Sensory 1

[00:00:00.34] In this lecture, we're going to be covering sensory system anatomy. Particularly, with how it is involved in neural engineering related to those sensory systems. So the most important senses for neural engineering are vision, hearing, vestibular sense, which is balance and rotation, somatic sensation, proprioception, and to a lesser degree, pain, or nociception. Other senses that are not as important, and are not currently any targets for neural engineered devices are smell, taste, itch, temperature, hunger, thirst, circadian rhythm, and more.

[00:00:40.95] So first, I want to review a few general principles related to all sensory systems. First, receptive fields. A receptive field is the portion of the sensory field that that particular neuron is sensitive to. So for vision, this is the area of the visual field that a neuron detects light from. And for hearing, this is the frequency range of sound that that portion of your inner ear detects. For touch, pain, temperature, proprioception, and other senses that involve the skin, this is the area of the body that that neuron is in, or sensitive to.

[00:01:23.10] The receptive fields also translate to a system of organization in sensory organs, and in the brain. For example, retinotopy in vision applies to the organization of the visual field on the retina in space. Tonotopy in hearing is the organization in frequencies. And somatotopy in touch, proprioception, and other body senses, is organization by the different parts of the body.

[00:01:53.04] Some neurons adapt at different speeds to the onset of a stimulus. Some neurons respond immediately when the stimulus appears. That's the top trace on these fingers. This neuron responds immediately in response to the onset of a stimulus, but then its signal fades out over time. The bottom trace on both of these, is the response of a neuron that is a slow onset neuron. It doesn't respond immediately when the stimulus appears, but the signal remains active for as long as the stimulus is present. The combination of the slow and rapid adaptation signaling the onset, and the duration of the stimulus together, can combine to form the entire stimulus signal.

[00:02:41.55] Finally, the last general principle I want to review is the features of sensory organs. So a sensory organ is the specific set of cells that are sensitive to stimuli in the environment. All of them have a sensor that detects information from the environment. And the examples in this picture, that's a touch receptor that's the receptive part of the cell, an inner ear hair cell that detects sound, and a rod in the eye that detects photons of light. All three cell types can both detect from the environment, and they also have to be able to translate that stimulus, that event in the environment, into a signal for the nervous system.

[00:03:26.94] And remember, as we progress through this part of the lecture, that for neural engineering purposes, not only do sensory systems all have these features, but that any artificial sensory signal that we generate through neural engineering, through electrical stimulation, or other artificial stimulation of the brain and body, must be useful. A person who is receiving a neural engineering treatment must be able to use the sensory signal that we create in order to accomplish tasks in their everyday lives.

[00:04:00.20] Now, we're going to review vision. So this is the eye, but only the retina, the layer of cells at the very back of the eye, farthest from the opening where the light comes in, is part of the nervous system. Light passes through the pupil, and then it's focused by the lens onto the fovea, which is part of the retina. And then that, layer of cells translates the light into a signal for the nervous system.

[00:04:31.32] So these two diagrams show the same thing. On the left, we have a photorealistic drawing that shows what the cells actually look like, and on the right, we have a schematic of the same thing. The light flows in both of these eye diagrams from the bottom of the slide, to the top. So the opening at the front of the eye, that pupil, is below the bottom of the slide.

[00:04:57.77] But the light sensitive layer is at the posterior, the rear most part of the eye, farthest from the light source. And not only that, but the light sensitive parts of the retina, the layer of rods and cones and their photosensitive molecules are at the rear of the retina. So the light has to travel through all of the layers of cells in order to reach the sensor.

[00:05:22.27] Despite this inefficient setup, the rods are as sensitive to as few as two photons. Cones require a few more. Both rods and cones are sensitive to photons, or particles of light. And the rods detect the presence of light, and cones detect wavelength of light, so what color is something. Then we get some initial processing of this information right there in the retina. So you can see that the rods and cones pass their information on to multiple cells, in multiple different layers.

