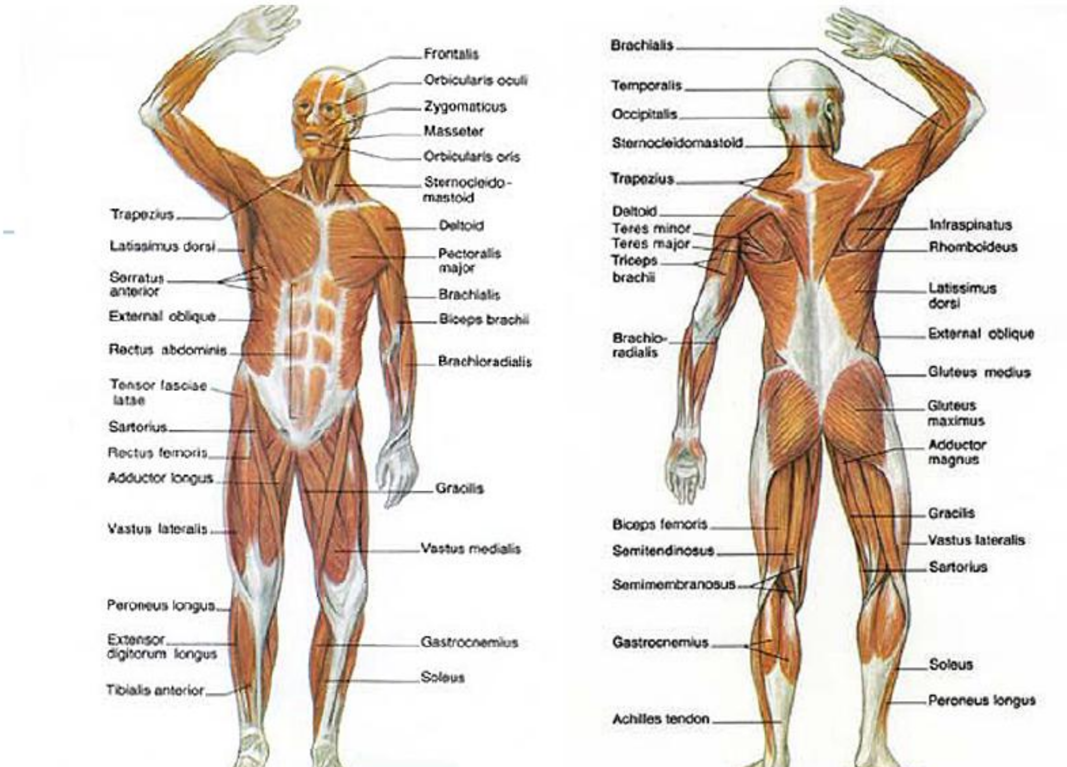






Skeletal Muscles

- Striated (long and dark bands)
- long cells with numerous nuclei
- Long cells
- covers bony skeleton
- Voluntary control (but some
- involuntary functions too)



Adapted by M.G. Little from Van De Graaff, K.M. and Fox, S.L. (1989) Concepts of Human Anatomy and Physiology. Brown, Dubuque. Fig. 9.20

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- Muscle fiber:
  - Diameter: 50-100 μm, length: 2-6 cm
  - Connection with the neural system:

end-plate

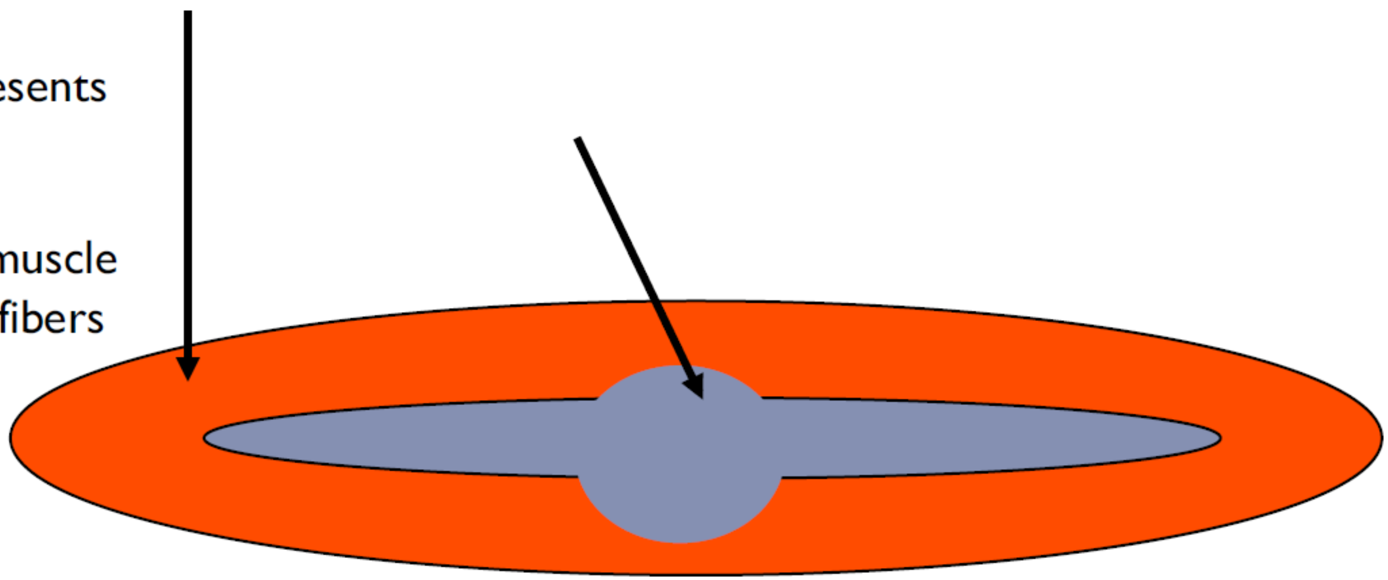
2. Anatomy of the Muscle

striated muscles are made of muscle fibers that have two parts, outer and inner:

Outer fiber = extrafusal fiber

Inner fiber = intrafusal fiber

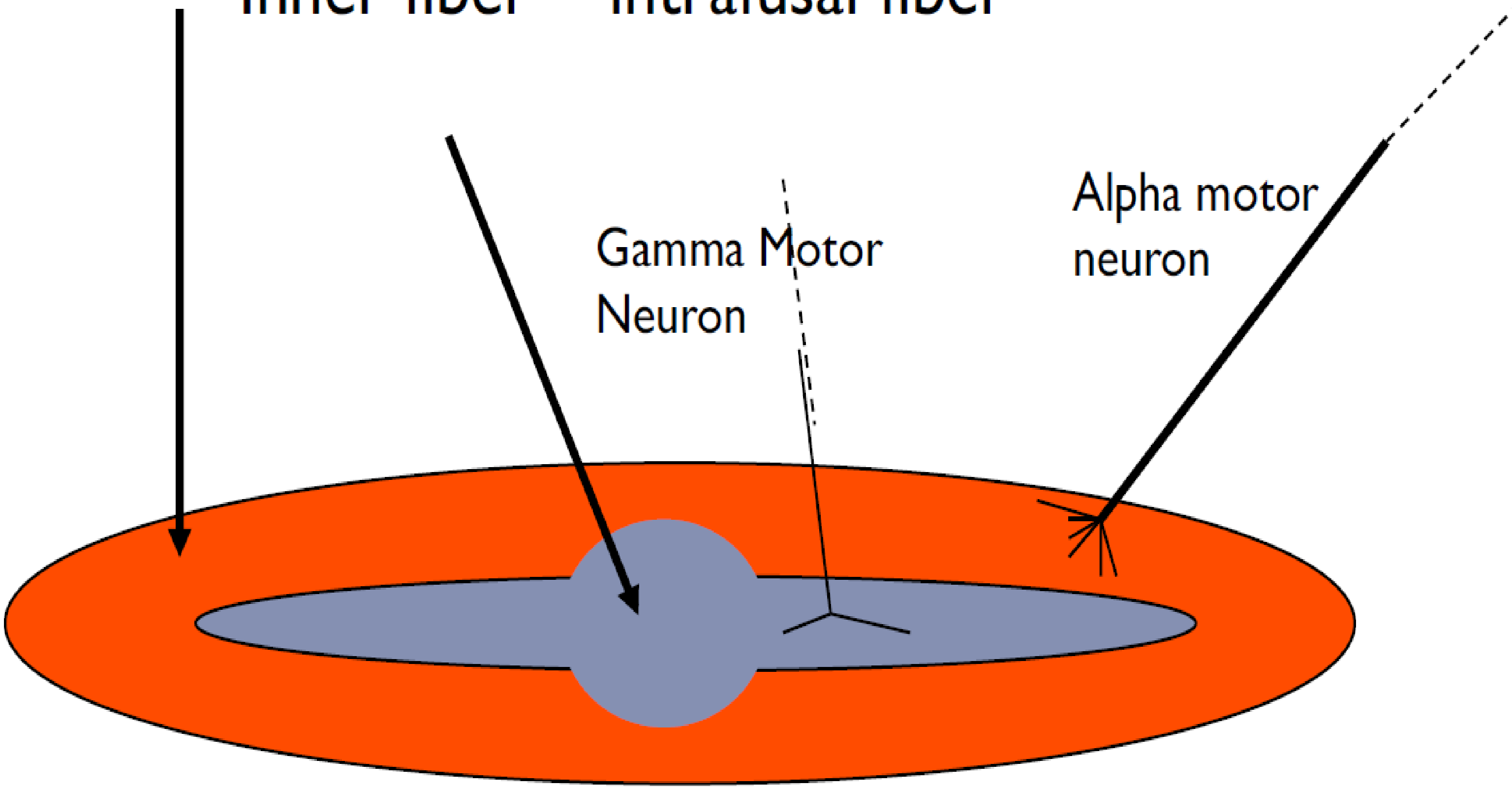
This represents only one muscle fiber - a muscle has many fibers



Wrapped around the intrafusal fiber is a sensory nerve that picks up the sensation of stretch.

