Chapter H: Central Nervous System

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H.4. Motor Systems

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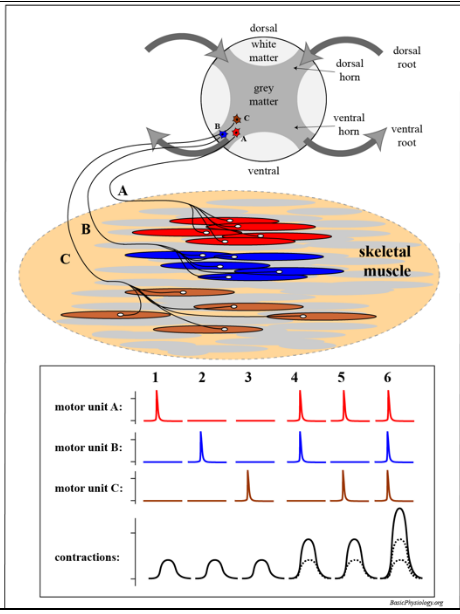
H.4.1. Motor System

A. Introduction:

1. As you can imagine, the large brains consist of several systems located in different parts of the large brains.	2. We can not consider ALL systems (there are so many) but will concentrate on the most important ones: a) The motor system b) The sensory system c) The autonomic system????
3. Of course, nothing is simple, certainly not in the brain. The motor system, for example, also consists of two different systems, fortunately collaborating with each other (!). These are: a) The pyramidal motor system b) The extrapyramidal motor system	

B. Remember the Motor Units in the spinal cord?

1. The function of the motor system, as you can imagine, is to determine our motility, for which we have the skeletal muscles, the muscles that are connected to our skeleton.	2. The skeletal muscle will contract when it is stimulated by an impulse (= an action potential) that comes from a nerve cell located in the spinal cord. This is what we called a motor unit (link: *A.4.6. Motor Units*).
3. This is in contrast to other types of muscle cells such as the smooth muscle cell or the cardiac cell which are innervated (excited) in their own organs (see *chapter A*).	4. Maybe it is good at this stage to repeat the picture from Chapter A:
	5. As you can see in this diagram, the action potential that will stimulate a group of cells in a skeletal muscle originate from nerve cells located in the ventral horn of the spinal cord; ‘a’, ‘b’ and/or ‘c’ nerve cell (and many more …)



6.
The major question in this chapter; how does this nerve cell know when to stimulate these skeletal muscle cells?

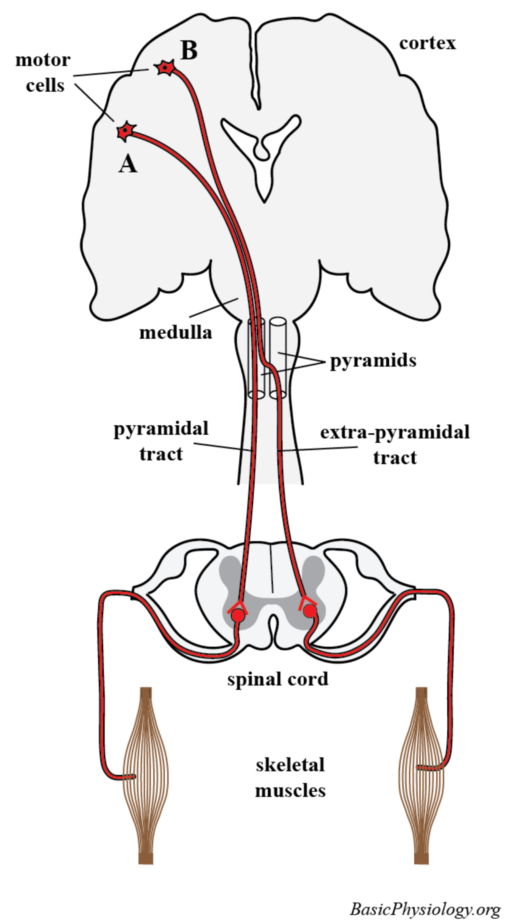
C. The pyramidal and the extra-pyramidal motor system:

1.
As you can see in the diagram, the principle is quite simple; there is a nerve cell, located in the cortex (= superficial layer) of the large brain. The axon from this cell then conducts the nervous impulses all the way through the brain, through the medulla into the spinal cord until it reaches the appropriate level in the spinal cord.

