

M U N I

M E D

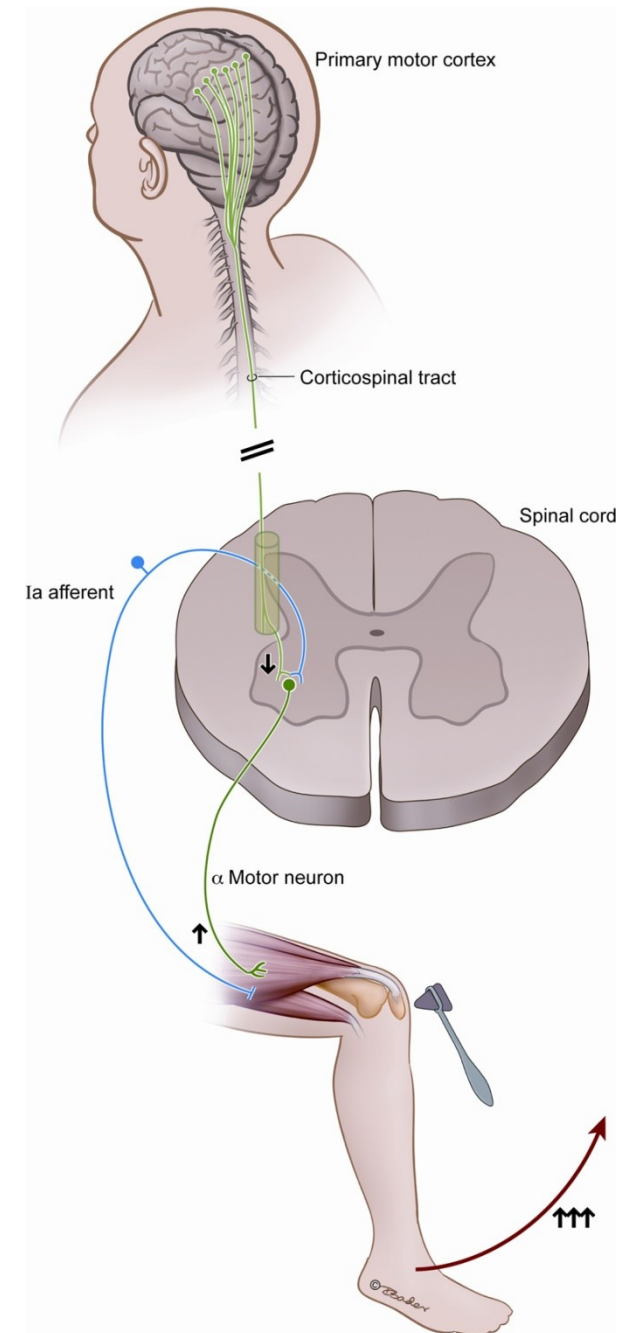
M U N I
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11

Motor system I

Introduction

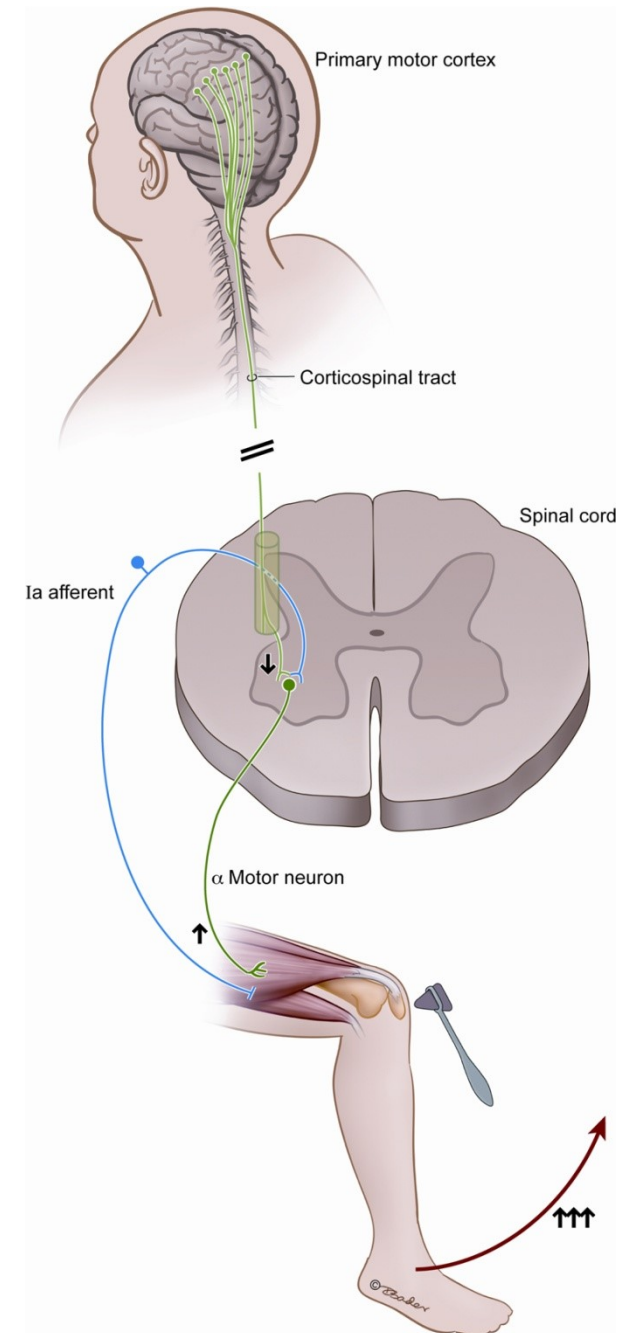
- Skeletal muscle contraction is initiated by lower motor neuron



http://www.frontiersin.org/files/Articles/42416/fnhum-07-00085-HTML/image_m/fnhum-07-00085-g001.jpg

Introduction

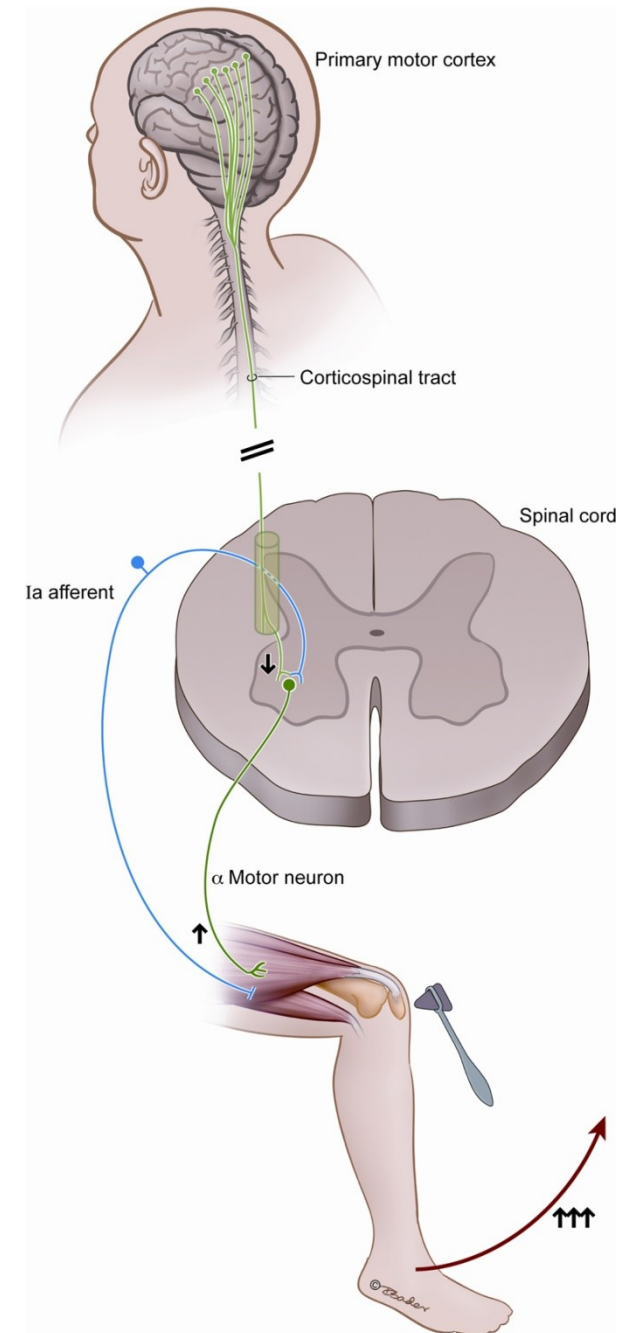
- Skeletal muscle contraction is initiated by lower motor neuron
- Lower motor neuron is a part of local reflex circuits



http://www.frontiersin.org/files/Articles/42416/fnhum-07-00085-HTML/image_my/fnhum-07-00085-g001.jpg

Introduction

- Skeletal muscle contraction is initiated by lower motor neuron
- Lower motor neuron is a part of local reflex circuits
- The information from several sources is integrated in the lower motor neuron
 - Higher levels of CNS
 - Upper motor neuron, tectum, n. ruber, brain stem
 - Proprioception

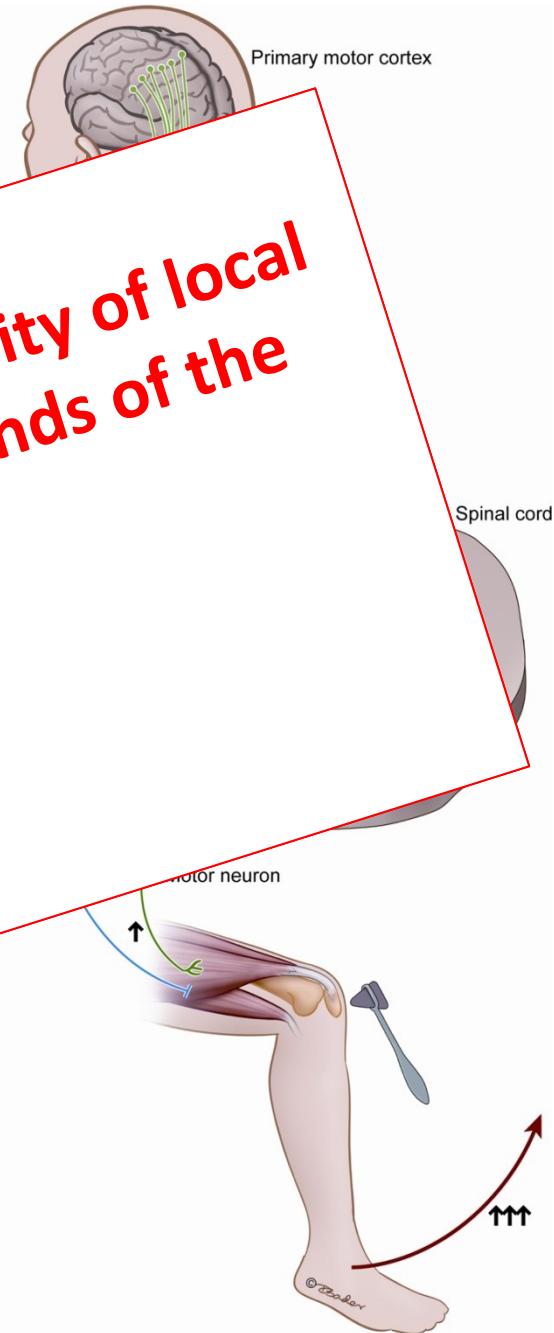


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Introduction

- Skeletal muscle contraction is initiated by the lower motor neuron
- Lower motor neuron reflex
- The information is integrated
 - Higher motor centers
 - Upper motor neuron
 - Rubrospinal tract
 - Proprioceptive input

Lower motor neuron regulates the activity of local reflex circuits, according to the demands of the higher regions of the CNS



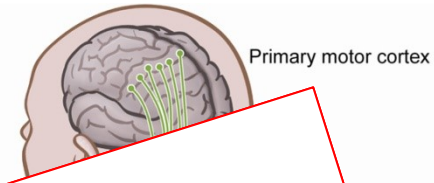
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Introduction

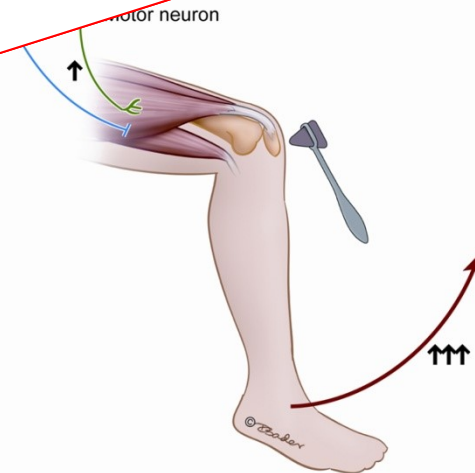
- Skeletal muscle contraction is initiated by the lower motor neuron
- Lower motor neuron reflex
- The information is integrated
 - Higher brain regions
 - Upper motor neuron (corticospinal tract)
 - Proprioception

Lower motor neuron regulates the activity of local reflex circuits, according to the demands of the higher regions of the CNS

Proprioception is crucial for the regulation of local circuit activity



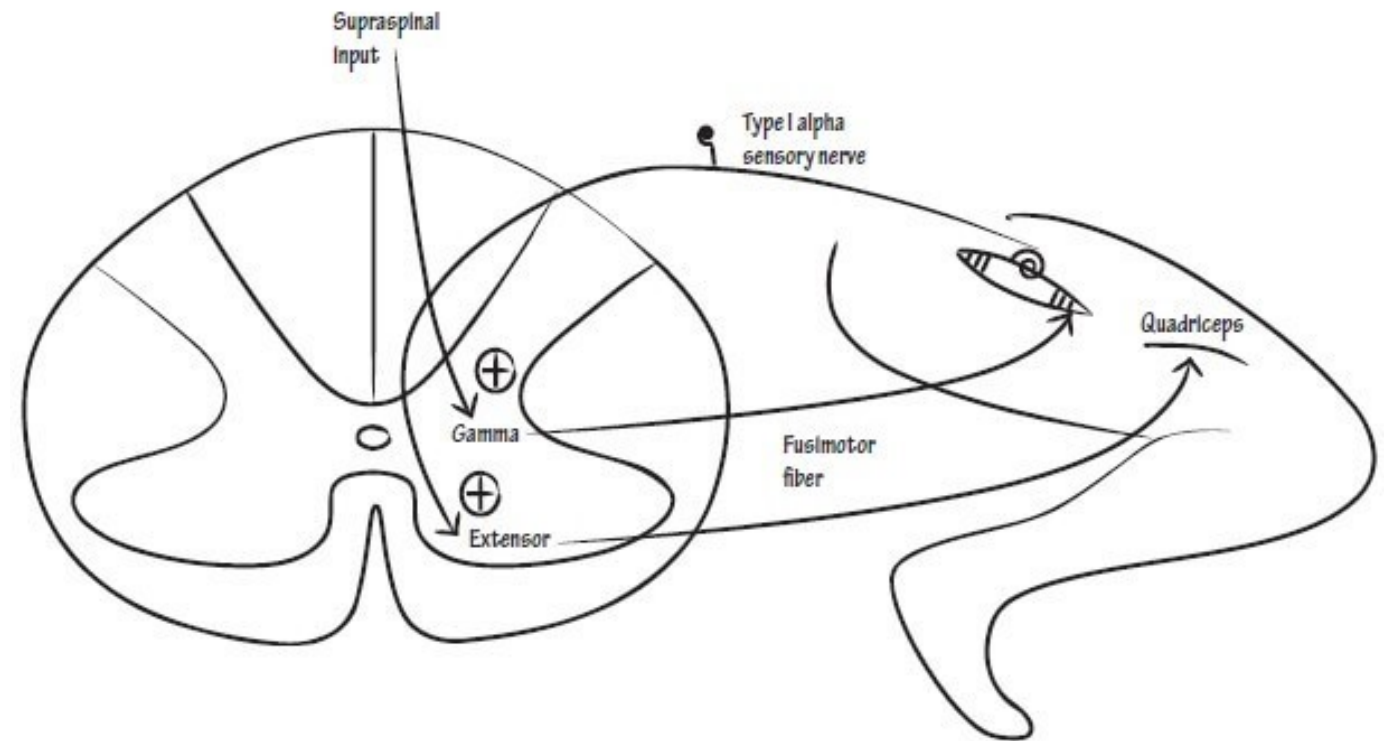
Spinal cord



http://www.frontiersin.org/files/Articles/42416/fnhum-07-00085-HTML/image_m/fnhum-07-00085-g001.jpg