Outer fiber = extrafusal fiber

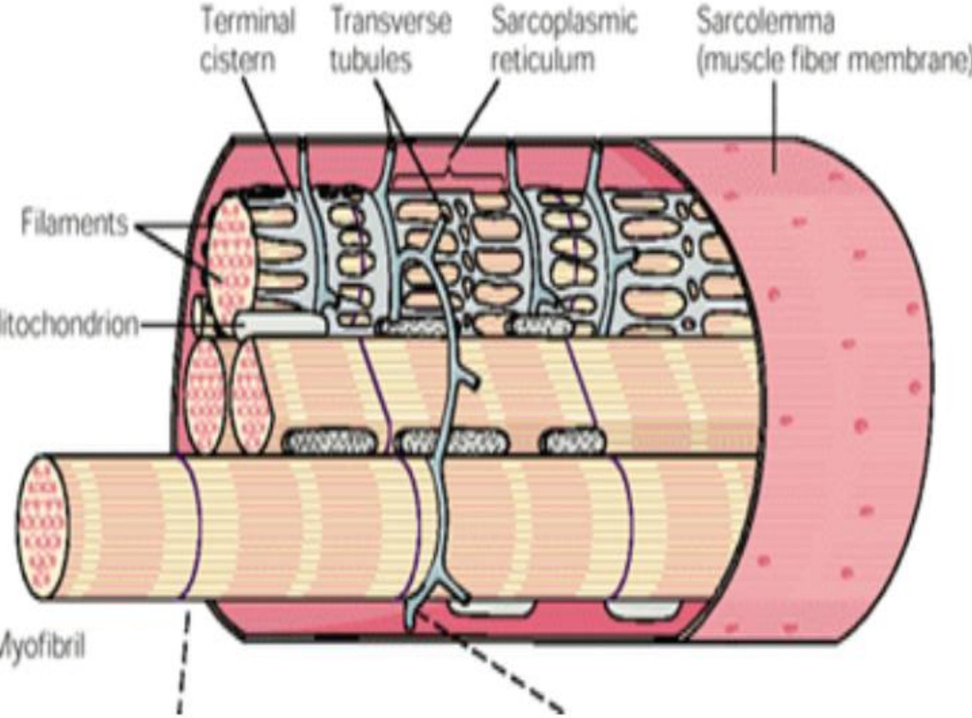
Inner fiber = intrafusal fiber

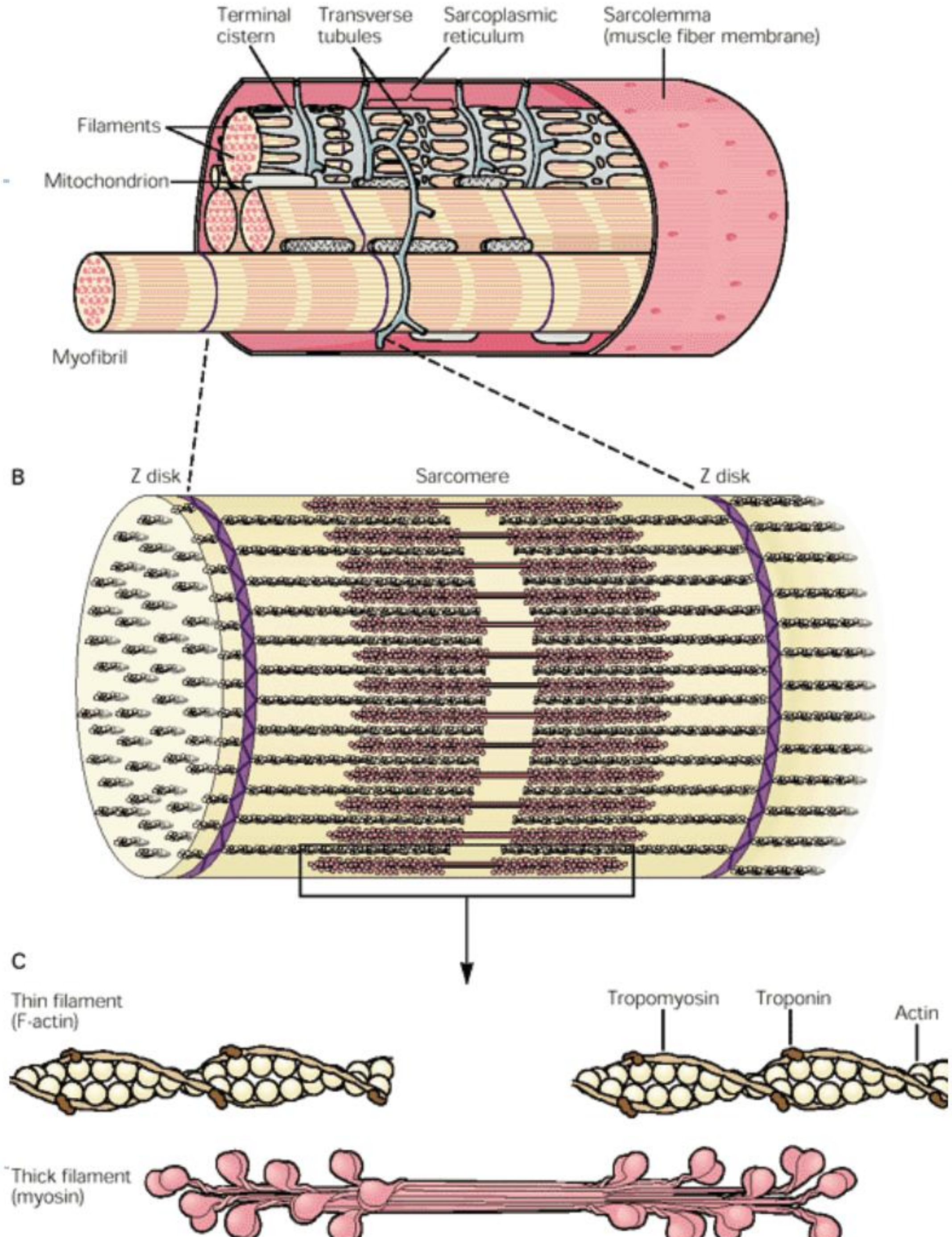


Each muscle fiber has a **gamma motor neuron** that synapses on the intrafusal fiber. The **alpha motor neuron** synapses on the extrafusal fibers. One alpha motor neuron can stimulate numerous fibers. This is called the **motor unit**. The neural link between the alpha motor neuron and the muscle fiber is called the **neuromuscular junction**.

The muscle fiber

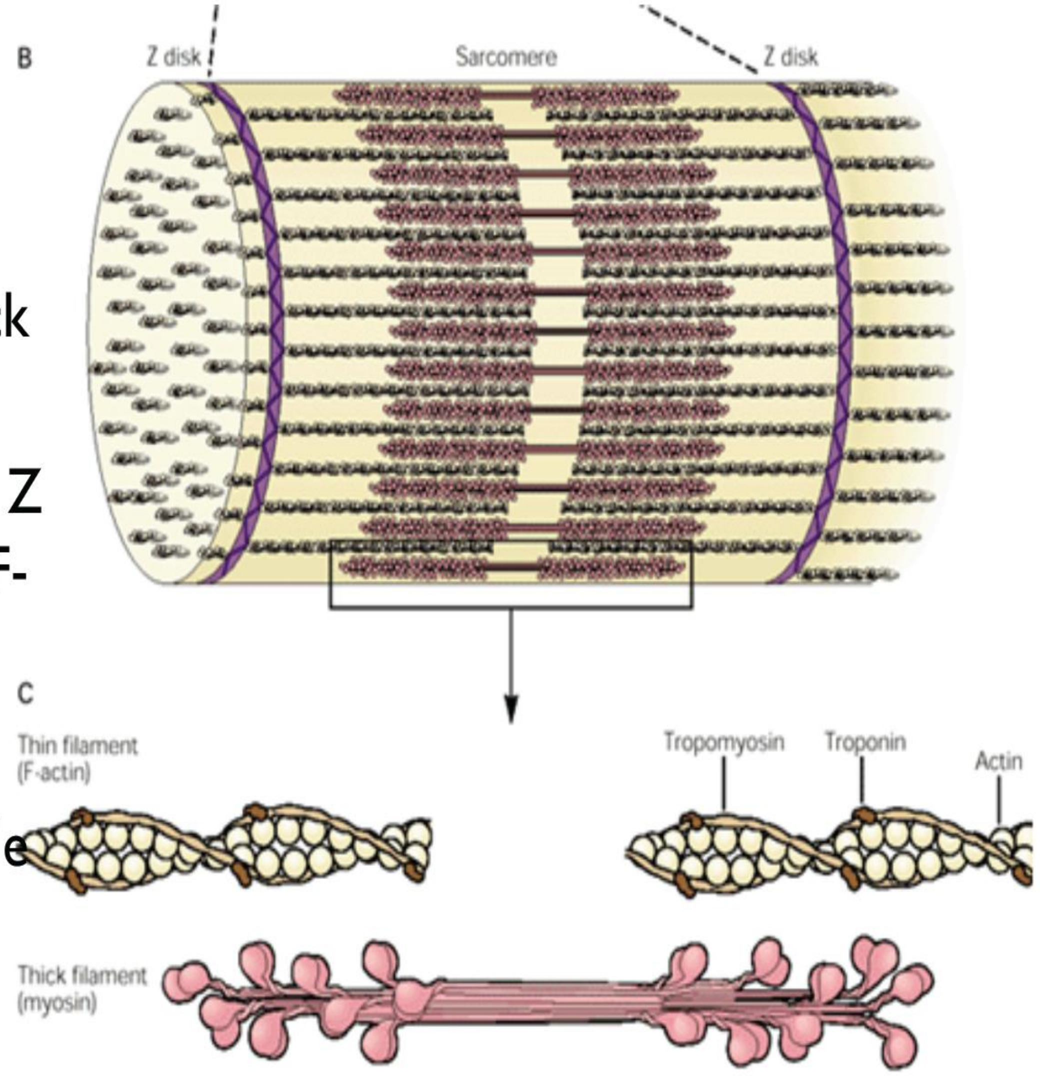
- Discrete cells → fibre (more nucleus)
- Average size: 50-100 μm diameter and 2-6 cm length
- Sarcolemma: membraine of the cell (double lipid layer, containing: Na, K, Cl and Cl channels)
- Myofibrils: containing the contractile proteins
- Sarcoplasmatic reticulum: intracell membrane system around the myofibrils
- Mitochondrias



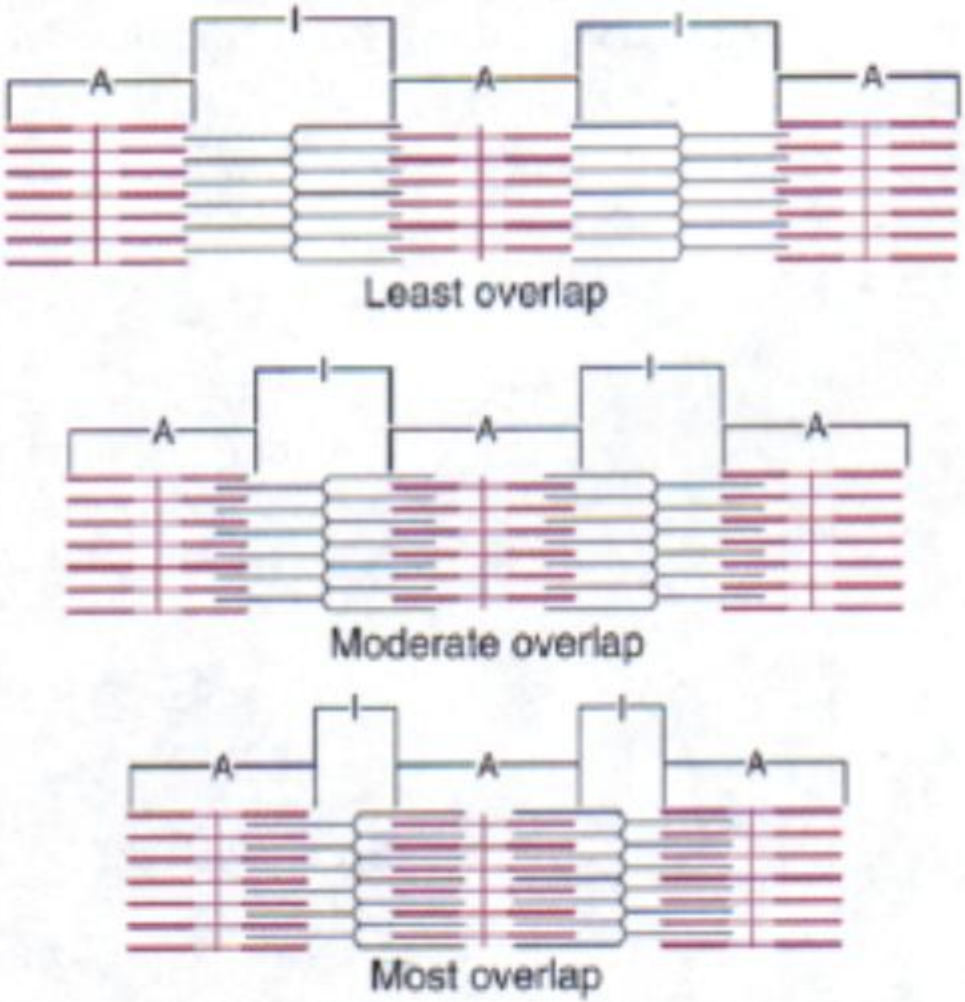

Terminal cistern
Transverse tubules
Sarcoplasmic reticulum
Sarcolemma (muscle fiber membrane)
Filaments
Mitochondrion
Myofibril
B
Z disk
Sarcomere
Z disk
C
Thin filament (F-actin)
Tropomyosin
Troponin
Actin
Thick filament (myosin)

