Sensory 3

[00:00:00.35] Now we're going to go over somatosensation, pain, proprioception, and other senses that occur in the body. And these are the most important for neural engineering today, so we're going to go over them in a little more detail.

[00:00:16.56] First, we have touch receptors. And these are distributed throughout the skin. They're all over your body, but not distributed evenly. So you have a much higher density of these receptors in your fingertips than in the middle of your back. You need all of these different types of touch receptors in order to have a full sensation of touch.

[00:00:37.76] So Tactile or Meissner corpuscle-- and Meissner is the older name for the same sensor-- detects a light touch, so just like if you touch something gently with your hand. Merkel cells detect pressure or firm touch. Bulbous or Ruffini corpuscle-- and again, Ruffini is the older name, Bulbous is the current name-- detect stretch. So if something is pulling on your skin, that is detected by these receptors.

[00:01:09.55] Lamellar or Pacinian corpuscles detect vibration and pressure. And hair follicles have detectors in the base of the hair follicle that detect when something is pulling on the hairs in your skin. We're going to come back to free nerve endings later in the lecture. Those detect pain.

[00:01:31.47] This information is all transmitted by different types of A-beta neurons. You can see some specific names marked in this diagram. The specific names aren't important, but what you should know about A-beta neurons is that they are very thick. The axons are very large, and they have myelin on them. So they transmit information very fast. The signal traveling through A-beta neurons travels between 35 and 75 meters per second.

[00:02:02.79] The receptive field of each touch receptor varies depending on the density of the touch receptors in that part of the body. Proprioceptors are located through your muscles and joints, and they give the location of your body in space. Muscle spindles are wrapped around individual muscle fibers, and they detect how stretched those muscles are. So the more structured it is, the more extended that muscle is. So that gives you the position of that joint. Golgi tendon organs, marked here as tendon receptors, detect the tension in each joint. So how much is the tendon being pulled on by the muscle and by the bone?

[00:02:55.72] And fibrous joint capsules detect the angle of the joint by how much the capsule surrounding the joint. And the capsule is just fibrous tissue. It doesn't contribute to the movement of the joint. It just encases and protects it. And how much is deformed also contributes to the angle of the joint.

[00:03:14.63] This diagram shows a muscle spindle receptor. And it's neuron is an A-alpha type neuron. And it's myelinated and ultrafast, even faster than touch. That information travels to the brain at 80 to 120 meters per second. If your proprioceptors stop working for some reason, or if you are building an artificial device that would replace or augment a limb, it would need to be able to communicate information about the position of that limb and space totally separate from whatever the limb is touching. It needs to know its own position and angle.

[00:03:53.02] This is because if you don't know the position of your own body, then you have to be either touching something with the skin or be looking at that limb in order to know where it is. This is extremely debilitating. And this is very rare. People who have suffered damage to proprioception have difficulty doing anything without looking at their limbs.

[00:04:19.54] Temperature is not currently a major focus of neural engineering. We're more focused on delivering touch and proprioceptive information than temperature. But it is an important part of general somatosensation. Temperature receptors are embedded in the skin, and they're also embedded inside of other types of tissue, including inside of your mouth.

[00:04:43.07] There are six different types of temperature receptor, each of which has a different peak sensitivity. So the combination of which receptors are active gives the approximate temperature of the stimulus or the environment. The coldest sensitivities, so the two that are marked farthest to the left, and the hottest, the one farthest to the right, also indicate pain.

[00:05:10.82] And some of these receptors are also sensitive to specific chemicals. So mint feels cool because it activates cold receptors. It doesn't just seem cool. It actually is the same sensation as cold. And capsaicin, the chemical that delivers spiciness, feels hot for the same reason.

[00:05:33.73] Pain is transmitted via nociceptors. Pain is used primarily to describe the subjective experience, the cognitive experience, of feeling nociception, which is the touch or other sensation that is painful. Triggers for pain include thermal, whether it's too hot or too cold, mechanical, including cut, strains, sprains, breaks, and other mechanical damage to the body, and chemical, including irritants from the environment and the release of histamines, which are a chemical inside of the body and they're released in response to things like bug bites or allergens.

