# Motor 2

[00:01:25.92] Voluntary motor information and all of these involuntary components that contribute to motor information then exit along the spinal cord at the ventral roots-- That's? Marked in green on this diagram-- where all of that information then travels out to muscles. So this is exiting between the vertebrae, or the gaps between the vertebrae, and the dorsal root ganglia, recall, is the inputs from proprioception and touch reception that we talked about in the last lecture.

[00:01:56.76] Damage can also occur to the ventral roots, to the green motor neurons marked here. The cord is undamaged, but the signal has nowhere to go. I should also mention here that a synapse occurs in the spinal cord just before the signal exits, so we have one neuron that travels all the way from the brain to the level of the spinal cord that that body part corresponds to. And then we have a new neuron that starts just before the signal exits the spinal cord.

[00:02:25.86] Now we have finally arrived at the muscle. The neuron has traveled from the spinal cord to the muscle, and then it releases acetylcholine, a neurotransmitter, directly onto the muscle in many hundreds of locations along the muscle fibers. Nicotinic-type acetylcholine receptors in the muscle cause electrical depolarization of the muscle fibers and the tightening of molecular complexes inside of that muscle fiber, which we will come back to in a moment.

[00:02:54.86] This process of a neuron reaching the muscle and delivering a signal to move through that muscle occurs all over the muscle. And the muscle will tighten only in the segments of the fibers where the acetylcholine is released, which is why you can have tension in only part of her muscle. These receptors are blocked by nicotine, which is a muscle relaxant, and they can be affected by other chemicals as well. And electrical stimulation, which is a very common tool in neural engineering, causes the same effect in the muscle fibers as acetylcholine release does. It just does it electrically instead of chemically.

[00:03:36.36] Muscles are comprised of groups of these fibers that are running parallel to each other. So on each of the fibers in this diagram, they have acetylcholine receptors and they have neurons delivering acetylcholine. Each one is very small, but you have hundreds of thousands of them per muscle. And the growth of the muscle depend on increasing the number of myonuclei, each of which controls a section of the muscle.

[00:04:06.29] This bottom diagram we're going to dive into a little bit more deeply now. Now we're going to dive more deeply into that last diagram on the previous slide, which shows myosin and actin, which form muscle complexes that actually cause the contraction of the muscle. All of this happens in many hundreds of thousands of groups of molecules within each muscle fiber and hundreds of thousands of muscle fibers per muscle.

[00:04:38.48] In this diagram, actin is blue and myosin is red. When the muscle is relaxed as on the top side of the diagram, there are large gaps between the segments of actin in the H zone because the myosin has released it hold. When the muscle tenses, the myosin-- it has these little round heads on the myosin molecule-- grabs onto the actin and ratchets along to bring the sets of actin closer to each other.

[00:05:14.19] The strength of the muscle depends on the number of myosin-acting complexes within that muscle fiber. When you're stronger, you have more of these groups of molecules that are working together to generate this mechanical force pulling the muscle tight.

[00:05:34.16] Although all muscles work the same on the cellular level, there are multiple types of muscle fiber, which is groups of myosin and actin encased inside of a complex cell. Type I are slow-twitch fibers, which contract slowly and maintain their contraction for a long time. So you can see the behavior of the type I muscle fiber in graphs B and C, which show that it doesn't activate very quickly but it's able to maintain its strength for a very long time. The amount of force that that muscle fiber can generate is very consistent over time.

[00:06:15.83] A type IIa, the middle type of fiber in this diagram, contracts so much faster but holds on for the medium term. You can see in graph B that it responds a little more quickly than a slow-twitch fiber, but it isn't able to hold on for as long. At 60 minutes in, the type I fiber is still going strong, but the type IIa fiber has dropped off considerably.

[00:06:41.10] And type IIb is very fast-twitch fibers, which contract almost instantly but degrade just as fast. All three muscle types can have varying strengths. So you can have a type IIb and a type I muscle that are both very strong, though generally the highest-strength fibers would be type II. So a weightlifter is depending primarily on type IIb fibers.

[00:07:09.60] Electrical stimulation as we use in neural engineering will cause all of these types of muscle fibers to contract equally. It doesn't separate them at all. It just indiscriminately says all of the muscle fibers in this area of the muscle contract now. So this is a major challenge for delivering stimulation for muscle reanimation or occupational therapy or any other function related to muscle types in neural engineering.

[00:07:38.37] Every joint also has opposing muscle groups. Skeletal muscles tend to come in pairs where one contracts and the other relaxes in order to move that joint. The muscles that control each joint are generally axial to that joint. So here in this example, we have the biceps and the triceps are influencing the lower arm, and they are located in the upper arm. The biceps cause the contraction of the elbow joint, and the triceps relax while the biceps are doing their job and vice versa. And you can have both muscles of a muscle group active at the same time to maintain an intermediate position of that joint.

[00:08:20.92] If we are attempting to replicate naturalistic muscle activity in neural engineering, we must work with both muscles or all of the muscles for some joints that have multiple muscles associated with that movement. And this is especially important for the hand, which moves via muscle synergies, which are more complex than just these simple pairs of opposing muscle groups for long-bone, one-directional joints. For hand movements, we have groups of multiple muscles that coordinate to form complex positions or movements. And this is important in engineering because we can't just move each muscle independently. We have to consider them as a group. It's a highly-coordinated and precise movement.