Sarcomere

- Contractile machinery of the muscle: sarcomeres and cross bridges
- Each sarcomere contains contractile proteins: thin and thick filaments; bounded by a Z disc
- Thin filaments: projects from the Z disc, actin monomers in a helix (F-actin)
- Thick filaments: float in the middle of the sarcomere, tropomyosin and troponin



Sliding Filament Theory



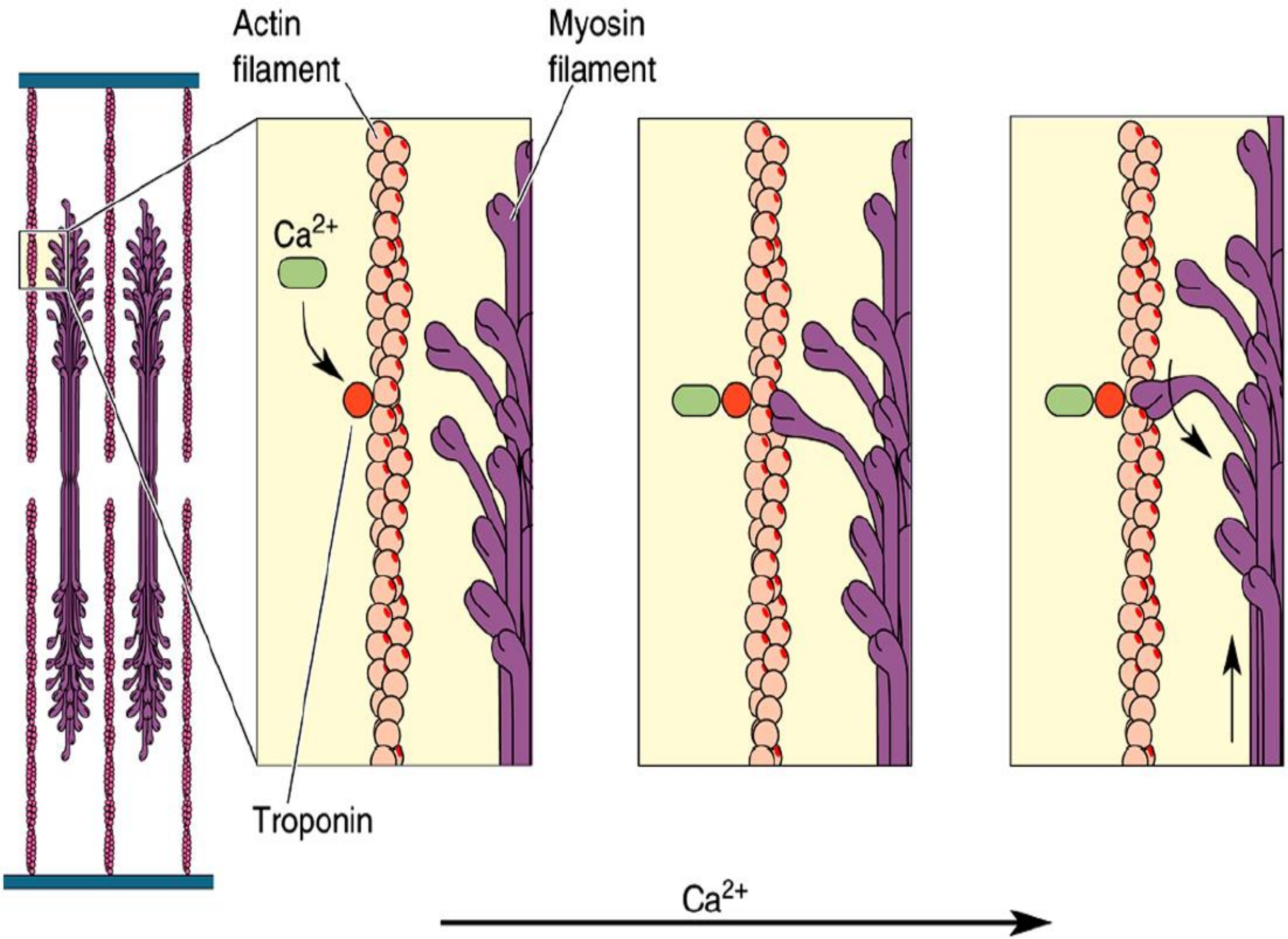
The thick and thin filaments do not shorten.

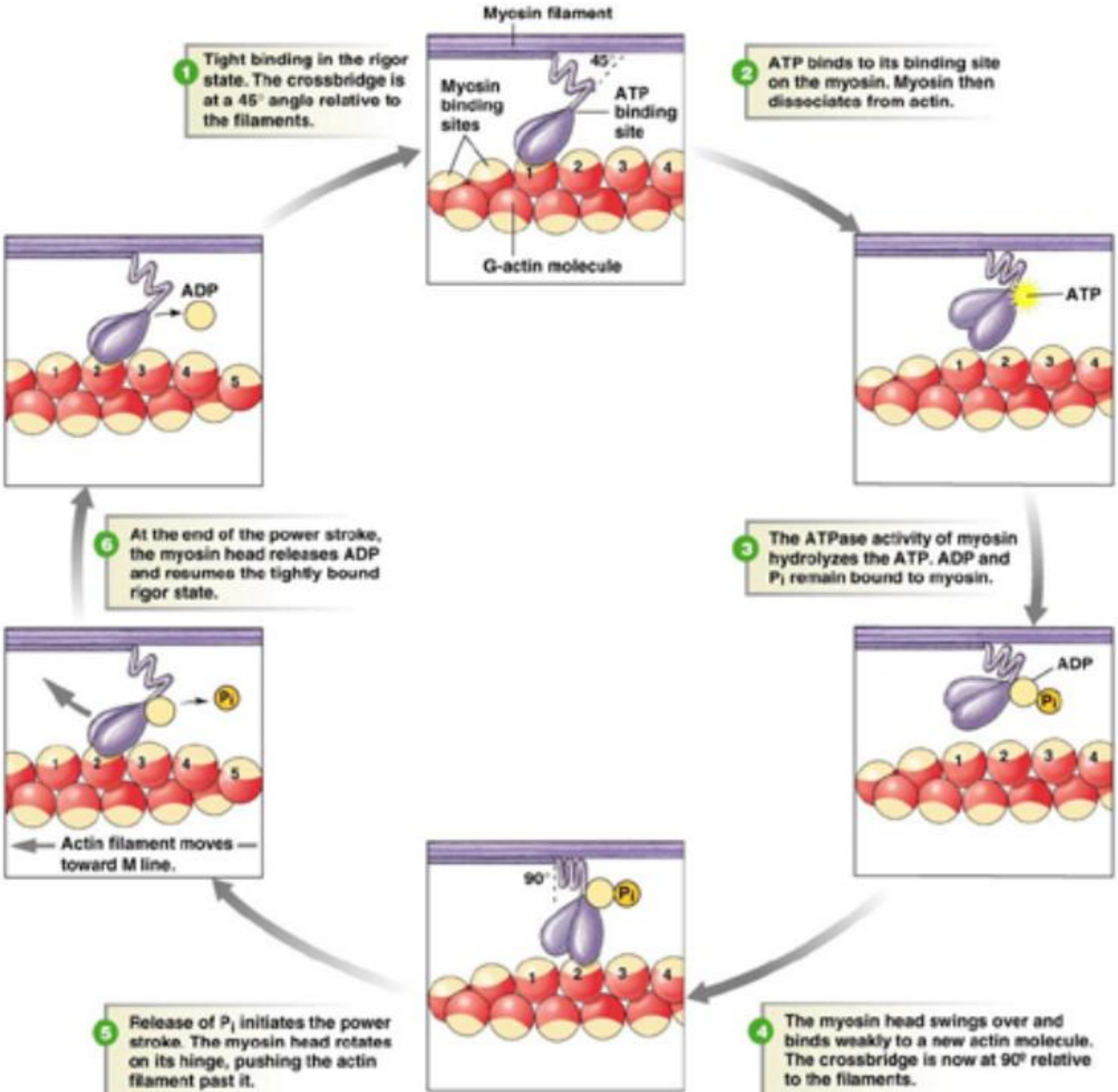
Thin filaments slide along thick filaments towards the center of the sarcomere.

This pulls the Z discs closer together, shortening the length of the sarcomere, the myofibril and the muscle fiber.

The A band is unaffected.
The I band gets narrower.

Excitation-Contraction Coupling

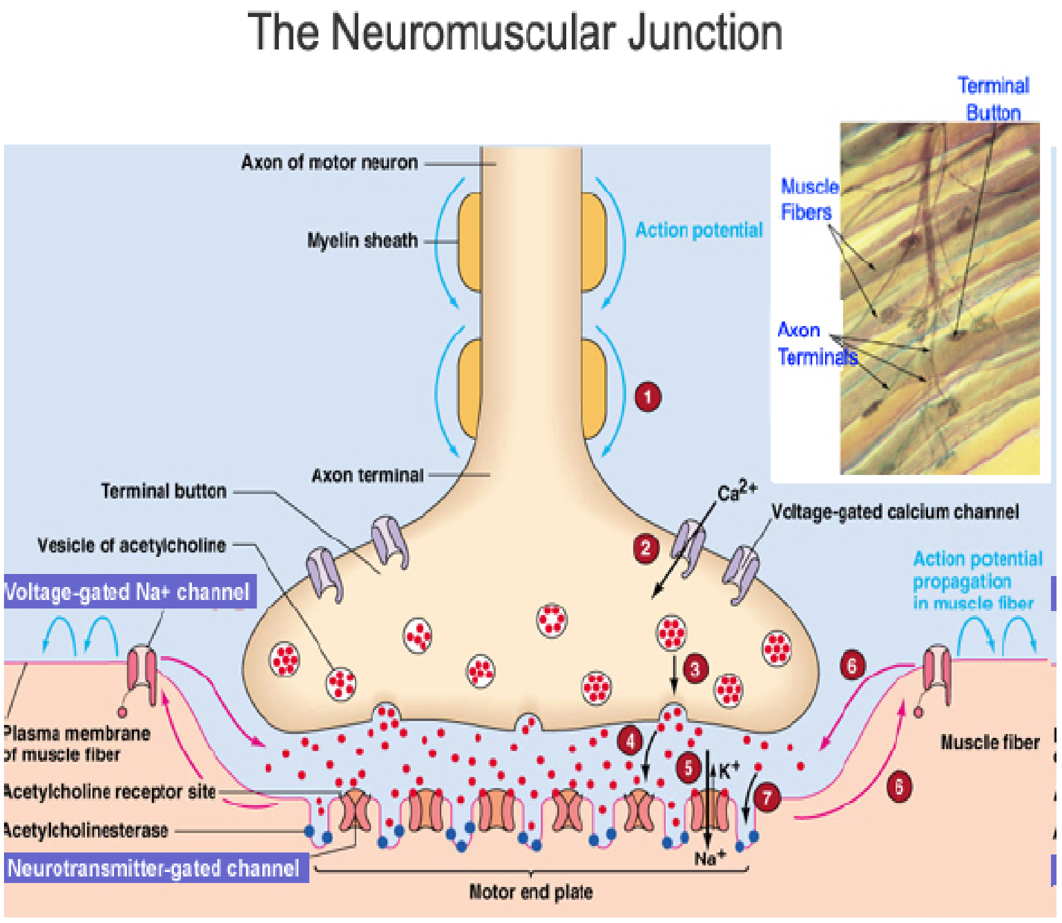




Myosin filament
45°
Myosin binding sites
ATP binding site
1
2
3
4
G-actin molecule
1 Tight binding in the rigor state. The crossbridge is at a 45° angle relative to the filaments.
2 ATP binds to its binding site on the myosin. Myosin then dissociates from actin.
ATP
3 The ATPase activity of myosin hydrolyzes the ATP. ADP and Pi remain bound to myosin.
ADP
Pi
4 The myosin head swings over and binds weakly to a new actin molecule. The crossbridge is now at 90° relative to the filaments.
90°
5 Release of Pi initiates the power stroke. The myosin head rotates on its hinge, pushing the actin filament past it.
Actin filament moves toward M line.
6 At the end of the power stroke, the myosin head releases ADP and resumes the tightly bound rigor state.