Lower motor neuron

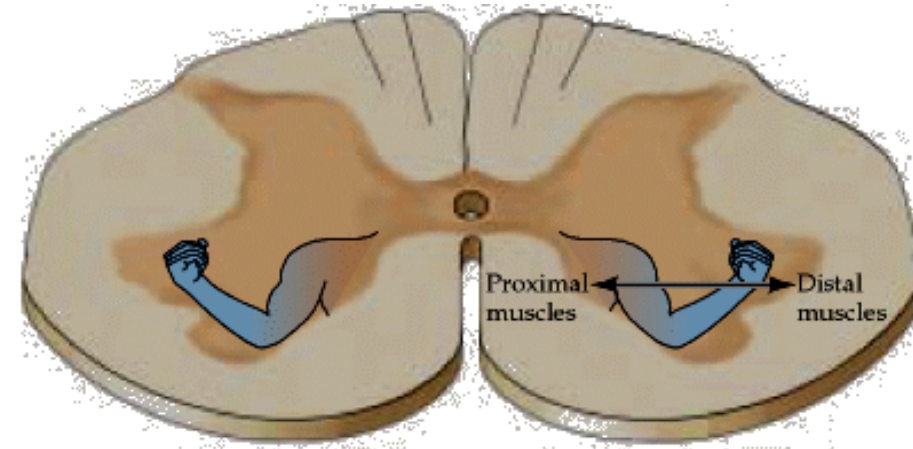
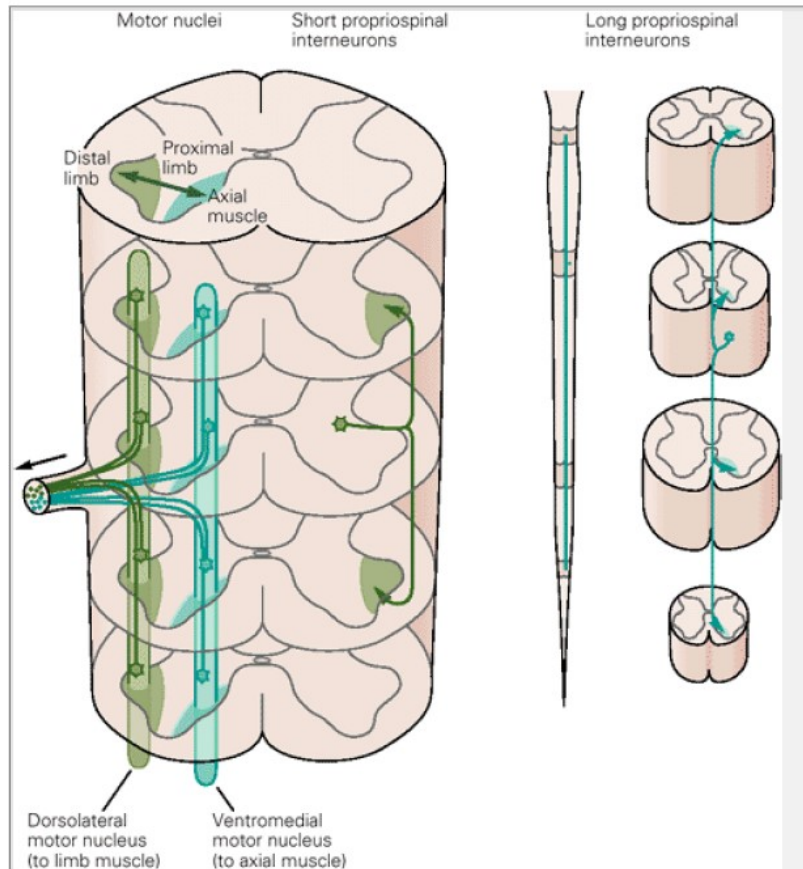
- **α motoneuron**
 - Innervation of contractile elements
 - Extrafusal fibers
 - Muscle contraction
- **γ motoneuron**
 - Innervation of muscle spindles
 - Intrafusal fibers
 - Alignment of muscle spindles
 - Gamma loop
- **β motoneuron**
 - Both extrafusal and intrafusal fibers



<http://epomedicine.com/wp-content/uploads/2016/07/gamma-loop.jpg>

Lower motor neuron

Topography



Motor unit

- A typical muscle is innervated by about 100 motoneurons which are localized in motor nucleus

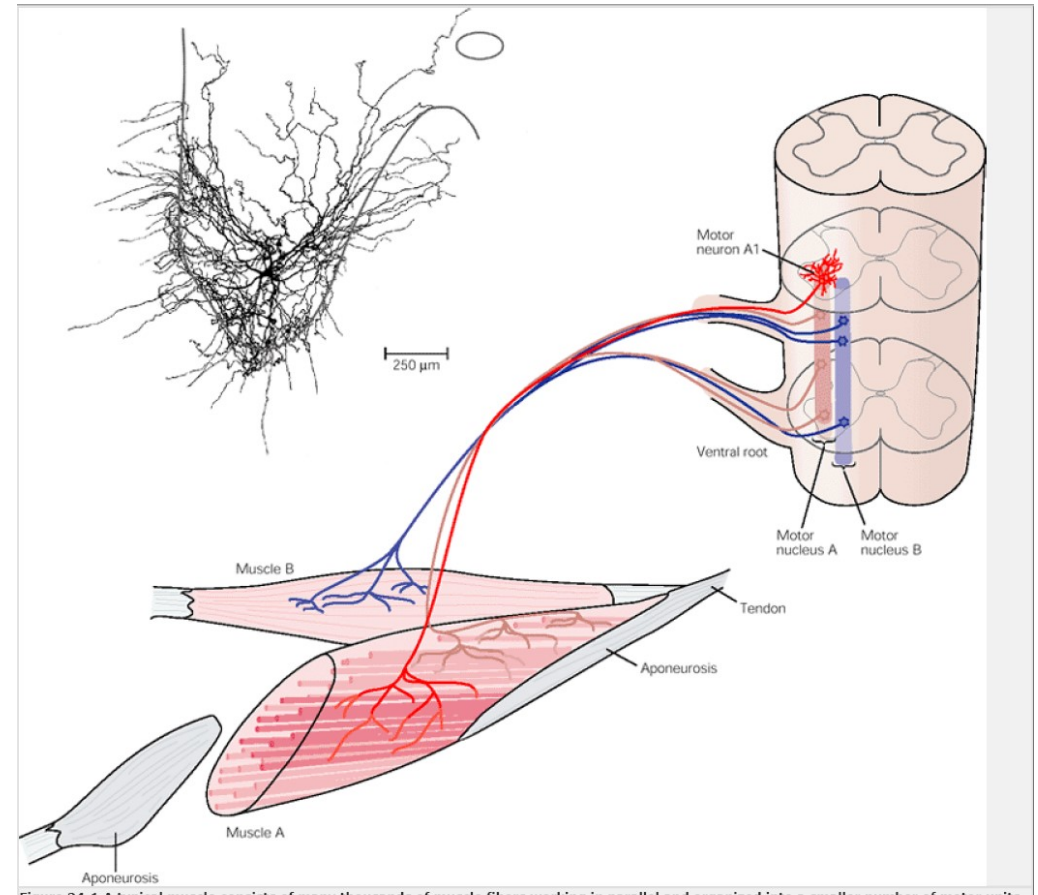


Figure 24.1 A typical muscle consists of many thousands of muscle fibers working in parallel and organized into a smaller number of motor units.

<http://www.slideshare.net/drpsdeb/presentations>

Motor unit

- A typical muscle is innervated by about 100 motoneurons which are localized in motor nucleus
- Each motoneuron innervate from 100 to 1000 muscle fibers and one muscle fiber is innervated by a single motoneuron

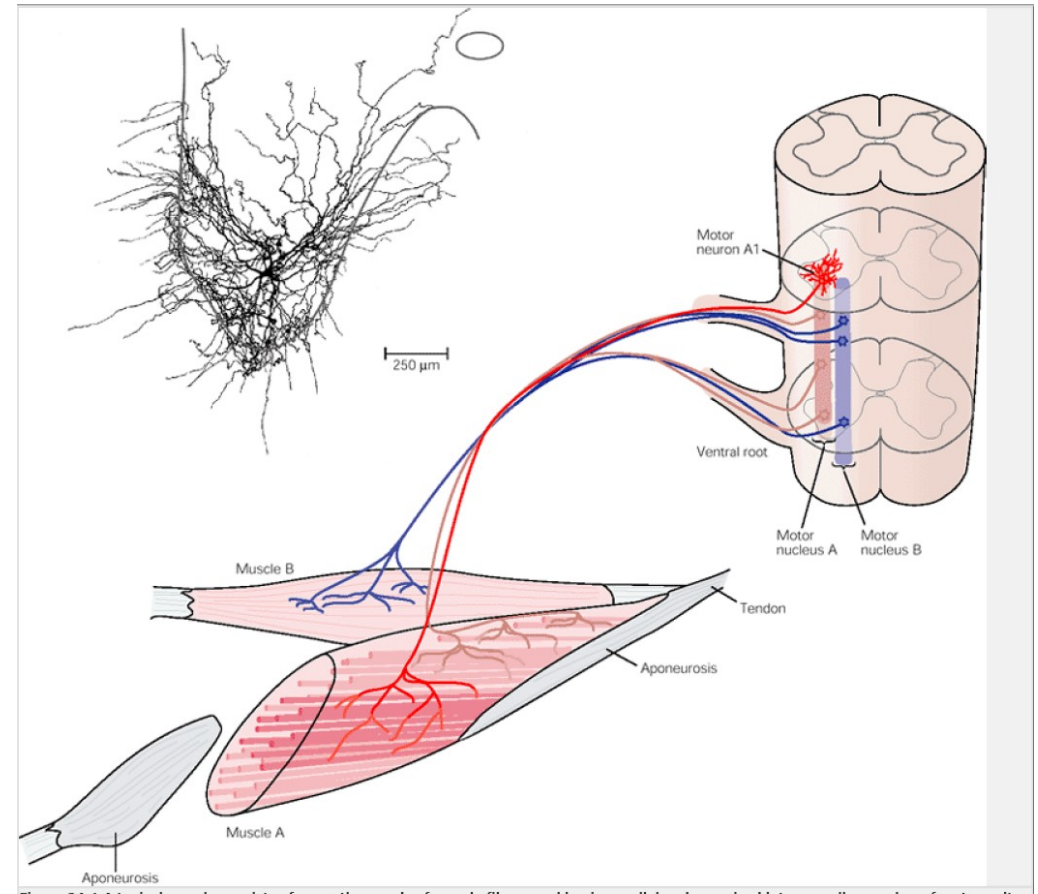


Figure 24.1 A typical muscle consists of many thousands of muscle fibers working in parallel and organized into a smaller number of motor units.

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Motor unit

- A typical muscle is innervated by about 100 motoneurons which are localized in motor nucleus
- Each motoneuron innervate from 100 to 1000 muscle fibers and one muscle fiber is innervated by a single motoneuron
- The ensemble of muscle fibers innervated by a single neuron and corresponding motoneuron constitutes the motor unit

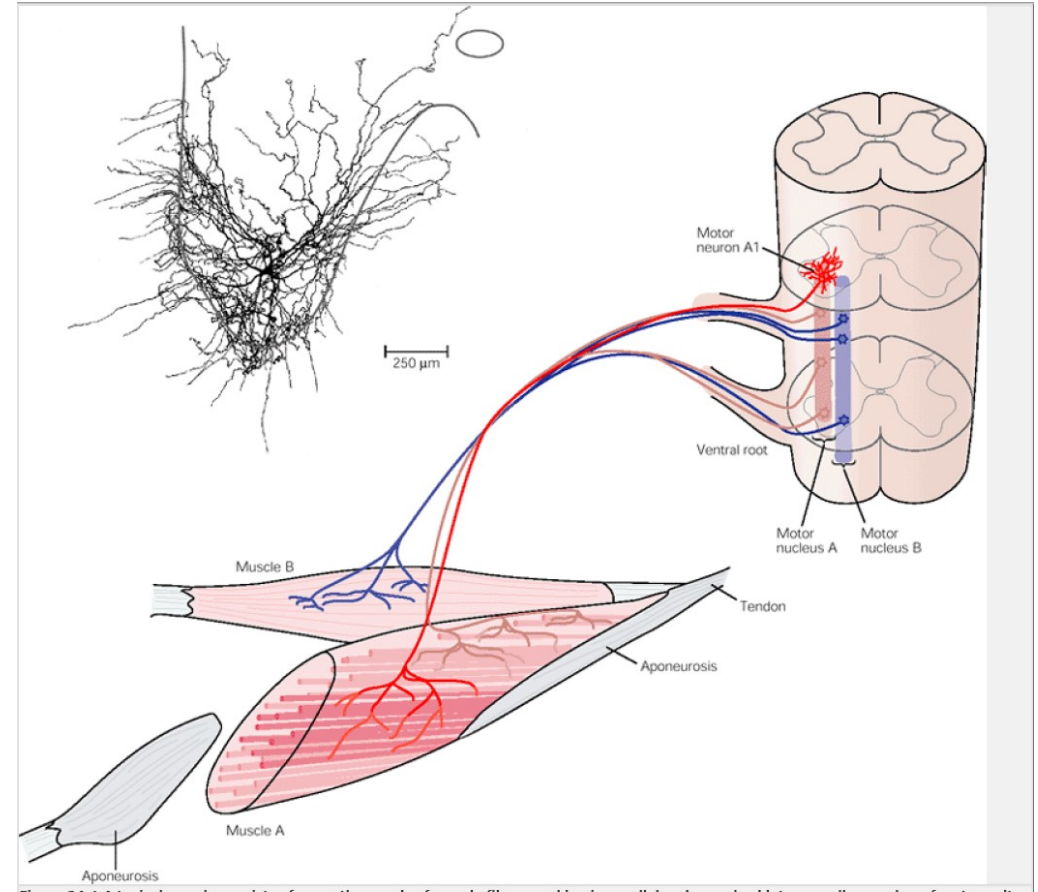


Figure 24.1 A typical muscle consists of many thousands of muscle fibers working in parallel and organized into a smaller number of motor units.

