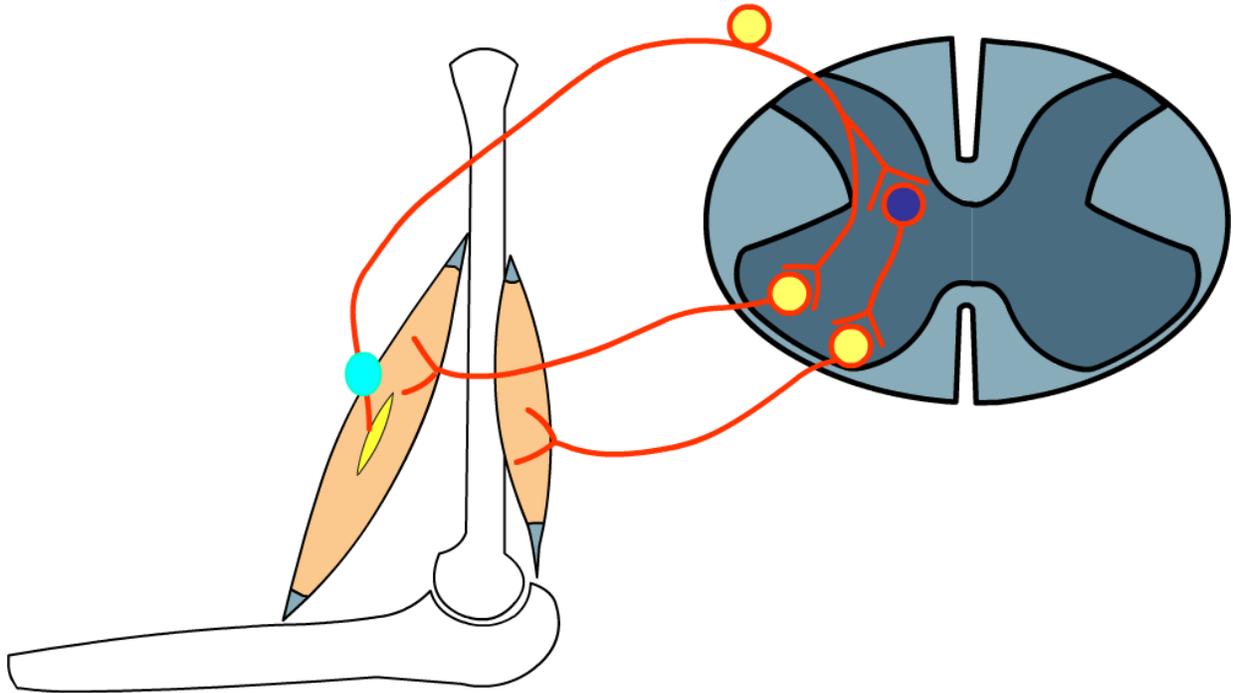


Muscle Receptors, Spinal Reflexes and Muscles



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Introduction

Close your eyes and touch your nose with your finger. Your ability to do so depends on

- 1) **proprioception**, the sense of limb **position** and
- 2) **kinesthesia**, the sense of limb movement.

The receptors which signal the position and movement of your limb are:

- 1) **joint afferents** These are located in the joints and are most sensitive to extremes in joint angle (position).
- 2) **muscle spindles** These are located in the muscle and are very important afferents for for sensing position and movement (velocity).
- 3) **golgi tendon organ** These are located in the muscle tendon and they detect tension (force).
- 4) **tactile afferents** These are the touch receptors in the overlying skin that are covered in the session on touch. The slowly adapting Ruffini afferents signal skin stretch or compression and are thus important for sensing the position of your fingers.

Why are the location of muscle spindles and Golgi tendon organs different?

Muscle **spindles** are located along side (**in parallel**) with the regular muscle fibers where they undergo the same length changes as the rest of the muscle.

Golgi tendon organs (Ib) are located in the tendon of the muscle, **in series** with the muscle fibers. Thus muscle contraction is relayed through the tendon, stretching the tendon and the Golgi tendon organ. Golgi tendon organ senses the **force the muscle exerts**.

Within spindles there are two types of fibers: **nuclear bag and nuclear chain**.

