2. Motor Receptors & The Spinal Cord Reflexes
Organization of the spinal cord for motor function

The cord gray matter is the integrative area for the cord reflexes.

Sensory signals enter the cord almost entirely through the sensory roots, also known as the posterior or dorsal roots.

After entering the cord, every sensory signal travels to two separate destinations:

First branch of the sensory nerve terminates almost immediately in the gray matter of the cord and elicits local segmental cord reflexes and other local effects,

Second branch transmits signals to higher level of the nervous system (that is, 1 to higher levels in the cord itself, 2 to the brain stem, or 3 even to the cerebral cortex).

Each segment of the spinal cord (at the level of each spinal nerve) has several million neurons in its gray matter. Aside from the sensory relay neurons the other neurons are of two types:

(1) anterior motor neurons and (2) interneurons.
(1) Anterior Motor Neurons.

**Anterior motor neurons** located in each segment of the **anterior horns** of the cord gray matter

Anterior motor neurons are **several thousand neurons**

**Anterior motor neurons** are 50 to 100 percent larger than most of the others

**Anterior motor neurons** give rise to the nerve fibers that **leave the cord** by way of the **anterior roots** and directly **innervate the skeletal muscle fibers**.

**Anterior motor neurons** are of two types, **alpha motor neurons** and **gamma motor neurons**.
Interneurons.

Interneurons are present in all areas of the cord gray matter—in the dorsal horns, the anterior horns, and the intermediate areas between them.

Interneurons are about 30 times as numerous as the anterior motor neurons. Interneurons are small and highly excitable, often exhibiting spontaneous activity and capable of firing as rapidly as 1500 times per second.

Interneurons have many interconnections with one another.

The interconnections among the interneurons and anterior motor neurons are responsible for most of the integrative functions of the spinal.

Some may synapse directly with the anterior motor neurons.

The interaction between interneurons allows the brain to perform complex functions such as learning, and decision making.
Only a few incoming sensory signals from the spinal nerves or signals from the brain terminate directly on the anterior motor neurons.

Instead, almost all these signals are transmitted first through interneurons, where they are appropriately processed. Thus, the cortico-spinal tract from the brain is shown to terminate almost entirely on spinal interneurons, where the signals from this tract are combined with signals from other spinal tracts or spinal nerves before finally converging on the anterior motor neurons to control muscle function.

Interneurons can be further broken down into two groups:

1. Local interneurons have short axons and form circuits with nearby neurons to analyze small pieces of information.

2. Relay interneurons have long axons and connect circuits of neurons in one region of the brain with those in other regions.
Renshaw Cells Transmit Inhibitory Signals to Surrounding Motor Neurons.

Renshaw cells located in the anterior horns of the spinal cord, in close association with the motor neurons,

Renshaw cells are a large number of small neurons. Almost immediately after the anterior motor neuron axon leaves the body of the neuron, collateral branches from the axon pass to adjacent Renshaw cells.

Renshaw cells are inhibitory cells that transmit inhibitory signals to the surrounding motor neurons. Thus, stimulation of each motor neuron tends to inhibit adjacent motor neurons, an effect called lateral inhibition.

Lateral inhibition is important for the following major reason:

The motor system uses this lateral inhibition to focus, or sharpen, its signals in the same way that the sensory system uses the same principle to allow unabated transmission of the primary signal in the desired direction while suppressing the tendency for signals to spread laterally.
Inter-segmental (or proprio-spinal) tract:

Proriospinal fibers are the fibers that interconnect adjacent or distant segment of the spinal cord

Proriospinal Fibers run from one segment of the cord to another.

Proriospinal fibers lie close to the gray matter

**Proriospinal Fibers** represent more than half of all the nerve fibers that ascend and descend in the spinal cord

**Proriospinal** ascending and descending fibers of the cord provide pathways for the multi-segmental reflexes, including reflexes that coordinate simultaneous movements in the forelimbs and hind limbs.

In addition, as the sensory fibers enter the cord from the posterior cord roots, they bifurcate and branch both up and down the spinal cord; some of the branches transmit signals to only a segment or two, whereas others transmit signals to many segments.
Muscle sensory receptors:

Proper control of muscle function requires not only excitation of the muscle by spinal cord anterior motor neurons but also continuous feedback of sensory information from each muscle to the spinal cord, indicating the functional status of each muscle at each instant. That is, what is the length of the muscle, what is its instantaneous tension, and how rapidly is its length or tension changing?