[00:06:17.96] So we discussed A-beta receptors a minute ago. Those are regular touch. And that's the two receptors on the far right of this diagram. Pain is associated with the other two types of neuron in this diagram.

[00:06:33.64] A-delta, which is the second from the left, has a little bit of myelin and a small diameter. So it responds to the onset of pain initially, and it's relatively slow. The information travels between 5 and 30 meters per second.

[00:06:53.74] Pain also travels via C fiber, which don't have myelin and have a very small diameter. And this is even slower signals. And it's the lasting pain, the long-term lingering pain. And it can be sustained by chemicals released in response to damage to your tissue, so it can last indefinitely. And this signal travels between 0.2 and 2 meters per second. So you can walk faster than this information can travel.

[00:07:25.85] I've been referring to different types of axons based on their size and their myelination throughout this beginning part of this lecture. Why would we want signals to travel at different speeds? Because some signals, like touch and body position from proprioception, require an immediate response. But others don't need as fast of a response, such as pain, and myelination and large axons are expensive to maintain.

[00:07:54.48] You can speed up a signal by increasing the axon diameter, adding myelin, or both. The increased diameter of the axon increases the resistance of the membrane, so the signal will travel faster because of the electrical properties of the cell. Some species don't have myelin. They just use huge axons to help their signals when they need them to travel fast get where they need to go.

[00:08:22.17] A good example of this is squids. They're so big, they're called squid giant axons because they don't have myelin. And as a consequence, they're a really popular organism for studying electrophysiology because the neurons are huge and easy to work with.

[00:08:38.43] This information is now going to travel from the body to the brain. We had previously reviewed the dermatome in an earlier portion of the lecture. This is the anatomical arrangement of how sensory information flows into the spinal cord from touch, proprioception, temperature, everything. The layout also reflects the motor commands as they flow out of the spinal cord. It's symmetric on the left and right sides of the body. It's asymmetric in this diagram just because there's a lot of segments of the dermatome, and they can't fit them all in easily.

[00:09:12.54] In general, the bottom and lower legs flow to the sacral, the lower part of the chord, the legs to the lumbar part of the chord, the torso and parts of the arms to the thoracic part of the chord, and the arms and hands to the cervical part of the chord. And the head bypasses the spinal cord entirely, though all of the sensory receptors and nerve types are the same in the head as they in the rest of the body. That information just doesn't travel to the brain via the spinal cord. The spinal cord gets physically larger as it travels towards the brain as more sensory information enters and less motor information has exited.

[00:09:51.54] Sensory information enters the spinal cord at the dorsal root ganglion, marked DRG on this diagram. Dorsal in the spinal cord means towards the back of the body. And there are gaps between the vertebrae, the bones of the spinal cord, where the dorsal root ganglion enter into the cord itself.

[00:10:14.40] The information is arranged somatotopically. It maintains the anatomical organization of the body in the cord. So you have a region of your spinal cord that's foot, and you have a region of the spinal cord that's hand and shoulder and so forth. You'll notice that there's another set of commands flowing out of the spinal cord. We'll come back to that in the next lecture.

[00:10:40.76] All of the information that we've just gathered from the body now needs to flow to the brain. We'll start with the diagram on the left side of this slide. This is the dorsal column. It handles touch and proprioception information. The information flows into the spinal cord at the dorsal root ganglion, and then travels up the dorsal columns until it reaches the medulla.

[00:11:03.94] We then have a synapse and start with a new neuron in the medulla, where the information then crosses over to the opposite side of the body. So it travels through the spinal cord on the same side of the body as the information was coming from. And then it crosses to the opposite side in the medulla. That information then travels to the thalamus, where we get another synapse, another new neuron. And from the thalamus to the primary somatosensory cortex.

[00:11:36.28] Damage to any one step of this will cut off the flow of sensory information from the body to the brain. So this would most commonly be damage to either the spinal cord, the first neuron in the chain, or a stroke that would damage either the second or third neuron in the brain.