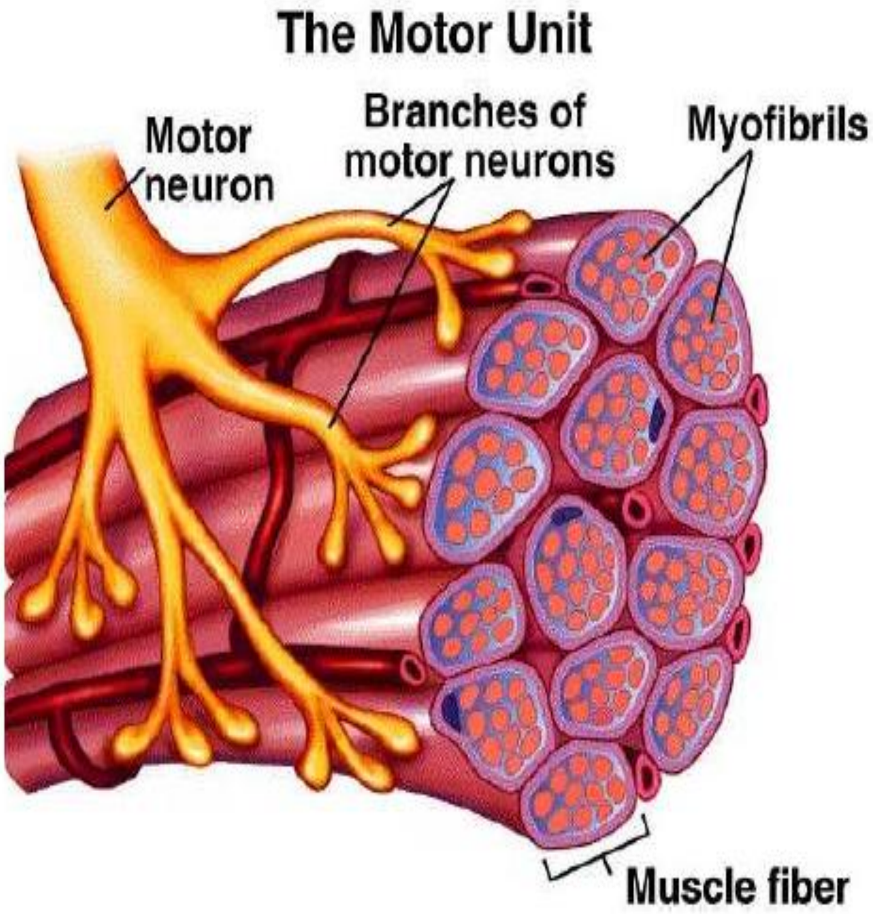
Neuro-muscular junction (NMJ)

- Axonal Terminals (Transmitter: Acetylcholin)
- Presynaptic potentials leads to ACh release
- Postsynaptic Membrane (junctional foldings)
- ACh receptors open, cation influx, membrane depolarization
- Endplate depolarization activates voltage-gated Na channels
- Release of Ca++ from the sarcoplasmatic reticulum (SR) into muscle cell cytoplasm
- Rise in intracellular Ca++ induces contraction



Motor unit: structure

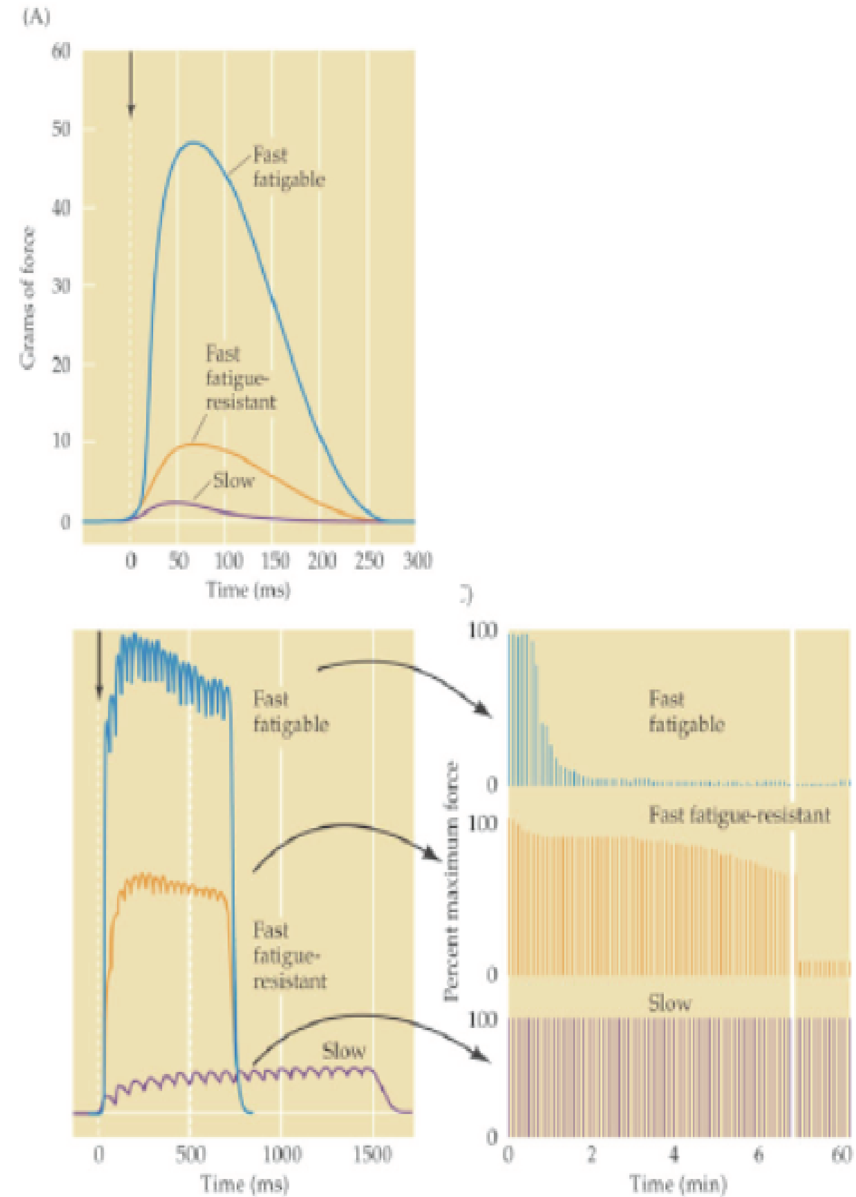
- Each motor axon is connected to multiple muscle fibers.
- Each muscle fiber is connected to a single axon.
- **Motor axon + innervated muscle fibers = Motor unit**
- Twitch fibers – large neuromuscular synapse which generates action potential- synchronous contraction of motor units (MUs).
- Tonic fibers – simpler synapse -> no AP -> graded contraction.



Types of the motor unit

- S (slow twitch)
  - type 1 muscle fibers
  - operating aerobically
  - slow twitch time and slow relaxation rate
- FR (fast twitch, resistant to fatigue)
  - type 2a muscle fibers
  - fast twitch and fast relaxation rate
  - aerobic metabolism and glycosis
  - Lower forces, resistant to fatigueness
- FF (fast twitch, fatigable) type
  - type 2b muscle fibersuse glycosis
  - High forces, fatigable
- Size principle: sequential recruitment

