The Somatic Nervous System

Mimi Jakoi, PhD
Jennifer Carbrey, PhD

The underlined headings correspond to the two Somatic Nervous system videos.

1. Introduction and structure

The efferent portion of the peripheral nervous system consists of the somatic nervous system and the autonomic nervous system. The autonomic nervous system controls the function of glands, smooth muscle, cardiac muscle, and the neurons of the GI tract. It is composed of two neurons in series that can either excite or inhibit the target organ. In contrast, the somatic nervous system contains single neurons that excite skeletal muscles. The movements controlled by the somatic nervous system can be voluntary or involuntary (reflexes).

Motor Unit

The axons of **motor neurons** are myelinated and have large diameters for fast conduction of action potentials. As the axon approaches a skeletal muscle fiber (muscle cell) it usually branches to form synapses with anywhere from three to one thousand muscle fibers. However, each muscle fiber is usually innervated by only a single neuron. A **motor unit** consists of a neuron and all of the muscle fibers it innervates. A single neuron innervates fibers from only one muscle and the innervated muscle fibers are usually spread throughout the muscle.

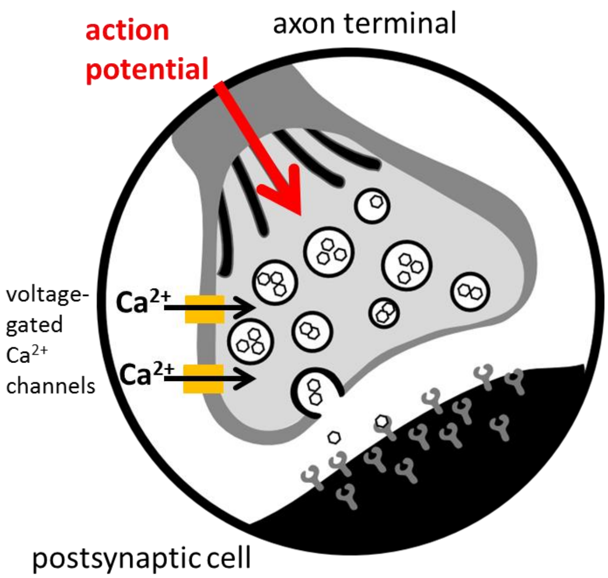

Figure 1. Neuromuscular junction. Image by OCAL (modified), http://www.clker.com/clipart-26784.html, public domain

The portion of the skeletal muscle fiber plasma membrane that synapses with the motor neuron axon is called the **motor end plate**. Once an action potential arrives at the axon terminal, the depolarization of the membrane opens voltage-gated calcium channels (Fig. 1). An increase in intracellular calcium at the terminal causes release of acetylcholine vesicles into the **neuromuscular junction**. The acetylcholine binds nicotinic channels at the motor end plate which causes them to open and allow sodium to enter (Fig.1). The sodium entry triggers voltage-gated sodium channels near the motor end plate, initiating an action potential which is propagated in all directions along the plasma membrane of the muscle fiber.

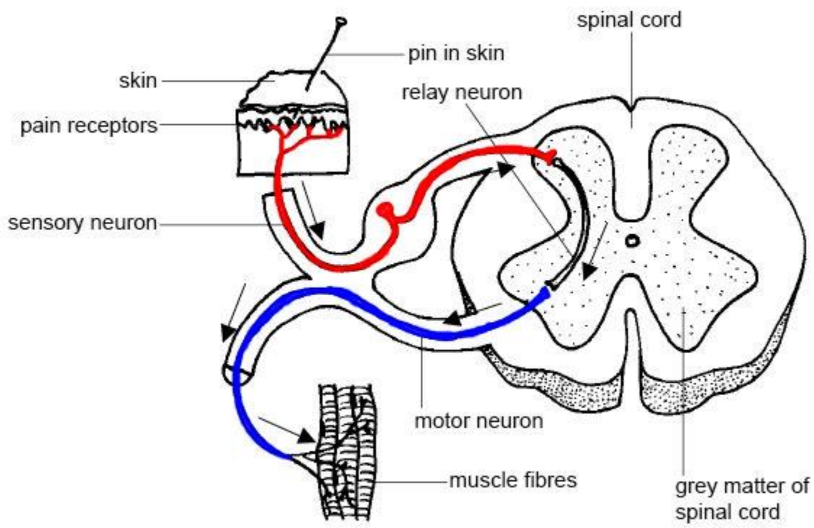

Figure 2. Spinal cord structure. Image by Ruth Lawson Otago Polytechnic (modified), Creative Commons Attribution 3.0 Unported license http://commons.wikimedia.org/wiki/File:Anatomy_and_physiology_of_animals_Relation_btw_sensory,_relay_%26_motor_neurons.jpg,

Spinal Cord Anatomy

The cell bodies of the neurons that innervate skeletal muscle of the body are found in the **ventral horn** of the spinal cord (Fig. 2, blue). The neurons that innervate the skeletal muscle of the head are in the brainstem. In the body, sensory signals come into the spinal cord from the **dorsal root ganglia,** which contain the cell bodies of sensory neurons (Fig. 2, red). These neurons can excite motor neurons in the spinal cord. Motor neuron axons travel through tissues as nerves and synapse on skeletal muscle cells. Excitation of **motor neurons** causes acetylcholine to be released at the neuromuscular junction causing contraction of the muscle. The muscle relaxes when the motor neuron is no longer excited.