2.
At this level, the axon synapses to a second nerve cell which is the cell that innervates the appropriate skeletal muscle fibber. That's all! Really?? Yes and no 😜!!!

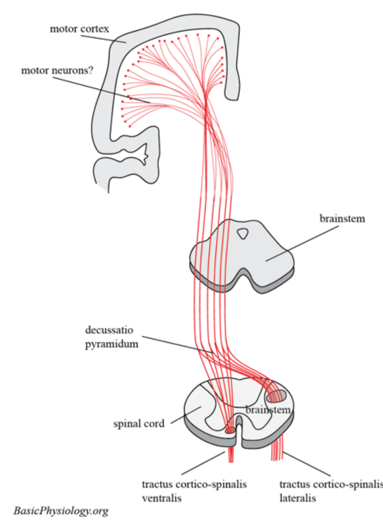
3.
Yes; there is one specific neuron in the large brain cortex that sends signals, through a second nerve cell in the spinal cord, to stimulate a group of fibres in a specific skeletal muscle.

4.
And since we have a lot of skeletal muscles in our body, there must be a lot of nerve cells in the cortex that are all coupled to specific muscles.

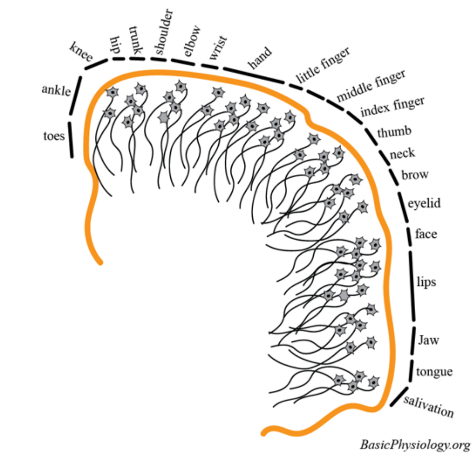


<table>
<tr><td></td><td></td></tr>
<tr><td>5.
But the diagram also shows something even more strange. Look at the second axon (axon B). It also starts from the same area and runs through the large brain, but, just below the medulla, it suddenly ‘jumps’ to the other side and innervates a spinal cord cell in the right side of the body!</td><td>6.
Why? No one knows. Evolution? In fact most of these motor axons cross-over, at this level, to the other side of the body; about 95%! In other words, our left cortex controls 95% of the skeletal muscles in the right body and the right cortex controls 95% of the left body!</td></tr>
<tr><td>7.
This crossing-over occurs in a specific region of the medulla called the pyramids (one left and one right).</td><td>8.
That is why the axons that run through the pyramid and remain on the same side (±5%) are called the pyramidal tract while those crossing over (±95%) are called the extra-pyramidal tract.</td></tr>
</table>

D. Cortical Homunculus:

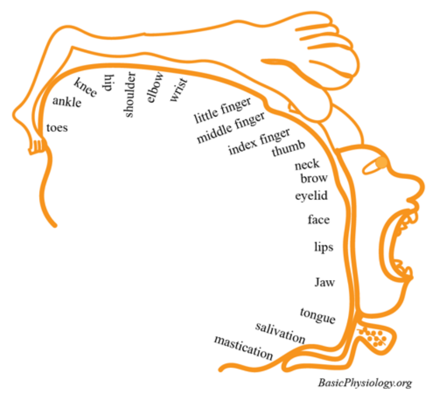
<table>
<tr><td>1.
This diagram is essentially a repitition of the previous diagram but with large number of axons plotted to show the extend of the motor nerve cells in the cortex and their axons running throuhg the brain and of course the large number (95%) of axons that cross-over to the other side. This crossing over is called ‘decussatio pyramidum’ which is latin for “crossing at the pyramid”.</td><td rowspan="2">
</td></tr>
<tr><td>2.
In the spinal cord, the two tracts are called tractus cortico-spinalis ventralis (same side) and tractus cortico-spinalis lateralis (opposite side). You don’t need a lot of latin to understand this!</td></tr>
<tr><td>3.
Ok, let’s go back to the cortex because there is something there which is even more interesting!
This diagram shows the relationship between the location of the motor neurons in the</td><td></td></tr>
</table>

cortex and the body parts that are mobilized by these skeletal muscles.