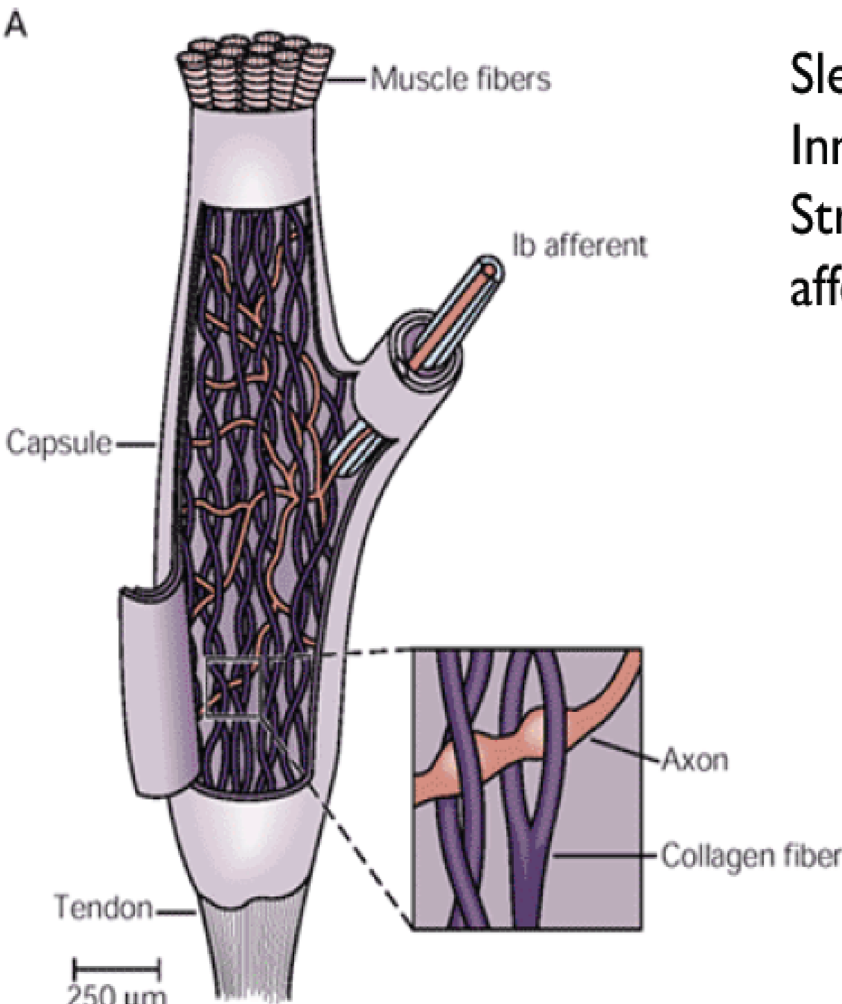
S -> FR -> FF



Proprioceptiv control of the somatosensory system

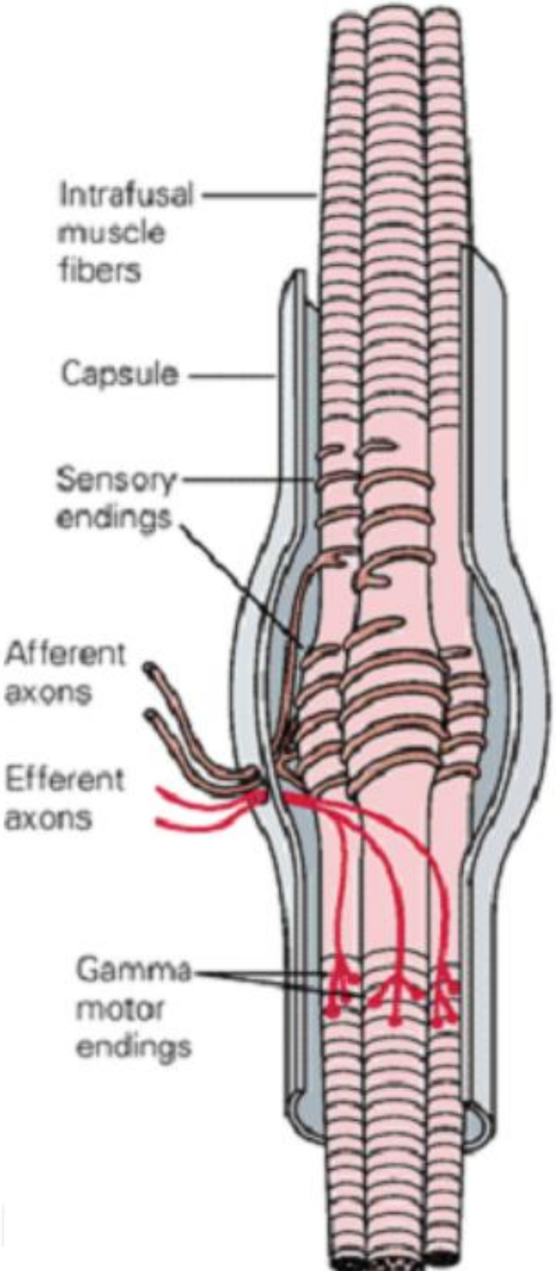
- Continous feedback needed about the muscles:
  - Flexio
  - Phase
  - Active contractions
- Golgi tendon organs and muscle spindles

Golgi tendon organ



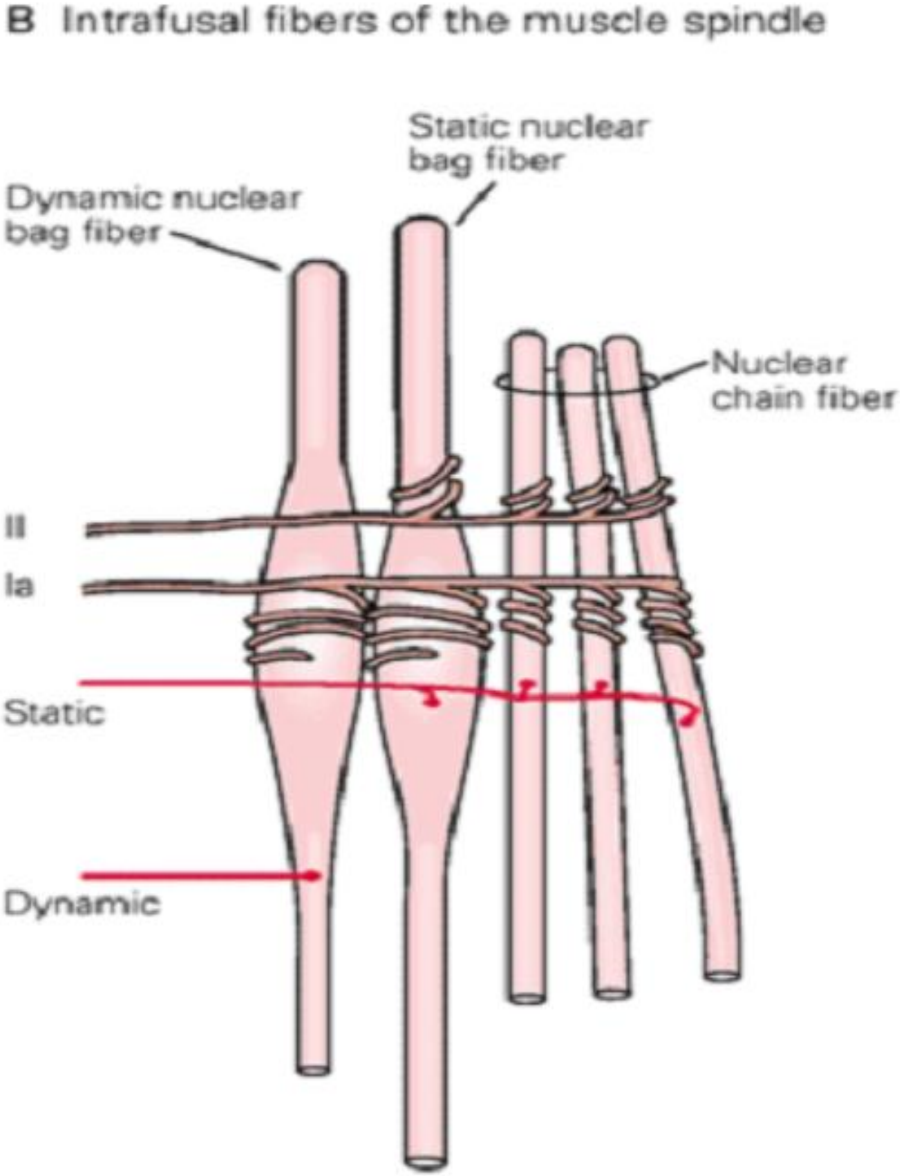
Slender, encapsulated structures, 1 mm long
Innervated by ones Ib fibre
Streching of the organ results in firing (Ib afferentation)

A Muscle spindle



Components of spindles:
Intrafusal muscle fibres
Large-diameter myelinated sensory ending
Small-diameter myelinated motor ending (gamma neurons)

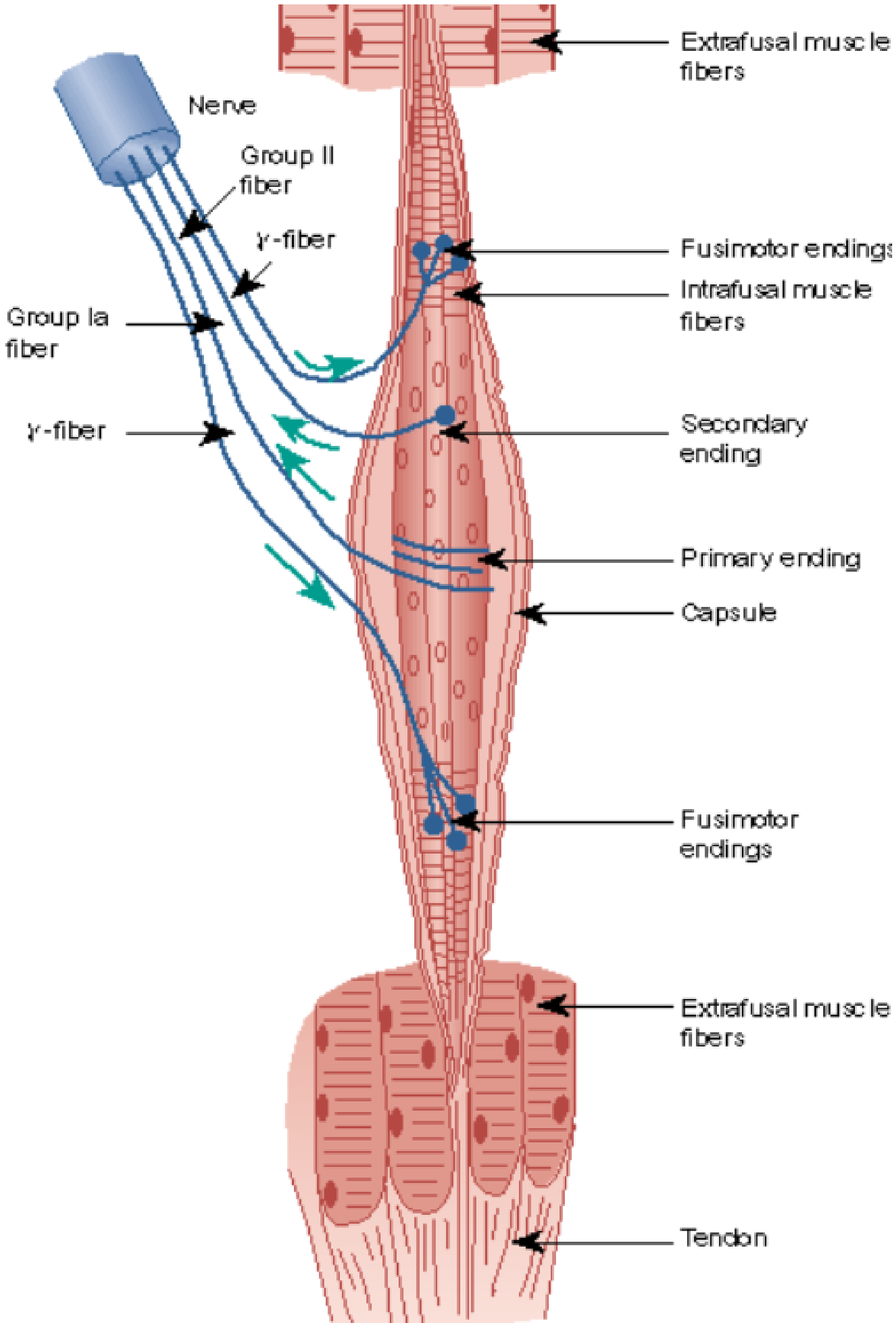
Components of intrafusal fibres:
Nuclear bag fibres (dynamic and static)(2-3)
Nuclear chain fibres (5)
Sesory fibre endings: primary (Ia), secondary (II)
Gamma neurons: static or dynamic



- Nuclear Chain fibers. These fibers are so-named because their nuclei are aligned in a single row (chain) in the center of the fiber. They signal information about the static length of the muscle.

- Static Nuclear Bag fibers. These fibers are so-named because their nuclei are collected in a bundle in the middle of the fiber. Like the nuclear chain fiber, these fibers signal information about the static length of a muscle.