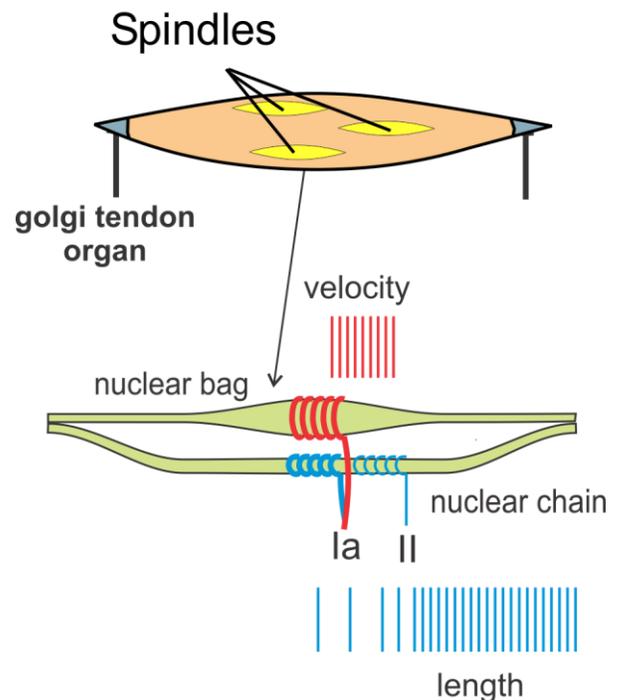
Large, primary afferents, **Ia**, originate from both bag and chain fibers.

Smaller, secondary afferents, **II**, originate only from chain fibers.

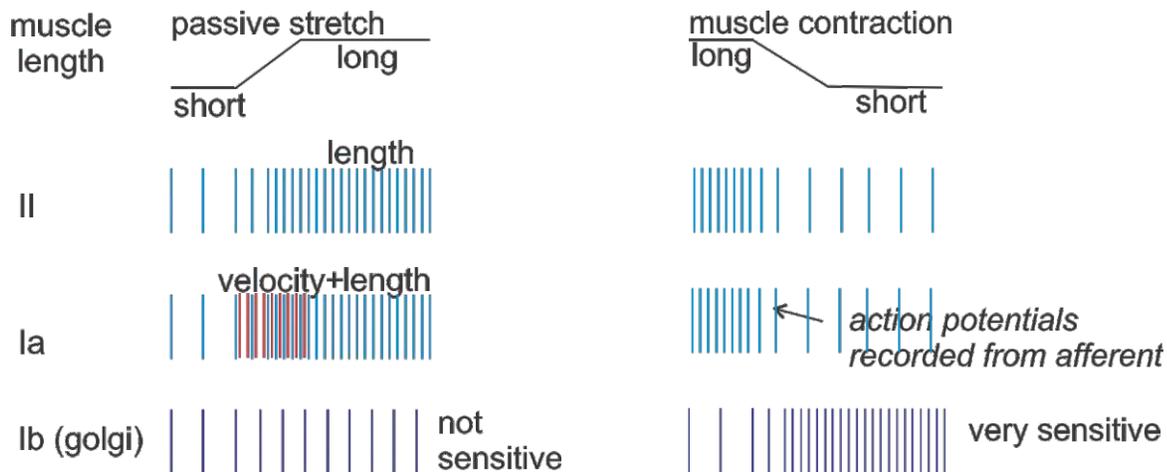
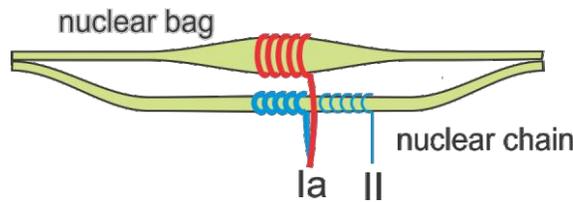
The numbers Ia, II, etc. refer to the size of the fiber. Ia is the largest and thus the most rapidly conducting.

The afferent from nuclear bag fibers signals velocity. Because they adapt quickly after stretch, bag fibers give a phasic burst of action potentials during stretch whose size signals the velocity or speed of muscle stretch and become silent when the position is constant.

Both afferents from a nuclear chain fiber fire in proportion to the fiber's length.



Compare the response of spindles and golgi tendon organs.



a) Response to **passive stretch** (i.e. when the doctor extends a patient's relaxed arm):.

The **II afferents** come from chain fibers and are therefore sensitive to **muscle length**.