[00:05:56.62] So the cell marked H, is called the horizontal cell. We also have bipolar cells, and retinal ganglion cells. We're not going to go into the detail of what all of these individual cell types do. But what you should know, is that horizontal cells and bipolar cells in particular, take the information from multiple rods and cones, and add them up to start forming very basic patterns of light and dark.

[00:06:23.55] Retinal implants, which we reviewed in the last lecture, primarily work by stimulating bipolar cells. They don't stimulate rods and cones because in those individuals, the rods and cones don't work. They stimulate two layers up, at the bipolar cells. As the information then passes through the retina, it gets passed to the nerve fiber layer, and the nerve fibers then travel through the top layer of the retina, and become the optic nerve.

[00:06:55.58] The density of rods and cones varies across the retina. So you have more density at the central part of the retina, which is called the fovea. And that's where you have the highest acuity vision. Outside of the fovea, which is very small, the number of rods and cones drops off, especially there are very few cones outside of the retina. Outside of the fovea, the density of light receptors drops off. In particular, there's mostly rods outside of the fovea. There's not very many cones. And in particular, there's very few blue cones.

[00:07:30.45] In addition to the difference in acuity between the fovea, and the rest of the retina, you also have a blind spot. Which you might have heard about the fact that you have a blind spot. And this is where the nerve fibers enter through the layer of the retina, because it has to get through there somehow, and it travels to the brain.

[00:07:53.25] A major challenge for users of retinal implants, is they're relatively poor resolution. There are hundreds of thousands of rods and cones in the eye, but the current retinal stimulator technology only delivers at most, a few hundred stimulation points, instead of hundreds of thousands.

[00:08:11.56] So these users only have a very small range of vision, and it's very low resolution. It looks like a pixelated image, like an old style computer game. However, despite the drawbacks, having some capacity to distinguish light from dark, enables users of retinal implants to accomplish tasks that they would not necessarily be able to accomplish without them.

[00:08:37.46] Color vision is done by the activation of cones. So they're preferentially sensitive to certain wavelengths of light, and sensitive to a broader range. We talk about them colloquially as being red, green, and blue cones. But they are more precisely described as long, medium, and short wavelength cones, depending on their peak wavelength sensitivity. You detect color by the combination of how many cones of each color are activated depending on the wavelength of light.

[00:09:16.05] So if you look on this chart, if you are looking at light with a wavelength of about 450 nanometers. That's right near the point where the blue cone line crosses the red and green cone lines. Then you would have activation of all three cone types, but the ratio of how many of each type are active tells you what color you're looking at.

[00:09:46.96] Color blindness most commonly occurs due to a mutation in the gene that creates the green cone proteins. The green cone wavelength in these individuals is too close to the red cone. So people who have this most common form of color blindness can't tell the difference between shades of red, yellow, and green very easily.

[00:10:12.59] More rarely, people will lack one, or more cone types entirely. Most commonly, people are missing green. But it's possible to be missing any cone type, and extremely rare to be missing all three cone types.

[00:10:27.89] Now that we've gotten the information into our retinas, and it's been translated by the rods and cones, our sensory organ, to the nervous system, now we need to go from the eyes to the brain. So in this diagram, we are looking at a brain from underneath. So you'll notice right and left are swapped because this brain is upside down.

[00:10:48.18] So if you start by looking at the right visual field, the left side of the diagram, that information is detected partly by the right eye, and partly by the left eye. So tracing from the right eye, which is carrying some information from the left and the right visual field, the information travels via the optic nerve to the optic chiasm, which is the x-shaped structure near the middle of the brain. This is on the underside of the brain, and this is where information crosses from one side of the brain to the other.

[00:11:21.53] So all of the information from the right visual field ends up on the left side of the brain, and all of the information from the left visual field ends up on the right side of the brain regardless of which eye it started at.