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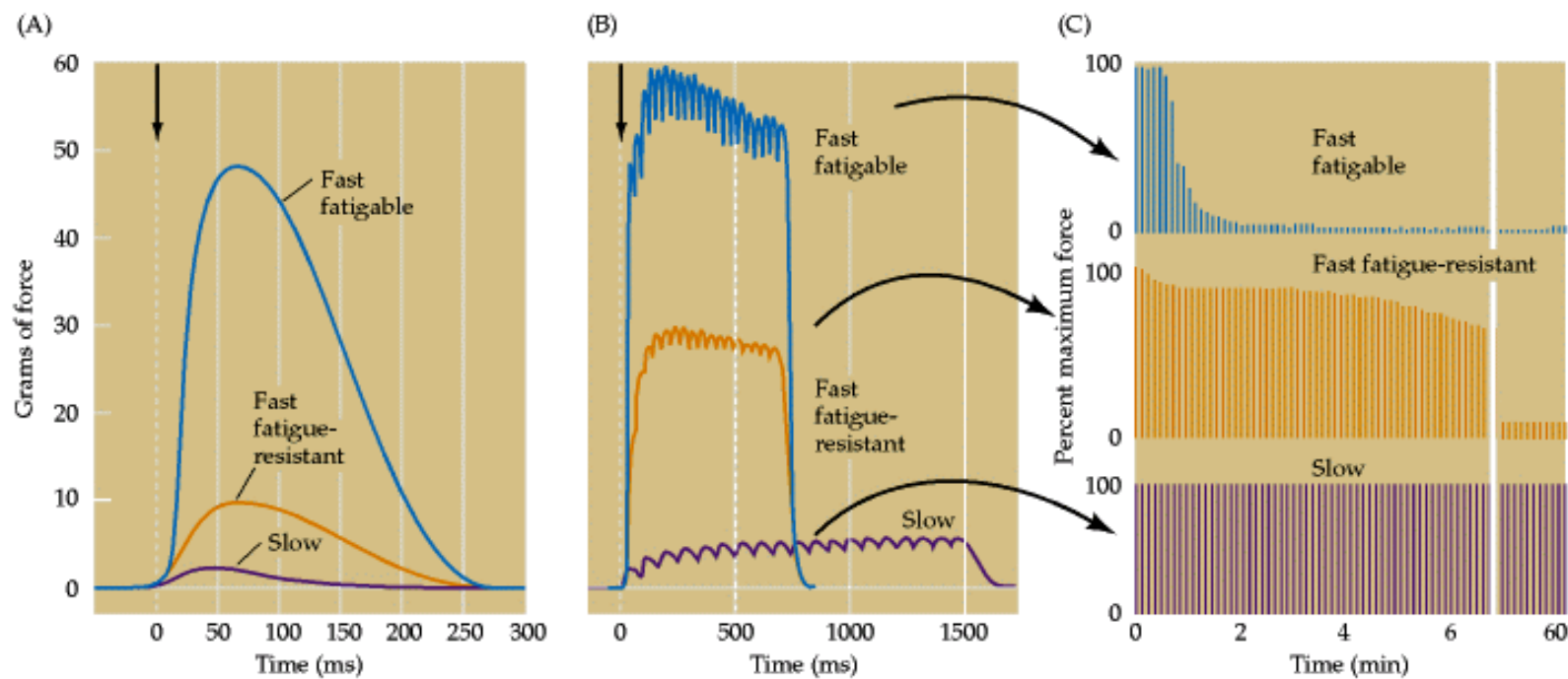
Types of muscle fibers

Fast fibers

- Performance
- Fast fatigue-resistant – normal performance
- Fast fatigable – high performance

Slow fibers

- Endurance
- Fatigue resistant



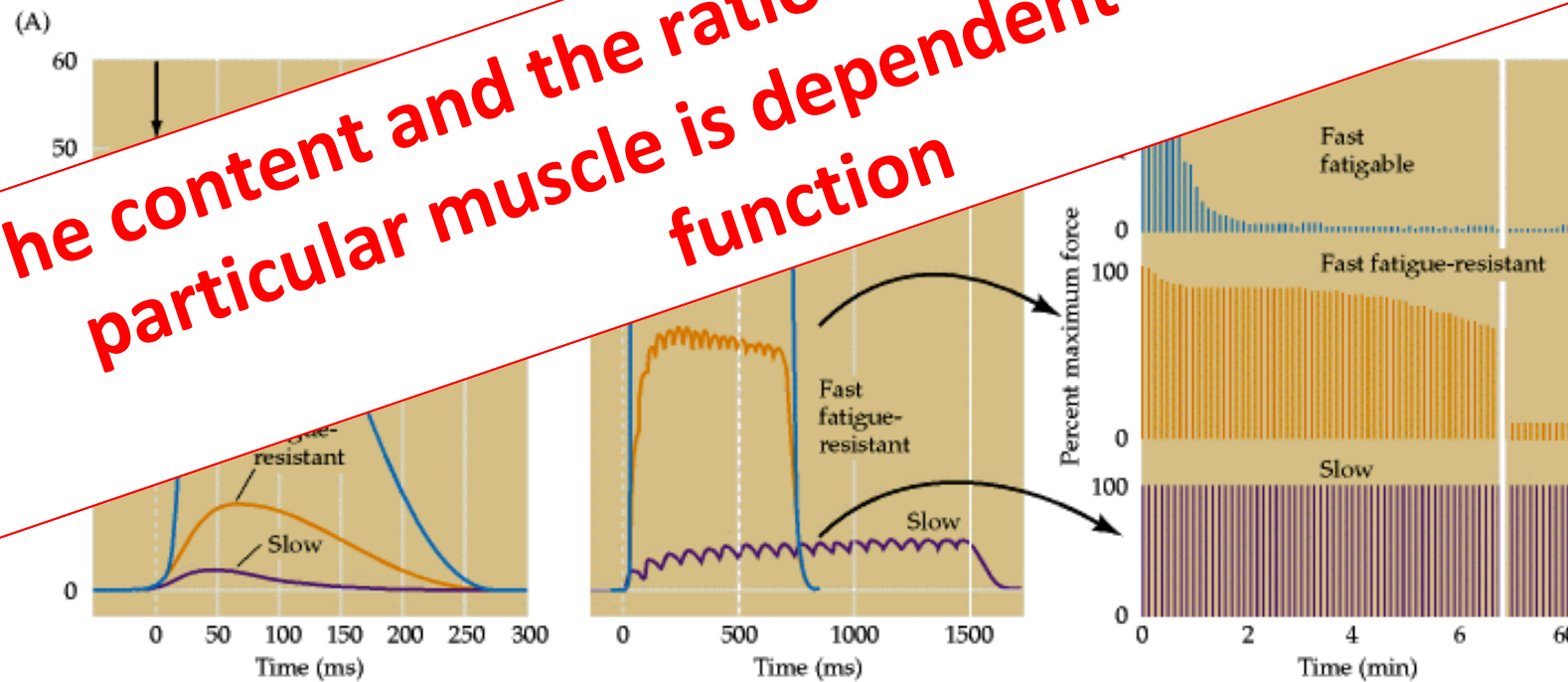
Types of muscle fibers

Fast fibers

- Performance
- Fast fatigue-resistant – normal performance
- Fast fatigable – high performance

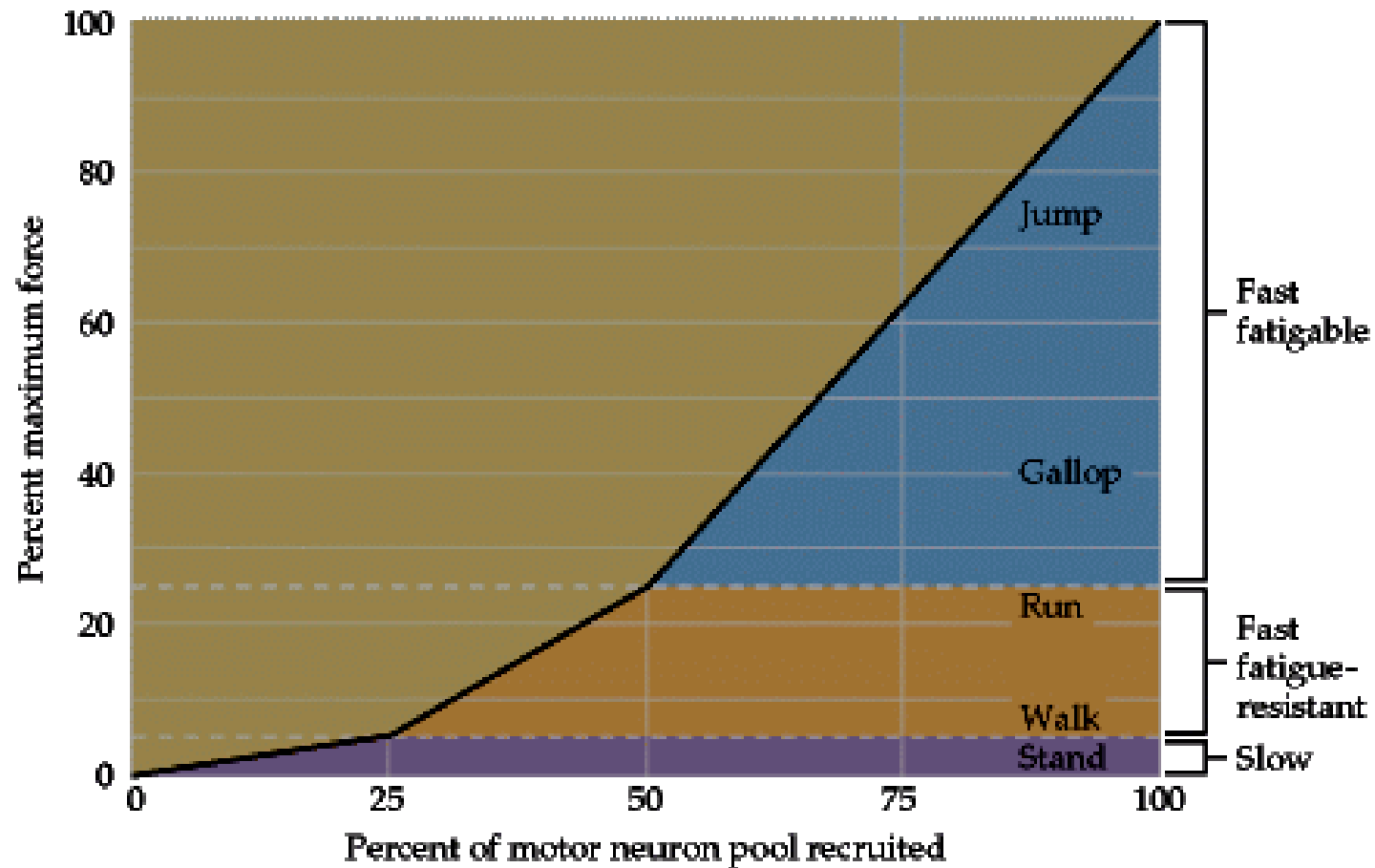
Slow fibers

The content and the ratio of fast/slow fibers in particular muscle is dependent on muscle function

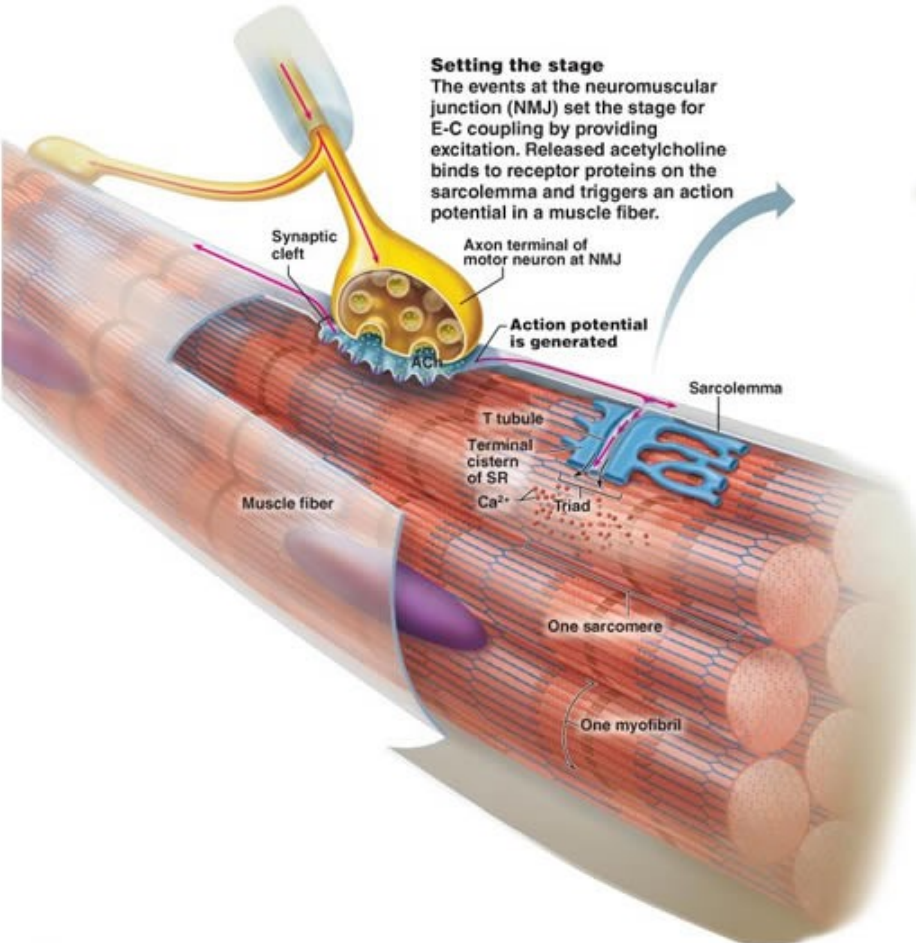


The recruitment of motor neurons

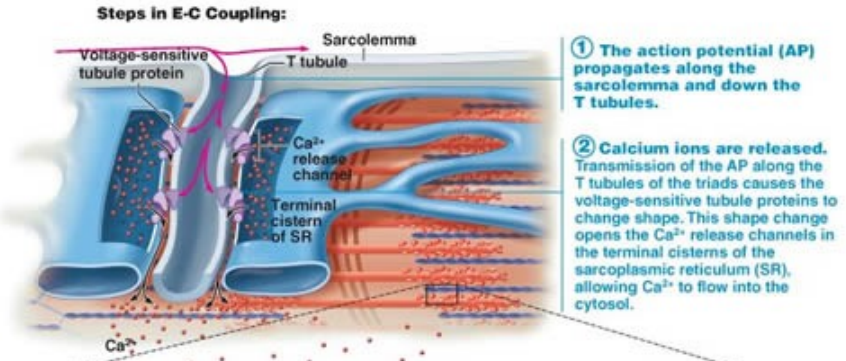
m. gastrocnemius in a cat



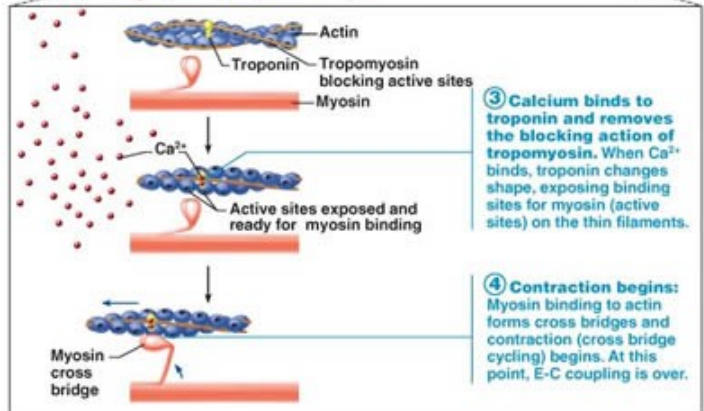
Neuromuscular junction



Setting the stage
The events at the neuromuscular junction (NMJ) set the stage for E-C coupling by providing excitation. Released acetylcholine binds to receptor proteins on the sarcolemma and triggers an action potential in a muscle fiber.



