CENTRAL NERVOUS SYSTEM

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- ○ Anatomy
- ● Physiology
- ○ Pathology
- ○ Biochemistry
- ○ Microbiology
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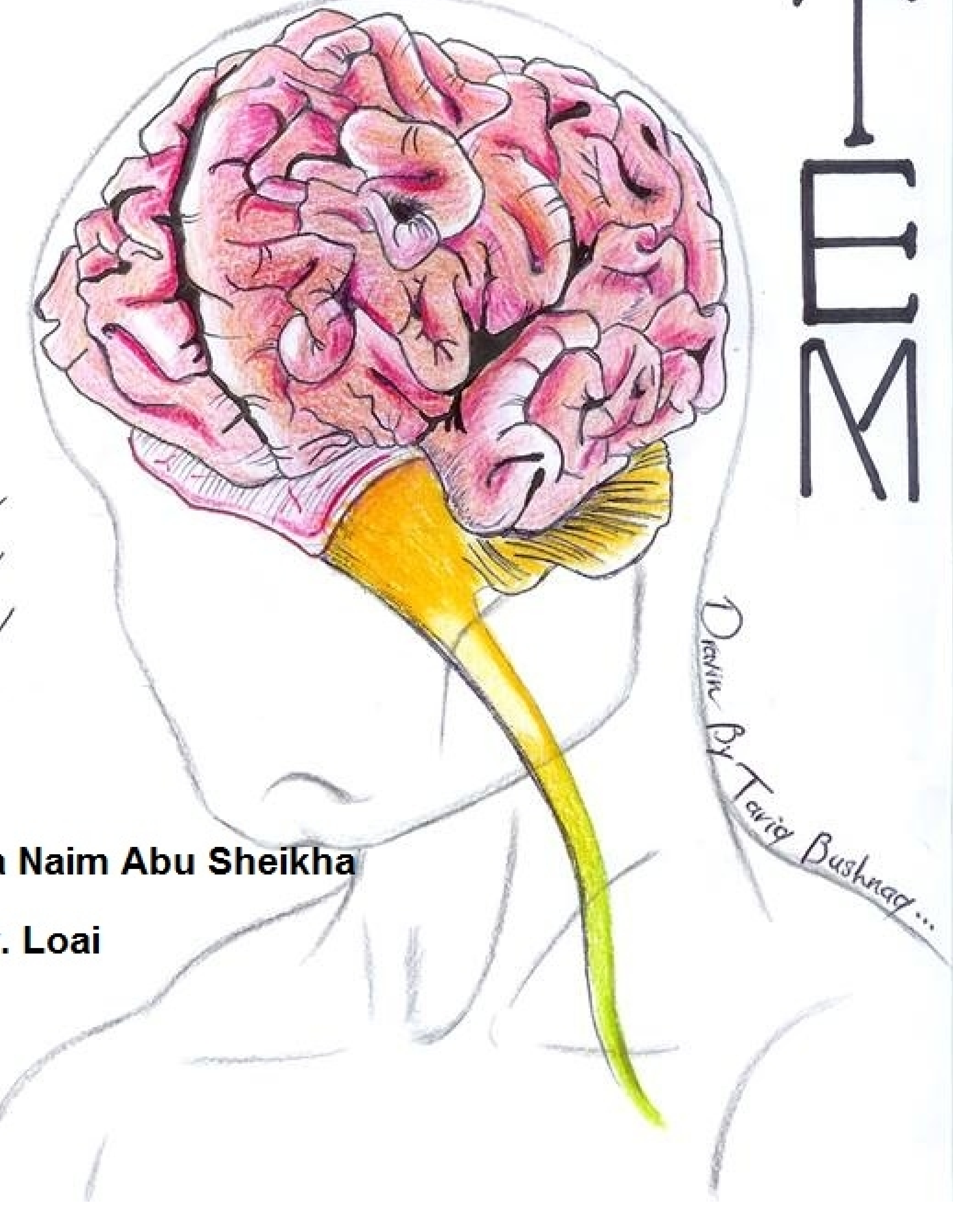