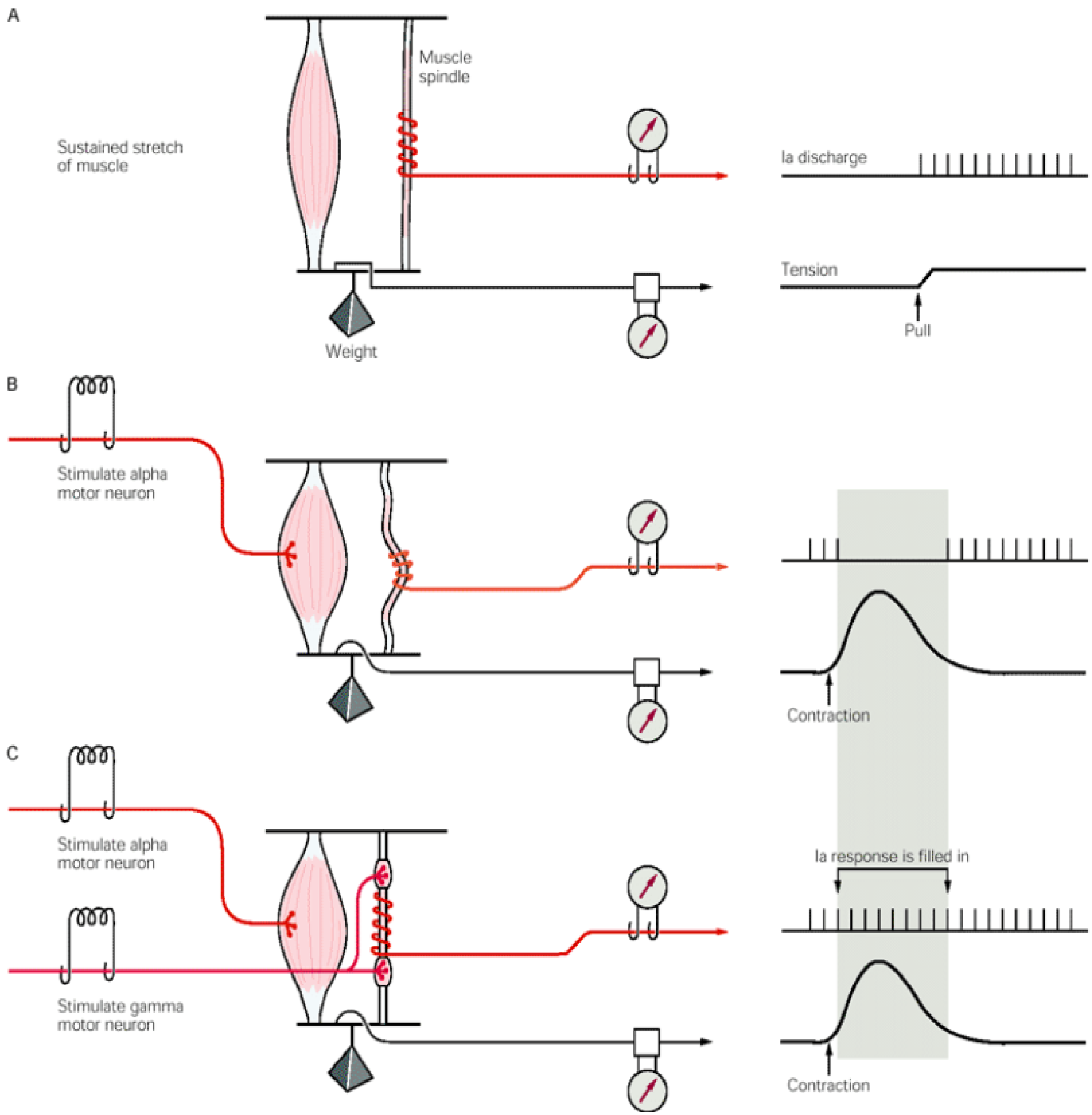
- Dynamic Nuclear Bag fibers. These fibers are anatomically similar to the static nuclear bag fibers, but they signal primarily information about the rate of change (velocity) of muscle length.
A typical muscle spindle is composed of 1 dynamic nuclear bag fiber, 1 static nuclear bag fiber, and ~5 nuclear chain fibers.



Organisation of muscle spindles

- respond to change in muscle length
- γ-fibres from ventral horn
- Group Ia and II fibres are afferents to the spinal cord

Alpha-gamma coactivation



A. Sustained tension elicits steady firing in the Ia sensory fiber.

B. A characteristic pause occurs in the ongoing discharge of the Ia fiber when the alpha motor neuron alone is stimulated. The Ia fiber stops firing because the spindle is unloaded by the resulting contraction.

C. If a gamma motor neuron to the spindle is also stimulated, the spindle is not unloaded during the contraction and the pause in discharge of the Ia fiber is filled in.

Sensory fibres

Ia	Primary spindle endings	12-20 µm myelinated	Muscle length and rate of change of length
Ib	Golgi tendon organs	12-20 µm myelinated	Muscle tension
II	Secondary spindle endings	6-12 µm myelinated	Muscle length (little rate sensitivity)
II	Nonspindle endings	6-12 µm myelinated	Deep pressure
III	Free nerve endings	2-6 µm myelinated	Pain, chemical stimuli, and temperature (important for physiological response to exercise)
IV	Free nerve endings	0.5-2 µm nonmyelinated	Pain, chemical stimuli, and temperature

Afferents in the motor system

A. Afferensek

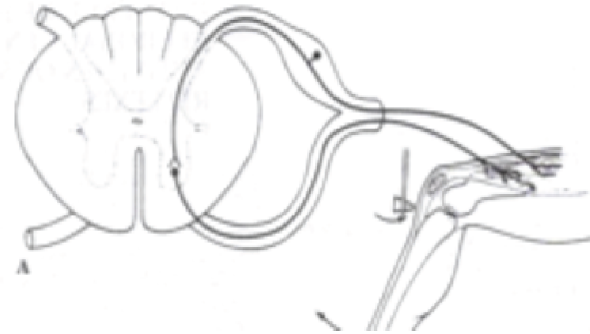
Rost-osztály	Átmérő, vezetési sebesség	Eredés és receptor	Adekvát inger	Funkciók, amelyekben részt vesz
I a.	12–20 µm 70–120 m/s	izomorsó, annulo-spirális receptor	izomrost megnyúlása	miotatikus reflex (motoneuron-serkentés, antagonista gátlás), kontrakcióhossz szabályozása
I b.	12–20 µm 70–120 m/s	Golgi-féle ínszerv	izomrost feszülése	túlfeszítés elleni védelem (fordított miotatikus reflex), feszülés beállítása
II	5–12 µm 30–70 m/s	extenzor és flexor izmok virágszerű receptorai	izomrost nyúlásváltozásai	miotatikus reflex, hosszbeállítás, agonista–antagonista ellentét, keresztezett extenzorreflex
		bőr alacsony küszöbű mechanoreceptorai	kismértékű bőrdeformáció (tapintás, nyomás)	flexorreflex, keresztezett extenzorreflex, rálépési és fogási reflexek, járás
III	2–5 µm 12–30 m/s	izombeli ismeretlen receptor	izomdestrukció (fájdalom?)	flexorreflex, keresztezett extenzorreflex, általában védekezés a káros és fájdalmas hatások ellen; központi fájdalomérzés afferentációja
		bőrbeli mielinizált idegvégződések	hőmérséklet változása; szöveti destrukció (gyors, fájdalomérző rostok)	
IV	0,5–1 µm 0,5–2 m/s	bőr nem mielinizált szabad idegvégződései	szöveti károsodás	flexorreflex, keresztezett extenzorreflex. Fájdalomérző afferentáció lassú komponense

Efferents

B. Efferensek

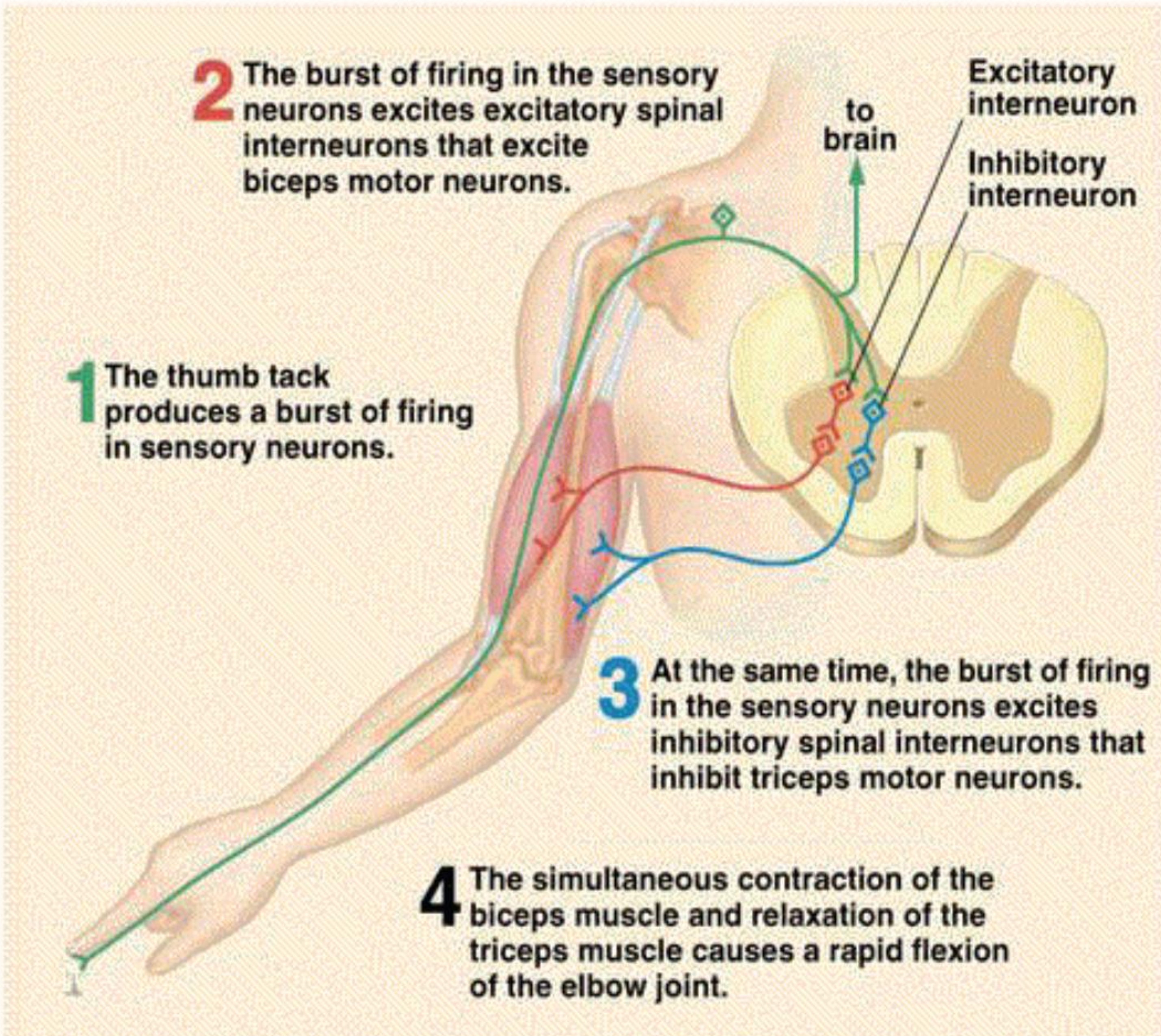
Rost-osztály	Átmérő, vezetési sebesség	Eredés	Célobjektum	Kisülési típus	Utókisülés
A α gyors	12–30 μm 50–135 m/s	nagy alfa motoneuron	gyors munkaizomrostok	fázisos	hosszú
A α lassú	12–30 μm 20–135 m/s	kisebb alfa motoneuron	lassú munkaizomrostok	tónusos	rövid vagy nincs
A γ	4–8 μm 10–20 m/s	gamma motoneuron	intrafuzális izomorsórostok	fázisos vagy tónusos	?