- ① The action potential (AP) propagates along the sarcolemma and down the T tubules.
- ② Calcium ions are released. Transmission of the AP along the T tubules of the triads causes the voltage-sensitive tubule proteins to change shape. This shape change opens the Ca²⁺ release channels in the terminal cisterns of the sarcoplasmic reticulum (SR), allowing Ca²⁺ to flow into the cytosol.

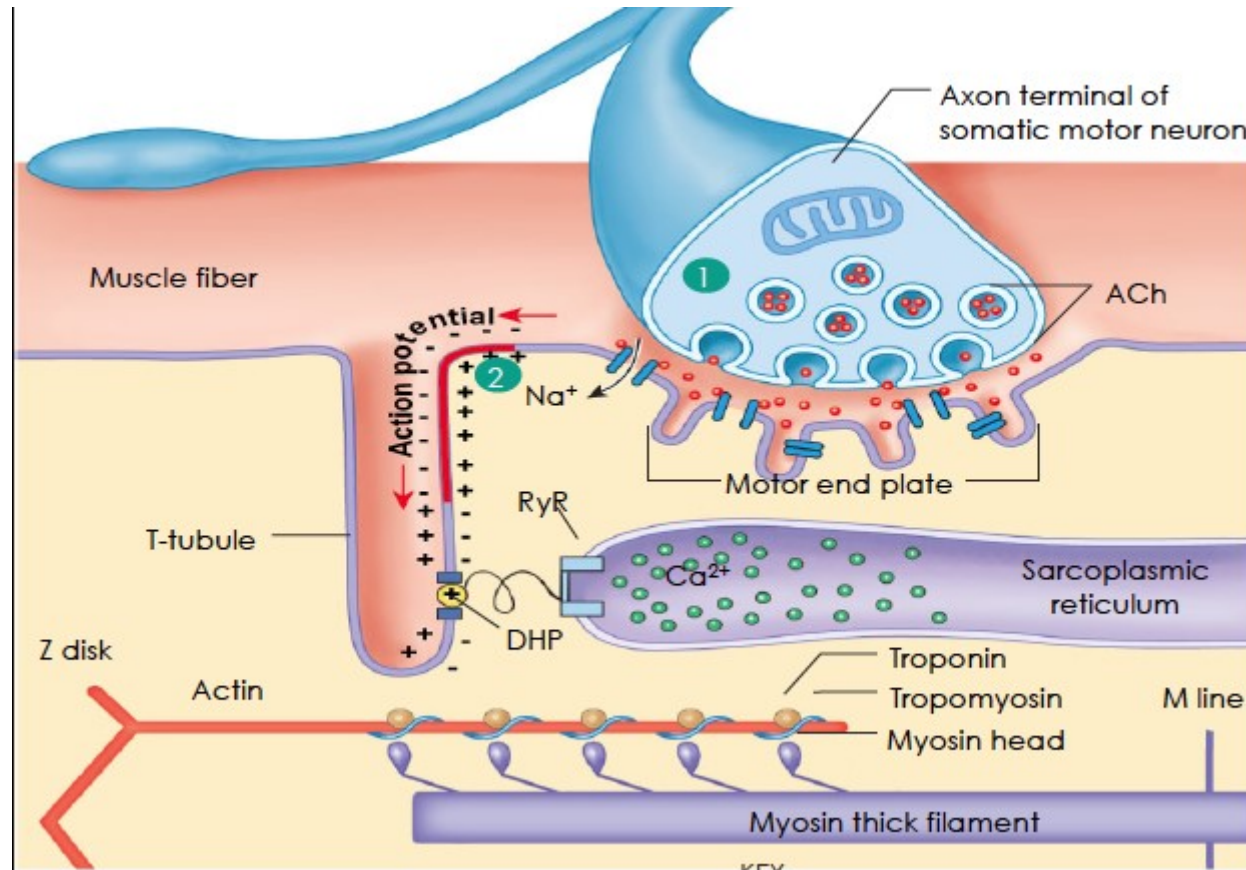


- ③ Calcium binds to troponin and removes the blocking action of tropomyosin. When Ca²⁺ binds, troponin changes shape, exposing binding sites for myosin (active sites) on the thin filaments.
- ④ Contraction begins: Myosin binding to actin forms cross bridges and contraction (cross bridge cycling) begins. At this point, E-C coupling is over.

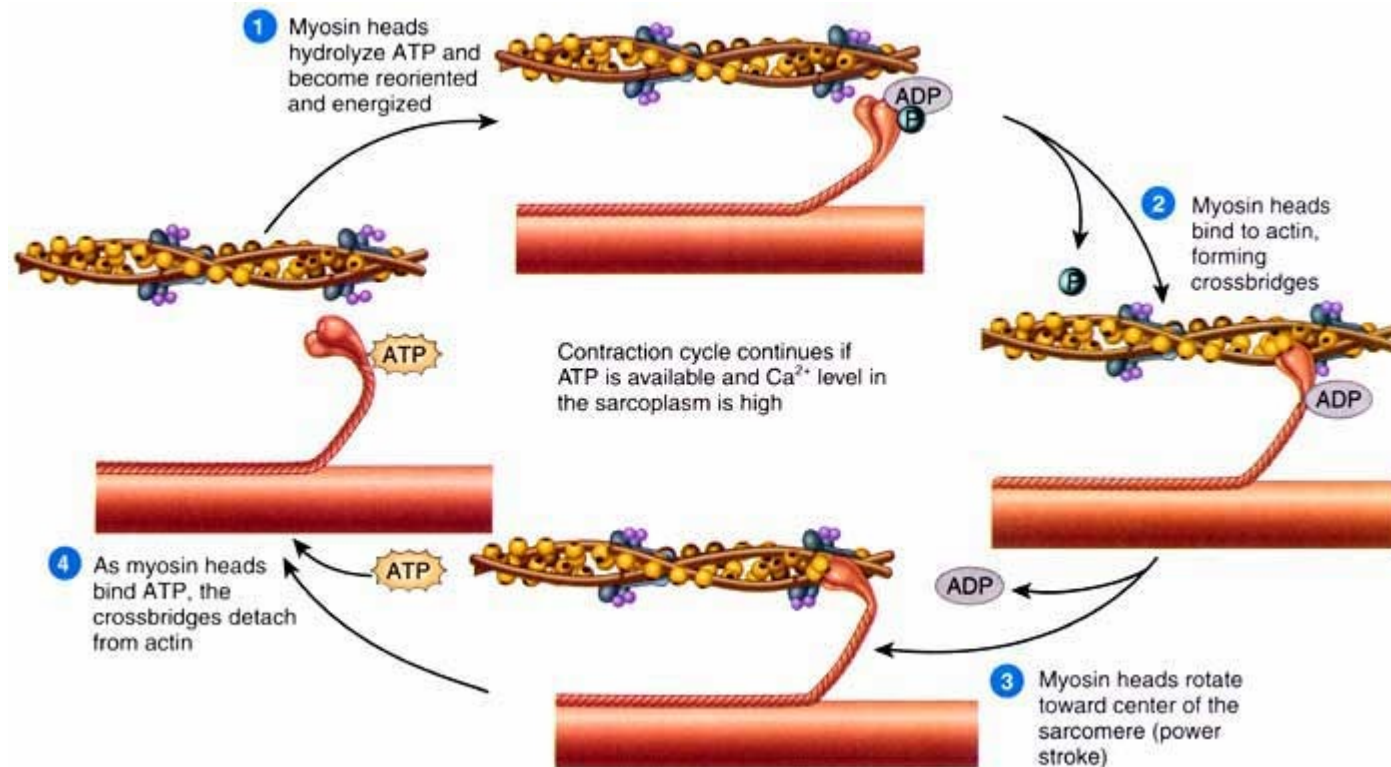
The aftermath
When the muscle AP ceases, the voltage-sensitive tubule proteins return to their original shape, closing the Ca²⁺ release channels of the SR. Ca²⁺ levels in the sarcoplasm fall as Ca²⁺ is continually pumped back into the SR by active transport. Without Ca²⁺, the blocking action of tropomyosin is restored, myosin-actin interaction is inhibited, and relaxation occurs. Each time an AP arrives at the neuromuscular junction, the sequence of E-C coupling is repeated.

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Neuromuscular junction



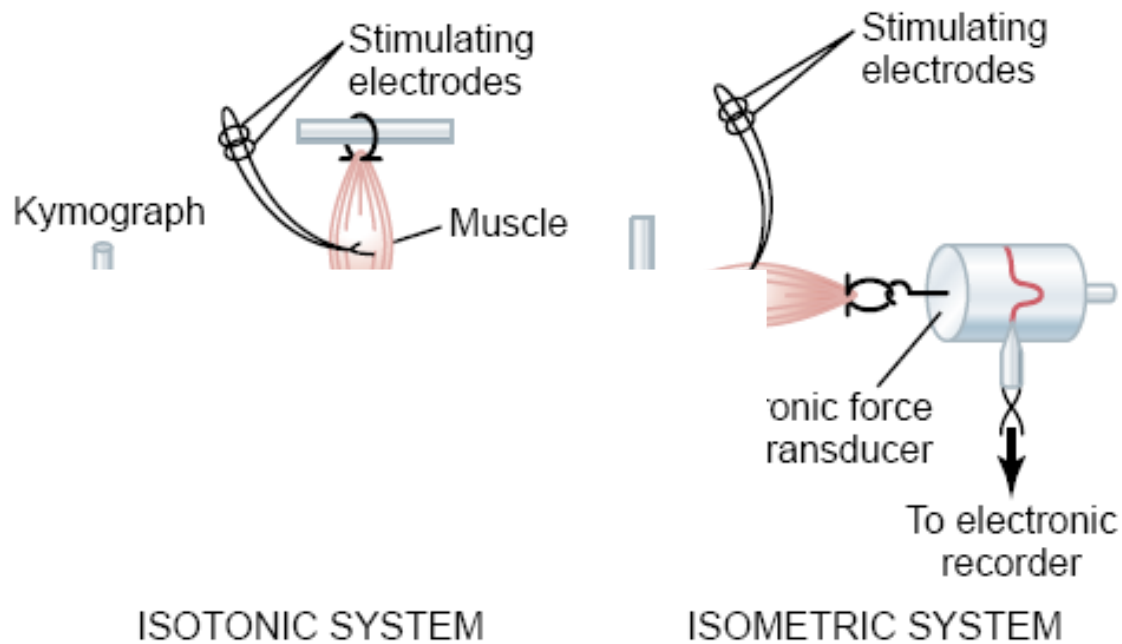
Muscle fibers



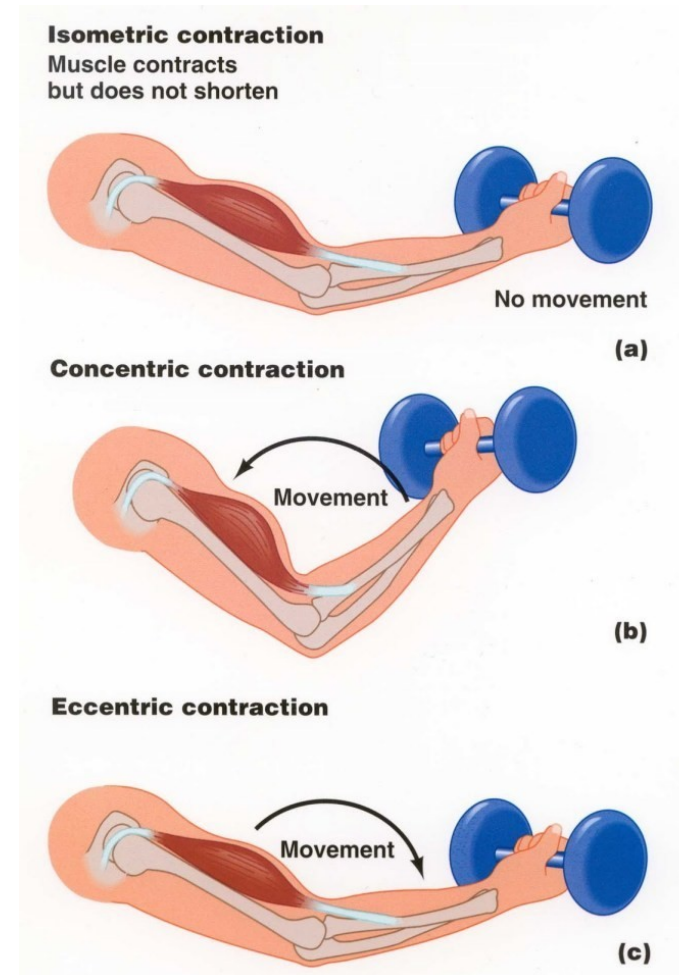
<http://www.sivabio.50webs.com/mus019.jpg>

Types of muscle contraction

- Isotonic contraction
 - Constant tension
 - Concentric x excentric contraction



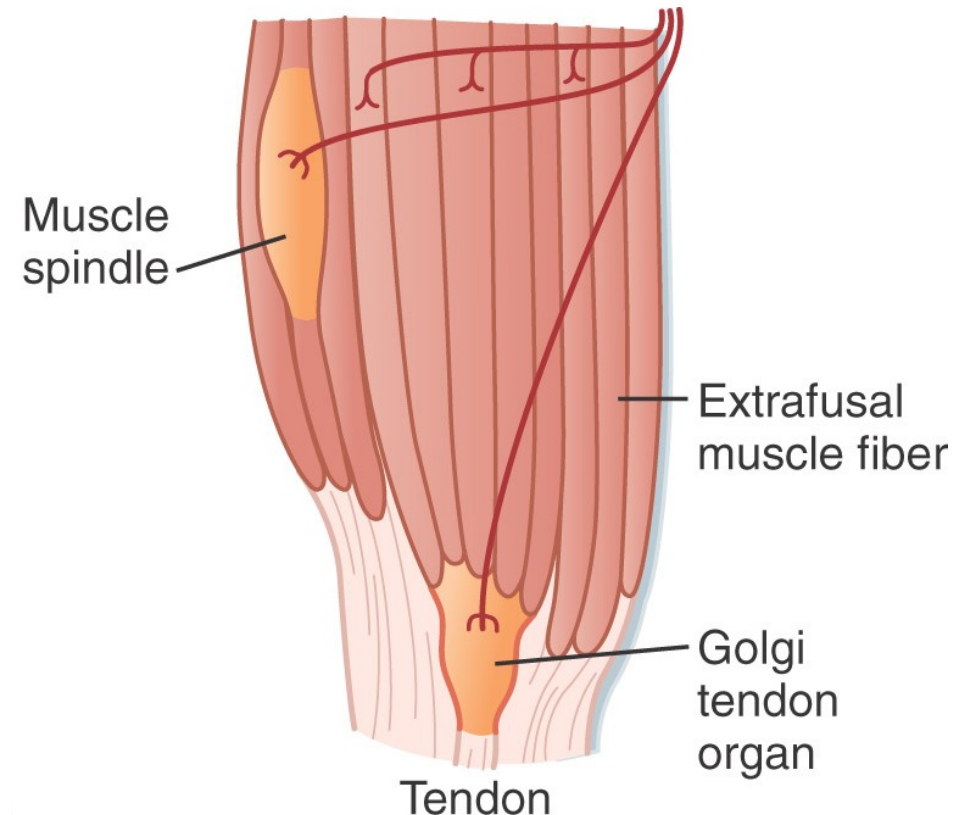
- Isometric contraction
 - Constant length