4.
Now you can see which neurons innervate the muscles in the legs (toe, ankle, knee), innervate the muscles in the face (lips, jaw etc.), and more. As you can see, some areas, indicated by the black bars, are larger than others. For example, the number of neurons innervating the muscles in the lip is much higher than those innervating the muscles in the neck, for example.

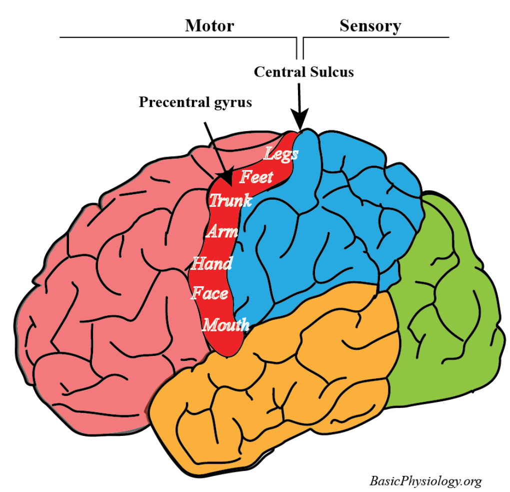
5.
In fact, in many neurology books, you will see a diagram depicting a human being drawn along the motor cortex with their size related to the number of neurons that innervate those areas.



6.
Sometimes, this is called the cortical "homunculus". This is Latin (again!) for a small human being, but distorted to reflect the degree of motor neuron innervation of the body parts.

7.
Another way to look at this cortex, is shown in this diagram.
Here you can see the location of the **precentral gyrus** with, in white, the location of the motor neurons innervating several major body parts, from the legs (top) all the way to the mouth (bottom).

8.
Btw, this is an important name to remember; precentral gyrus. **Gyrus** means a ridge-like elevation of the brain tissue. "Precentral" means "before the central sulcus". The central sulcus is a groove that separates the precentral gyrus from the postcentral gyrus.

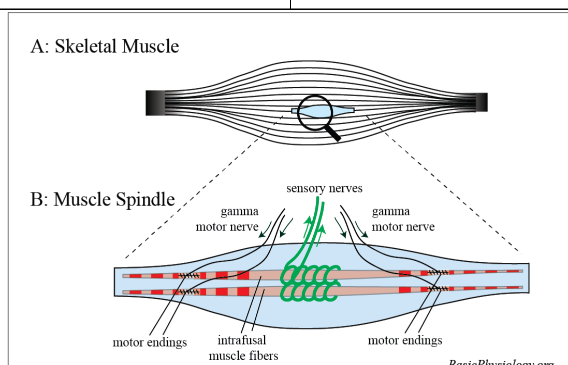


9. Sorry for all these terms but these are quite common in this field; sorry!!	

H.4.2. Muscle Spindle and Tendon Organ

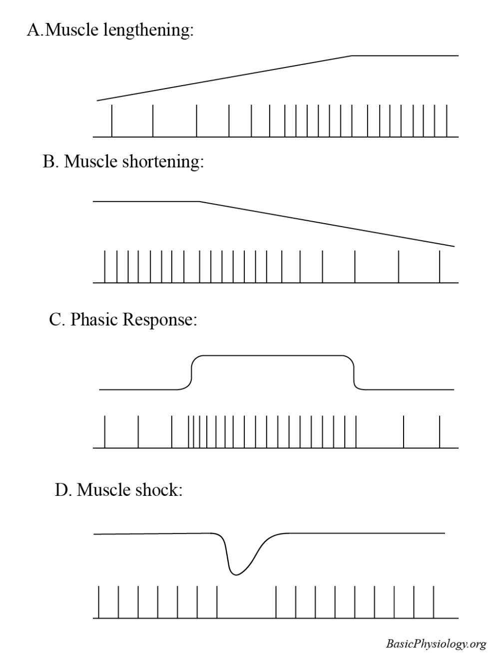
A. The Muscle Spindle:

<table>
<tr><td>1.
Muscle spindles are stretch receptors that are located/distributed in the belly of skeletal muscles.</td><td>2.
They primarily detect changes in the length of the muscles which is (of course) very useful to know, for the brain!</td></tr>
<tr><td>3.
For this function, special muscle fibres are located inside the spindle. These are called intrafusal fibres (and the ‘normal fibres outside the muscle spindles are now called extrafusal fibres).</td><td>4.
Around these intrafusal muscle fibres, there are loops of sensory nerve endings wrapped around the fibres. These detect the length/tension in these intrafusal fibres and send that information to the brain.</td></tr>
<tr><td>5.
In addition, the muscle fibres in the muscle spindles can also be stimulated, just like the extrafusal fibres, with efferent nerves, called gamma motor neurons.</td><td>6.
As we will see later, these innervations may influence the sensitivity and the function of the muscle spindles.</td></tr>
<tr><td colspan="2">

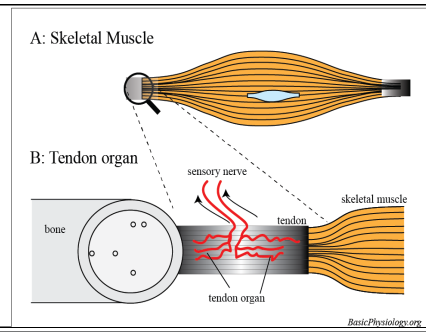
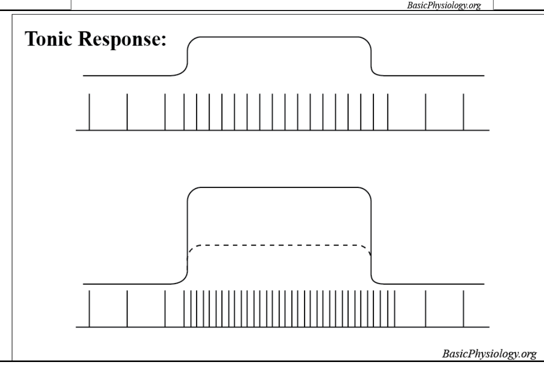


</td></tr>
<tr><td>7.
How many muscle spindles are there in a typical skeletal muscle? Not many, about 25 to 100, on average, in a single muscle.</td><td>8.
But there is a large variation in muscles. Some muscles, such as muscles in the legs or the arms have quite a lot of muscle spindles whereas other muscles such as the facial muscles have little or even no muscle spindles at all.</td></tr>
<tr><td colspan="2">9.
We don’t really know yet what determines this variation. Amount of cerebral control is of course important. But why facial muscles don’t have muscle spindles at all, no idea!</td></tr>
</table>

B. Function of the muscle spindles:

<table>
<tr><td>1.
The function of the muscle spindle is to constantly measure the length of the skeletal muscle, which it does with the sensory endings wrapped around the intrafusal fibres.</td><td>2.
At rest, the muscle spindles discharge a constant rhythm of action potentials that propagate to the brain.</td></tr>
<tr><td>3.
When the muscle is gradually stretched, the action potential frequency gradually increases (panel A) whereas, when the muscle is shortened, the opposite occurs (B).</td><td rowspan="3">
</td></tr>
<tr><td>4.
If there is a sudden increase in the length of the muscle (a jerk) then the firing of the action potentials will suddenly increase and then gradually settle back to that particular length (C).</td></tr>
<tr><td>5.
And, when the muscle is suddenly shortened, the opposite occurs (D).</td></tr>
<tr><td>6.
Btw, why are the gamma motor nerves innervating the intrafusal fibres?</td><td>7.
These gamma motor nerves are constantly sending action potentials to the intrafusal fibres which makes these fibres always (slightly) contracted.</td></tr>
<tr><td>8.
That is important because it means that the fibres are constantly alert to changes in the skeletal muscle length.</td><td>9.
Suppose, that the intrafusal fibres were not constantly contracted but just hang loose in the spindle, then they would not detect any change in the skeletal muscle. In other words, constant contraction keeps these fibres alert all the time!</td></tr>
</table>