Final Common Pathway



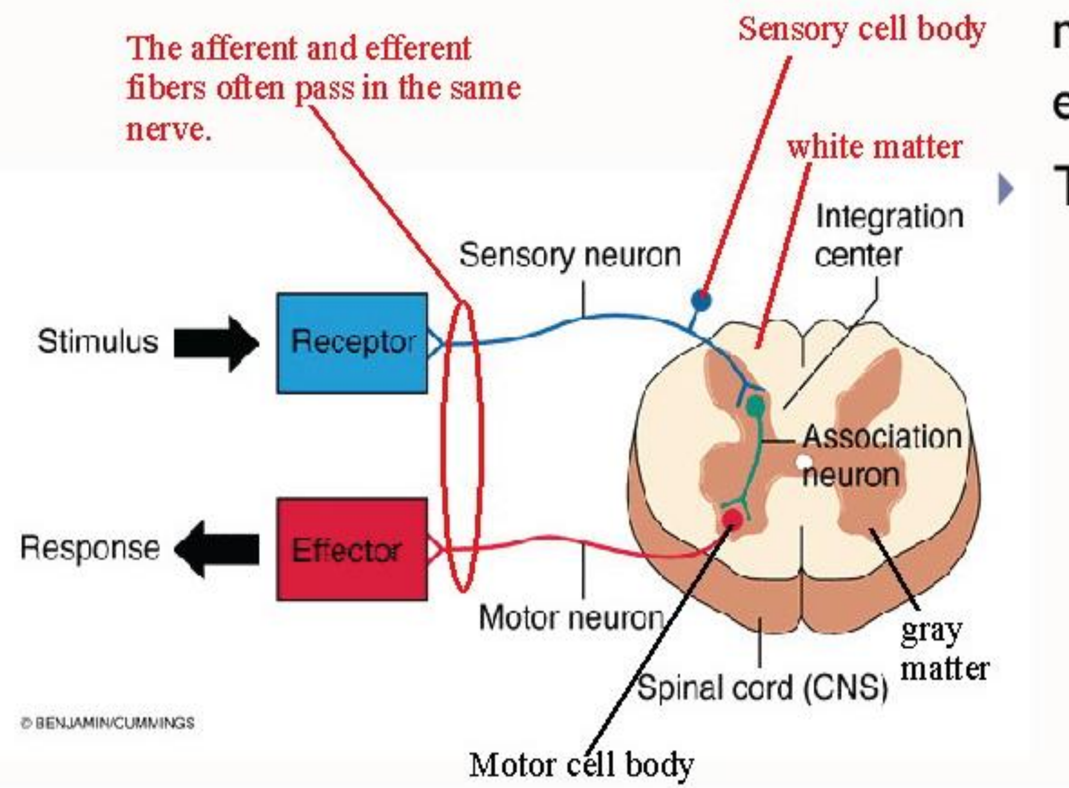
- Motor unit – a lower motor neuron (ventral horn cell/ CN nucleus) + muscle fibers under its control
  - alpha motor neuron
  - axon (nerve)
  - synapse
  - muscle fibers
- Final common pathway – many motor units through which all activities in the motor system must act

▸ Reciprocal Innervation of Antagonistic Muscles



Spinal cord reflexes

A Reflex Arc Shows How Neuron Types Work Together.

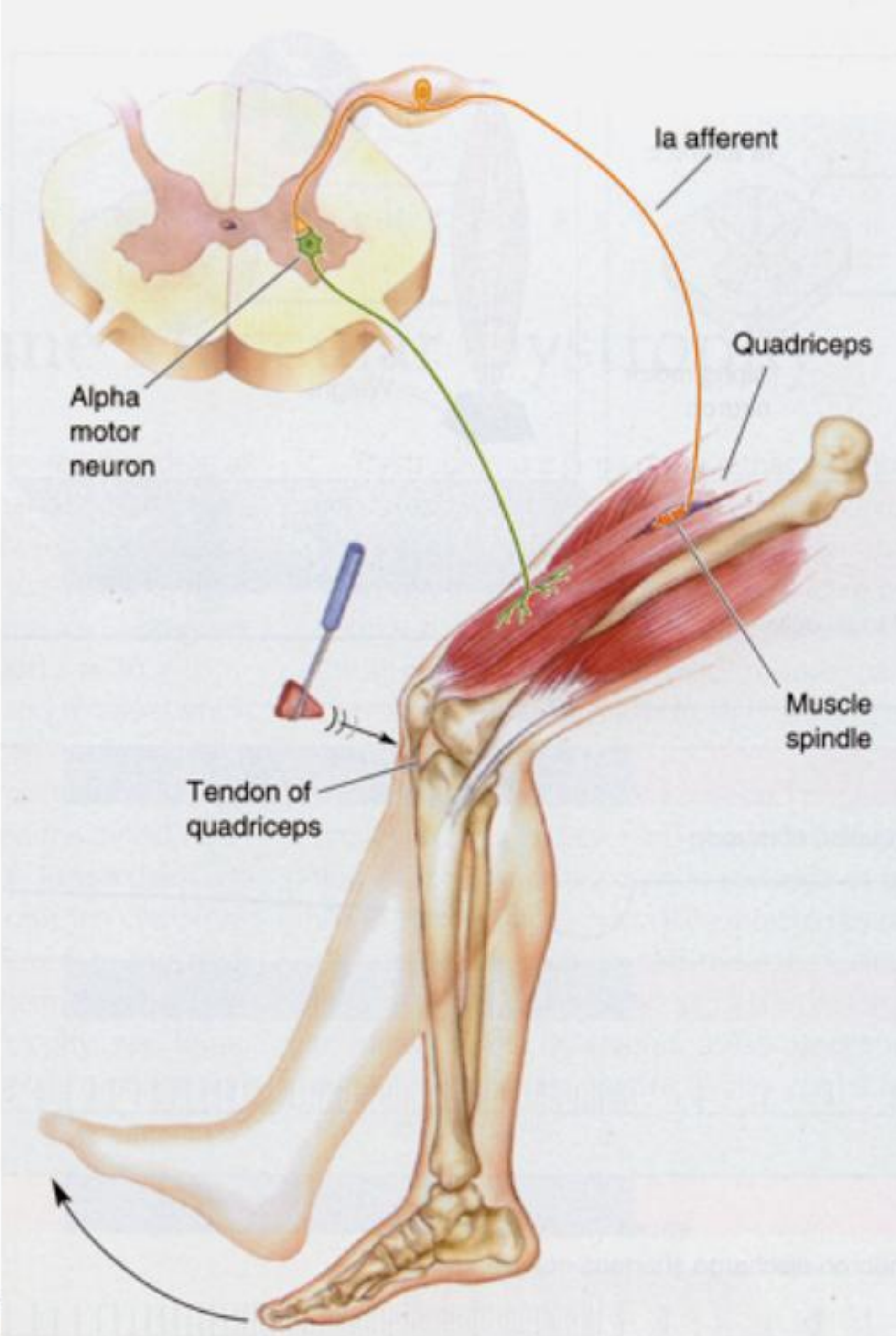


- Involuntary coordinated patterns of muscle contraction and relaxation elicited by peripheral stimuli
- Types:
  - Myotactic (strech) reflex
  - Autogeneric inhibition reflex
  - Flexor reflex
  - Crossed-extensor reflex

Myotactic (strech) reflex

- A major role of the myotatic reflex is the maintenance of posture, diagnostic value (knee-jerk)
- Example: waiter holding an empty tray, somebody puts on a glass of beer

1. increased weight stretches the biceps muscle, which results in the activation of the muscle spindle's Ia afferents
2. Ia afferents: cell bodies in the dorsal root ganglia of the spinal cord, send projections into the spinal cord, and make synapses directly on alpha motor neurons that innervate the same muscle
3. activation of the Ia afferent causes a monosynaptic activation of the alpha motor neuron that causes the muscle to contract
4. the stretch of the muscle is quickly counteracted, and the waiter is able to maintain the tray
5. when the stretch reflex is activated, the opposing muscle group must be inhibited to prevent it from working against the resulting contraction of the homonymous muscle



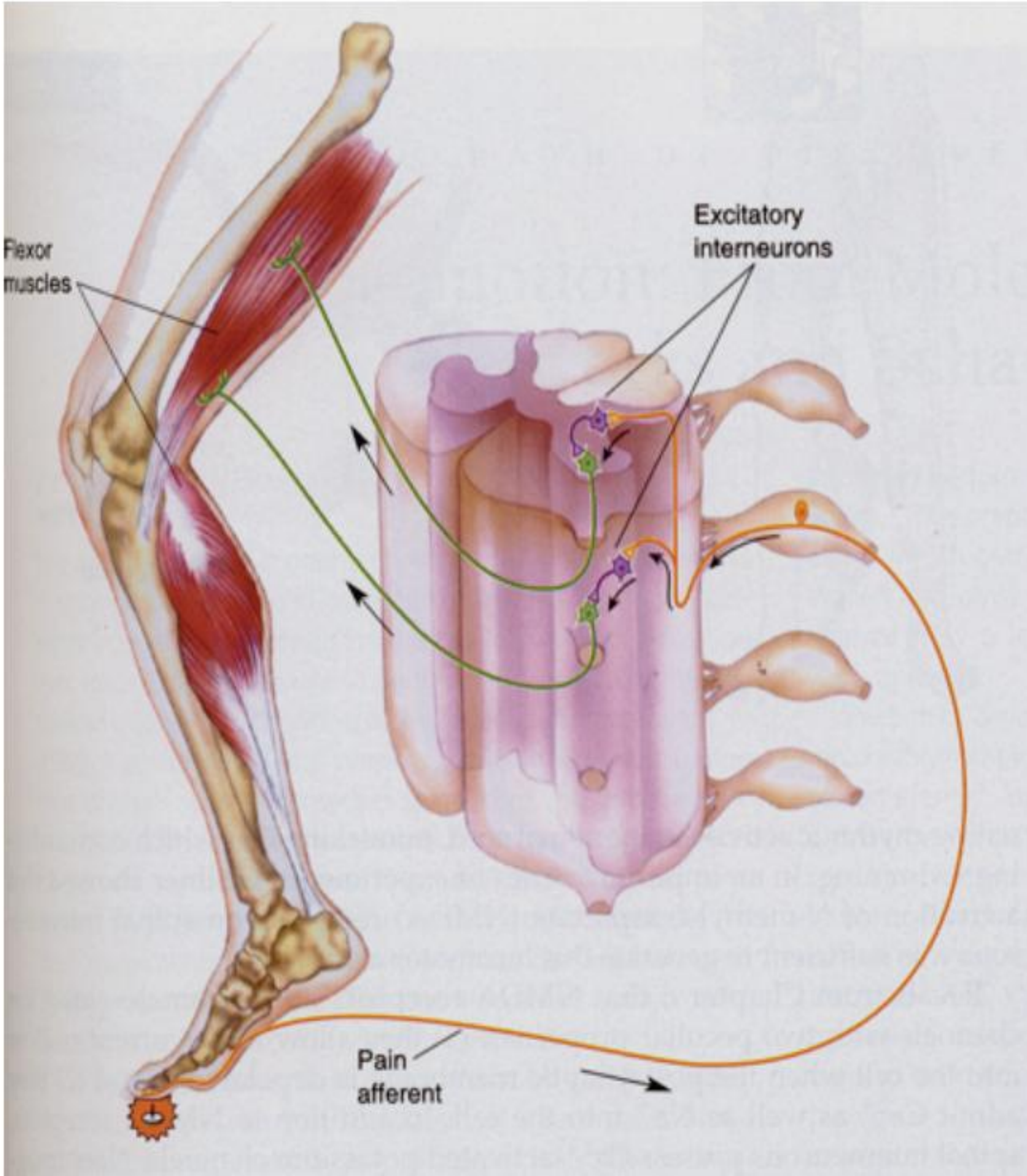
Knee-jerk
(mono-synaptic)

myotatic
stretch

Flexor reflex

- Example:accidentally touching a hot stove or a sharp object, as we withdraw our hand even before we consciously experience the sensation of pain

1. reflex initiated by cutaneous receptors and pain receptors
2. sharp object touching the foot causes the activation of Group III afferents of pain receptors and go up the cord.
3. branch of the afferent innervates an excitatory interneuron in the lumbar region of the spinal cord; excites an alpha motor neuron that causes contraction of the thigh flexor muscle
4. Group III afferent also continues upward to the L2 vertebra, where another branch innervates an excitatory interneuron at this level
5. This interneuron excites the alpha motor neurons that excite the hip flexor muscle; withdrawal of the whole leg
6. Group III afferents innervate inhibitory interneurons that in turn innervate the alpha motor neurons controlling the antagonist muscle.