To provide this information, the muscles and their tendons are supplied abundantly with two special types of sensory receptors:

1. Muscle spindles, which are distributed throughout the belly of the muscle and send information to the nervous system about:
   - muscle length
   - rate of change of length (velocity of a muscle)

2. Golgi tendon organs, which are located in the muscle tendons and transmit information about:
   - tendon tension (load), force applied to a muscle
   - rate of change of tension.
The signals from these two receptors are
1. almost entirely for the purpose of intrinsic muscle control
2. They operate almost completely at a subconscious level.

Even so, they transmit tremendous amounts of information
1. to the spinal cord
2. to the cerebellum
3. to the cerebral cortex,

helping each of these portions of the nervous system function to control muscle contraction

Receptor function of the muscle spindle
Structure and motor innervation of the muscle spindle.

Ordinary muscle fiber is called (extra-fusal)
Muscle spindle is also called (intra-fusal)
Muscle spindle is 3 to 10 millimeters long.
Muscle spindle is built around 3 to 12 tiny intra-fusal muscle fibers that are pointed at their ends and attached to the glycocalyx of the surrounding large extra-fusal skeletal muscle fibers.

Each intra-fusal muscle fiber is a tiny skeletal muscle fiber.
There are also two types of muscle spindle intra-fusal fibers:

(1) Nuclear bag muscle fibers
Nuclear bag muscle fibers is 1-3 in each spindle,
Nuclear bag muscle fibers several muscle fiber nuclei are congregated in expanded “bags” in the central portion of the receptor area
Types of nuclear Bag:
a. Static Nuclear Bag fibers (bag2 fibers).
These fibers signal information about the static length (no change in length) of a muscle.
b. Dynamic Nuclear Bag fibers (bag1 fibers).
These fibers 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

(2) Nuclear chain fibers
A typical muscle spindle is composed of 3-9 nuclear chain fibers
Nuclear chain fibers are about half as large in diameter and half as long as the nuclear bag.
Nuclear chain fibers have nuclei aligned in a chain throughout the receptor area
Sensory Innervation of the Muscle Spindle.

The receptor portion of the muscle spindle is its central portion. The central region of each of these fibers (that is, the area midway between its two ends) has few or no actin and myosin filaments. Therefore, this central portion does not contract when the ends do.

Sensory fibers originate in this area and are stimulated by stretching of this mid-portion of the spindle. One can readily see that the muscle spindle receptor can be excited in two ways:

1. Lengthening the whole muscle stretches the mid-portion of the spindle and, therefore, excites the receptor.
2. Even if the length of the entire muscle does not change, contraction of the end portions of the spindle’s intra-fusal fibers stretches the mid-portion of the spindle and therefore excites the receptor.

Two types of sensory endings, the primary afferent and secondary afferent endings, are found in this central receptor area of the muscle spindle.
Primary Ending or primary afferent (Ia):
In the center of the receptor area, a large sensory nerve fiber encircles the central portion of each intra-fusal fiber, forming the so-called primary afferent ending (or annulo-spiral ending).

This nerve fiber is a type Ia fiber averaging 17 micrometers in diameter, and it transmits sensory signals to the spinal cord at a velocity of 70 to 120 m/sec, as rapidly as any type of nerve fiber in the entire body.

Because they innervate all 3 types (dynamic and static nuclear bag fibers and nuclear chain fibers) of intrafusal fibers, Group Ia afferents provide information about both length and velocity.
Secondary Ending secondary afferent (II):
This sensory ending is called the secondary afferent ending; sometimes it **encircles** the intrafusal fibers in the same way that the type Ia fiber does, but often it spreads **like branches on a bush** (termed **flower spray endings**). Usually one but sometimes two smaller sensory nerve fibers (type II fibers with an average diameter of 8 micrometers) innervate the receptor region on one or both sides of the primary ending. This sensory ending innervates the ends of the **nuclear chain fibers and the static nuclear bag fibers**. Because they do not innervate the dynamic nuclear bag fibers (only static nuclear bag fibers and nuclear chain fibers), Group II afferents signal information **about muscle length only**.

The Group II afferent increases its firing rate steadily as the muscle is stretched. Its firing rate does not depend on the rate of change of the muscle; rather, its firing rate depends only on the immediate length of the muscle.
Motor innervation of extra-fusal muscle fibers by Alpha Motor Neurons (skeleto-motor fibers)
The alpha motor neurons give rise to large, lower motor neuron of the brainstem and spinal cord.
The alpha motor neurons are type A alpha (Aα) motor nerve fibers.
The axon of Alpha (α) motor neurons (also called alpha motoneurons) connects with its extrafusal muscle fiber via a neuromuscular junction.
The alpha motor neurons averaging 14 micrometers in diameter.
The alpha motor neurons fibers branch many times after they enter the muscle and innervate the large skeletal muscle fibers. Stimulation of a single alpha nerve fiber excites anywhere from three to several hundred skeletal muscle fibers, which are collectively called the motor unit.
Motor Innervation of the Muscle Spindle

The fusimotor system is a system by which the central nervous system controls muscle spindle sensitivity.