C. The Tendon organ:

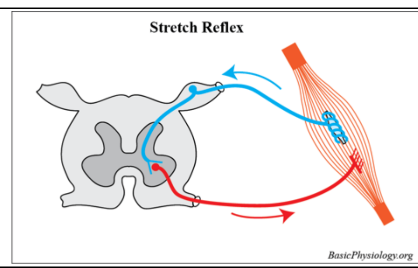
<table>
<tr><td>1.
And then, we have another sensor in the skeletal muscles or, rather, in the tendons that fix the muscles to the skeleton.</td><td>2.
The tendon organ records the tension in the attached muscle; irrespective whether this is induced by active contraction or otherwise.</td></tr>
<tr><td>3.
The amount of tension is ‘translated’ into the frequency of action potentials that are then send to the brain. The higher the tension, the higher the number of action potentials.</td><td>
</td></tr>
<tr><td>4.
Btw, the tendon organ is sometimes also called the Golgi tendon, since Golgi was the first person to describe this structure (born in 1843!).</td><td>
</td></tr>
<tr><td colspan="2">5.
Remember Golgi? Yes! He discovered and described the function of the Golgi body; a group of vesicles located in many cells that collect small molecules into vesicles for further transportation (see A.2.1.F.).</td></tr>
</table>

H.4.3. Motor Reflexes

A. Introduction:

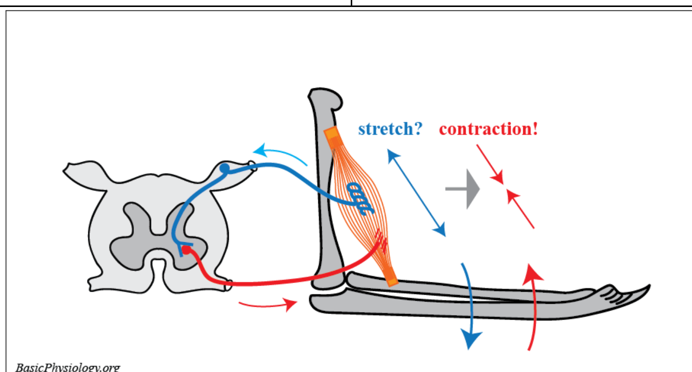
1. What are reflexes? These are 'automatic' responses in the body. These can be motor or sensory responses, usually induced by a stimulus.	2. For example, if you are in a dark room and see suddenly a bright light, then your pupils will react, automatically. Likewise, if your finger suddenly feels something sharp, the muscles in your arm will automatically jerk your hand away from this stimulus. This is called the withdrawal reflex.
3. Reflexes are always very fast, and, you cannot control them.	4. On this page, we will discuss the neuronal reflexes, that occur in the central nervous system. We will start with the most simplex reflex; the muscle stretch reflex.

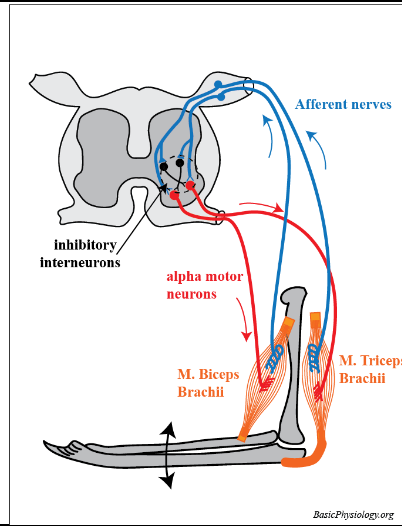
B. Muscle Stretch Reflex:

1. Probably the most 'basic' type of reflex is the stretch reflex, also called the myotatic reflex.	2. As you can see in the diagram, it consists of a muscle spindle and a motor endplate, both located in the same muscle. From the muscle spindle, a sensory nerve propagates to the spinal cord where it enters into the dorsal root.
3. There the nerve connects, in the anterior horn, with a synaps to an alpha-motor neuron. The axon of this neuron leaves the spinal cord, through the dorsal root, to the motor endplate of the same muscle.	
4. Its function is simple. When the muscle is (suddenly) stretched, this stretch is detected by the intrafusal fibers in the muscle spindles.	5. This stretch induces action potentials in the muscle spindle that propagate, through the sensory nerve to the spinal cord. The nerve ends as a synapse onto the body of the motor neuron, in the anterior horn.
6. There it stimulates the neuron to produce action potentials that propagate, through the	7.

motor nerve, to the motor-endplates of the same muscle.	This will lead to muscle contractions that will reduce the length of the muscle to its original length. It is like a feed-back loop!
8. This reflex works very fast! From stretch to contraction, about 25 msec!	