<https://i0.wp.com/colebradburn.com/wp-content/uploads/2013/02/contractions.jpg>

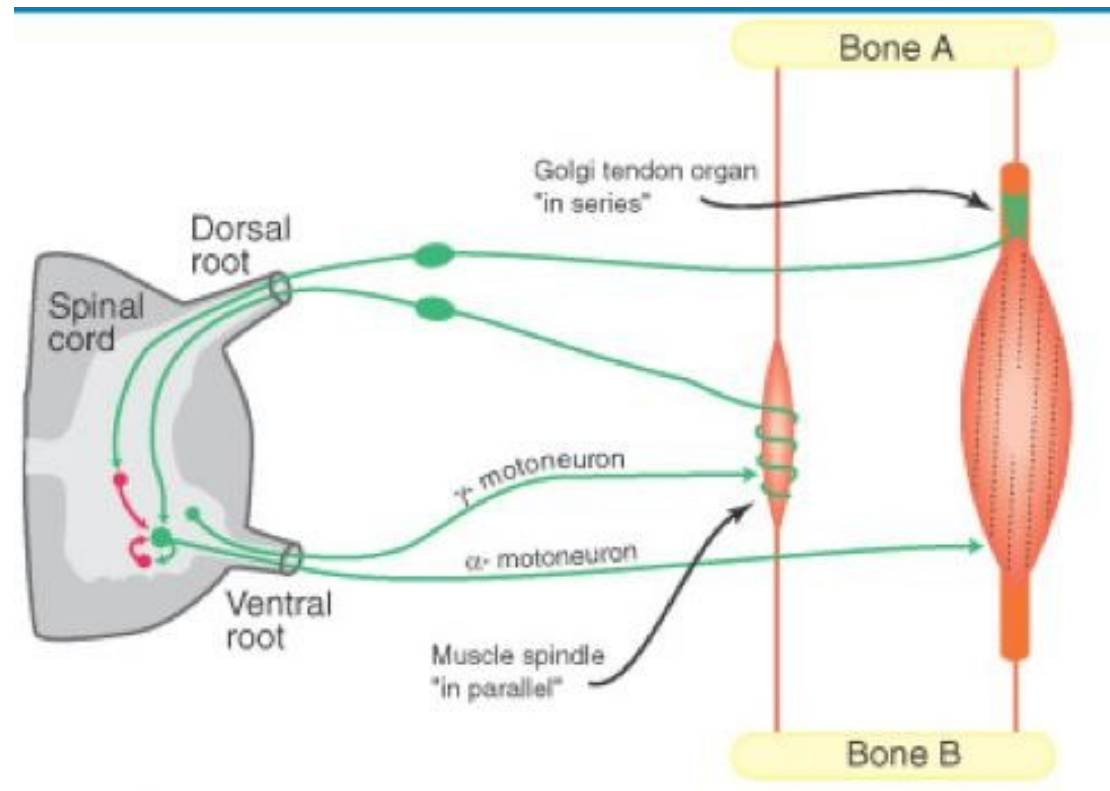
Proprioception

- Information about the position of body parts in relation to each other
(The sum of information about lengths of particular muscles)
- Information about movement
(The force and speed of muscle contraction)
- Reflex regulation of muscle activity
- Muscle spindles
 - Lie in parallel with extrafusal muscle fibers
- Golgi tendon organ
 - Arranged in series with extrafusal muscles



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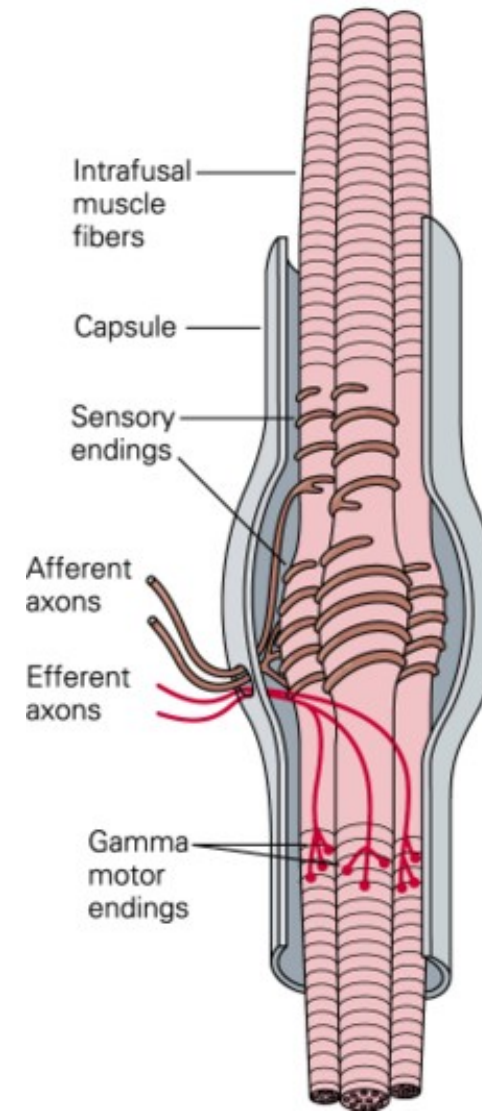
Muscle spindle and Golgi tendon organ



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Muscle spindles

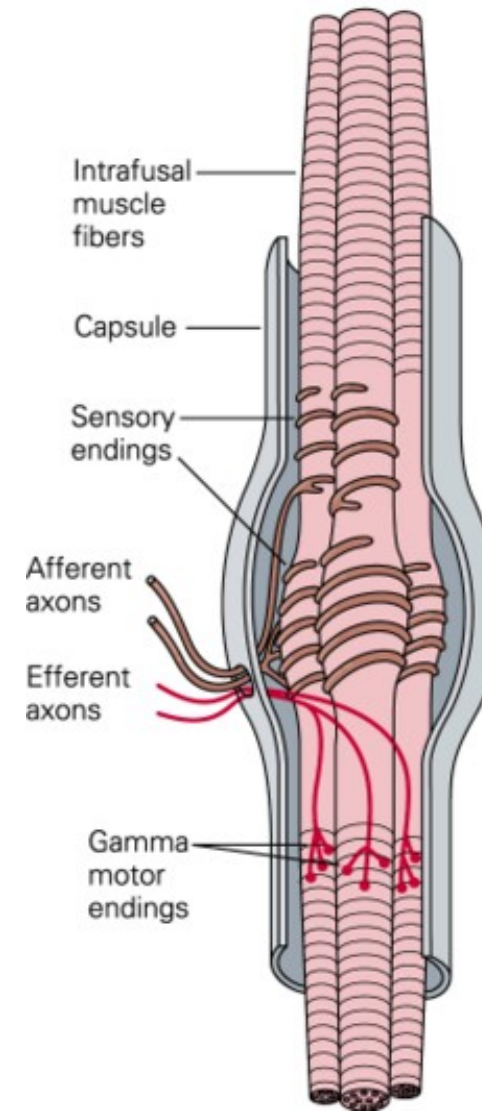
- Non-force generating contractile structures
- The contractility is for spindle length adjustment
- Encapsulated structure filled with a fluid
- Intrafusal fibers



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Muscle spindles

- Non-force generating contractile structures
- The contractility is for spindle length adjustment
- Encapsulated structure filled with a fluid
- Intrafusal fibers
 - Lie in parallel with extrafusal muscle fibers (Stretch/shorten along with extrafusal fibers)
 - Efferent connections (into muscle spindle)
 - γ motoneuron
 - Afferent connections (from muscle spindle)
 - Information about change in muscle length
 - Reflex regulation of the α motoneuron activity

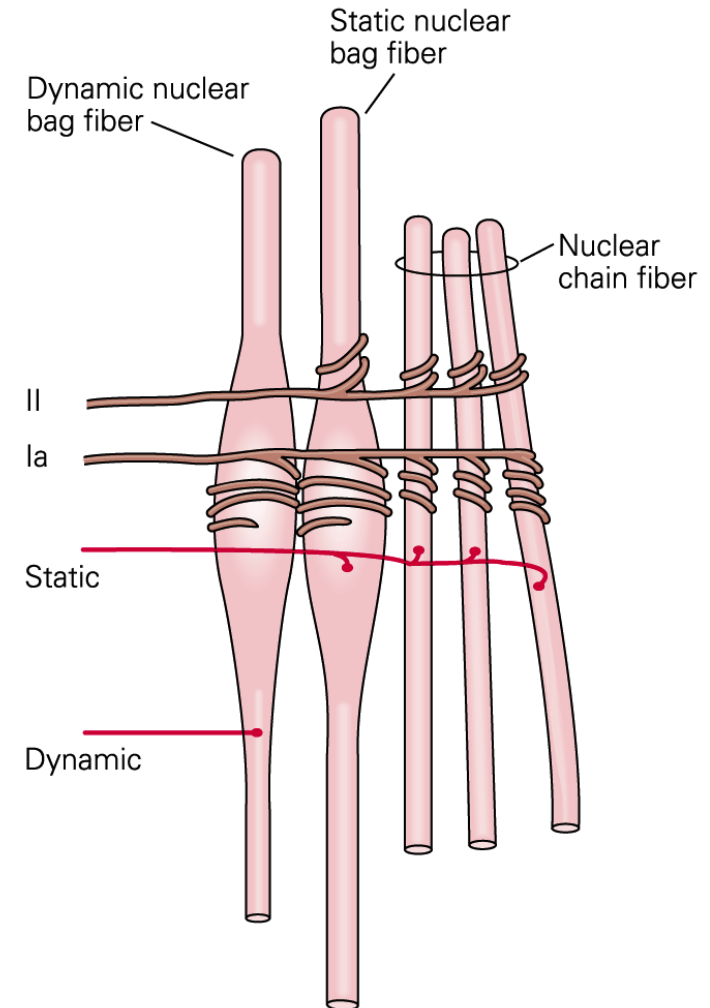


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Muscle spindles

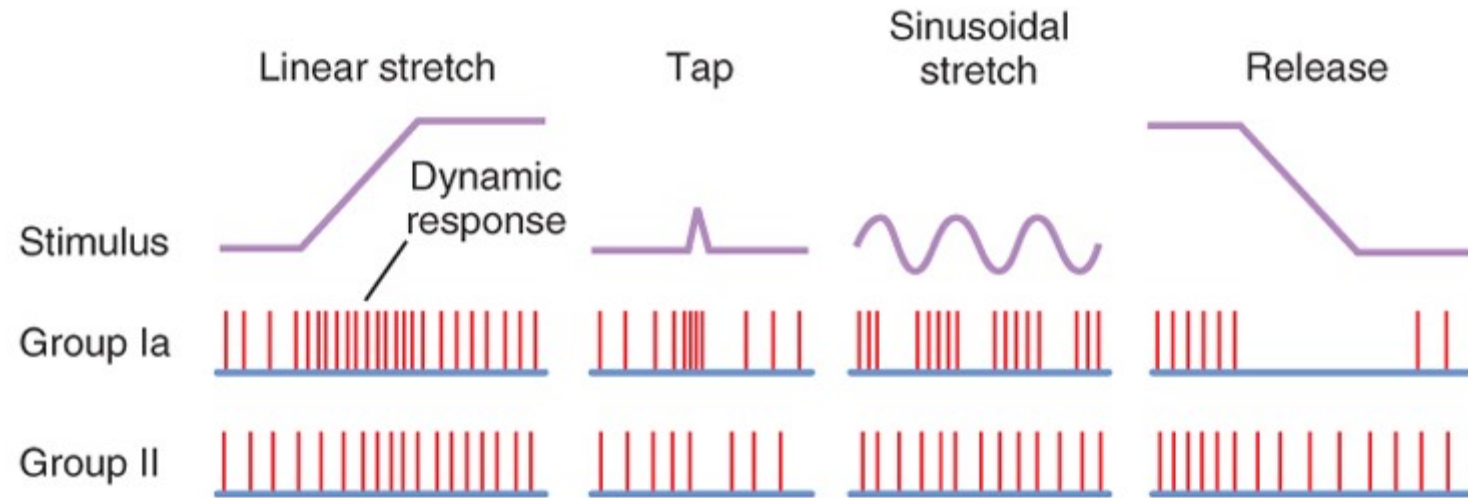
- Static fibers
- Dynamic fibers
- Afferent connections (from spindle)
 - II – static fibers
 - Information about muscle length (position)
 - Ia – static and dynamic fibers
 - Information about muscle length and contraction (movement)
 - Reflex regulation of the α motoneuron activity
- Efferent connections (into spindle)
 - Static γ motoneurons
 - Dynamic γ motoneurons
 - Spindle length adjustment

B Intrafusal fibers of the muscle spindle



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Afferent signaling from muscle spindles