The fusimotor system consists of

1. muscle spindles
2. fusimotor neurons (beta & gamma motor neurons) because they activate the intrafusal muscle fibers.

Fusimotor drive causes a contraction and stiffening of the end portions of the intrafusal muscle fibers.

In humans, the motor component is provided by

up to 12 gamma motor neurons

by 1 or 2 beta motor neurons
Gamma Motor Neurons.

Gamma motor neurons are about one half than alpha motor neurons
Gamma motor neurons are type A gamma ($A\gamma$) motor nerve fibers
Gamma motor neurons helps control basic muscle “tone”
Gamma motor neurons innervate only intrafusal muscle fibers
Gamma motor neurons originate in the anterior horn of the spinal cord and innervate the polar regions of the intrafusal muscle fibers.

Gamma motor neurons are
1. smaller than alpha motor neurons
2. averaging 5 micrometers in diameter
3. myelination
4. 4 to 24 meters per second slower than in alpha motor neurons.

When Gamma motor neurons stimulate the polar regions of the intrafusal muscle fibers to contract it stretches the non-contractile equatorial region. This allows the gamma motor neurons to control how sensitive muscle spindles are to being stretched. The contraction of the intrafusal fibers doesn't cause a difference in the overall tension of the muscle.
Gamma motor neurons do not directly adjust the lengthening or shortening of muscles. However,

1. Gamma motor neurons role is important in keeping muscle spindle taut by contracting the polar part of muscle spindle which is the only part contains actin and myosin to cause enough stretching of the equatorial region so that the Ia and II fibers receive their adequate stimulus, thereby allowing the continued firing of alpha neurons, leading to muscle contraction.

2. Gamma motor neurons play a role in adjusting the sensitivity of muscle spindles.
Types of gamma motor neurons:

1. Static gamma motor neurons (gamma-s)

Static gamma motor neurons innervate 1. static nuclear bag fibers (bag2 fibers) and 2. nuclear chain fibers. Static gamma motor neurons

- a. increase the firing of static nuclear bag fibers (bag2 fibers) and nuclear chain fibers, in response to an increase in magnitude of change in length
- b. has very little effect on dynamic nuclear bag fibers
- c. controls the static sensitivity of the stretch reflex.

For this reason, Static gamma motor neurons is mostly used in the maintenance of postures and slower movements such as lifting a box, rather than activities requiring rapid changes in muscle length.
Dynamic gamma motor neurons (gamma-d)

Dynamic gamma motor neurons innervate the dynamic nuclear bag fibers (bag1 fibers)

a. Dynamic gamma motor neurons can enhance the sensitivities of la sensory neurons and increases its discharge in response to velocity, the rate of change, of muscle length rather than simply the magnitude as it is with static gamma motor neurons.

b. Has very little effect on static nuclear bag fibers and nuclear chain fibers.

c. Dynamic gamma motor neurons firing removes the slack in dynamic nuclear bags, bringing la fibers closer to the firing threshold.

Therefore, this type of gamma motor neuron can be used for activities requiring quick changes in muscle length to adjust such as balancing on a rail.
Continuous discharge of the muscle spindles (tonic discharge) under normal conditions.

What will happen when the muscle is stretched by 10 Kg?

Normally, when there is some degree of gamma nerve excitation, the muscle spindles emit sensory nerve impulses continuously.

Stretching the muscle spindles increases the rate of firing of sensory nerve impulses (positive signals).

Shortening (un-stretched) the spindle decreases the rate of firing of sensory nerve impulses (negative signals).

![Diagram of muscle spindle](image_url)
First step:
Stimulation of muscle spindle (Muscle stretch)

When the muscle is stretched by 10 Kg this will also stretch the muscle spindle and this stretch will stimulate muscle spindle causing:

A. “Static” Response.

When the receptor portion of the muscle spindle is stretched slowly, the number of impulses transmitted from both the primary (Ia) and the secondary (II) endings increases almost directly in proportion to the degree of stretching and the endings continue to transmit these impulses for several minutes if the muscle spindle remains stretched. This effect is called the static response of the spindle receptor.

The type II fibers which are attached to the chain & Static nuclear intra-fusal fibers monitor the static stretch and length of the muscle. These fibers are slowing adapting therefore they fire while the muscle is stretching and continue to fire after the muscle has stopped moving.
B. “Dynamic” Response. Ia primary

When the length of the spindle receptor increases suddenly, the primary ending (but not the secondary ending i.e. Ia) is stimulated powerfully. This stimulus of the primary ending is called the dynamic response, which means that the primary ending responds extremely actively to a rapid rate of change in spindle length.