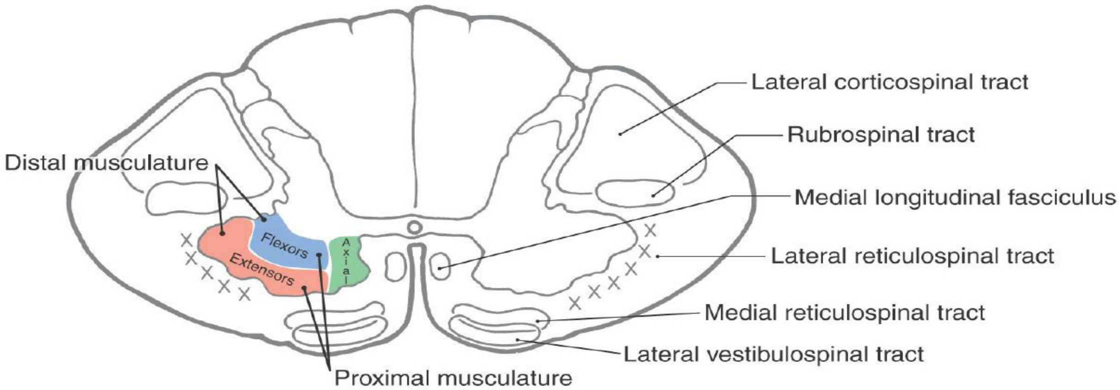
Done By: Aya Naim Abu Sheikha

Dr. Name: Dr. Loai

Lec #: 7

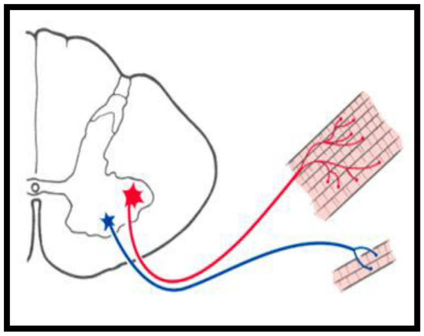
The motor system

The motor system is the efferent division of the CNS which carries information of the nervous system to the periphery. It sends orders to muscles stimulating them to contract, resulting in movement, and to glands stimulating secretions. 90% of the motor system's output is through the spinal cord. Cell bodies of motor neurons form the grey matter of the spinal cord, and their axons reach glands or muscles to stimulate glandular secretion or muscular contraction.



Notice how **medially** placed columns supply the <u>axial (trunk) musculature</u>, while **laterally** placed columns supply the <u>limb musculature</u>. Also motoneurons innervating **extensor** muscles lie in <u>front</u> of motoneurons innervating flexors. Understanding this is very important in order to understand different motor pathways and their functions.

A **motor unit** is defined as *a single motor neuron and the muscle fibers it innervates.* When a motor unit is activated, all its fibers contract. The number of muscle fibers within each unit can vary from muscle to another and from a certain part of the body to another depending on the size of the load; some could be formed of 5-6 muscles fibers while other units could consist of a hundred fibers and therefore supplied by a larger neuron.

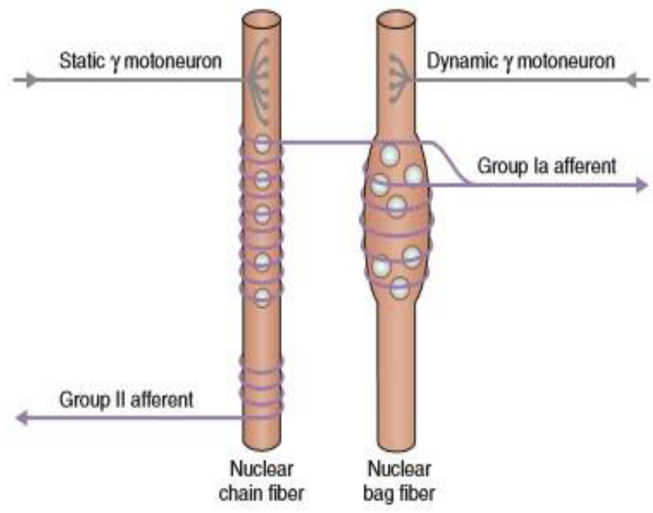


The spinal cord sends efferent fibers to muscles through the ventral (motor) horn and receives afferent sensory fibers from muscles. This sensory information also reaches the cerebral cortex through the pathways explained in the previous lectures; but one of the targets of these sensation, that reaches it by collaterals, is the spinal cord.

There are 2 types of sensory receptors in muscles: **Muscle spindle** (sensitive to stretch) and **Golgi tendon organ** (sensitive to tension-contraction more than stretch).

Muscle spindle

Are *sensory receptors* within the muscle that primarily detect changes in the length of the muscle. There are two **types of intrafusal fibers** present in muscle spindles: nuclear bag fibers and nuclear chain fibers.



Nuclear chain fibers result in a static response and are innervated by static gamma motor neurons, whereas **nuclear bag fibers** result in a dynamic response and are supplied by dynamic gamma motoneurons.

The following three paragraphs (In which I used Dr.Faraj's handout and Guyton) are merely for clarification as the doctor didn't explain the 2 boxes below clearly:

The group Ia afferent fibers (innervating the central region of nuclear bag and nuclear chain fibers) detect the **velocity of length change**, and the group II afferent fibers (innervating the nuclear chain fibers) detect the **length of the muscle fiber**. Keep in mind that primary endings (Ia) are rapidly -adapting receptors, while secondary endings (II) are slowly-adapting.

When the length of the spindle receptor increases suddenly, the primary ending (but not the secondary ending) is stimulated powerfully. Which means that primary endings respond extremely actively to a rapid ***rate of change*** in spindle length, but only while the ***length is actually increasing, thus, the reflex functions to oppose sudden changes in muscle length.*** This dynamic response is the result of stretching of the **nuclear bag intrafusal fibers**. Therefore, this response can be increased by stimulating **dynamic gamma motoneurons** which supply the nuclear bag fibers. (This is the basis of the tendon jerks)

From the slides:

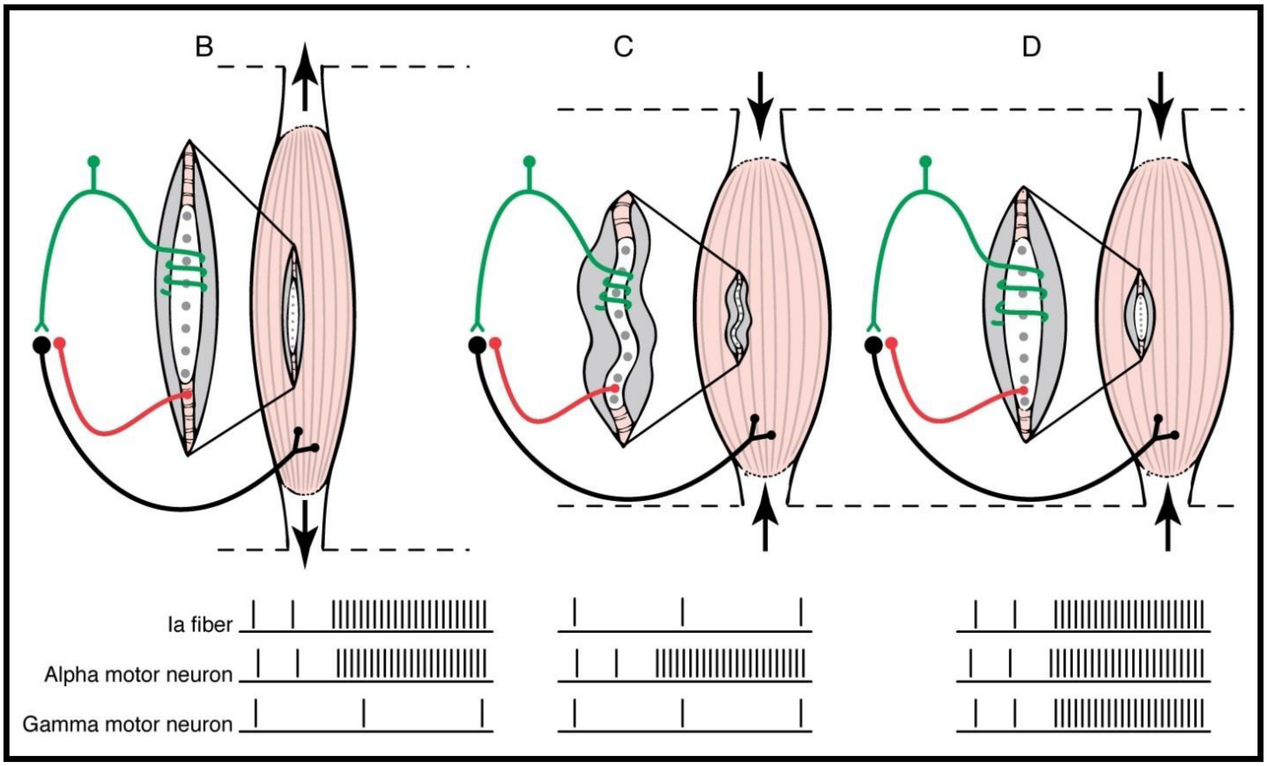
<u>Nuclear bag fiber (Annulosprial ending)</u>
Nuclei arranged in cluster
Dynamic/Static
-Primary, Ia, 80-120 msec (12-20)
-Rate of change in length (dynamic) versus only Change in length not rate (static)
-Dynamic bag fibers to Dynamic gamma motor neurons (sensitivity)
-Static bag fibers to Static gamma motor neurons (length)

<u>Nuclear chain fiber (Flower-spray ending)</u>
Nuclei arranged in single row
-Secondary, II, 35-70 msec (6-10)
- Change in length only, not rate of change

Note that the stretch of the muscle spindle is proportional to the stretch of extrafusal muscle fibers, and so is contraction(this is due to their parallel arrangement in the muscle). So if a muscle is 5 cm in length and the spindle is 2.5 cm and the muscle shortened by contraction to 2.5 cm, the spindle will become 1.25 cm (this is necessary in order to sense the change in muscle length when it returns to its original length after the end of the contraction). Also stretching this muscle to 10 cm would increase the length of the spindle to 5cm. In this hypothetical example, the length of the muscle spindle is around half the length of the muscle of which it is a part.

So the ratio between the length of the muscle and the length of the spindle always remains constant in order for the spindle to remain sensitive to stretch, allowing the sensory neuron of the spindle to detect change in length and rate of lengthening.

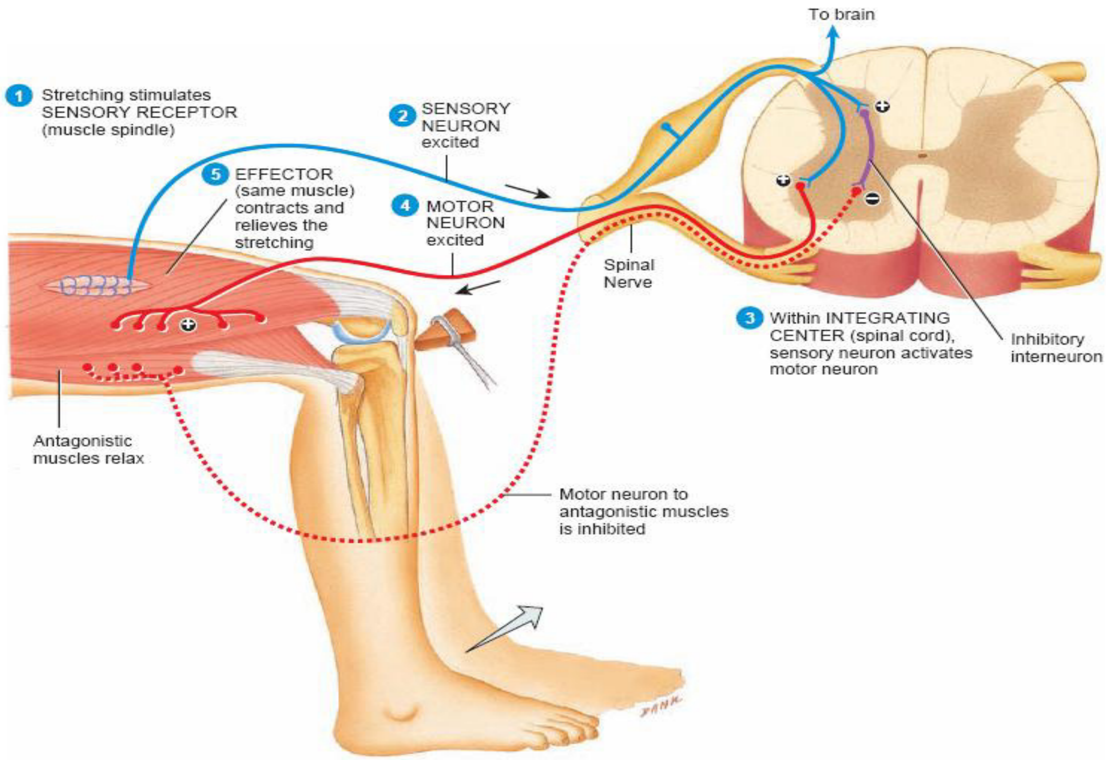
Keep in mind that muscle spindles are mechanical receptors as they have mechanical ion channels which are always functioning. (A mechanoreceptor is a sensory receptor that responds to mechanical pressure or distortion. As the muscle spindle is lengthened, it is believed that stretch-sensitive ion channels open on the sensory neurons leading to membrane depolarization and action potential generation)