C. Body Position and Posture:

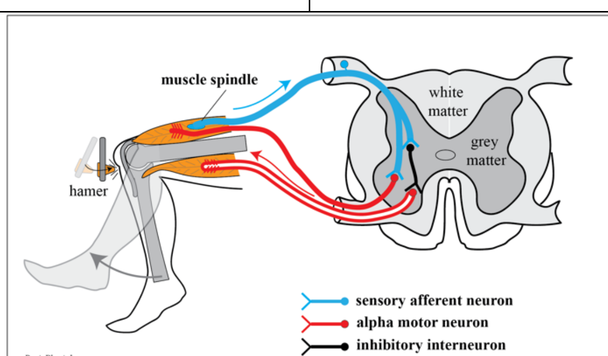
1. Why do we need this stretch reflex?	2. To keep our posture! Without this reflex, our body would collapse.
3. Look at this simple diagram. The biceps muscle holds the lower arm at an angle to the upper arm, in this case about 90 degrees.	4. If for some reason, the lower arm moves downwards, then the intrafusal fibers in the muscle spindle will also be stretched which will evoke action potentials.
	
5. These action potentials will propagate to the spinal cord where it will excite the alpha-motor neurons of the biceps.	6. These action potentials will propagate back to the biceps to increase its contraction force which will move the lower arm back to its original position. All this automatically and very fast (25 msec!).
7. But what about the other muscles that are also attached to the arms around the elbow joint? After all, they also play an important role in keeping up this position.	
8. But, as you can see in this second diagram, it now becomes a bit more complicated in the spinal cord.	

9. As one muscle, for example the biceps, is contracting, then the 'opposite' muscle, the triceps, must do the opposite; relax!	

10. And if the triceps contracts, then the biceps must relax. And all this very very fast!	11. Fortunately, this is taken care of by negative intermediary neurons (in black in the diagram). So, when one alpha motor neuron is activated, the 'opposite' motor neuron is inhibited.
12. And, as you have to realize, this is the case for all our skeletal muscles in our body, adjacent to all our joints, from elbow to knee joint etc.	

D. Knee jerk reflex:

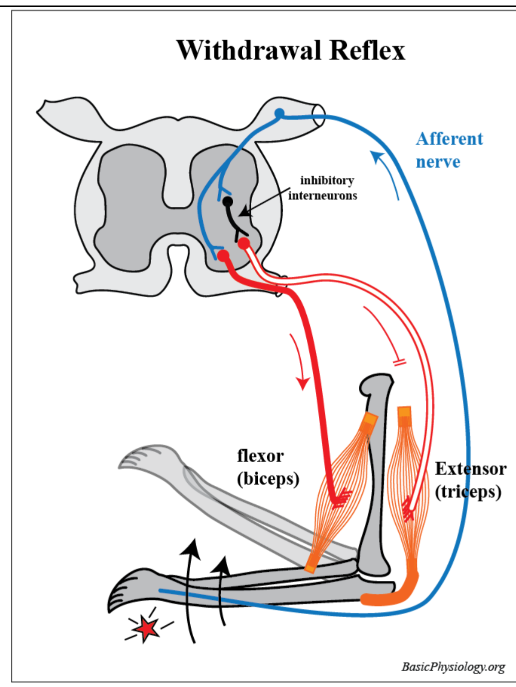
1. A nice way to test this system, which is often used by doctors, is the knee jerk reflex.	2. In this test, a hammer is used to strike the tendon of the knee patella.



