Motor 1

[00:00:00.42] In this lecture, we're going to review motor systems of the body, initiation of movement, and the effect of damage at various points along the motor system. We tackled the left side of this diagram in the last lecture. Sensory information, especially somatosensory information, flowing up the spinal cord, from the body, to the brain. Now we will tackle the right side of this diagram-- motor commands flowing from the brain to voluntary muscles, and the transformation of a sensory experience, primarily handled by primary somatosensory cortex, and sensory integration area, to a motor response, which is the handoff from the parietal cortex sensory regions to the frontal cortex motor regions.

[00:00:47.29] We will be dealing exclusively with skeletal muscle control in this lecture, not smooth or visceral muscles, and not cardiac muscles. Cardiac muscle is pretty well studied, and pacemakers and other interventions into the muscles of the heart are relatively common. This is outside of the purview of neural engineering, for the most part. Smooth muscles are not as well studied as skeletal muscles, and require significantly more complex interventions, generally requiring significant amounts of surgery, and larger more diverse research and care teams.

[00:01:22.90] So they're much more difficult to research in the context of neural engineering, and consequently, have not received as much attention. But just know for now that smooth muscles, for especially bowel and bladder function, are a major priority of the field, and are considered one of the top priorities for neural engineering interventions, by potential users of such devices. Skeletal muscles though are the most popular and therefore the best developed area of neural engineering.

[00:01:54.09] First we're going to review motor cortical regions. So there are three primary regions of cortex shown on this diagram, that initiate muscle movements. First, is the premotor cortex, marked here in green, which is involved in planning motor sequences, and the desired motor outputs of movements. The supplementary motor area, marked here in red, is probably related to bimanual coordination, or coordinating activities, that involve both sides of the body, sequential movements, and posture.

[00:02:30.39] And the primary motor cortex, marked in blue, sends commands to the body as specific combinations of muscle tensions. You can think of the primary motor cortex as acting as the compiler. So the premotor cortex, and the supplementary motor area, develop a plan, or a program for movement. And for those of you who are familiar with how computer programs work, the primary motor cortex acts as the compiler to turn that into a sequence of specific commands for the body to execute.

[00:03:04.62] The frontal eye fields are also located just anterior to the premotor cortex, and control eye movement, especially eye movement related to body movement. All voluntary motor commands originate in the premotor, supplementary motor, and primary motor collective of regions. All of the other motor related regions of the brain that we are going to talk about, do not initiate voluntary movement. They only refine voluntary movements, and initiate involuntary movements, such as balance adjustment, or involuntary eye movements.

[00:03:41.24] There's a one-to-one relationship between specific cells, or segments, of these areas of cortex, and specific areas of the body, and specific movements of those areas of the body. We observe specific changes in cellular structure and function in the premotor and primary motor cortex, as the person acquires new skills. In many amputees, the region associated with the lost limb also will shrink, because it's no longer being used.

[00:04:15.79] Further, we can, and have in animals, cause specific changes in motor cortex, synoptic strength, or the connection between specific cells, just by stimulating them with electricity, and without the animal actually learning any new skill. We have not yet successfully done so in humans yet, but if we were able to do so we could, theoretically, program a skill into a person's motor cortex without them having to go through the hours of practice associated with that skill.

[00:04:46.02] As I mentioned, the motor cortex is organized by region of the body, just like the somatosensory regions. But the dividing lines between these areas are not clean. And this may be related to complex, or coordinated movements, that involve multiple brain areas. Again, just like somatosensory cortex, the size of different areas of the motor homunculus, is scaled by sensitivity, or fine movement level, not body part size. So the hand and face are dramatically overrepresented, and the trunk is underrepresented.

[00:05:22.08] And notice here that the primary motor cortex wraps around over the longitudinal sulcus, into the gap dividing the hemispheres. The premotor cortex does not, because that section in the longitudinal sulcus gap, is occupied by the supplemental motor area, not part of the premotor cortex. The effective damage, such as from stroke, corresponds to the region of the body associated with the damaged region. So if the stroke is in the foot area of motor cortex, only that region of the body will be affected.

[00:05:59.64] Conversely, if we want to control a prosthetic, or a user's own body with muscle reanimation, we can record from the corresponding area of motor cortex, to the part of the body, to generate a signal, and its use should be intuitive for the user. But these critical motor regions are only the first step of the motor process. The motor cortex then sends its information to the basal ganglia, before that information gets sent out to the body. So the pathway is, premotor and supplementary motor area form a plan of movement, primary motor forms that into a compiled plan of movement, and then that gets sent to the basal ganglia next.

[00:06:43.08] The basal ganglia does not just refine movements. It's also heavily involved in the learning of movements, and in reward functions. On the left side of this slide, we have the anatomical pathway of information between brain regions. And on the right, we have a schematic of the information being passed around. These two diagrams show the same thing, in two different ways. The regions involved are the putamen and caudate, which are together called the striatum, which is thought to be involved in the executive control of movement. So like, sort of top level control of movement, learning of new movements, and dealing with unexpected or novel stimuli. The globus pallidus, which can be divided into the external and internal segments, is involved in general movement function. The substantia nigra is involved in motor planning, reward seeking, procedural learning, eye movements, and addictive behaviors. That's marked SNC on this diagram on the right.