Motor stretch reflex

Alpha motoneurons innervate extrafusal skeletal muscle fibers. Action potentials in α motoneurons lead to action potentials in the extrafusal muscle fibers they innervate, which results in contraction. Gamma motoneurons innervate muscle spindles, both work together in order for the ratio between the length of the muscle and the length of the spindle to always remain constant. Higher levels send contraction orders through both motoneurons, so that the ratio remains constant.

Stretching the whole muscle by external force stretches the muscle spindle,



activating **group Ia afferent fibers** in the muscle spindle resulting in the increase of their firing rate. These group Ia afferents enter the spinal cord and synapse **directly** on and activate **α motoneurons** (**MONOSYNAPTIC-NO INTERNEURON**). Sensory afferents are also sent to higher levels for processing of the information. Activation of alpha motoneurons causes contraction of the muscle that was originally stretched. When the muscle contracts, it shortens, thereby decreasing stretch on the muscle spindle. The muscle spindle returns to its original length, and the firing rate of the group Ia afferents returns to baseline.

It's very important to understand that **<u>in the case of stretch reflexes, only alpha motoneurons are activated</u>**. Remember how we said that the ratio between the length of the muscle and the length of the spindle always remains constant; this means that stimulation of the alpha motoneuron causes contraction of the extrafusal muscles fibers AND consequently proportional contraction of the muscle spindles as well. Stimulation of the gamma fibers would result in further shortening of muscle spindles (correction note: I believe muscle spindle is lengthened not shortened when gamma fibers are stimulated) leading to disruption of the ratio and further contraction of the whole muscle to fix the ratio and WE DON'T WANT THAT because the whole muscle will become shorter than its length prior to stretch.

Stretch reflex initiates a reciprocal inhibition of the antagonistic muscle in order for the agonist to contract properly; because contraction of the agonist results in stretching of the antagonist; so if it was not inhibited, this would generate a stretch reflex in the antagonistic muscle and it would contract making the agonist muscle stretched again.

Note that the stretch reflex is the only monosynaptic reflex in the body. It is also the fastest, which makes sense because the Ia afferent fibres are rapidly conducting fibres due to being thickly myelinated.

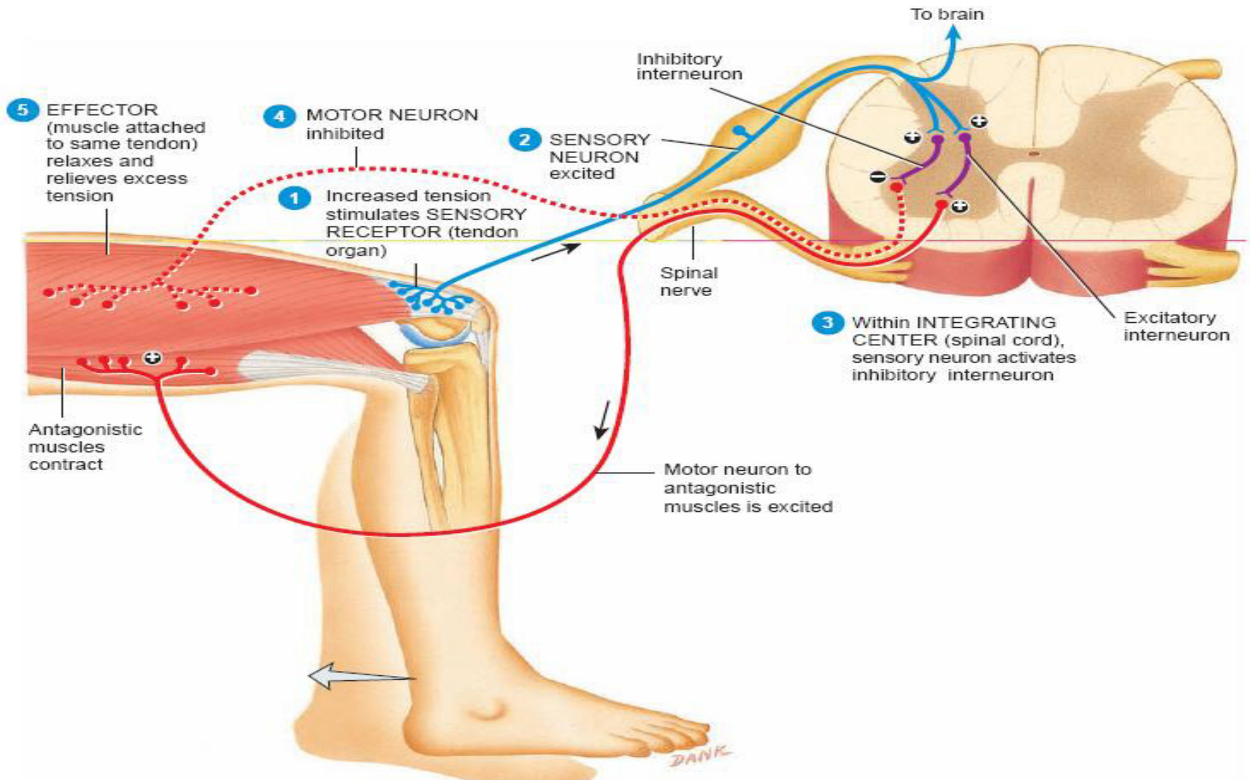
<u>Tendon reflex (autogenic inhibition)</u>