The rate at which the length changes is monitored by the Ia fibers around the dynamic bag fibers because these fibers are more compliant and less sensitive to stretch. These fibers are rapidly adapting so there is a quick change in their firing rate during muscle stretch but once the stretch is completed the Ia adapts and stops firing.

Dynamic (Bag 1 (1) primary afferent (1), Ia (1) dynamic nuclear Bag only)

Static (Bag 2 (2) secondary afferent (2), II (2) static nuclear bag + nuclear chain

<table>
<thead>
<tr>
<th>Static response</th>
<th>Dynamic response</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. II (secondary)</td>
<td>a. Ia. (primary)</td>
</tr>
<tr>
<td>b. static Bag &amp; chain,</td>
<td>b. Dynamic Bag &amp; static Bag &amp; chain,</td>
</tr>
<tr>
<td>c. Length changes</td>
<td>c. velocity changes &amp; Length</td>
</tr>
<tr>
<td>d. slow stretch,</td>
<td>d. rapid stretch,</td>
</tr>
<tr>
<td>e. Slow adapt,</td>
<td>e. rapid adapt,</td>
</tr>
</tbody>
</table>

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Diagram:
The difference in the firing of rates of the muscle spindle before and after a stretch or a change in length is called the **dynamic response**.

If the difference is small, this means there was a **slow change** in muscle length.

If the difference is large, there was a **rapid change** in length.

There is a linear relationship between the rate of discharge of the afferent fibers and the length of the muscle.

**Second step:**

Stimulation of alpha motor neurons (**Muscle contraction**)

When the whole muscle is stretched, the muscle spindle is also stretched and its sensory endings are activated at a frequency proportional to the degree of stretching (“loading the spindle”).

Spindle afferents stop firing when the muscle contracts (“unloading the spindle”).
A subsequent contraction of the muscle, however, removes the pull on the spindle, and it becomes slack, causing the spindle afferents to cease firing. This decrease in firing rates is known as the dynamic index.

These information sent from muscle spindle through sensory nerve (Ia and II) will end in the spinal cord.

Once the signal reaches the spinal cord it has a monosynaptic synapse with an alpha motor neuron that leads to the muscle where the spindle is located. This causes autogenic excitation and results in muscle contraction.
First, it keeps the length of the receptor portion of the muscle spindle from changing during the course of the whole muscle contraction. Therefore, co-activation keeps the muscle spindle reflex from opposing the muscle contraction. 

Second, it maintains the proper damping function of the muscle spindle, regardless of any change in muscle length. For instance, if the muscle spindle did not contract and relax along with the large muscle fibers, the receptor portion of the spindle would sometimes be flail and sometimes be overstretched, in neither instance operating under optimal conditions for spindle function.

Gamma motor neurons like alpha motor neurons, their cell bodies are located in the anterior grey column of the spinal cord. Gamma motor neurons produce muscle tone. 

Muscle tone maintained all times except during REM (rapid eye movement).
Brain Areas for Control of the Gamma Motor System

The gamma efferent system is excited specifically by

First: signals from the bulbo-reticular facilitator region of pons in the brain stem and, secondarily, by impulses transmitted into the bulbo-reticular area from

1. the cerebellum,
2. the basal ganglia, and
3. the cerebral cortex
4. the vestibular nuclei

The bulbo-reticular facilitatory area is particularly concerned with antigravity contractions, and the muscles have an especially high density of muscle spindles, emphasis is given to the importance of the gamma efferent mechanism for damping the movements of the different body parts during walking and running.
The Muscle Spindle System Stabilizes Body Position During Tense Action.

One of the most important functions of the muscle spindle system is to stabilize body position during tense motor action.

- **bulboreticular facilitatory region** and its allied areas of the brain stem
- excitatory signals through the gamma nerve fibers
- **intrafusal muscle fibers** of the muscle spindles
- **shortens** the ends of the spindles and stretches the central receptor regions
- **increasing** spindles signal output
- if the spindles on both sides of each joint are activated at the same time, reflex excitation of the skeletal muscles on both sides of the joint also increases, producing tight, tense muscles opposing each other at the joint.
- The net effect is that the position of the joint becomes strongly stabilized, and any force that tends to move the joint from its current position is opposed by highly sensitized stretch reflexes operating on both sides of the joint.