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II – Static fibers

- Static response

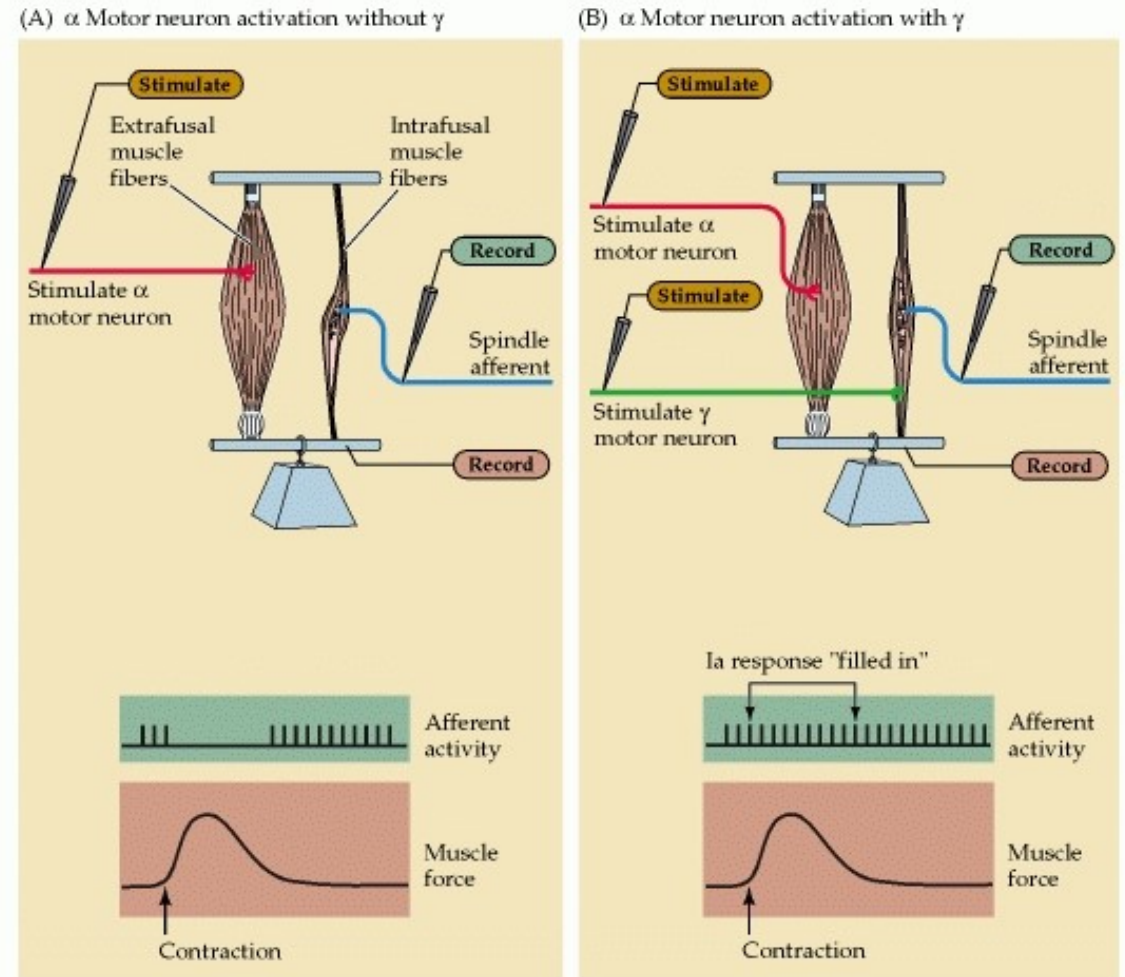
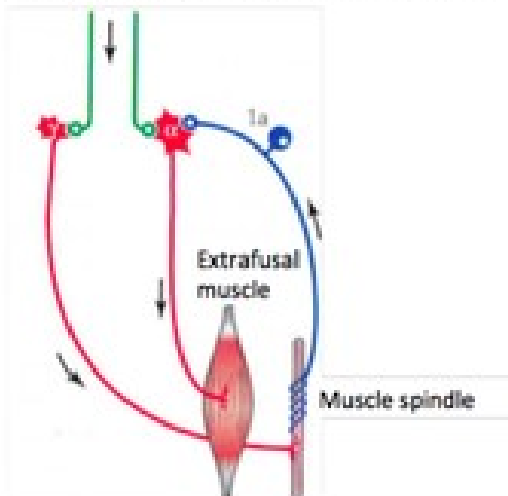
Ia – Static and dynamic fibers

- Static and dynamic response

Efferent signaling into the muscle spindle

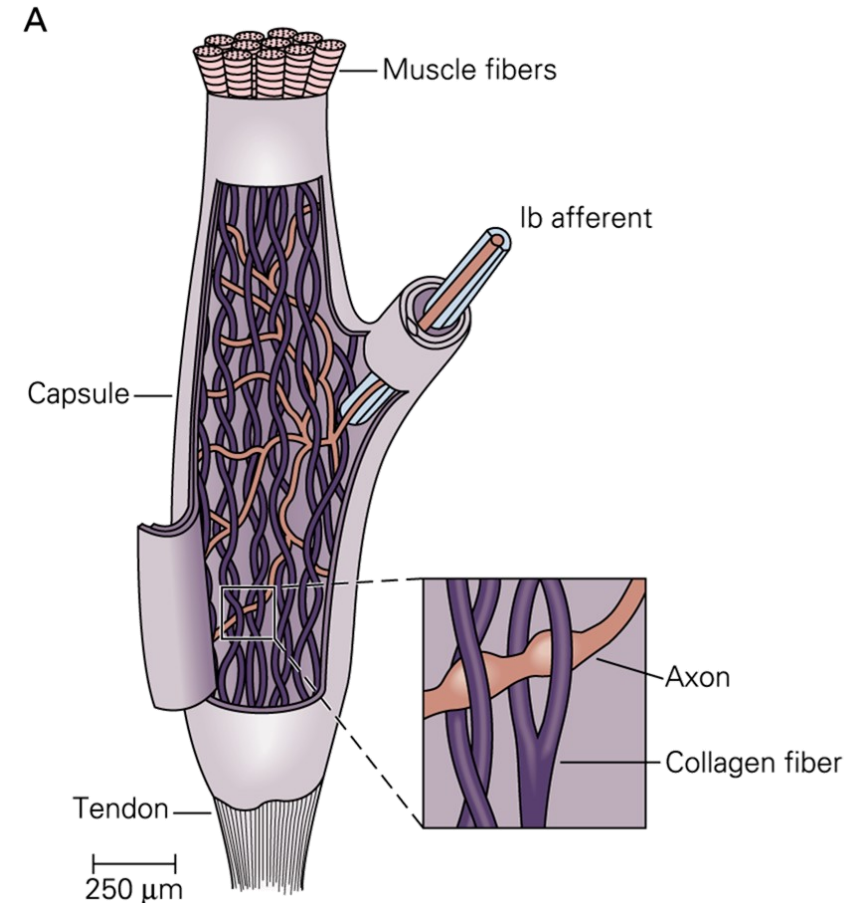
- γ motoneurons adjust the length of intrafusula fibers
- Regulation of sensitivity
- α and γ coactivation

The CNS co-activates alpha and gamma motoneurons



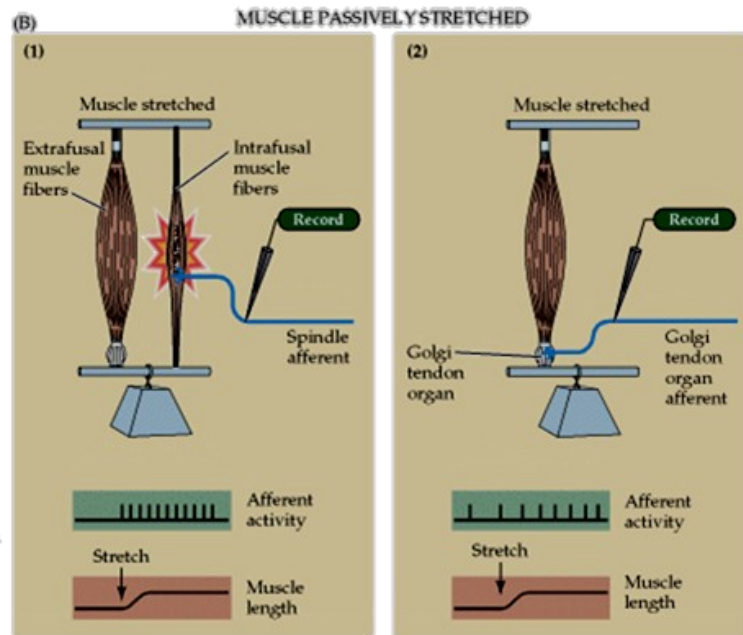
Golgi tendon organs

- Non-contractile encapsulated structures
- Collagen fibers
- Ia fibers
- Mechanoreception
- Arranged in series with extrafusal muscles
- Information about changes in tendon tension/force
- Reflex regulation of the α motoneuron activity

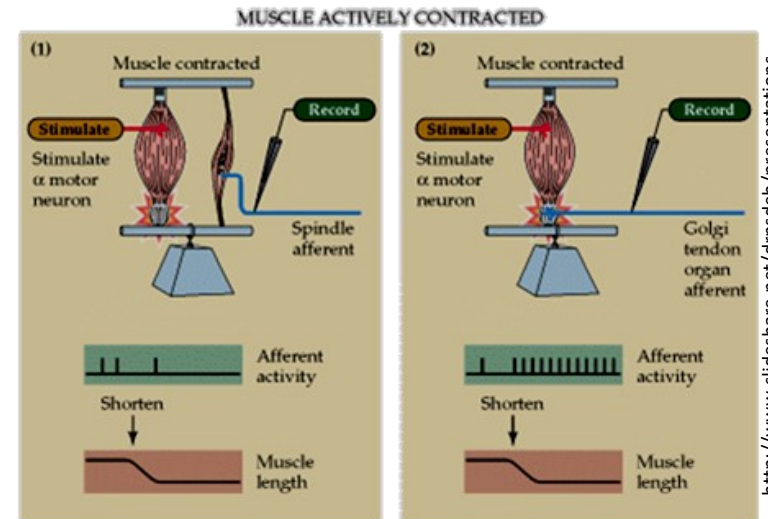


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Reaction of muscle spindles and the Golgi tendon organs to muscle fiber stretch/contraction