[00:11:58.11] The spinothalamic tract on the right side of this diagram candles information about pain and temperature. The information, again, enters the spinal cord at the dorsal root ganglion. But it immediately has its synapse and starts the second neuron and crosses to the opposite side of the spinal cord. So pain and temperature information travels through the spinal cord on the opposite side of the body as where the information came from in the first place. It then passes through the medulla all the way up to the thalamus, starts a new neuron, and then gets passed to multiple regions of the cortex.

[00:12:41.51] Primary somatosensory cortex, marked on this diagram in purple, handles the bulk of sensory information coming in from the body, including touch, proprioception, temperature, and the location aspect of nociception. Secondary somatosensory cortex, marked in green, handles touch and pain and particularly handles change in the level of processing devoted to different sensations, based on how much attention you're paying to them.

[00:13:08.35] The inferior parietal lobule, marked here in yellow, is sensory integration area, which I've mentioned before. It takes information from all of your senses, including vision, hearing, touch, and everything else, and incorporates it into a coherent model of your surroundings and feeds that to cognitive areas in the premotor cortex, where it contributes to motor responses to stimuli in the environment.

[00:13:36.57] Both S1 and S2 are arranged somatotopically by body part. Most of the body parts that are near each other are also near each other here in the homunculus or somatotopic organization in the cortex. The size of each area of the body is proportional to its touch sensitivity, not its body size. So your hands and face are overrepresented. And this is mirrored on the left and right sides of the brain.

[00:14:08.80] If we want to deliver artificial sensation to a person, for example, as corresponding to a prosthetic or robotic limb, we could deliver electrical stimulation to the somatosensory cortex. We can deliver the stimulation to the specific region of the primary somatosensory cortex that corresponds to the body part that should be experiencing that sensation. And we can tailor the type of stimulation we deliver in order to generate different types of sensations, such as pressure or light touch.

[00:14:45.49] Delivering artificial stimulation that feels like it's corresponding to a specific part of the body is pretty straightforward conceptually, even if it's technically difficult. You just find the right part of the somatosensory cortex that corresponds to that part of the body and deliver stimulation to that location. There are challenges related to getting the right resolution and targeting only a single area of the body and not having the sensation feel like it's smeared in space. But it's a straightforward concept.

[00:15:18.94] Delivering different types of somatosensation or proprioception is considerably more difficult. This means, for example, finding different artificial stimulation patterns that correspond to pressure, vibration from touch, proprioception of different types, and so forth and delivering it to the correct location in primary somatosensory cortex that corresponds with the desired location of the body.

[00:15:49.25] Sensory feedback is absolutely necessary to dexterous, fine motor control. It's like when you're trying to tie your shoes if you have gloves on. It's really difficult not just because the gloves are bulky, but because you can't feel what you're doing. So somatosensory feedback and proprioceptive feedback, the location of your body in space, is not optional for developing a fully functional, brain computer interface that can control, for example, a prosthetic or other robotic limb.

[00:16:23.99] Finally, I wanted to say a couple words about nociception or the experience of pain. Pain is the subjective experience, and nociception includes all the components of location, type of pain, and the negative experience. And there are multiple brain regions involved. S1, marked in this diagram in blue, is the location of pain as I mentioned on the previous slide.

[00:16:50.42] The insula is not shown on this diagram. It's marked by the arrow on the lateral view of the brain, on the right side of the slide, which points to the area that the insula is underneath or medial to that area. And it handles the type or classification of pain.

[00:17:08.51] And the anterior cingulate, marked in white on the medial view on the left side of the slide, handles the negative experience, aversion, or the desire to make it stop hurting. Although pain is subjectively unpleasant, it is an absolutely necessary component of a fully functioning sensorimotor system.

[00:17:31.04] A person who does not feel pain, which is caused by a rare condition called congenital insensitivity to pain where peripheral pain receptors are nonfunctional, often suffers severe injuries especially in early childhood. One of the primary symptoms for diagnosing congenital insensitivity to pain is that infants with the condition have a tendency to chew through their tongue.

[00:17:57.47] Children often suffer many broken bones, burns, and other injuries throughout their childhood because there is no signal for them to stop doing something that's causing damage to their body. They have to cognitively decide, oh, this thing is bad for me. It's causing damage to my body even though it feels fine and even interesting to them.