Remember that we said types of sensory receptors in muscles are: Muscle spindles (sensitive to stretch) and Golgi tendon organ (sensitive to tension; contraction more than stretch).

This is a protective mechanism because Golgi Tendon organ basically inhibits contraction of muscles under tension, forcing their relaxation and preventing tearing of the muscle.

Because there is no order for muscle relaxation, **<u>Golgi tendon organ works through inhibition of contraction</u>**. As tension increases in a muscle, the firing rate of action potential increases, so Golgi tendon works through decreasing the firing rate of action potential and decreasing activity of the alpha motoneurons.

Contraction of the muscle causes the extrafusal muscle fibers to shorten, activating the Golgi tendon organs attached to them. In turn, the group Ib afferent fibers that synapse on inhibitory interneurons (which synapse on the α motoneurons) in the spinal cord. Activation of the inhibitory interneurons (i.e., activated to inhibit) results in inhibition of firing of the α motoneurons, producing



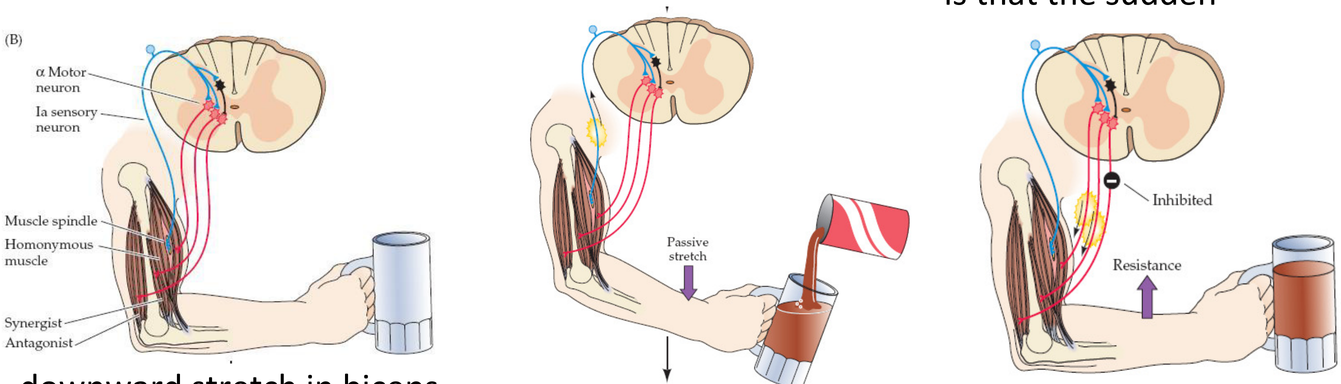
relaxation of the muscle that originally was contracted. As the muscle relaxes, the reflex also causes antagonistic muscles to contract (antagonistic muscles can't contract before relaxation of the contracted muscle), so reciprocal inhibition is also present here, with group Ib activity exciting the alpha-motoneurons of the antagonist muscles.

The tendon reflex is NOT MONOSYNAPTIC,due to the presence ofinhibitory ***interneurons*** (which synapse on the α motoneurons). There's also an inhibitory **interneuron** used to relax the antagonistic muscle (Reciprocal innervation).

Jerk reflexes are used a lot clinically and are performed especially by neurologists to check if they're present or absent/normal or areflexia or hypereflexia.

Reflexes help us perform many daily activities as they provide quick responses without waiting for orders and delay from the cortex. Drinking a cup of tea for example is a voluntary action; meaning the planning, excitation and activity pattern comes from the cortex to the muscle. (The cortex computes and processes information regarding the location of the cup with respect to the hand, and it computes forces that are necessary to move the arm.)