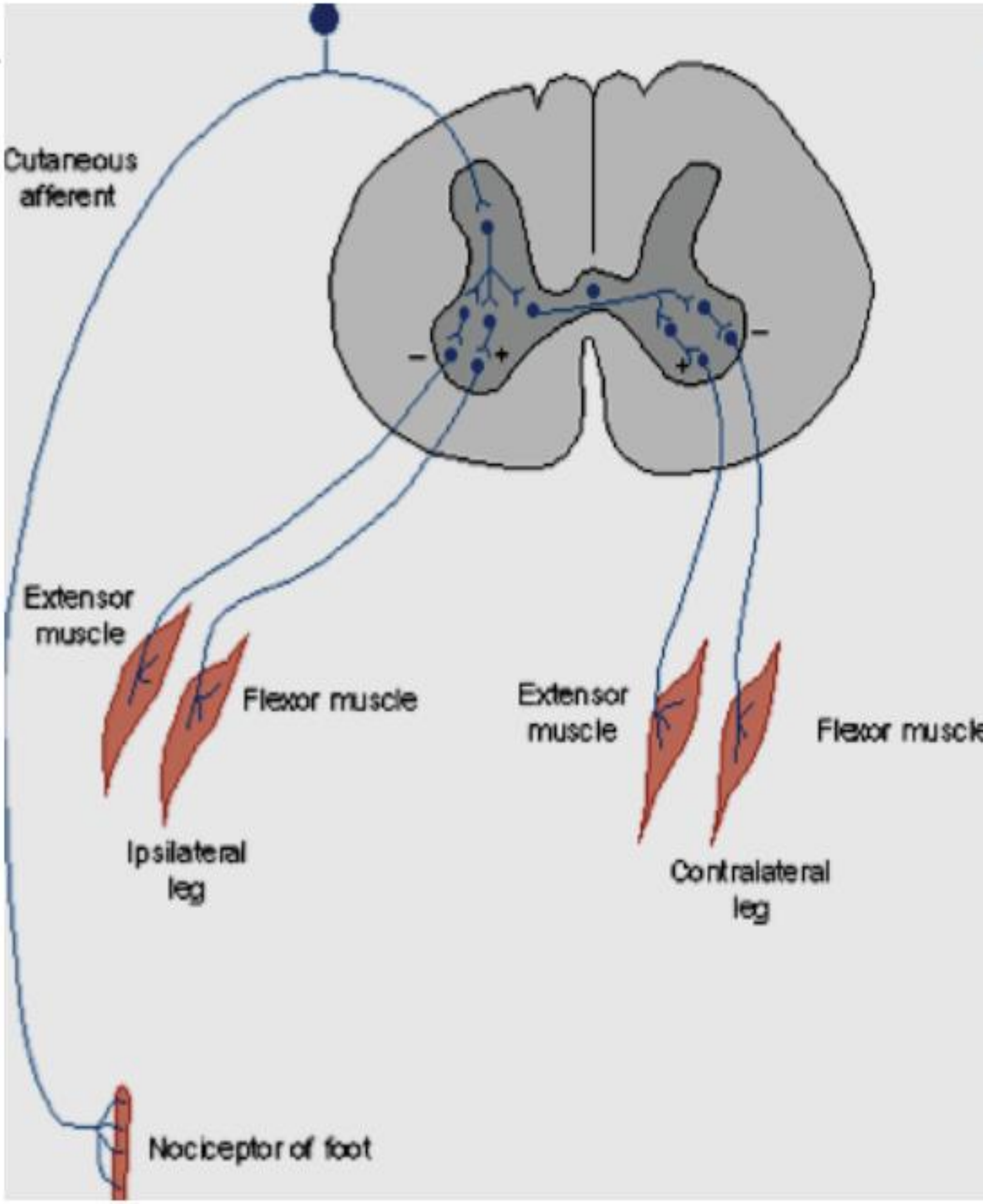


With-drawal flexion reflex (di-synaptic)

Crossed extension reflex

- Further circuitry is needed to make the flexor reflex adaptive.
- the flexor reflex incorporates a crossed extension reflex to protect the body from loosing the balance

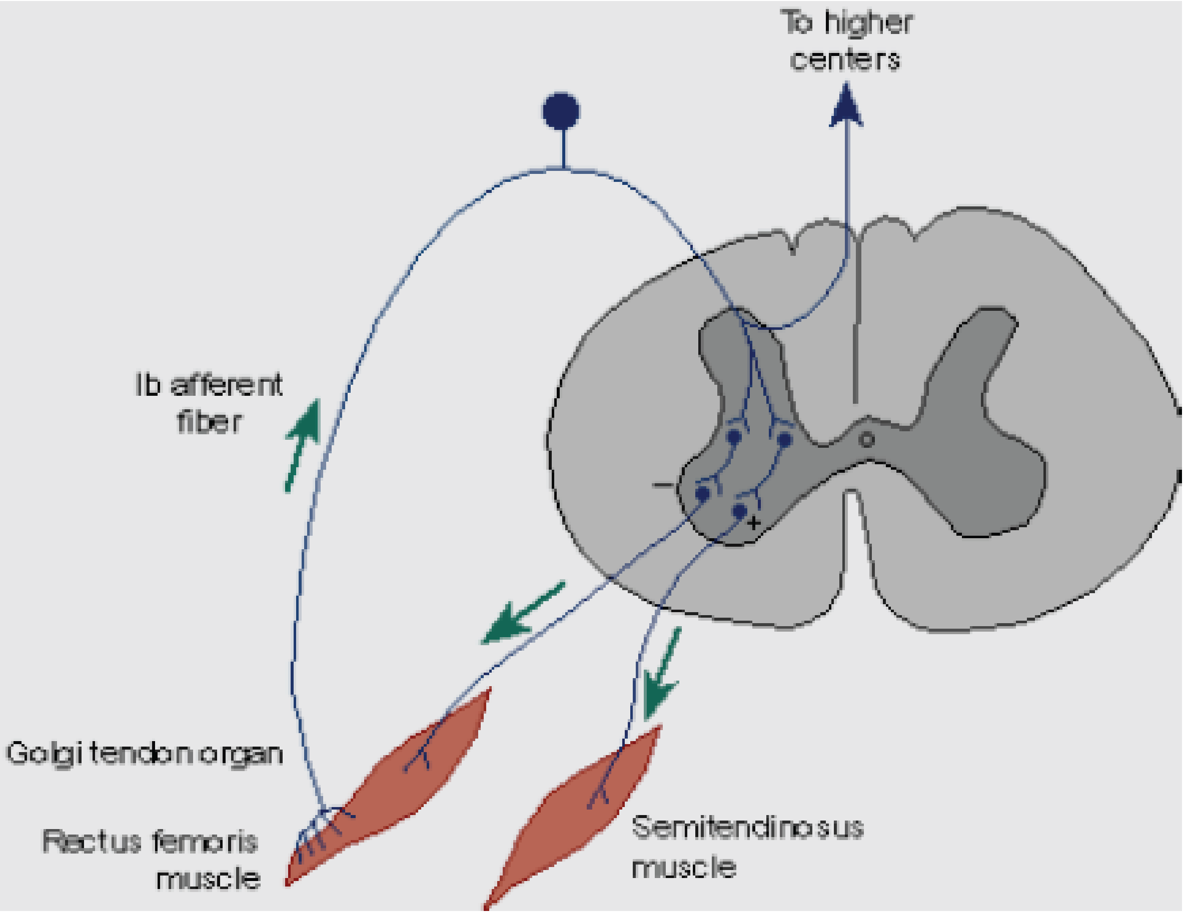
1. Group III afferent innervates an excitatory interneuron that sends its axon across the midline into the contralateral spinal cord
2. excites the alpha motor neurons that innervate the extensor muscles of the opposite leg



Reflexes supporting posture:

1. Crossed extensor reflex

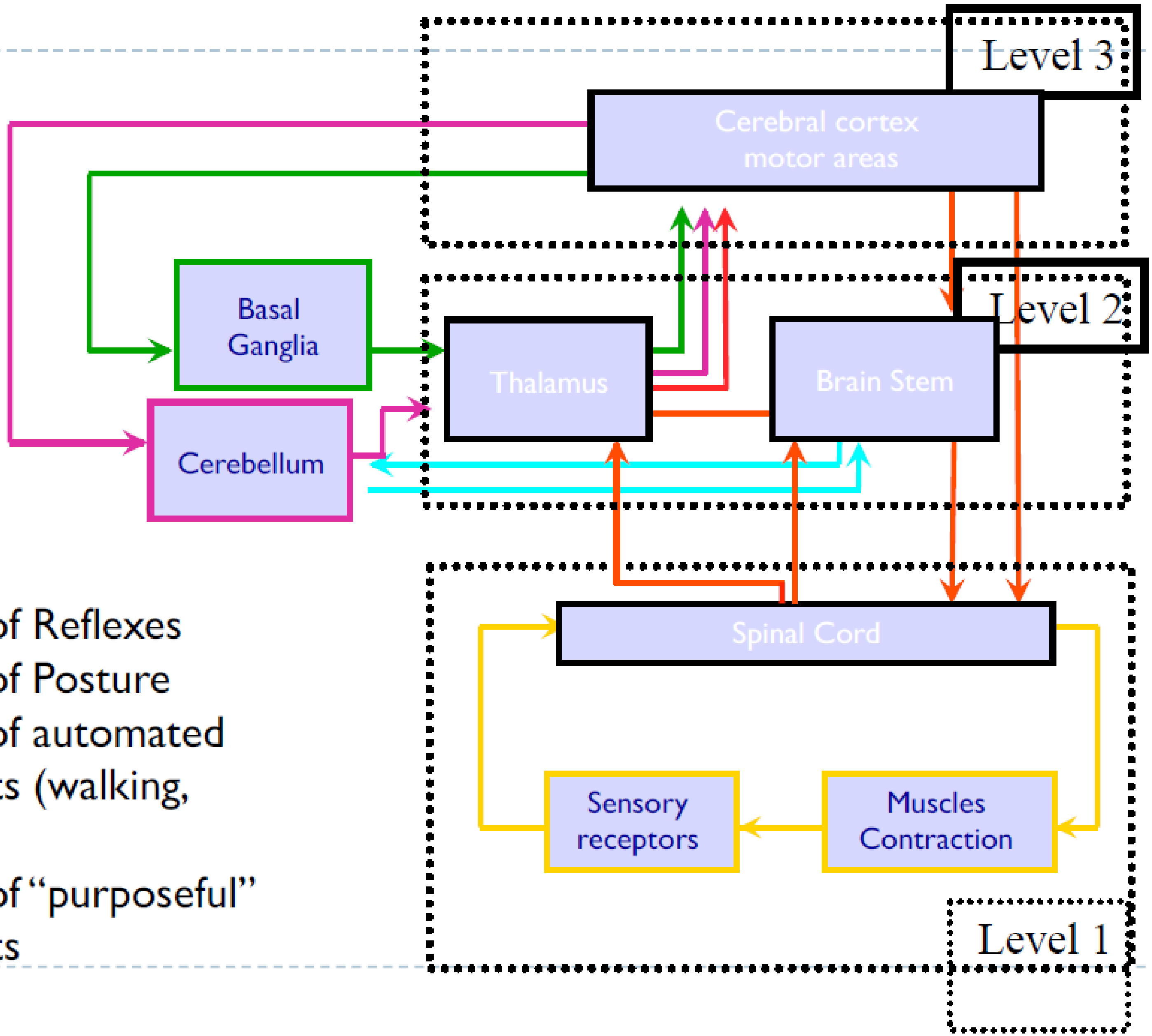
Reflexes supporting posture:
2. Golgi tendon reflex



Renshaw cells

- Axons of alpha motor neurons special inhibitory interneuron called the Renshaw cell in the spinal cord
- inhibits the very same motor neuron that caused it to fire
- negative feedback loop is thought to stabilize the firing rate of motor neurons

Organization of the motor system



- Control of Reflexes
- Control of Posture
- Control of automated movements (walking, breathing)
- Control of "purposeful" movements