Ia afferents come from both bag and chain fibers and are therefore sensitive to **velocity** (phasic response) as well as to **muscle length** (tonic response). (They are also very sensitive to vibration.)

Golgi tendon organs, Ib afferents, change little, because the force acting on the tendon, when the muscle is relaxed, is small.

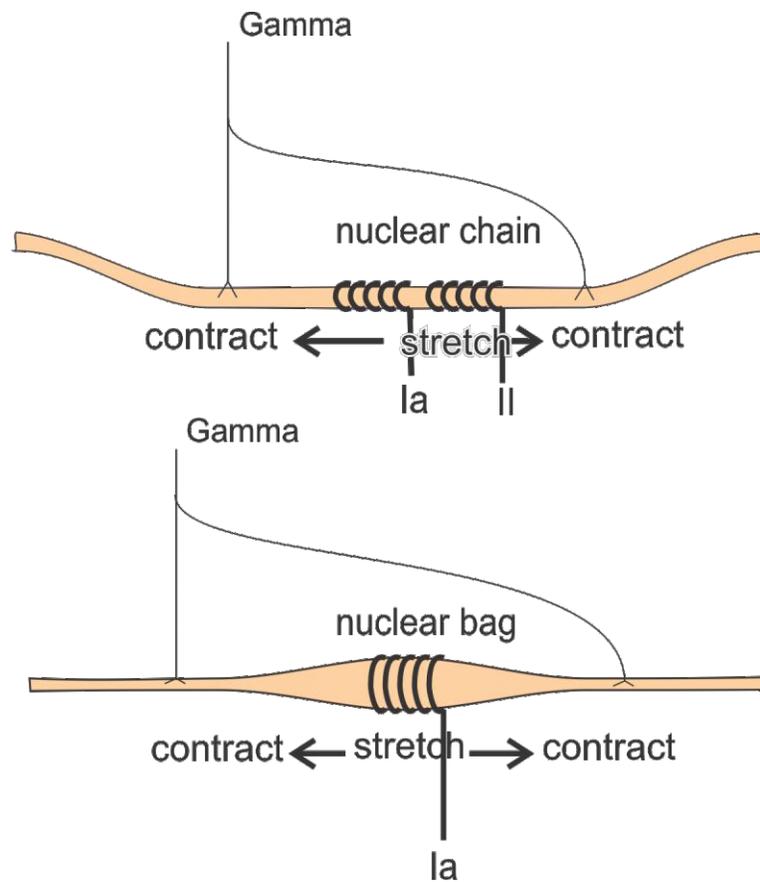
b) Response to **muscle contraction** (i.e. when the patient contracts the muscle to lift a weight):

Contraction causes the tendon to stretch and the spindles to shorten. The **spindles** become **silent**.

Golgi tendon organs are very **sensitive** to muscle contraction because the force generated by the muscle must be transmitted through the tendon to move the limb

Gamma drive controls the sensitivity of the muscle spindle.

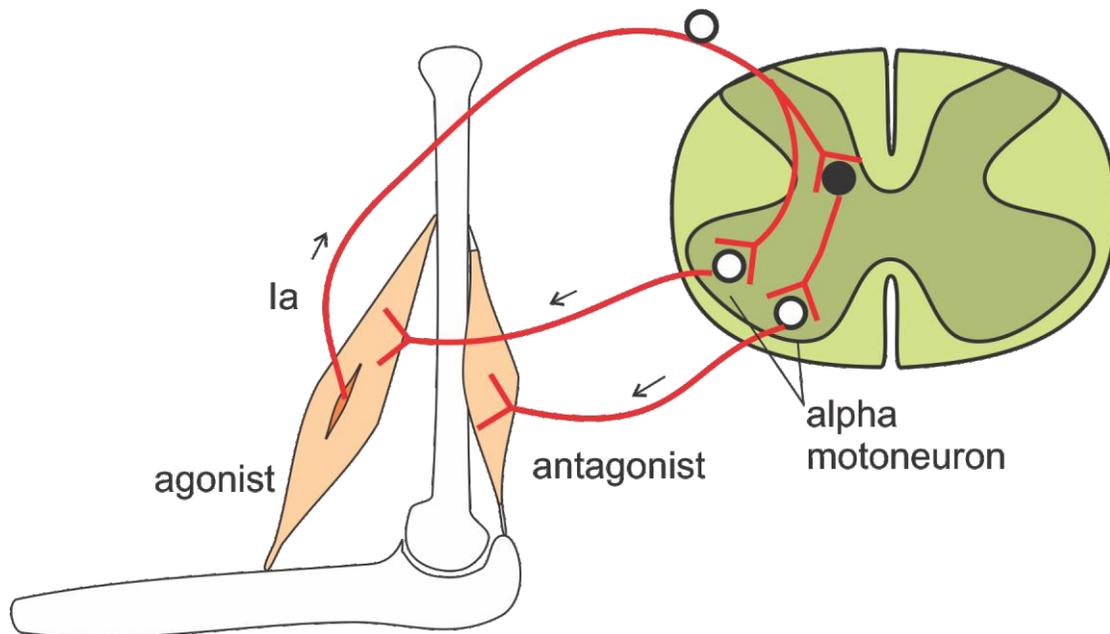
Gamma drive from the spinal cord causes contraction of the **ends** of bag and chain fibers. This **stretches** the **central region** where the afferents are located, increasing their sensitivity. Gamma drive is the spindle's **volume control**, adjusting its sensitivity.



