Brain systems 1

[00:00:01.28] Now, we're going to review major systems of the brain. Those that are most relevant for neural engineering, sensory and motor systems, we're going to come back and review in significantly more detail later in the course. But because neural engineering also involves other systems of the brain involved in behavior, decision-making, and more, we're going to go over these so you have some context.

[00:00:25.02] Before we continue, I want to remind you that neurons communicate between each other using chemicals, neurotransmitters, which are released from one neuron onto another neuron. This signal always travels in one direction and only from the presynaptic to the postsynaptic cell. And the signals travel within a neuron through the membrane potential, which is generated by charged ions flowing in and out of the cell. But you can think of it as being an electrical signal.

[00:00:59.31] I also want to remind you that the brain can be broken down into smaller and smaller divisions, each of which has a specific job. We're going to go into the specific job of many of these brain regions over the course of this lecture. We're going to review brain systems related to senses, motor systems, including the cerebellum, autonomic control, memory, emotions other than fear, fear-- which is separate from all other emotions-- and executive functions, which are higher-level processing that we think of as being thinking.

[00:01:39.20] First, your senses-- you have many senses, many more than the five we usually talk about in school. The most relevant for engineering are touch, proprioception-- which is the sense of where your body is in space-- vision, hearing, and the vestibular sense, which gives orientation and rotation. We'll return to these senses that are most relevant for neural engineering later and cover them in their anatomy in more detail.

[00:02:11.22] You also have smell, taste, pain-- which is separate from touch and proprioception-- itch-- which is also separate-- temperature, hunger, thirst, and circadian rhythm or what time of day it is, and several more. Each of these senses has a region of the brain that is responsible for receiving the information detected by that sense's sensory organs and processing it and understanding it. So we'll go through each of these individually for the senses that are most relevant for neural engineering when we go into more depth on senses.

[00:02:48.14] But for now, notice that visual information is processed in the purple area at the most posterior area of the brain. Sometosensory information is processed in primary somatosensory cortex, marked here in blue, which also processes some proprioception information and some pain. Hearing is processed in the maroon area located in the temporal cortex. And vestibular information is processed partially by sensory motor cortex and partially by the cerebellum and other non-cortical areas.

[00:03:30.01] Also note, the yellow area marked here on this map as censory analysis. This area refers to the sensory integration region which takes information from multiple senses and combines them to form a coherent, multi-sensory picture of the world. Every sense has a sensory organ which is responsible for detecting the information for that sense from the environment.

[00:03:55.04] For vision, this is the retina, which is located at the rear of the eye. And the structure of the retina is somewhat counterintuitive. In this picture, the rods and cones, which are located at the top of the image on the right, are actually at the rear of the eye. So light flows from the bottom of the picture to the top of the picture. The light-sensitive cells or at the rear-most layer of the eye.

[00:04:20.06] The information travels back forward through the eye, through several layers of cells, where it's then sent on to the brain. The eye is remarkably sensitive. The rods and cones are sensitive to as few as two photons to become active. You can detect light at very low levels despite this inefficient setup.

[00:04:42.23] Your inner ear does double duty. The cochlea, which is part of the inner ear, has a membrane that is sensitive to different frequencies. And this is how you hear. Sound waves travel through the ear and activate different parts of the cochlea. The vestibular system's sensory organ is also located in the inner ear, where the semicircular canals detect the rotation of your body, and the utricle detects the position.

[00:05:10.97] Touch receptors are located throughout the skin, but they're unevenly distributed. For your fingertips, they're very sensitive. They have a lot of these receptors. But in other areas where you're less sensitive, such as in your upper back, you have relatively few of these receptors. You have lots of different types, and each one is responsible for detecting a different type of touch. We'll go into more detail later, but you need all of these types of receptors for full sensation.

[00:05:40.98] Proprioception uses a separate set of sensors. Some are in muscles, and some are in connective tissue that detect stretch. So depending on how much your joints are angled and your muscles are stretched, the proprioceptors will detect that and send that information to your brain to tell you the current position of your body. Touch, proprioception, and other information coming from the body is organized through a system called the dermatome, which spatially aligns all of the information coming to and from your body through levels of the spinal cord.