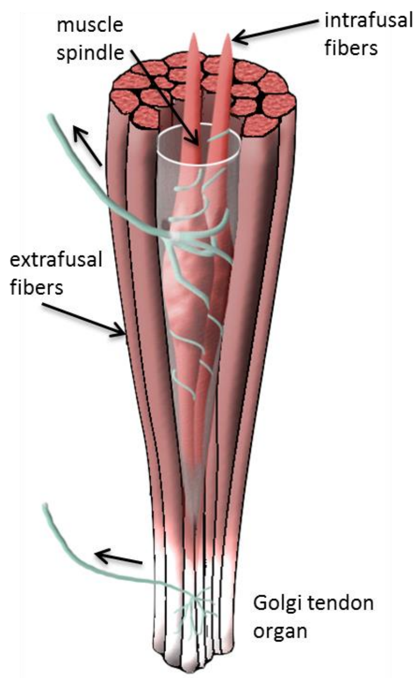

Figure 3. Sensory receptors in skeletal muscle. Image by Rick Melges, Duke University

2. Control of Movement

The spinal cord is not just a conduit connecting the peripheral nervous system and the brain. Instead, movements such as walking as well as reflexes are organized by the spinal cord. In situations when control by **upper motor neurons** in the brain is necessary, they act on the **lower motor neurons** of the spinal cord to influence reflexes and voluntary movements.

Two types of lower motor neurons. The portion of a skeletal muscle that controls posture and movement, the extrafusal muscle fibers, are innervated by **alpha motor neurons**. A specialized type of skeletal muscle fiber, the intrafusal muscle cell, resides in the **muscle spindle** in the interior of the muscle (Fig. 3). The intrafusal muscle fibers are innervated by **gamma motor neurons**. During muscle contraction, alpha and gamma motor neurons are coactivated. Stretching of the intrafusal fibers in the muscle spindle is sensed by stretch receptors and sent via afferent sensory neurons to the spinal cord. This allows for monitoring of the length of the muscle which helps control muscle tone.

Two types of muscle sensory receptors. In order for the body to be able to control muscle contraction properly, there must be feedback about the contractile status of individual muscles. The muscle spindle is an important muscle sensory receptor that provides information about muscle length and the rate of change of muscle length. In addition, **Golgi tendon organs** are encapsulated sensory receptors situated in tendons near the junction with the muscle (Fig. 3). They detect changes in muscle tension instead of changes in muscle length. Both types of sensory receptors send information to the spinal cord and the brain that is usually subconscious.

Muscle Stretch Reflex. If a muscle spindle within a muscle is quickly stretched, the muscle stretch reflex causes contraction of the muscle as well as nearby muscles. This is what occurs when the patellar tendon is struck during a physical exam (Fig. 4). The afferent sensory neuron relays the stretch signal from the muscle spindle to its cell body in the dorsal root of the spinal cord. The sensory neuron synapses with the motor neuron in the spinal cord that controls that muscle. In addition, the sensory neuron activates an inhibitory neuron which inhibits the motor neuron (reducing its likelihood of firing an action potential) leading to the muscle on the opposite side of the limb, causing it to relax (Fig. 4). The muscle spindle reflex is important in allowing maintenance of the length of a certain muscle.