Three spinal reflexes

For each:

- What is the spinal circuit?
- What is the stimulus and what is the motor response?
- What is the function?



1. The monosynaptic stretch reflex is activated by Ia spindle afferents.

When length increases, both the muscle and spindle are stretched. This increases Ia activity.

This increases alpha motoneuron activity.

The muscle contracts and its length decreases.

This reflex **regulates length**. It tries to maintain a constant length.

Because this reflex is monosynaptic and is carried by large fibers, it has the shortest latency of all spinal reflexes.

This is the reflex tested clinically by the tendon tap.

The reflex action on the antagonist is reciprocal. An inhibitory inter-neuron causes the antagonist muscle to relax.

2. The reflex mediated by the Golgi tendon organ (Ib)

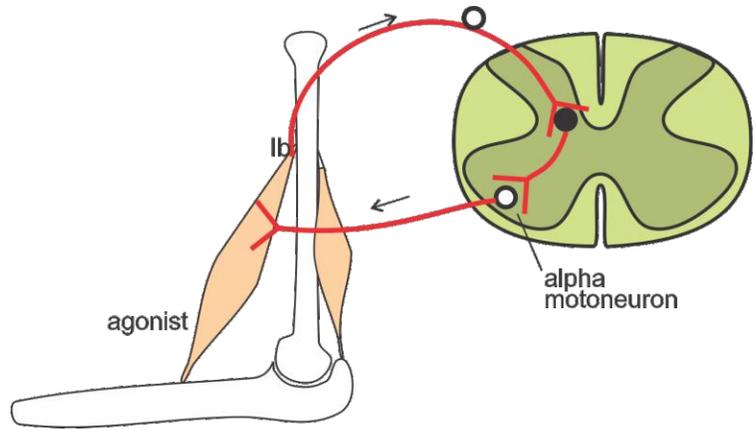
When tension generated by the muscle increases, Ib afferents are activated.

Via an inhibitory interneuron, this increases the Ib inhibition of alpha motoneurons.

This decreases muscle contraction and muscle tension.

This reflex regulates tension i.e. it maintains a **constant tension**.

It is used to maintain a constant grip on a paper cup.



3. Withdraw reflexes mediated by pain receptors

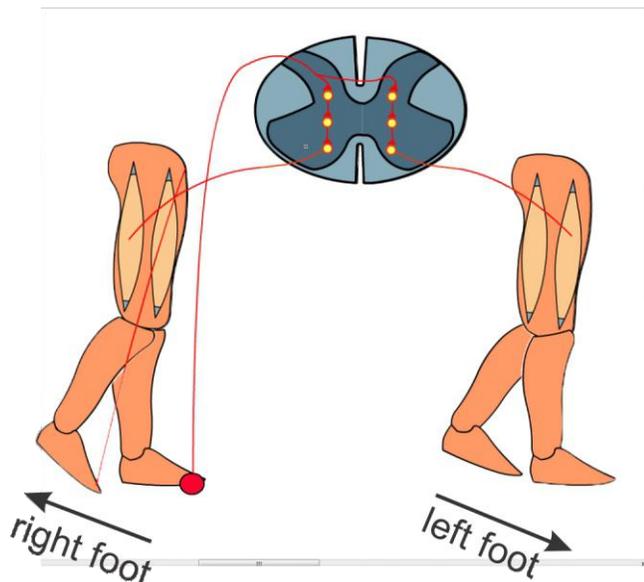
This reflex produces two responses:

1. contraction of **flexors** on the **same side**, which results in a **withdraw** from the painful stimulus (red dot).