Any time a person must perform a muscle function that requires a high degree of **delicate and exact positioning**, excitation of the appropriate muscle spindles by signals from the bulboreticular facilitatory region of the brain stem stabilizes the positions of the major joints. This stabilization **aids tremendously in performing the additional detailed voluntary movements (of fingers or other body parts) required for intricate motor procedures.**
Muscle reflexes

Muscle reflex arc components

Reflexes or reflex actions are involuntary, almost instantaneous movements in response to a specific stimulus. There are two types of reflexes:

1. Autonomic reflex (affecting inner organs)
2. Somatic reflex (affecting muscles):

The basic unit of this reflex is (reflex arc).

A somatic reflex arc defines the pathway by which a reflex travels, from the stimulus to sensory neuron to motor neuron to reflex muscle movement.

This arc consists of:

1. Sense organ
2. An afferent sensory neuron
3. Synapses in the central integration station or sympathetic ganglion
4. An efferent motor neuron
5. Effector organ

Sensory neurons are typically classified as the neurons responsible for converting various external stimuli that come from the environment into corresponding internal stimuli.

Motor neurons located in the central nervous system that projects its axon outside the CNS and directly or indirectly control muscles.
General properties of reflexes:

1. Reaction time and central delay:
   - Reaction Time: the time between the application of stimulus and the response.
   - Central delay: the time taken for the reflex activity to transverse the spinal cord. The central delay of knee jerk is (0.6 to 0.9 ms).

2. Adequate stimulation:
   The stimulation that triggers a reflex is generally very precise (i.e. adequate stimulation) e.g., the scratch reflex in a dog requires multiple touch stimuli arranged in a line, as would be produced by an insect crawling across the skin; if the touch stimuli are widely separated, or not in a line, there is no scratching (fleas take advantage of this; by jumping instead of crawling, they don't evoke the reflex)

3. Final common path:
   The motor neurons that supply the extra-fusal fiber in skeletal muscle are the efferent side of many reflex arcs. All neural influences affecting muscular contraction ultimately funnel through them to the muscles, and they are therefore called (final common paths).
Final common pathway by spinal cord (Spinal organization of motor systems)
a. Convergence
• occurs when a single α-motoneuron receives its input from many muscle spindle group I a afferents in the homonymous muscle.
• produces spatial summation because, although a single input would not bring the muscle to threshold, multiple inputs will
• also can produce temporal summation when inputs arrive in rapid succession
b. Divergence
• occurs when the muscle spindle group I a afferent fibers project to all of the α-motoneurons that innervate the homonymous muscle.
4. Central excitatory and inhibitory states:
The spinal cord modified the output signals to excitatory or inhibitory output depending on the needs.
5. Habituation and sensitization of reflex responses:
The reflexes responses are stereotype do not exclude the possibility of their being modified by experience.
Reflex responses can habituate (decline in amplitude in response to repeated stimuli) or be sensitized (augmented postsynaptic responses after a habituated stimulus is paired with a noxious stimulus)
Muscle stretch reflex (myotatic reflex) or monosynaptic reflex

Neuronal Circuitry of the Stretch Reflex

The simplest manifestation of muscle spindle function is the muscle stretch reflex. Whenever a muscle is stretched suddenly,

- excitation of the muscle spindles

Excitation of type Ia proprioceptor nerve fiber originating in a muscle spindle

- entering a dorsal root of the spinal cord.

A branch of this fiber then goes directly to the anterior horn of the cord gray matter and

- synapses with anterior motor neurons that send motor nerve fibers back to the same muscle from which the muscle spindle fiber originated also of closely allied synergistic muscles.

Thus, this monosynaptic pathway allows a reflex signal to return with the shortest possible time delay back to the muscle after excitation of the spindle.

- Proprioceptor: a sensory receptor which receives stimuli from within the body, especially one that responds to position and movement
Dynamic Stretch Reflex and Static Stretch Reflexes.
The stretch reflex can be divided into two components:

1. The dynamic stretch reflex
   - When a muscle is suddenly stretched
   - Simulation of dynamic nuclear bag impulses
   - Transmitted by primary nerve (Ia) causing
   - Signal is transmitted to the spinal cord,
   - Which causes an instantaneous strong reflex contraction (or decrease in contraction) of the same muscle from which the signal originated.
   - Thus, the reflex functions to oppose sudden changes in muscle length.
   - The dynamic stretch reflex is over within a fraction of a second after the muscle has been stretched to its new length
   - Example: Knee jerk and ankle jerk

2. The static stretch reflex
   - When the muscle is stretched slowly static stretch reflex is elicited by the continuous static receptor signals transmitted by
   - Both primary and secondary endings.
   - Static stretch reflex are weaker and continues for a prolonged period thereafter.
   - The importance of the static stretch reflex is that it causes the degree of muscle contraction to remain reasonably constant; this is why it plays an important role in control of posture e.g. when the person is standing, gravity continues stretching on the antigravity muscle making them to continue stretching as long as the gravity making them stretched.
"Damping" تقليل الاهتزازات Function of the Dynamic and Static Stretch Reflexes in Smoothing Muscle Contraction.