[00:06:15.53] So the levels of the spinal cord are C, which is cervical, T for thoracic, L for lumbar, and S for sacral. Information traveling to and from the lower parts of your body travels farther down the spinal cord, which makes a lot of sense. So information coming from the hands enters the spinal cord at the C6, C7, and C8 levels of the spinal cord.

[00:06:42.16] Whereas information traveling from the feet enters at the sacral and lumbar levels. So obviously, information that is traveling to and from the feet has to go through the upper parts of the spinal cord. But the dermatome provides the spatial organization of how information enters and exits. It also gives some insight into what parts of the body might be affected by a level of spinal cord injury.

[00:07:09.27] So if a spinal cord injury is in the thoracic level, only the thoracic, lumbar, and sacral parts of the body are going to be affected. If it's in the lumbar level, or in the lower lumbar level specifically, only the feet and lower legs are going to be affected. Whereas if the injury is at C2, the one at the highest levels of the spinal cord, then the whole body will be affected.

[00:07:36.91] So to recap, every sense has an area of the brain that is responsible for processing that sensory information. And every sense has a sensory organ that is responsible for collecting the information from the environment and sending it to the brain to be processed. When we talk about sensory neural engineering, we need to consider what is the need? Why would a person need a sensory-oriented neural engineering device? What deficit do they have that might need augmentation?

[00:08:05.47] What are the desired outcomes? When we build this device, what do we want the outcome to be? What do we want to build? Any given goal might have multiple design options. Where in the body would we need to target? What parts of the brain, or what sensory organs would be targeting our device to? And what kinds of challenges would we encounter, both with the design and the implementation of the device?

[00:08:29.84] Now, we're going to discuss motor control or control of muscles and movements. We're going to return to both motor control and sensory systems in greater detail later in the course because they're the most relevant brain systems for neural engineering. When we talk about motor control in neural engineering, we're usually referring to the somatic nervous system, the control of skeletal muscles. This is voluntary, conscious control of your own movement.

[00:08:56.71] Spinal reflexes also control skeletal muscles, but it's an unconscious-- it doesn't even involve the brain response to something that needs very quick responses, like falling off balance or stepping on something. We can also talk about control of the autonomic nervous system, both smooth muscle of internal organs and cardiac muscle. There are several regions of cortex whose primary job is to develop and execute motor activities.

[00:09:26.29] The premotor cortex, marked here in green, generates a broad plan for what movements the person wants to execute. It then sends that plan to the primary motor cortex, which turned that plan into specific command for individual muscles or groups of muscles. The supplementary motor area, marked in pink, helps the premotor cortex generate plans, especially for very complex movements or movements that involve coordinating the left and right sides of the body.

[00:09:59.47] Before the information travels from the primary motor cortex to the body, it travels to some motor support regions. On the left, we have the basal ganglia, which is a group of sub-cortical regions that help refine movements and make them more precise. And on the right, we have the cerebellum, which helps especially with balance. Note that the motor signals travel from the primary motor cortex to the basal ganglia, where the movement refinement occurs and then back to the primary motor cortex before the signal travels out to the body.

[00:10:36.59] After the motor command is generated and refined, it exits the primary motor cortex and travels via the brain stem to the spinal cord and eventually to the body. The information crosses from the left side of the brain to the right side of the body and vice versa in the brain stem. So by the time it ever reaches the spinal cord, it's already on the same side as its destination.

[00:11:03.65] So when we discuss neural engineering and motor systems, we need to discuss what is the need. Why might a person need augmentation, replacement, or other modification of their motor system? What is the desired outcome? Do we want to help a person control their body more precisely or at all? Do we want to control a prosthetic, or an orthotic, or a computer?

[00:11:25.76] What do we want to build? Where in the body do we need to target this? It depends on the level of injury or type of injury what parts of the body we can access in order to find what these motor commands were. And what kind of challenges would we encounter in building and programming this system?