[00:07:49.69] The substantia nigra is what's damaged in individuals who have Parkinson's disease, and it's the most common type of disease that affects the basal ganglia. The subthalamic nucleus, and ventral tegmental area, are both involved in motor functions, but their individual functions are not clearly delineated. It's very difficult to separate out what each segment of the basal ganglia does, because they are all so tightly linked to each other. But they are thought to be involved in impulse control. This thalamus does not do any major processing as part of its role in the basil ganglia. It just relays this information back to the cortex, and combines basal ganglia and brain stem information.

[00:08:33.14] And not marked on this diagram is the nucleus accumbens, which connects to both the basal ganglia, and the limbic system-- which you'll remember from way back in the system's lecture-- is involved in reward functions, as well as motivation and aversion. The path to these regions is highly complex, and not fully distinct what each segment of the pathway, and what each individual region does. But overall, the cortex excites the striatum. The substantia nigra and VTA also contribute modulation, or varying activity to the striatum. The direct pathway shown on the right side of the schematic, facilitates movement. And the indirect pathway inhibits, or flattens out movement. And these balance each other, in order to achieve a level of movement that is smooth and precise at any scale.

[00:09:24.55] So I've referenced a few times over the course of this diagram, that many of these regions are involved in motivation or reward. The set of regions is involved in movement function. Why would it also be involved in reward function? But that's because movement is often in pursuit of a reward. So any rewarding stimulus, something that is positive for the organism involved, would want to generate a movement to replicate that positive experience. So movement and reward functions are very tightly linked. And the basal ganglia is the center of that linkage between those systems.

[00:10:08.16] The cerebellum contains about 55% of all of the neurons in the brain. The cortex contains about 45%, and all of the subcortical structures could together have about 5%. The cerebellum is definitely involved in movement, especially in balance, eye movement, and fine motor control, such as detailed movement, but not initiation of movement, or decisions related to movements. It's probably also involved in skill learning, which is the acquisition of new sequences of movements in a skillful fashion. It may also be involved in language sensory association processing, and non-skilled memories. But the cerebellum is not very well studied. There have not been very many experiments or researchers who have examined the cerebellum in depth. So we just don't know about that yet.

[00:11:07.50] There are almost no circuits, like the basal ganglia, within the cerebellum-- groups of regions, or of sequences of cells, that do multiple steps of processing. Most of the information handled by the cerebellum moves in, and then back out via the same, or a different path, almost immediately. It does very linear straight forward processing. Damage to the cerebellum does not cause paralysis. It only causes poor balance and unrefined movements, which again contributes to the understanding that all motor initiation comes from the primary motor cortex. And it mostly has inputs. So the cerebellum takes in a massive amount of information, and condenses it down and refines it by 40 times. So the amount of output is very refined, and precise, and efficient.

[00:12:05.05] So damage to the cerebellum causes poor balance, coordination, and unbalanced eye movements, which make it very difficult to read. A lot of people who have cerebellum damage can't read. And neural engineering devices are not currently usable in the cerebellum, partly because its function is so poorly understood, and partly because there are far fewer conditions that affect the cerebellum, than there are that affect the cortex, or the peripheral nervous system.

[00:12:34.84] So we now have had a motor plan developed by the premotor cortex. It gets passed to primary motor cortex, refined by basal ganglia, and passed back to primary motor cortex. And it gets refined by the cerebellum, and then passed directly out to the body. The information then travels from the primary motor cortex, to the posterior internal capsule, which is a white matter tract, that passes through the middle of the brain-- actually passes right through the middle of the basal ganglia-- and it travels to the medulla, where most of the information crosses from the side of the brain, to the opposite side of the body.

[00:13:12.04] And it maintains a rigid anatomical organization that originated back at the primary motor cortex, and premotor cortex, where we have this motor homunculus gets maintained through the entire spinal cord. So there's a foot area of spinal cord, and a hand area of spinal cord. Damage at any point along this pathway, will cause inflammation to not continue along the way to its destination. So all of the areas below the level of damage would be affected, if that part of the body is in the damaged region. So if the foot region of the spinal cord is damaged, then nothing is going to get passed on to the foot. And medulla damage, in particular, is usually fatal, because of its role in other neural functions, such as breathing and heart rate. So all of the information travels from the primary motor cortex, into the spinal cord. It's all the same neuron, through this entire segment of the pathway into multiple tracks in the spinal cord carry motor information.

[00:14:08.28] So the lateral corticospinal tract carries voluntary motor information. The rubrospinal tract carries information from the cerebellum to the legs and arms, to maintain balance hand shape, and finger control. It also has anatomical organization, but it's not as strong as the lateral corticospinal tract. It gets a little bit more mushy. The vestibulospinal tract-- remember, back in the vestibular segment of the last lecture, we talked about that information gets passed directly to the spinal cord. It bypasses the brain, because that information needs to be acted on quickly. And it gets passed through the vestibular spinal track to the body, where it helps maintain balance and posture. And finally, the reticulospinal, marked here as tectospinal, tract comes from the pons and medulla, and is also involved in balance. Think about the effect of damage in different parts of the spinal cord, not just what parts of the body would be affected, but what specific motor functions would be affected, and how this might vary, depending on not only what type of damage it is, but the combination of type of damage, and part of the body affected.