An especially important function of the stretch reflex is its ability to prevent oscillation or jerkiness of body movements, which is a damping, or smoothing, function. Signals from the spinal cord are often transmitted to a muscle in an unsmooth form, increasing in intensity for a few milliseconds, then decreasing in intensity, then changing to another intensity level, and so forth. When the muscle spindle apparatus is not functioning satisfactorily, the muscle contraction is jerky during the course of such a signal.

In curve A, the muscle spindle reflex of the excited muscle is intact. Note that the contraction is relatively smooth, even though the motor nerve to the muscle is excited at a slow frequency of only eight signals per second. Curve B illustrates the same experiment in an animal whose muscle spindle sensory nerves had been sectioned 3 months earlier. Note the unsmooth muscle contraction. Thus, curve A graphically demonstrates the damping mechanism's ability to smooth muscle contractions, even though the primary input signals to the muscle motor system may themselves be jerky. This effect can also be called a signal averaging function of the muscle spindle reflex.
Stretch myotatic reflex (is monosynaptic)

Knee Jerk and Other Muscle Jerks Can Be Used to Assess Sensitivity of Stretch Reflexes.

Clinically, a method used to determine the sensitivity of the stretch reflexes is to elicit the knee jerk and other muscle jerks.

The knee jerk can be elicited by simply striking the patellar tendon with a reflex hammer; this action instantaneously stretches the quadriceps muscle and excites a dynamic stretch reflex that causes the lower leg to “jerk” forward.

Muscle reflexes can be obtained from almost any muscle of the body either by striking the tendon of the muscle or by striking the belly of the muscle itself. In other words, sudden stretch of muscle spindles is all that is required to elicit a dynamic stretch reflex.

The muscle jerks are used by neurologists to assess the degree of facilitation of spinal cord centers.

Facilitation of spinal cord centers: means how spinal cord centers handle injuries. It occurs when sensory information from an area of pathology is sent via the afferents to the spinal cord.
• https://www.youtube.com/watch?v=VzCwXaU_tJ0
• https://www.youtube.com/watch?v=jK0JS2OsvKA
• https://www.youtube.com/watch?v=fLzvuYnw0OY
• https://www.youtube.com/watch?v=iMLYbZfMgP8
• https://www.youtube.com/watch?v=8xse2WWWoYl
Stretch myotatic reflex or knee jerks reflex  
Tapping on the patellar tendon
▼
causes the quadriceps to stretch.
▼
Stretch of the quadriceps stimulates group la afferent fibers,
▼
which activate α-motor neurons
▼
that make the quadriceps contract.
▼
Contraction of the quadriceps forces the lower leg to extend.
As the muscle contracts, it shortens, decreasing the stretch on the muscle spindle and returning it to its original length.
Increases in γ-motor neuron activity increase the sensitivity of the muscle spindle and therefore exaggerate the knee-jerk reflex.
When a stretch reflex occurs, the muscle that antagonizes the action of the muscle involved (antagonists) relax. This phenomenon is said to be due to reciprocal innervation. Impulses in the Ia fibers from the muscle spindles of the protagonist muscle causes post-synaptic muscle cause post-synaptic inhibition of the motor neurons to the antagonists. The pathway mediating this effect is bi-synaptic. A collateral from each Ia fiber passes in the spinal cord to an inhibitory interneuron (Golgi bottle neuron is the inhibitory interneuron which is involved in the phenomenon of Reciprocal Innervation by which the antagonist muscles relax during protagonist muscle contraction) that synapses directly on one of the motor neurons supplying antagonist muscles. The best example is the reflex contraction of the biceps muscle and relaxation of triceps muscle, the reflex contraction of the quadriceps muscle and relaxation of hamstrings muscle.

When contraction of a muscle is stimulated, there is a simultaneous inhibition of the antagonist muscle this is called (Sherrington’s Law of reciprocal innervation)
Golgi Tendon reflex:
The Golgi tendon organ

The Golgi tendon organ is a specialized receptor that is located between the muscle and the tendon at the musculo-tendinous junctions of somatic muscle.

Each skeletal muscle contains a large number; approximately 1 Golgi tendon organ for every 10 muscle fibers.

Unlike the muscle spindle, which is located in parallel with extrafusal fibers, the Golgi tendon organ is located in series with the muscle.