2. contraction of **extensors** on the **opposite side**, which allows one to **maintain posture** and balance.

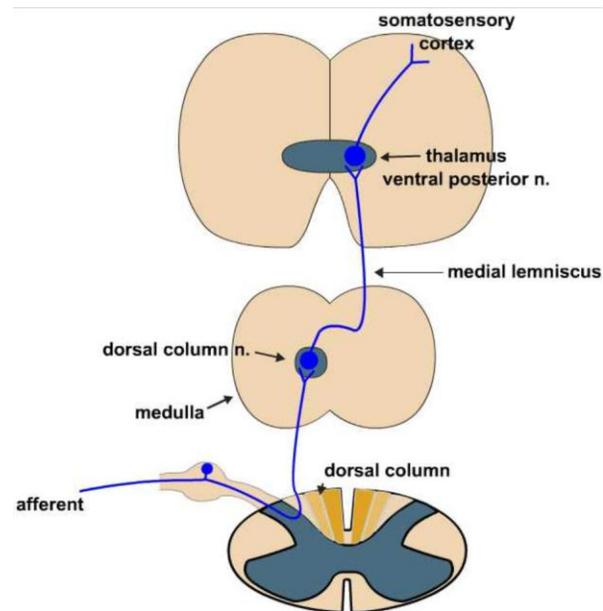
Other amazing things the spinal cord can do on its own:

- a) scratching
- b) walking & running



The pathway for transmission of proprioception to the primary somatosensory cortex

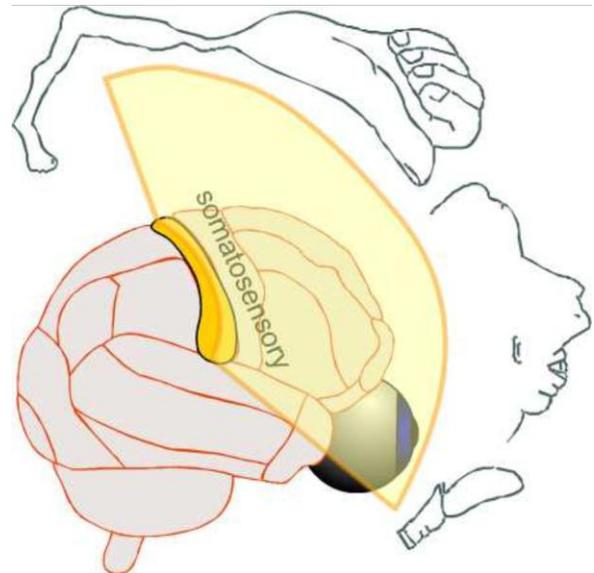
In addition to driving the spinal reflexes, each of the afferents that signal the sense of limb position and movement, communicate to the cortex through the **dorsal column medial lemniscal** system to reach area **3a of primary somatosensory cortex**, an area located at the bottom of the central sulcus.



Somatosensory cortex is somatotopically organized i.e. afferents from various parts of the body are sequentially represented along the bottom of the central sulcus.

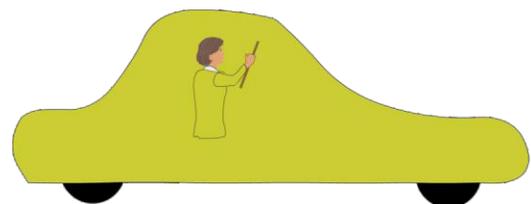
This body map is distorted with sensory information from the mouth, tongue and fingertips having larger representations than the rest of the body.

From the somatosensory cortex information flows to the parietal cortex which contains many more maps. These map both the locations of one's body parts and the locations of objects that one can act on, for example the locations one can reach either with the arms, legs, or even your head. This is called your **peripersonal** space.



These maps are elastic. They expand when one uses tools such as a stick, a baseball bat, or even a car.

Over time one's map of the exterior surface of one's car becomes almost as familiar as one's skin and one can park a car in the tightest of spots without a scratch.