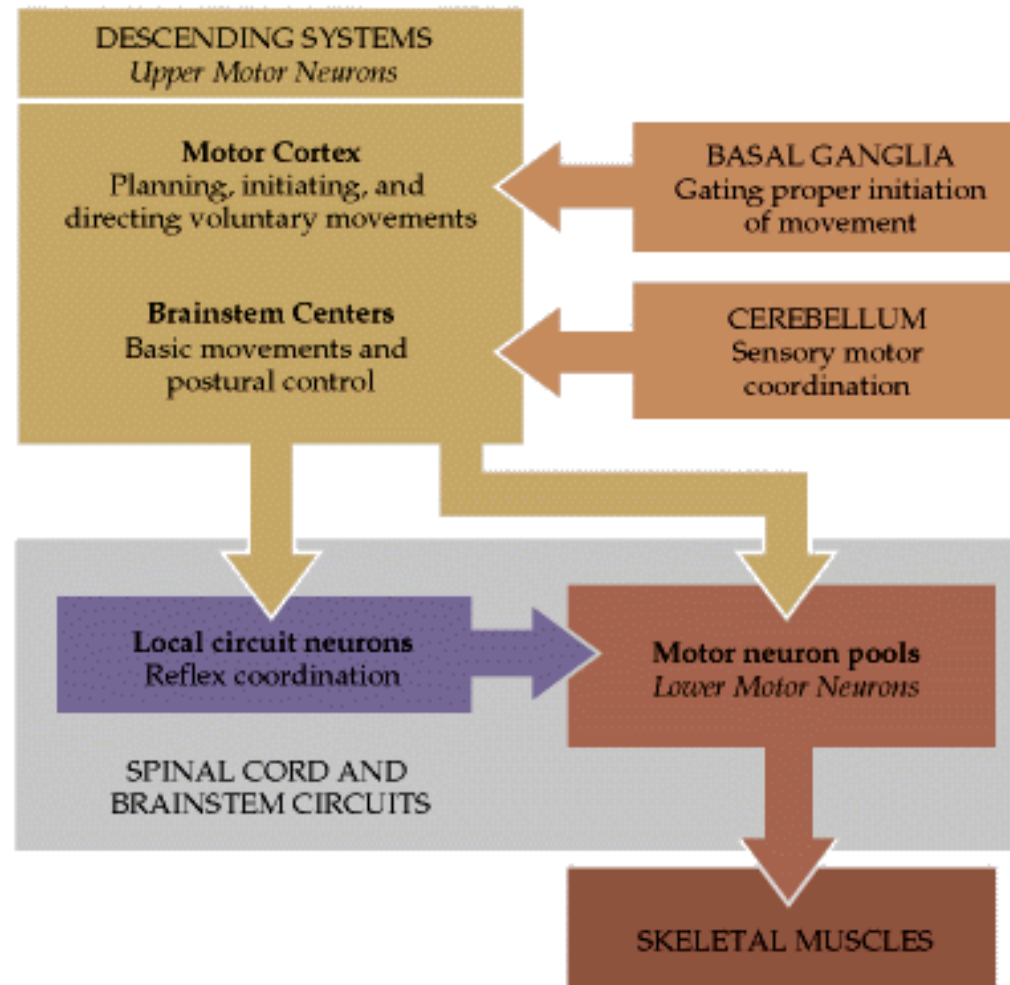


Stretch (passive)
Muscle spindles reaction

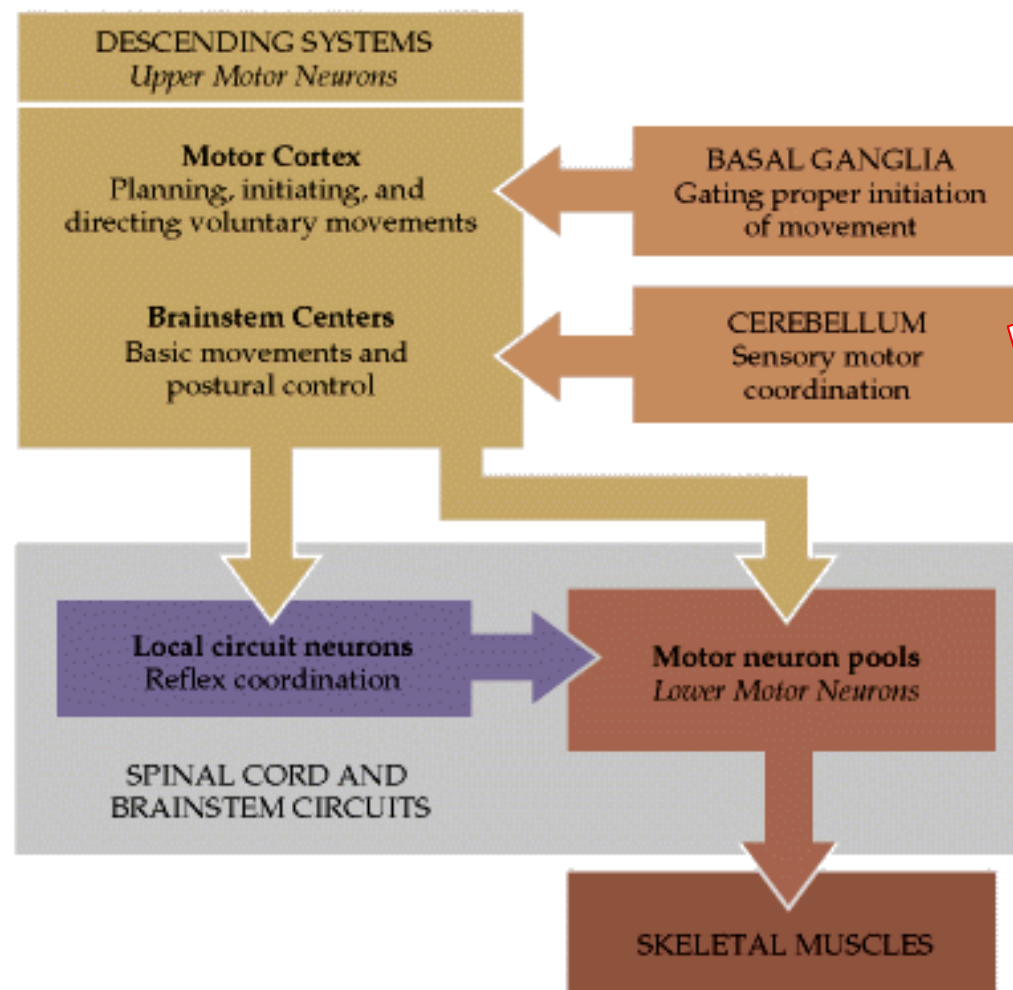


Contraction (active)
Golgi tendon organ reaction

Hierarchic organization of motor system



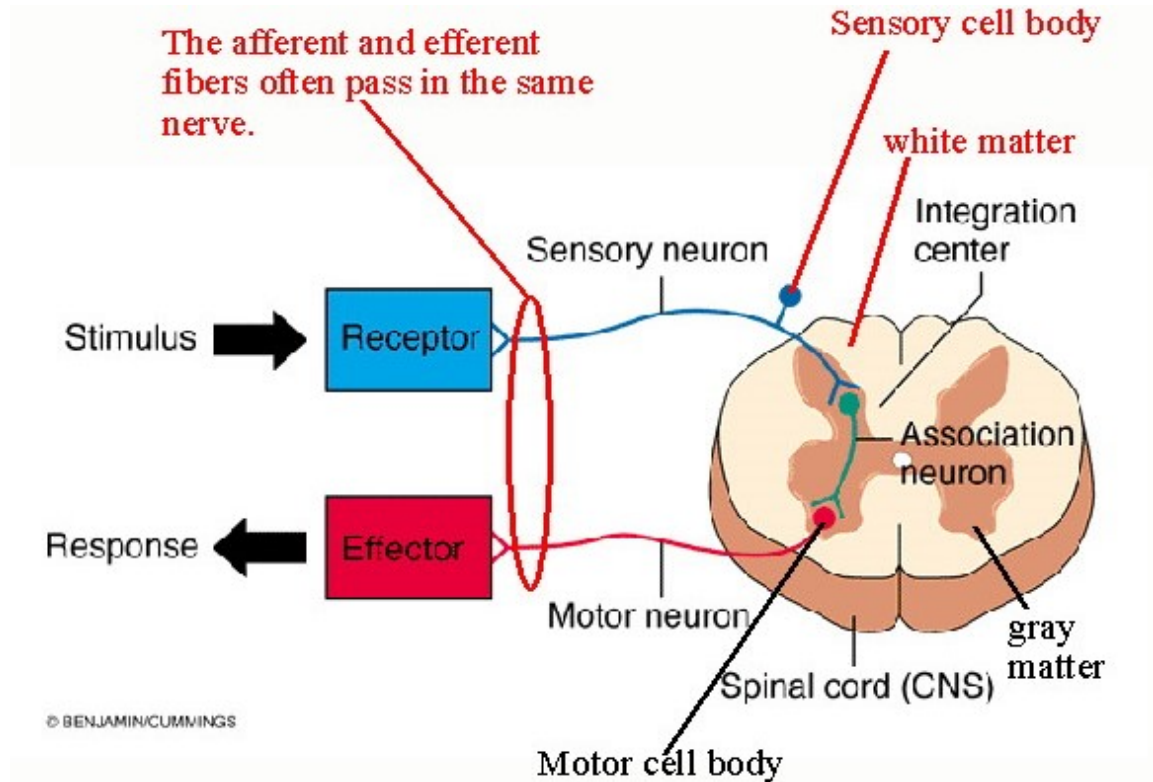
Hierarchic organization of motor system



Reflex movement
Rhythmic movement
Voluntary movement

Reflex

- Reflex movement
 - Stereotype (predictable)
 - Involuntary
- Proprioceptive
- Exteroceptive
- Monosynaptic
- Polysynaptic
- Monosegmental
- Polysegmental



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Proprioceptive reflexes

- **Myotatic reflex**

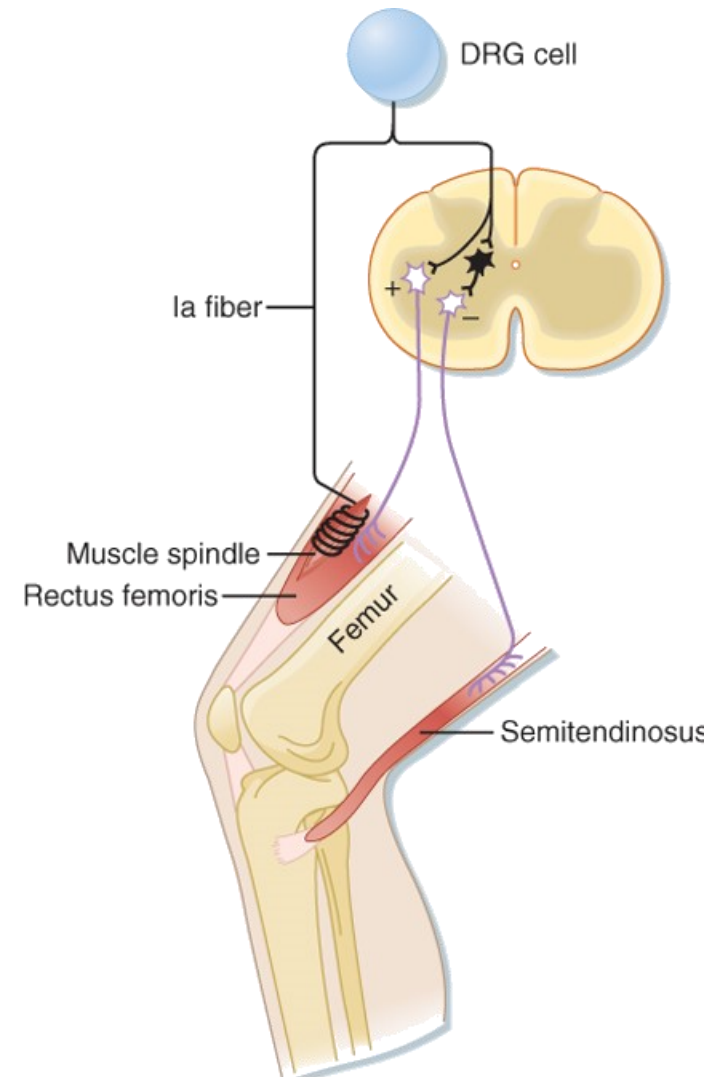
- Monosynaptic
- Monosegmental
- Muscle spindle
- Homonymous muscle - activation
- Antagonist muscle - inhibition

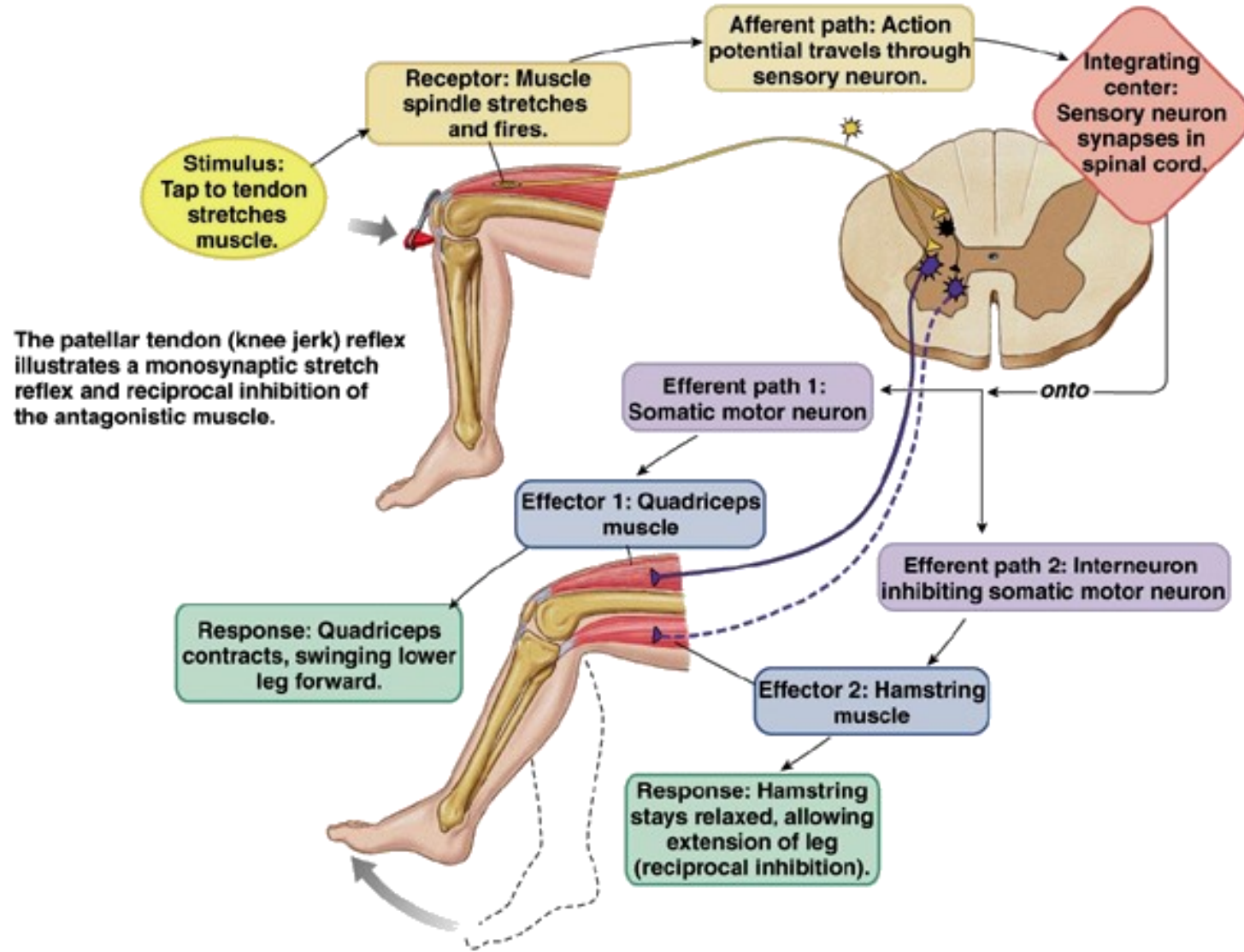
- ✓ Phasic response (Ia)

- Protection against overstretch of extrafusal fibers

- ✓ Tonic response (Ia a II)

- Maintains muscle tone

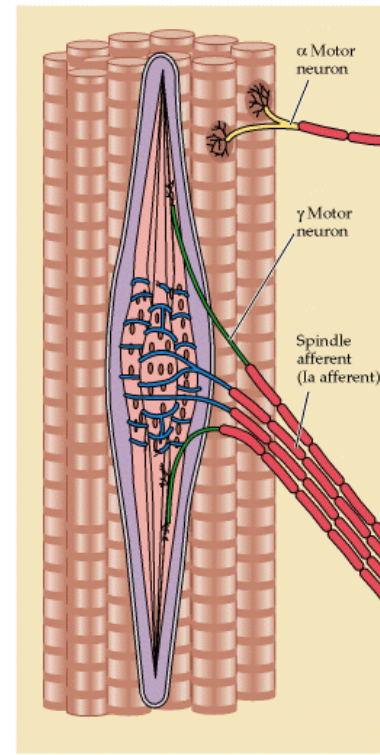




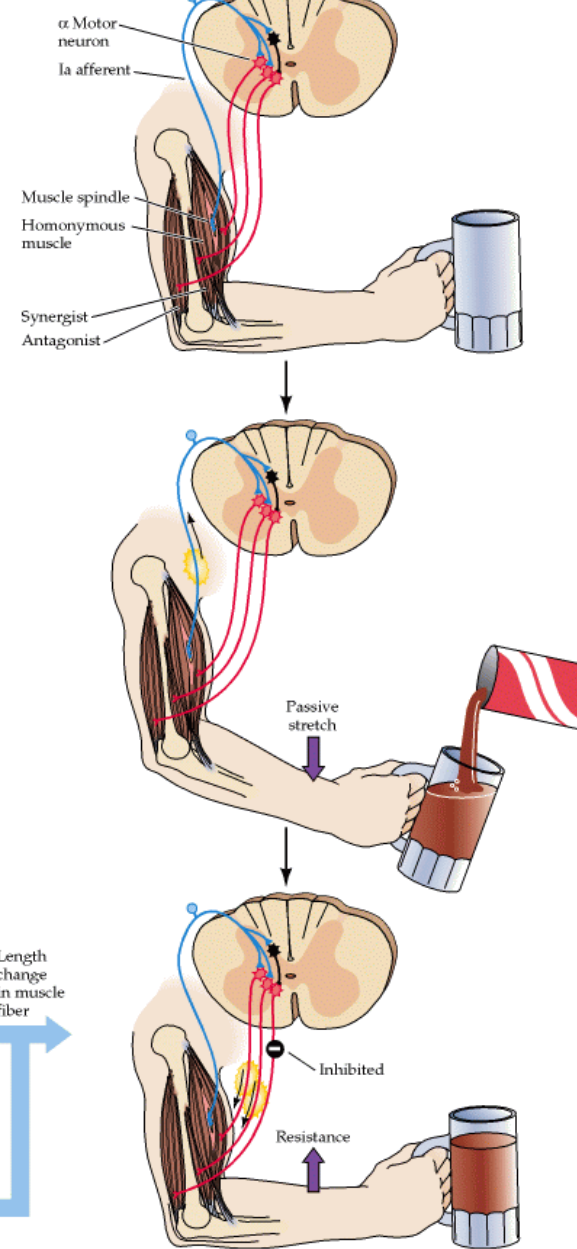
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Fig. 13-7

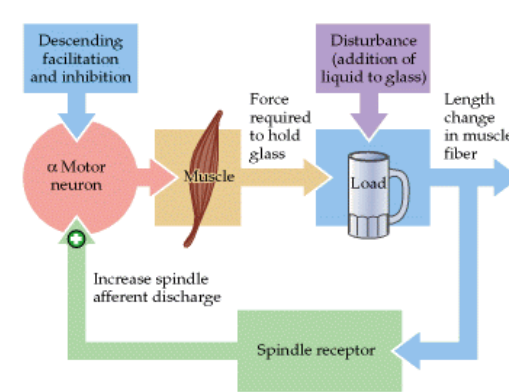
(A) Muscle spindle



(B)

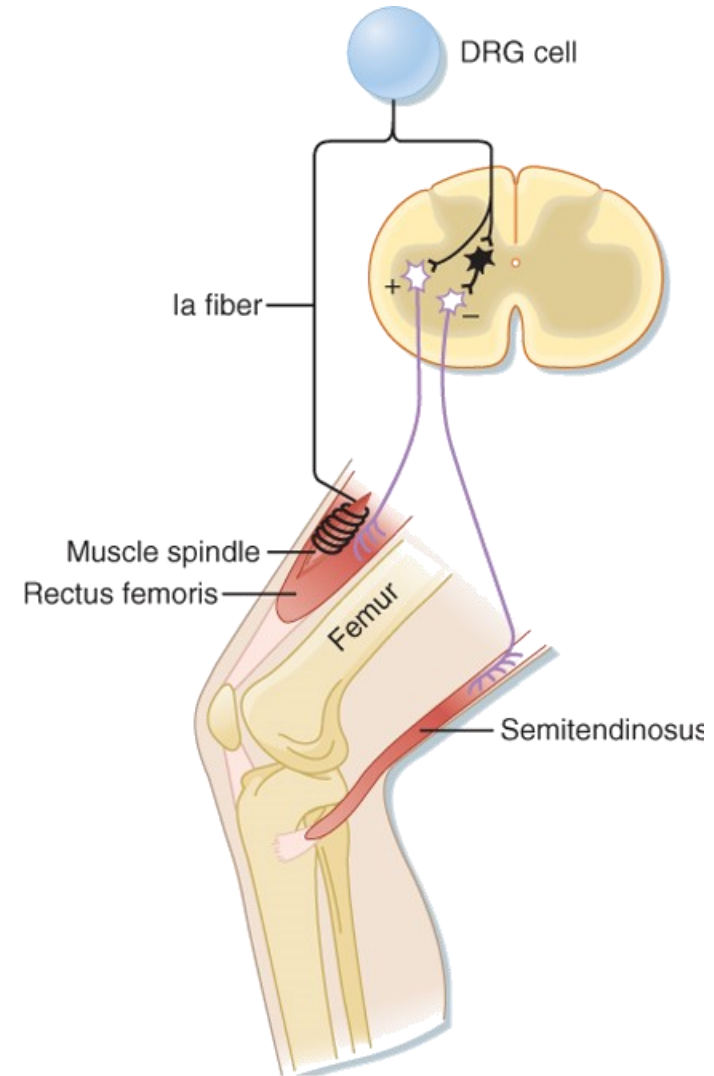


(C)