3. This tendon is attached to the upper leg muscle. The sudden 'jerk' of the tendon will	4.

suddenly stretch the muscle fibers including the muscle spindles inside that muscle.	As the intrafusal fibers are also suddenly stretched, they will send action potentials along their afferent nerves to the spinal cord.
5. This will excite the corresponding alpha motor neuron which will contract this muscle and move the lower leg, suddenly, upwards, like a 'kick'.	6. At the same time however, the opposite muscle must be inhibited (relaxed) to allow this jerk movement to take place.
7. Therefore, that muscle must be inhibited. This is performed by an interneuron, located in the spinal cord and activated by action potentials from the same excited muscle spindle.	8. However, the action potentials in that interneuron will inhibit action potentials of the opposite muscles, allowing that muscle to relax.

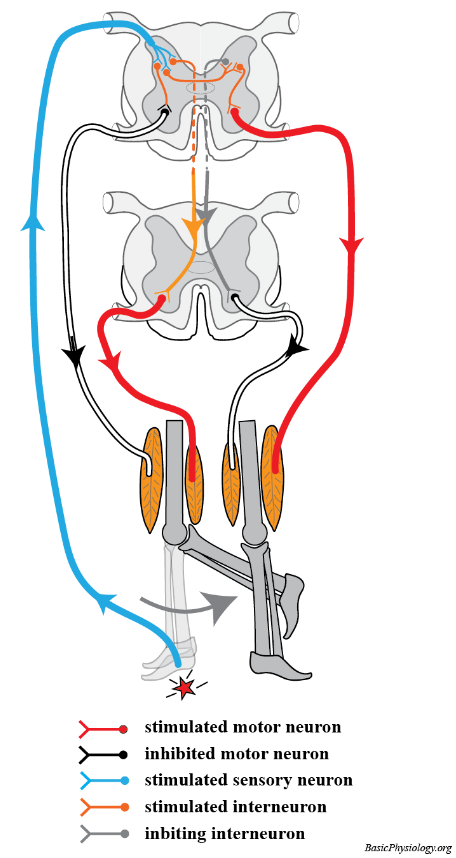
E. Withdrawal reflex:

1. The withdrawal reflex occurs when your hand (or foot) encounters a sharp (or hot) object inducing a sudden withdrawal of your limb.	
2. The purpose of this reflex is to jerk your hand away from this dangerous stimulus.	
3. And again, this must happen very fast, to avoid further damage to your hand.	
4. The diagram shows the most important pathways of this withdrawal reflex. Starting with the hand where a sharp object has stimulated a painful stimulus.	
5. This induces action potentials in the sensory nerves that travel to the spinal cord. Once in the spinal cord, the nerve synapses to a motor neuron and to an interneuron.	6. The motor neuron is connected and excites the corresponding flexor (in this case the biceps) to contract strongly.

7. The interneuron is connected, as an inhibitory neuron, to the motor neuron of the opposite muscle; the extensor.	8. This is important because you want the arm to move rapidly away from the painful stimulus and therefore, the extensor muscle must not contract, but relax.

F. Cross-over reflex:

1. In the arms, the withdrawal reflex works fine; jerk your hand and arm away from the painful stimulus. That's all!	2. But in the legs, jerking your foot suddenly away from a painful stimulus is more complicated.
3. If your right foot/leg is suddenly jerked away, then you would suddenly fall over! And, remember, all this happens very quickly.	4. To avoid your falling over, your other leg must take over your posture. Fortunately, we have neuronal connections for this!
5. But since several muscles in the upper and lower legs are involved in this reflex, the neuronal connections must also cross-over to the other side of the spinal cord and to other segments in the spinal cord.	
6. So, the flexor in the right leg must be stimulated to withdraw the foot from the painful stimuli. This is a simple withdrawal reflex.	
7. At the same time, the opposite extensor muscle in the right leg must be inhibited. Like in the withdrawal reflex	
8. But, the muscles in the left leg must also be excited. But this time it is the extensor that must be stimulated while the flexor must be inhibited. The opposite action!	

	Cross-over Reflex 
9. Fortunately, as you can see in the diagram, there are several interneurons that connect the motor neurons in the right way.	
10. Btw, the withdrawal effect is only functioning in the legs. Not in the arms! We don't need that in the upper limbs.	11. That's because you will not 'fall over' when you suddenly 'withdraw' an arm. The legs are keeping us stable, thanks to all the stretch reflexes in our legs.

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