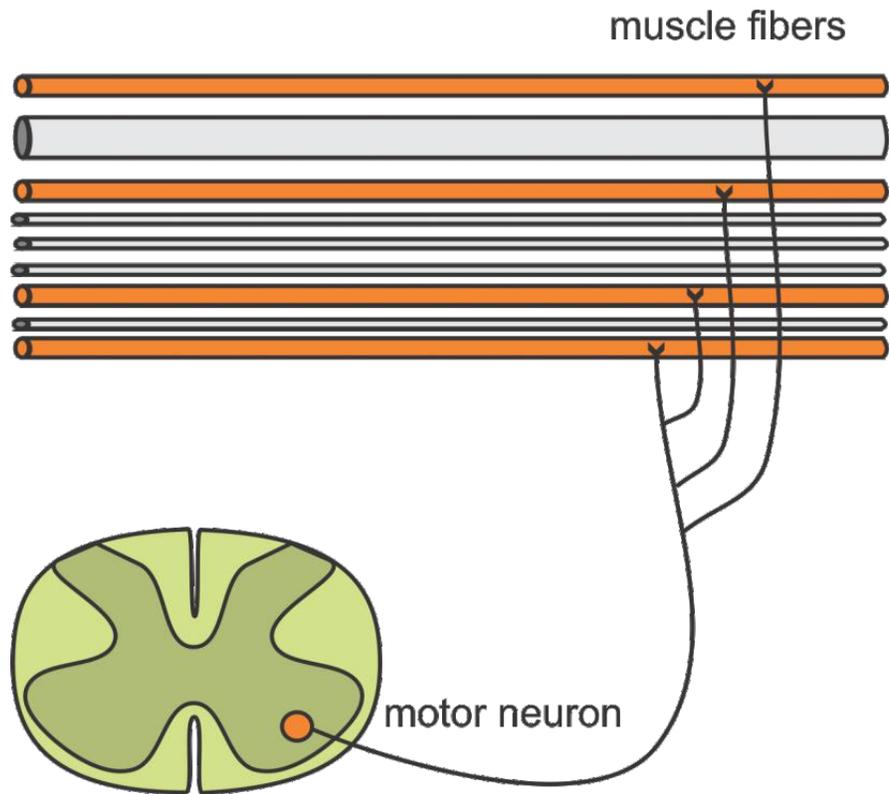


A muscle consists of many motor units.

A **motor unit** consists of a single **motor neuron** that originates from the spinal cord and all the **muscle fibers** this neuron innervates.

All muscle fibers of a motor unit are of the same type because the motor neuron determines the characteristics of the muscle fibers.

The motor unit is the smallest unit of muscle activity. Each action potential in the motor neuron always produces activation of all its muscle fibers.



The **Innervation Ratio** is the number of muscle fibers a motor neuron innervates. In the figure this number is 4. Typical examples are
extra ocular muscles ~ 10 (fine graded increments in force)
soleus muscle (a postural muscle) ~ 100
gastrocnemius (for large forces) ~ 2000

Fasciculations are spontaneous activations of one motor neuron which occur after hypersensitivity of a motor neuron or injury of its axon. Hypersensitivity of motor neurons can occur after loss of cortical input. Fasciculations activate all the muscle fibers innervated by a motor neuron and thus produce a large and visible contraction. A **spasm** is the activation of many motor neurons.

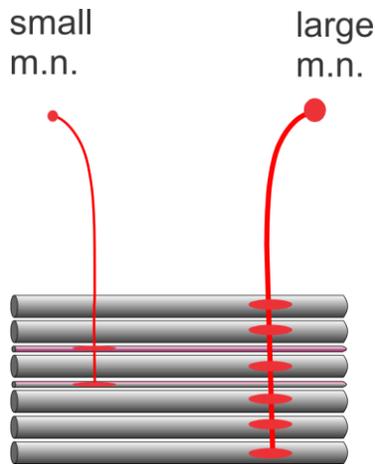
Fibrillations are spontaneous activations of a single muscle fiber. Hypersensitivity of the synapse at a muscle fiber produces spontaneous contractions of individual muscle fibers which are invisible to the naked eye. Hypersensitivity can occur after death of the motor neuron.

The fiber types and their distinguishing features

There are several distinct muscle fiber types each with unique properties and functions. Two are shown here. Others have intermediate properties.