Suppose you're holding the cup and suddenly someone puts something heavy in it, so the force pulling the cup downwards will be larger than the tension in your biceps and the cup will begin to fall downwards. If we want to wait for the cortex to process this and send orders, the cup will fall out of your hands. What happens here is that the sudden

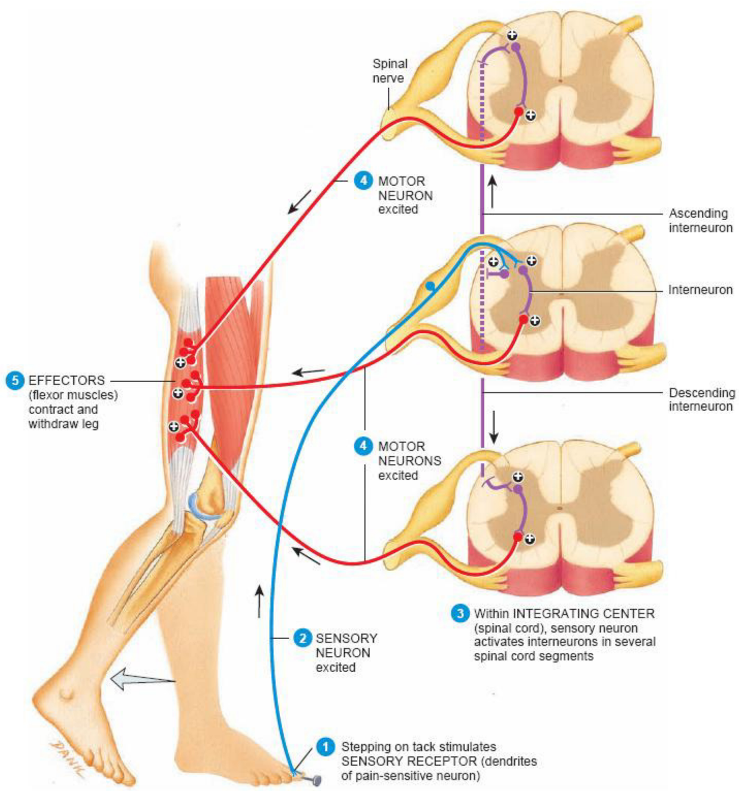


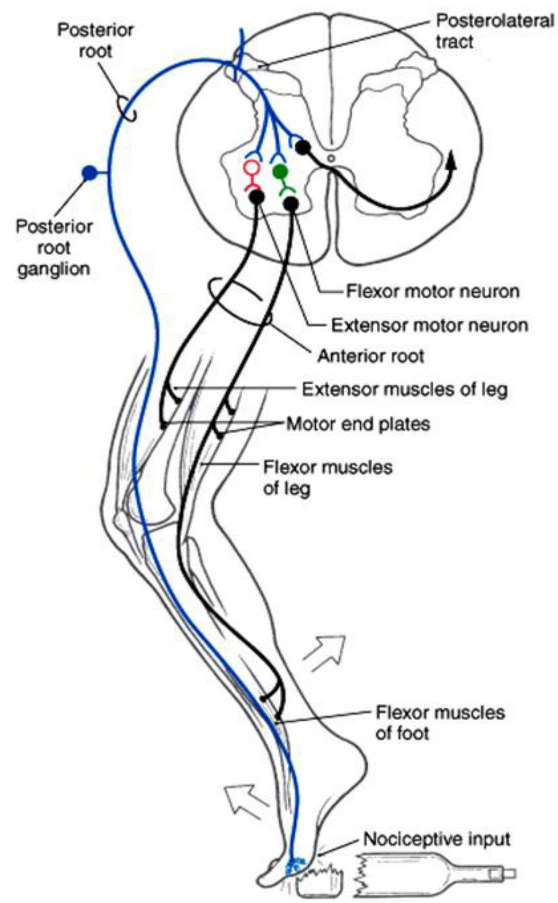
downward stretch in biceps activates the muscle stretch reflex and your arm responds immediately by lifting the cup upwards. During the movement, sensory information from the limb is acquired and transmitted back to the cortex. Reflex pathways ensure stability of the limb.

Flexer reflex (nociceptive/withdrawal reflex)

The flexor-withdrawal reflex is a reflex that occurs in response to painful or noxious stimulus. As the name indicates, this reflex is initiated by nociceptive receptors.

Upon coming in contact with a painful stimulus, flexor reflex afferent fibers (groups II, III, and IV) are activated. These afferent fibers synapse on multiple interneurons in the spinal cord (polysynaptic reflex), and conveys pain through the anterolateral system (which is a sensory pathway from the skin to the thalamus). Reflexes are activated on the **ipsilateral side** of the pain stimulus, causing flexor muscles to contract and extensor muscles to relax, producing **flexion** on the ipsilateral side. Sometimes contralteral side is





involved too, in the trunk for example both sides are activated. Sometimes more than one spinal level is activated depending on the force of the stimulus.

Crossed extension reflex

On the contralateral side (sometimes the trunk is involved too) of the pain stimulus, reflexes are activated that cause extensor muscles to contract and flexor muscles to relax,producing extension on the contralateral side. This is useful formaintenance of balance.