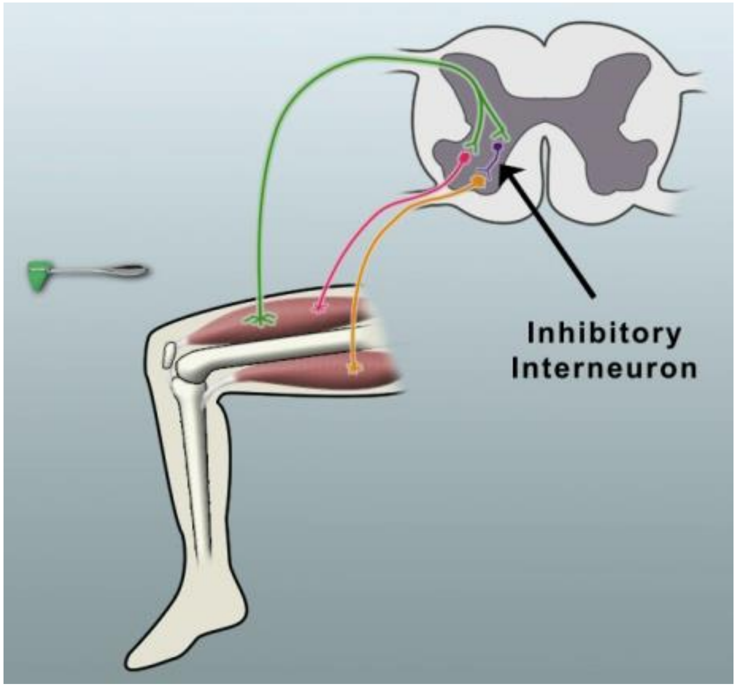

Figure 4. The circuitry of the muscle stretch reflex. Image by Rick Melges, Duke University

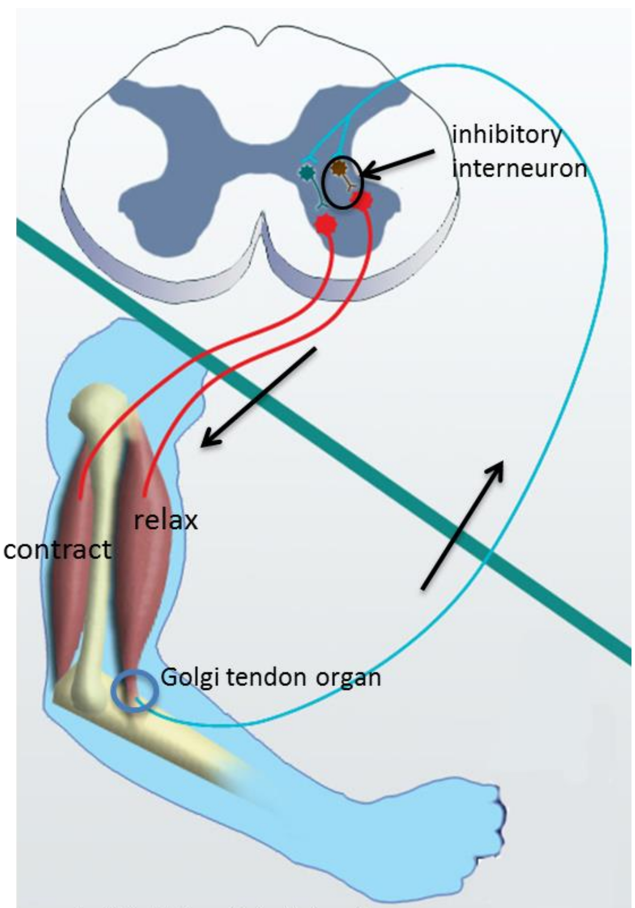

Figure 5. The circuitry of the Golgi tendon reflex. Image by Rick Melges, Duke University

Golgi Tendon Reflex. If the Golgi tendon organs of a muscle are stretched and stimulated, muscle contraction is inhibited through inhibition of the motor neuron leading to that muscle. This is because the afferent neuron activates an inhibitory neuron which is synapsing with the motor neuron (Fig. 5). In addition, the opposing muscle is stimulated to contract through the interaction of an excitatory interneuron with the afferent neuron (Fig. 5). The Golgi tendon reflex acts to protect muscles and tendons from damage due to excessive tension. In addition, they may play a role in equalizing the load across different parts of a muscle.

Withdrawal Reflexes. A withdrawal reflex occurs when a part of the body such as a portion of a limb is subjected to a painful stimulus. The **flexor reflex** causes contraction of one muscle and relaxation of the opposing muscle to move that portion of the body away from the insult. A short time after the flexor reflex initiates, the **crossed extensor reflex** initiates on the opposite side of the body. This reflex allows for the opposite side of the body to support the body's weight or to push the body out of the way of the painful stimulus.

Locomotion. Walking and running require the legs to alternate between forward flexion (the **swing phase**) and backward extension (the **stance phase**). The repetition of this pattern is synchronized with the other leg so that the two legs remain in opposite phases. In most animals, if the spinal cord is separated from the brain the four legs can still make coordinated walking motions. This is accomplished through **central pattern generators** which are oscillatory neural circuits of lower motor neurons in the spinal cord. Even though these circuits control the basic movements of walking, they are greatly influenced by the brain. For instance, running occurs when the brain causes the central pattern generators to shorten the stance phase. In addition, posture and goal-directed locomotion require input from the brain. However, the central pattern generators allow relatively simple modifications by the brain to control a very complicated process such as locomotion.