Slow contracting and fatigue resistant fibers:

- activated by **small** motor neuron
- **red color** (drum stick) fatigue resistant because rich in mitochondria myoglobin & blood vessels
- generate a prolonged small force due to a small innervation ratio to thin muscle fibers
- well developed in a long distance runner



Fast contracting and fatigue prone fibers:

- activated by **large** motor neuron
- **pale color** (chicken breast) use a brief anaerobic breakdown of glycogen stores
- generate a brief large force due to large **innervation ratio** to **thick** muscle fibers (hard to supply with O_2)
- well developed in a **weight lifter**

Slow fatigue resistant fibers are very efficient. If a fiber is slow to contract, it is also slow to relax. This allows a relatively steady tension with a low frequency activation.

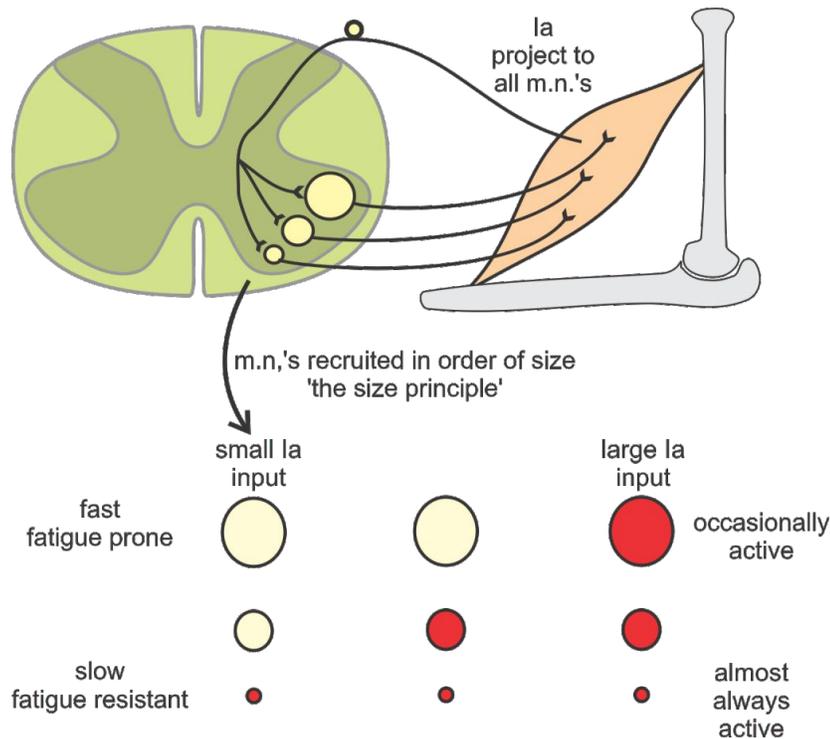


How is the contraction of the muscle graded?

- 1) by grading the motor neuron **firing frequency**
- 2) by grading the # of motor neurons activated

The **size principle** states that **small** m.n. have a **lower threshold** and are thus recruited before large motor neurons.

Thus a small input only recruits small motor neurons.
As the input increases, progressively larger motor neurons are recruited.



A small Ia input first recruits only small motor neurons, which in turn activate small muscle fibers. These fibers generate a small (fine), slow increment in tension. The fibers are fatigue resistant, which is good because they are almost always active. They are ideal for postural support muscle.

A large Ia or cortical drive recruits both small and large motor neurons. Large motor neurons (m.n.'s) activate large muscle fibers.

These generate a large (coarse), fast increment in tension. The tension fatigues rapidly, which is OK because large m.n.'s are only occasionally activated. Large m.n.'s are ideal for weight lifting.

Practice problems

1. The stretch reflex mediated by Ia fibers
 - a) is dysynaptic to agonist muscles.
 - b) is mediated by small diameter fibers.
 - c) is primarily involved in regulating tension.
 - d) is primarily involved in regulating length and change of length.
 - e) mediates the flexor reflex.

2. Fast contracting, fatigue prone, muscle motor units are characterised by
 - a) a large muscle force.
 - b) a red colour.
 - c) a small innervation ratio.
 - d) the first to be recruited.
 - e) innervation from small motoneurons.

Answers

1. d)
2. a)

See also <http://www.tutis.ca/NeuroMD/L4SpindleMuscle/MuscleProb.swf>