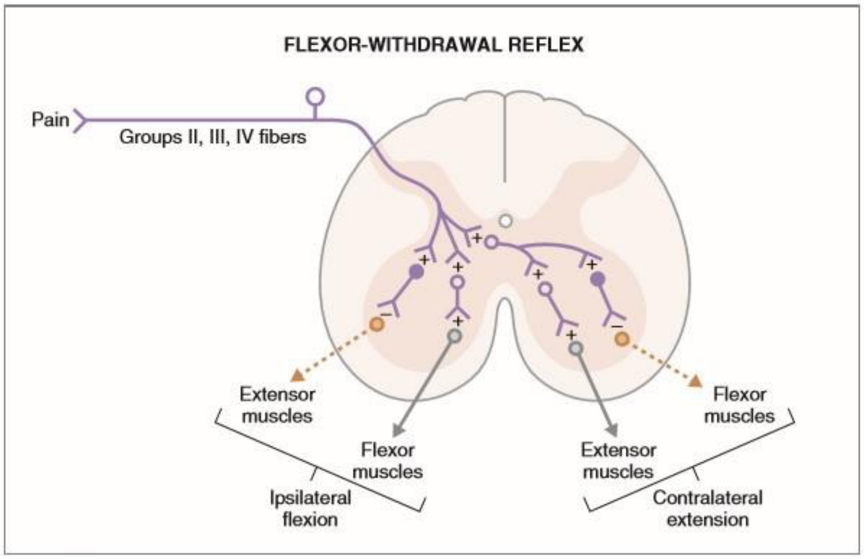
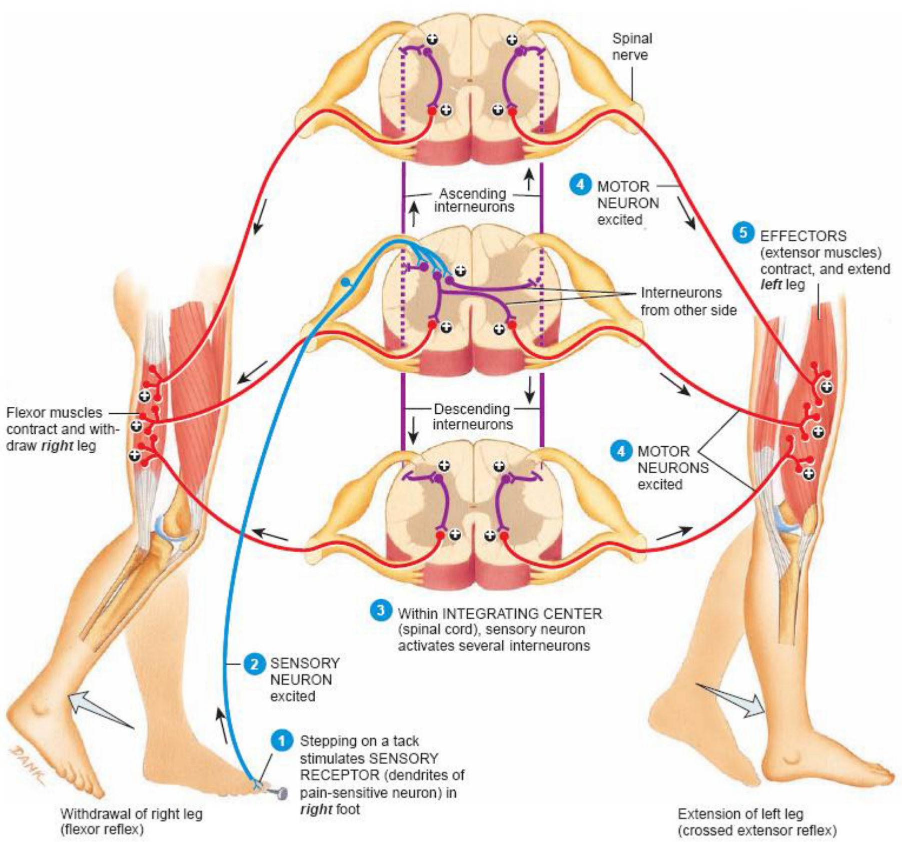
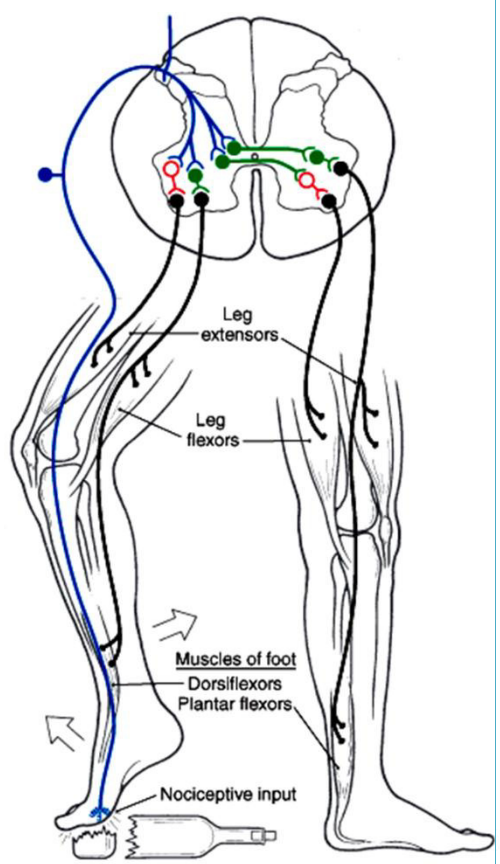


Figure 3–34 Operation of the flexor-withdrawal reflex. *Solid lines* show excitatory pathways; *dashed lines* show inhibitory steps. *Open* neurons are excitatory; *filled* neurons are inhibitory.