[00:09:07.81] Finally, this brings me to the difference between a prosthetic and an orthotic, both of which attempt to replicate or augment naturalistic movement for a person who has deficits in that control. A prosthetic replaces a missing limb, shown here with a realistic hand shape and a realistic cover for the hand. But most prosthetics are far simpler than this. They look like hook hands or very simple mechanical-looking hands. And most prosthetics currently on the market are not powered. They operate with pulleys that the user controls by swinging their shoulder in different directions, or they just have a fixed position and they're more an aesthetic choice.

[00:09:57.31] More advanced prosthetics are most commonly controlled based on muscle activity in the remaining part of the limb. So a person using this prosthetic shown in this picture has that cuff in the upper-left part of the picture, wraps around the surviving part of the upper arm and reads muscle activity in that segment of the arm in order to control what the hand is doing. That depends on having some capacity to control a prosthetic with the surviving portion of the arm. And I'm showing here a hand prosthetic, but it can be any limb or portion of a limb or multiple limbs.

[00:10:41.26] In contrast an orthotic shown on the bottom-right side of the slide wraps around the person's own limb and provide some stability or strength that they lack. The one shown in this picture treats a condition called foot drop, which is the inability to pull the foot back to a 90-degree angle after it moves as part of a walking movement. There can be simple, unpowered versions like the one shown here, which are also common for relatively minor injuries such as sprains and strains as well as more serious lingering conditions.

[00:11:12.85] Experimental versions also come in powered versions that provide additional strength that the user may lack, but this is significantly more complex because it requires estimating the person's goal movement usually based on EMG, attempting to guess what level of strength they were trying to apply, and augmenting the level that the person can't supply on their own. So although powered orthotics seem like they should be really straightforward, they're actually much more complex because it doesn't just require estimating the person's movement. It requires estimating the person's movement and extrapolating that to their desired movement. And much like prosthetics can be any limb or combination of limbs, orthotics can be feet, hands, legs any combination thereof, or even theoretically a person's entire body.

[00:12:07.70] Now we're going to review some of the cognitive aspects of movement control. An efferent copy is a cognitive model linking movement to sensation. The neural correlates of the efferent copy have not yet been identified, but it's a forward model that predicts a sensation based on the motor commands. So if you trace down from that motor command on the top left of this diagram, go from the motor command to a motor output, and then from the motor output to a sensory output, and then from the motor output to a sensory input, the response to that motor command. If you then go from the motor command and trace across, we have the motor command generates an efferent copy-- so a copy of that command to the primary somatosensory cortex in the parietal lobe, where the model estimated what this sensory feedback is going to be if the motor command is executed as predicted.

[00:13:15.49] The efferent copy model then compares for a discrepancy or an agreement between the predicted sensory feedback and the actual sensory feedback to that movement. It's used to distinguish between a sensation that's a direct result of your own actions versus a sensation that occurs as the result of an event in the environment, such as getting knocked off course, an unexpected event occurring, and other things that might cause the predicted feedback to not match the expectation.

[00:13:54.04] The opposite of an efferent copy is the inverse model, which generates motor commands based on the sensation, as we talked about in the sensory systems lecture.

[00:14:04.87] The efferent copy is seen in action here at this baseball game. Much of our movement, especially in sports, depends on outdated sensory information that is hundredths or even tenths of a second out of date, which doesn't sound like much. But when you or something in your environment is moving very fast like this baseball, that much time is critical. So our movements are based on this forward model, like the efferent copy. In this example, the ball is arriving at the bat long before the visual information can be processed by this player's visual cortex. So his swing is based on the predicted trajectory from when the ball has barely left the pitcher's hand.

[00:14:54.88] In most people, this process takes between 100 and 120 milliseconds, but it can be trained to as fast as 60 to 90 milliseconds, but that's still not fast enough to track the ball. In sports in particular, increasing skill is based in part on improving a player's subconscious predictive ability to respond to an environmental stimulus, like a baseball, before the stimulus actually arrives. And this is why things like curveballs are so challenging-- because they're very difficult to predict, even a conscious prediction, let alone a subconscious prediction like what's being generated by S1. So it's very hard for the player to tailor their movements both consciously and subconsciously to match that stimulus.

[00:15:47.26] Finally, we're going to conclude the motor system's lecture by reviewing reflexes. Reflexes occur when an extremely fast response is needed, faster than the time it takes for a signal to travel from sensory input in the body all the way to the brain, be processed, trigger a response, and that response signal to return to the body, which takes an average of about one eighth of a second. Some reflexes are skeletal muscles, but not all of them, such as the pupil dilation reflex when you look at a bright light, the gag reflex, and many more, including a large variety found only in infants.

[00:16:26.97] A reflex arc is shown on this slide, which is a special sensory processing circuit where the sensory information travels from the body-- in this case, a Golgi tendon organ-- to the spinal cord and then immediately from the spinal cord back out to the corresponding muscle to trigger our response. The entire sensory motor transformation, which normally happens in the hand off of information from sensory integration areas and primary somatosensory cortex to premotor cortex and other motor regions, happens here in the spine.

[00:17:02.10] This individual is demonstrating a typical knee reflex. This reflex arc is particularly involved in maintaining balance, which, at this point, it should be apparent to you that maintaining balance is not trivial given the number of regions of the brain and circuits in the body involved in its maintenance.

[00:17:20.51] Notice that this reflex is fairly small. This individual has an abnormal patellar reflex. It's highly exaggerated. Reduced reflexes are often linked to peripheral nerve damage, so the reflex arc is disrupted. Exaggerated reflexes as seen here are linked to issues with the upper motor neuron, which reaches from the primary motor cortex to the spinal cord. And an extra reflex response, so if the leg swings too many times, is linked to a cerebellum problem, which you'll recall is highly involved in balance.