[00:11:36.83] From the optic chiasm, the information becomes the optic tract, and it travels through the lateral geniculate nucleus of the thalamus. After the information has left the thalamus, it becomes the optic radiation, which is a wide band of white matter that travels through the posterior part of the brain, and ends up in the visual cortex.

[00:12:01.49] Most neural engineering that is related to blindness, at this time, is focused on blindness caused by damage to the retina, most commonly, retinitis pigmentosa. But I want you to think about what would happen if damage occurred at any other point in the pathway from the eye to the brain. What parts of the visual field would be affected? And what could we do in order to engineer around that damage?

[00:12:29.86] Once the information reaches the occipital cortex, it's processed by cortex that is dedicated to processing visual information. A small amount of visual information is also processed by some cortical regions, including the thalamus, and that's mainly for the purpose of setting eye movement. So the thalamic region helps figure out what direction your eyes need to point.

[00:12:55.06] So I'm going to just walk through a very basic overview of what happens in the primary visual processing areas. This is an extremely complex set of processing that we don't fully understand, and I just want to give you a brief overview of what we do know. And what I'm showing here, is the left hemisphere, which corresponds to the right visual field, but this happens symmetrically on both hemispheres of the brain.

[00:13:21.94] So the information travels first to V1, or the first area of visual cortex, which processes static and moving objects, patterns, and color. And all of the visual information passes through this region. From V1, it then gets passed to V2, which handles depth perception, boundaries, and the illusory boundaries, and the figure ground problem, so distinguishing an object from its background, and color processing.

[00:13:53.41] Then the information gets split. Some of the information travels to the dorsal visual stream, which determines where objects are. The first area here, is V3, which determines movement of the entire visual field. So this would happen if you are moving, or if you're looking at a moving picture. So, the entire field is moving. It also starts getting into more finer color gradations.

[00:14:23.50] That information then gets passed to V5, also known as MT, which processes moving objects. And V6, which accounts for your own movement of your own body. The rest of the information gets passed to the ventral stream, which determines what the object is. The first area here is V4, which processes geometry, and complex shapes. And it's also controlled by attention. So if you're paying attention to an object, you're going to see more activation in this area of the brain. And you're going to have better accuracy in identifying objects.

[00:15:05.15] And then to IT, or inferior temporal lobe, which identifies the objects, and helps provide the name of those objects. Which, the naming especially, happens in the left hemisphere of the brain. Visual information also gets passed on to other parts of the brain where it's involved in cognitive tasks, and motor responses. In particular, the information from the dorsal stream, the

"where is it," stream of information, gets passed from parts of the parietal lobe, where it's initially being processed, to the inferior parietal lobule. Which you might remember from earlier in the course, is the sensory integration regions. So it helps integrate visual information with other senses, in order to coordinate a response.

[00:15:51.44] Faces go through some special processing that other objects don't go through. So this diagram shows the activation of different brain areas for different stimuli. So you can see that some areas are specifically active only for faces or bodies, and some prefer other types of inanimate objects. Humans in general, and especially faces, are subject to special processing. And the other object recognition areas are not necessarily especially sensitive to faces.

[00:16:22.83] These are the occipital face area, which is the red blob furthest to the left on this diagram, the superior temporal gyrus, which is the red blob on the right of this diagram, and the fusiform face area, which isn't shown on this diagram. It's part of the medial temporal lobe, and it's located near the hippocampus. The fusiform face area is also particularly important for identifying specific people. So it's not just, this is a face, and what is its expression, but who is that face?

[00:16:55.57] Finally, I want to review eye movements. The movement of the eye is responsive to environmental , stimuli that is to say, what you're looking at, and your own body movement, in order to keep your eyes stable so you can continue looking at something even when you are moving.

[00:17:13.21] The eye rotates with three pairs of opposing muscles, which pull the eye left and right, up and down, and rotation clockwise, or counterclockwise. Eye movements receive commands from several regions of the brain, especially the frontal eye fields, and the cerebellum.