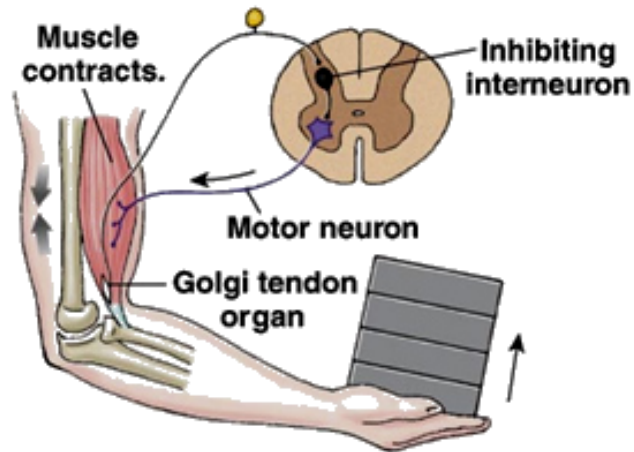


Proprioceptive reflexes

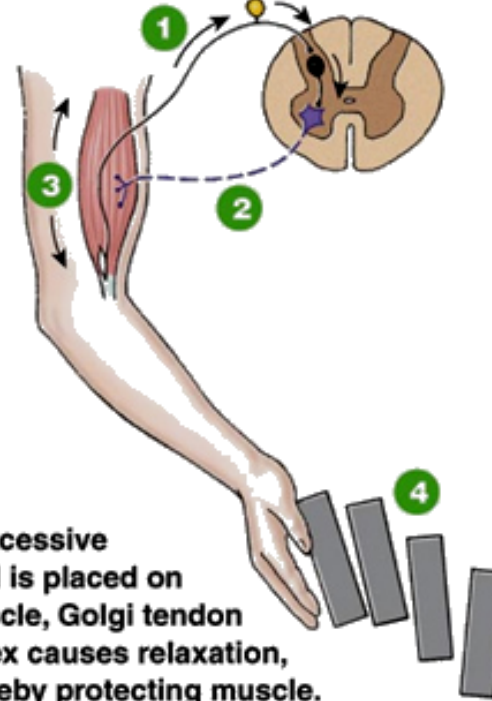
- **Inverse myotatic reflex**
 - Monosegmental
 - Disynaptic/polysynaptic
 - Golgi tendon organ
 - Homonymous muscle – inhibition
 - Antagonist muscle – activation
- ✓ Protection against muscle damage caused by extensive force



Golgi tendon reflex protects the muscle from excessively heavy loads by causing the muscle to relax and drop the load.



(d) Muscle contraction stretches Golgi tendon organ.



(e) If excessive load is placed on muscle, Golgi tendon reflex causes relaxation, thereby protecting muscle.

1 Neuron from Golgi tendon organ fires.

2 Motor neuron is inhibited.

3 Muscle relaxes.

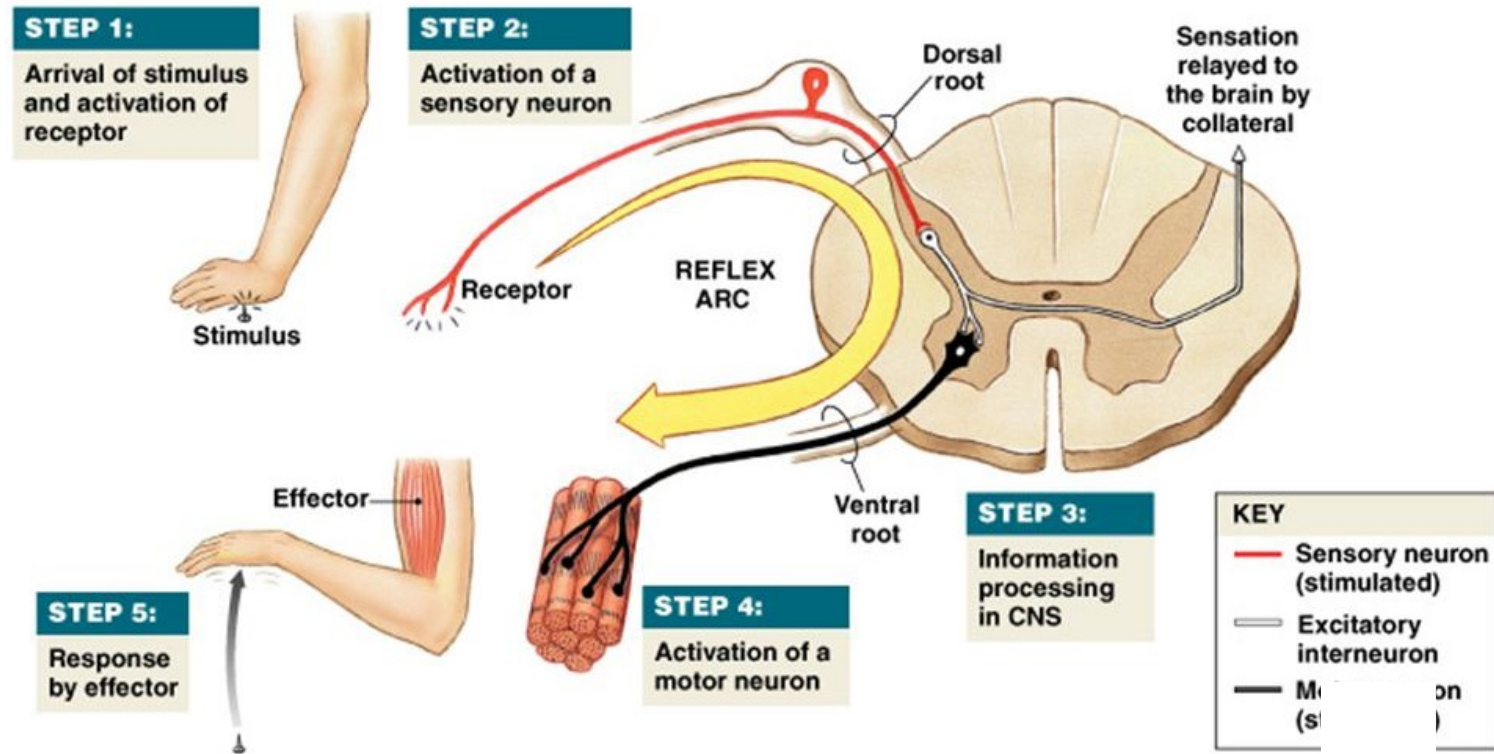
4 Load is dropped.

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Fig. 13-6b

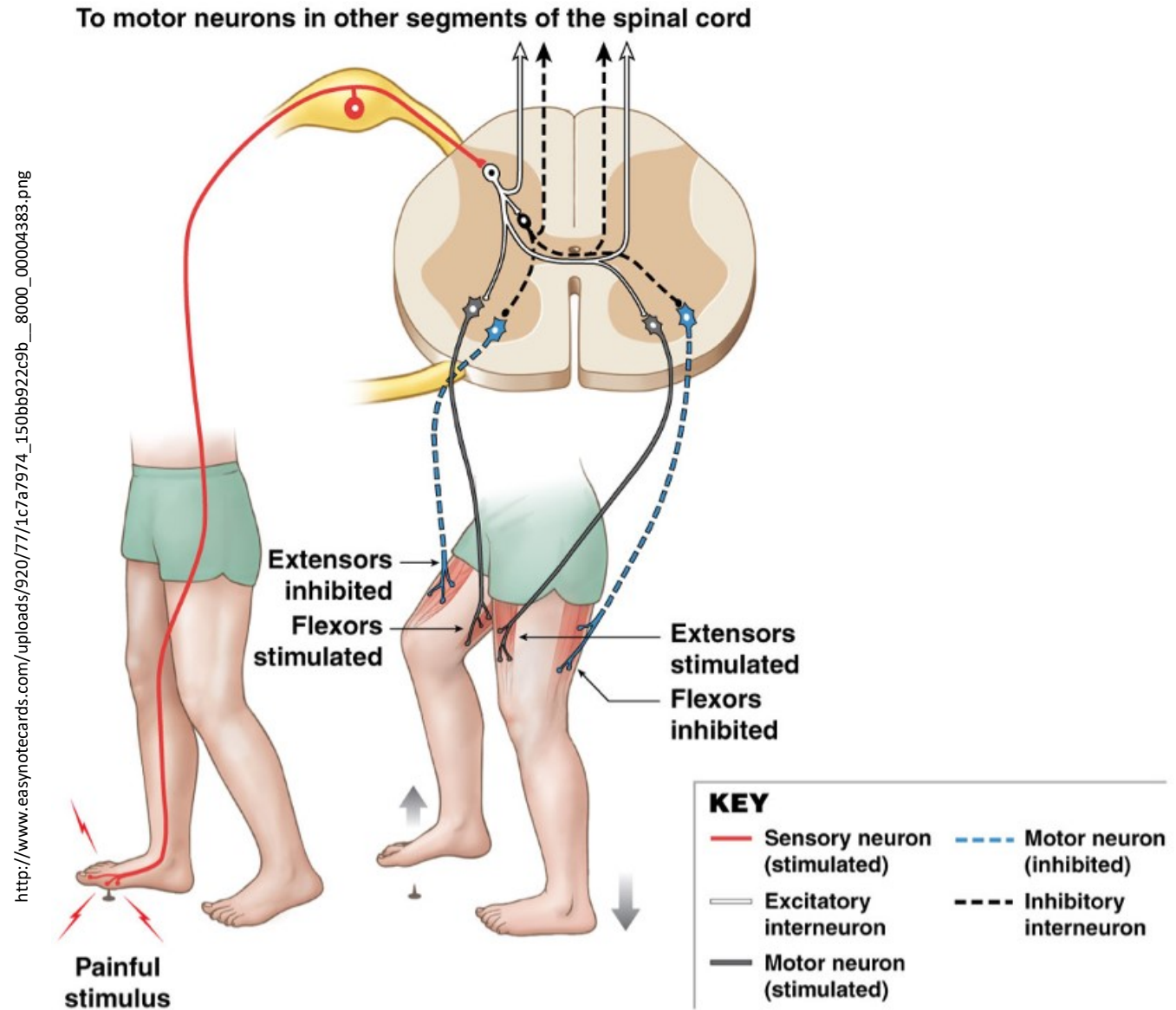
Exteroceptive reflexes

- Polysynaptic
- Polysegmental

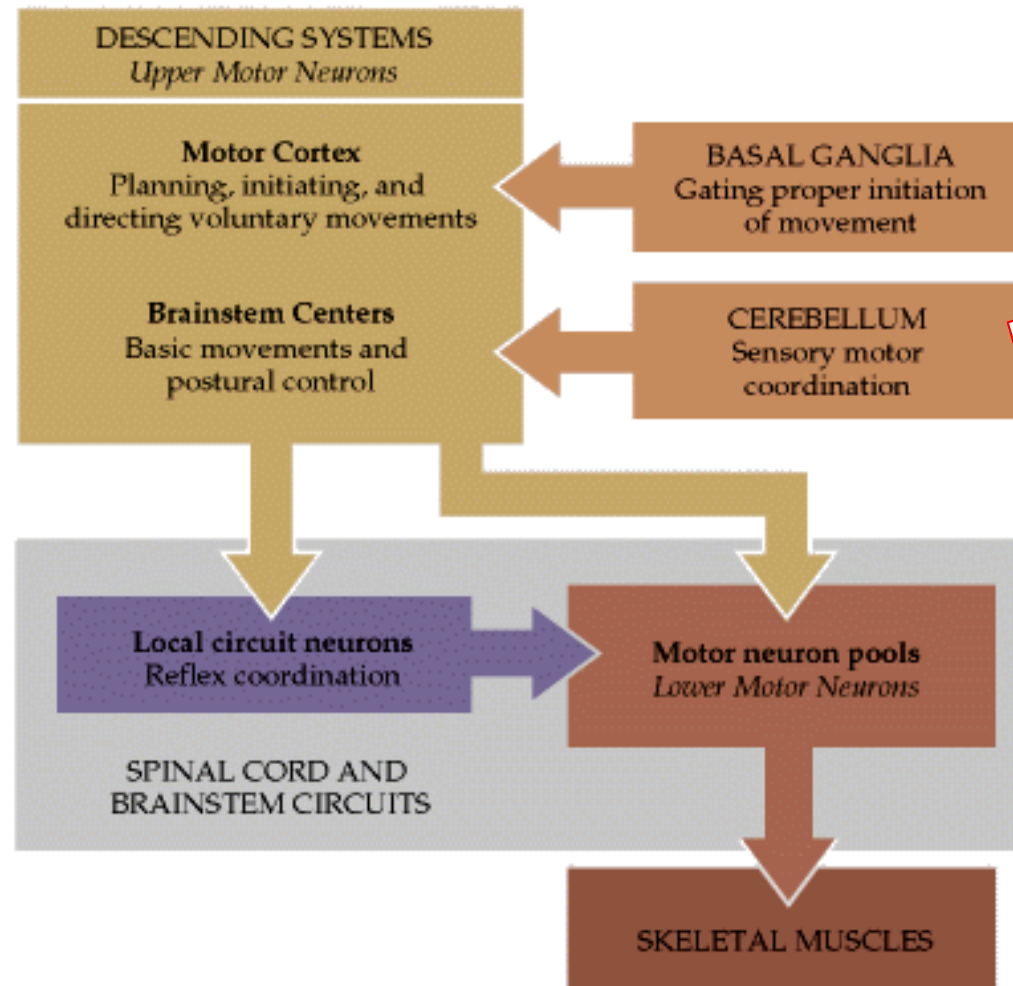


Exteroceptive reflexes

- Polysynaptic
- Polysegmental



Hierarchic organization of motor system



Reflex movement
Rhythmic movement
Voluntary movement

79. Upper and lower motor neuron, neuromuscular junction, muscle contraction

- Upper and lower motor neuron localization and function
- Lower motor neuron
 - Only the structure responsible for muscle contraction
 - Part of local reflex circuit
 - Overview of structures and main pathways controlling lower motor neuron (proprioception, higher levels of CNS including upper motor neuron, medial system, lateral system tr. corticospinalis, corticobulbaris...)
 - Types of lower motor neurons (alpha, gamma, beta)
- Upper motor neuron
 - Primary motor cortex, homunculus
- Motor unit definition
- Neuromuscular junction description
- Muscle contraction description

80. Hierarchic organization of motor system – reflex vs. voluntary motor activity

- Hierarchy of movement
 - Reflex – economical, uniform, protective, fast
 - Rhythmic – economical solution for complex uniform actions (breathing, walking...)
 - Voluntary – non-economical, unique, relatively slow
- Classification and description of reflexes
- Fixed action pattern and rhythmic movement (definition and examples)
- Voluntary motor control
 - Overview of structures involved in planning and execution of voluntary motor activity
 - Motor cortex organization (primary, premotor and supplementary motor cortex...)
 - Brief description of pyramidal tract

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