When force is applied to a muscle, the Golgi tendon organ is stretched, causing the collagen fibers to squeeze and distort the membranes of the primary afferent sensory endings. As a result, the afferent is depolarized, and it fires action potentials to signal the amount of force.

These ending produce generator potentials and action potential discharges with frequency proportional to the force exerted on the capsule. The tendon organ acts as a "force transducer and signals information about the load or force being applied to the muscle in a sustained fashion when the muscle is active."
A Golgi tendon organ is innervated by primary afferents called Group Ib fibers, which have specialized endings that weave in between the collagen fibers. These sensory structures appear to be quite localized, that is they will monitor force within a subdivision of tendon which represents the physical connection of a motor unit to the global tendinous structure of the muscle. Thus the CNS has information about the force output of individual motor units and can make feedback adjustments appropriately in the efferent side. Thus, the major difference in excitation of the Golgi tendon organ versus the muscle spindle is that the spindle detects

1. **muscle length** and
2. **changes in muscle length**, whereas

the tendon organ detects

**muscle tension** as reflected by the tension in itself.
Golgi tendon reflex or (inverse myotatic reflex) or Ib Reflex

- is disynaptic.
- is the opposite, or inverse, of the stretch reflex.

*Active muscle contraction* stimulates the Golgi tendon organs that detect muscle tension

- Golgi tendon organs connected to group Ib afferent fibers

- The group Ib afferents stimulate inhibitory interneurons in the spinal cord.

These inter-neurons inhibit α-motoneurons and cause relaxation of the muscle that was originally contracted. At the same time, antagonistic muscles are excited.
d. *Clasp-knife reflex*, an exaggerated form of the Golgi tendon reflex, can occur with disease of the cortico-spinal tracts (hyper-tonicity or spasticity).

For example, if the arm is hypertonic, the increased sensitivity of the muscle spindles in the extensor muscles (triceps) causes resistance to flexion of the arm. Eventually, tension in the triceps increases to the point at which it activates the Golgi tendon reflex, causing the triceps to relax and the arm to flex closed like a jackknife.

Golgi tendon reflex occurs when the tension become great enough, so the contraction suddenly ceases and muscle relaxes.

The Golgi tendon organ function:

The Golgi tendon organ detects:

a) The *rate of increase of tension on a muscle during active contraction* so helps control muscle tension and prevents excessive tension on the muscle.

When tension on the muscle—and therefore on the tendon—becomes extreme, the inhibitory effect from the tendon organ can be so great that it leads to a sudden reaction in the spinal cord that causes instantaneous relaxation of the entire muscle. This effect is called the *lengthening reaction*; it is probably a protective mechanism to prevent tearing of the muscle or avulsion of the tendon from its attachments to the bone.
b) the **absolute amount of tension** on a muscle during a isometric

The tendon organ, like the primary receptor of the muscle spindle, has both a dynamic response and a static response, reacting intensely when the muscle tension suddenly increases (the dynamic response) but settling down within a fraction of a second to a lower level of steady-state firing that is almost directly proportional to the muscle tension (the static response). Thus, Golgi tendon organs provide the nervous system with instantaneous information on the degree of tension in each small segment of each muscle.

The possible role of the tendon reflex to equalize contractile force among them fibers.

Another likely function of the Golgi tendon reflex is to equalize contractile forces of the separate muscle fibers. That is, the fibers that exert excess tension become inhibited by the reflex, whereas those that exert too little tension become more excited because of the absence of reflex inhibition. This phenomenon spreads the muscle load over all the fibers and prevents damage in isolated areas of a muscle where small numbers of fibers might be overloaded.
Since the Golgi tendon organ, unlike the spindle are in series with muscle fibers, they are characterized by:

1. Golgi tendon organs stimulated by both passive stretch and active contraction of the muscle.
2. The Golgi tendon organs threshold is low.
3. The degree of stimulation by passive stretch is not great, because the more elastic muscle fibers take up much of the stretch, and this is why it takes a strong stretch to produce relaxation. This relaxation is caused by Interneurons that release inhibitory postsynaptic potential.

Transmission of Impulses from the Tendon Organ into the Central Nervous System.

Signals from the tendon organ are transmitted through type Ib nerve fibers. These fibers, like those from the primary spindle endings, transmit signals both into

a. local areas of the cord

The local cord signal excites a single inhibitory interneuron that inhibits the anterior motor neuron. This local circuit directly inhibits the individual muscle without affecting adjacent muscles.

b. long fiber pathways

① the cerebellum by , the dorsal spino-cerebellar tracts at conduction velocities approaching 120 m/sec, the most rapid conduction anywhere in the brain or spinal cord.