The spinal cord is responsible for involuntary or automatic/unconscious movement, such as walking. All descending motor

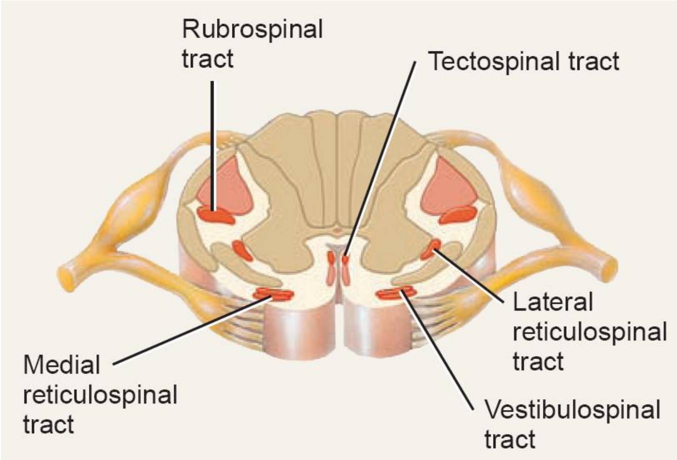




pathways synapse on motorneurons. Posture and movement depend on a combination of involuntary reflexes coordinated by the spinal cord and voluntary actions controlled by higher brain centers.

Brain stem control of motor function (extrapyramidal tracts)

Descending motor pathways are divided into pyramidal tracts and extrapyramidal tracts. Pyramidal tracts originate from the cortex while extrapyramidal tracts arise in the brain stem but are under the influence of the cerebral cortex.



Extrapyramidal tracts include:

1) Reticulospinal tracts
2) Vestibulospinal tract
3) Rubrospinal tract
4) Tectospinal tract

Reticulospinal tracts

Includes the **pontinereticulospinal tract** (or **medial reticulospinal tract** as it's found medially) and the **medullary reticulospinal tract** (or **lateral reticulospinal tract** as it's found laterally) arising from the reticular formation in the pons and medulla respectively. It's responsible for ipsilateral and contralateral movement, **mainly ipsilateral**.

Take a second look at the first figure in this sheet and notice again how: medially placed columns →axial (trunk) musculature, while laterally placed columns →the limb musculature. Also motoneurons innervating extensor muscles → anteriorly,while motoneurons innervating flexors → posteriorly.

Pontine reticulospinal tract:

The fibers of this pathway terminate on the medial anterior motor neurons andmainly **excite** axial muscles and **extensor** muscles of the limbs.

Medullary reticulospinal tract:

Located in the lateral column of the cord, the medullary reticulospinal tract transmits **inhibitory** signals through interneurons to the axial muscles and **extensor** muscles of the limbs motoneurons.

The balance between the two reticulospinal tract determines whether the muscles of the limbs will be extended or flexed, and are the principal motor pathways that control posture (muscle tone),that's why they're largely distributed in the body and are also found in flexors but are **mainly found in extensors and weight-bearing muscles**, (activation of extensor determines the activity of flexors through stretch reflexes.)

The reticulospinal tract synapses mainly on gamma motoneurons because by controlling the length of the muscle spindle, the length of the muscle will automatically be adjusted. So activation of gamma motoneurons will result in contraction of the muscle spindle and then eventually activation of alpha motoneurons, this is known as the **gamma-loop**. (Recall that the ratio between the length of the muscle and the length of the spindle always remains constant.)

The doctor says that what you should know is that the reticulospinal tracts innervate only gamma motoneurons because this is what matters clinically. He adds that the latest discoveries concluded that reticulospinal tracts also innervate alpha motoneurons, interneurons and inhibitory neurons, and that they are the means of re-learning or mastering a movement after development of lesions in the corticospinal tract.

Vestibulospinal tracts

Include medial and lateral vestibulospinal tracts which arise from the vestibular nuclei found between the medulla and pons. Both tracts project to **ipsilateral** motoneurons and interneurons. (The medial vestibulospinal tract is found only in the cervical spine and is excitatory to flexor muscles.) The lateral part of the vestibulospinal tract is the major portion and it helps to maintain an upright and balanced posture by **stimulating axial muscles and extensor muscles of the lower limb** (which, again, are the weight-bearing muscles/anti-gravity muscles), and inhibition of flexors. *Afferent information regarding head and eye movement and direction* are conveyed to the vestibulospinal tract which maintains a balanced posture.

Rubrospinal tract

Arising from red (rubro in latin) nuclie in the mid-brain and **allows you to do fine movements**. Functions by activation of **flexor** muscles (responsible for fine movement; mainly found in the upper limbs), and inhibition of extensor muscles. The rubrospinal tract is an indirect corticospinal tract (cortico-rubro-spinal) as it has almost the same function.

A bunch of notes the doctor mentioned while answering students' questions:

- Experiments have shown that over time, the rubrospinal tract can assume almost all the duties of the corticospinal tract when the corticospinal tract is lesioned.
- Remember this important principle: each higher level can control levels below it.
- The number and activity of neurons in the brain is not constant, and neither is the number of synapses on each neuron.
- It's been noticed that people who have amputated their upper limbs for one reason or the other, have developed fine movements in their lower limbs (like being able to write or play the piano using their feet), this is not due to further development of the rubrospinal tract in lower limbs, but **due to increased utilization and activation** of the parts of therubrospinaltract

reaching the lower limbs (which is no more than 10%). *The rubrospinal tract is more concerned with production of stiffness and learning new skills, than production of fine movement.*

The end

"The worst thing in the world can happen, but the next day the sun will come up. And you will eat your toast. And you will drink your tea."

— Rhian Ellis