② Additional pathways transmit similar information into the reticular regions of the brain stem and, to a lesser extent, all the way to the motor areas of the cerebral cortex.
Flexor reflex and withdrawal reflex:

In its classic form, the flexor reflex is elicited most powerfully by stimulation of pain endings, such as by a pinprick, heat, or a wound, for which reason it is also called a nociceptive reflex, or simply a pain reflex. Stimulation of touch receptors can also elicit a weaker and less prolonged flexor reflex.

If some part of the body other than one of the limbs is painfully stimulated, that part will similarly be withdrawn from the stimulus, but the reflex may not be confined to flexor muscles, even though it is basically the same type of reflex. Therefore, the many patterns of these reflexes in the different areas of the body are called withdrawal reflexes. The arm is jerked away from the stove.

- is polysynaptic.
- Somato-sensory and pain afferent fibers elicit withdrawal of the stimulated body part from the noxious stimulus.
  a. Pain (e.g., touching a hot stove) stimulates the flexor reflex afferents of groups II, III, and IV.
  b. The afferent fibers synapse poly-synaptically (via inter-neurons) onto moto-neurons in the spinal cord.
  c. On the ipsilateral side of the pain stimulus, flexors are stimulated (they contract) and extensors are inhibited (they relax) because of inhibitory effects of Renshaw cells.

In other words, the integrative centers of the cord causes the muscles to contract that can most effectively remove the pained part of the body away from the object causing the pain. Although this principle applies to any part of the body, it is especially applicable to the limbs because of their highly developed flexor reflexes.
Neuronal Mechanism of the Flexor Reflex

A painful stimulus is applied to the hand; as a result, the flexor muscles of the upper arm become excited, thus withdrawing the hand from the painful stimulus.

The pathways for eliciting the flexor reflex do not pass directly to the anterior motor neurons but instead pass first into the spinal cord interneuron pool of neurons and only secondarily to the motor neurons. The shortest possible circuit is a three- or four-neuron pathway; however, most of the signals of the reflex traverse many more neurons and involve the following basic types of circuits:

1. Diverging circuits to spread the reflex to the necessary muscles for withdrawal;
2. Circuits to inhibit the antagonist muscles, called reciprocal inhibition circuits; and
3. Circuits to cause after-discharge that lasts many fractions of a second after the stimulus is over.

Myogram of the flexor reflex

- Within a few milliseconds after a pain nerve begins to be stimulated, the flexor response appears.
- Then, in the next few seconds, the reflex begins to fatigue, which is characteristic of essentially all complex integrative reflexes of the spinal cord.
- Finally, after the stimulus is over, the contraction of the muscle returns toward the baseline, but because of after-discharge, it takes many milliseconds for this contraction to occur.
Reciprocal inhibition and reciprocal innervation

We previously pointed out that excitation of one group of muscles is often associated with inhibition of another group. For instance, when a stretch reflex excites (agonist) muscle, it often simultaneously inhibits the antagonist muscles, which is the phenomenon of reciprocal inhibition, and the neuronal circuit that causes this reciprocal relation is called reciprocal innervation. Likewise, reciprocal relations often exist between the muscles on the two sides of the body, as exemplified by the flexor and extensor muscle reflexes described earlier.
Cross extensor reflex
About 0.2 to 0.5 second after a stimulus elicits a flexor reflex in one limb, the opposite limb begins to extend. This reflex is called the **crossed extensor reflex**. Extension of the opposite limb can push the entire body away from the object, causing the painful stimulus in the withdrawn limb.

**Neuronal Mechanism of the Crossed Extensor Reflex.**
Because the crossed extensor reflex usually does not begin until 200 to 500 milliseconds after onset of the initial pain stimulus, it is certain that many interneurons are involved in the circuit between the incoming sensory neuron and the motor neurons of the opposite side of the cord responsible for the crossed extension.
After the painful stimulus is removed, the crossed extensor reflex has an even longer period of after-discharge than does the flexor reflex. Again, it is presumed that this prolonged after-discharge results from reverberating circuits among the inter-neuronal cells.
General relation of withdrawal reflex with stimuli

1. The intensity of stimuli:
   A. Increase intensity of stimuli will produce greater flexion; this is because more muscles involve in the action and more nerves are involved.
   B. Increase intensity of stimuli will produce prolonged flexion; this is called (after-discharge). It is presumed that this prolonged after-discharge result from (re-verberatory circuit). After discharge time in flexion arm (i.e. withdrawn arm is 0.1 to 3 second after irritation is over), but it is much longer in the extensor.

2. The site of stimulation (local sign):
   A. If the medial surface of the limb is stimulated; the response will be flexion and abduction.
   B. If the lateral surface of the limb is stimulated then the response will be flexion and adduction.