# Neurobiology

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## Lecture 5.1: Sensory Systems

Hi everyone, welcome back to Neurobiology. In the initial part of this course, we looked at various components of the brain, the membrane properties, the neurons, the action potentials within neurons, and then in the last series of videos, we looked at how neurons connect to each other at chemical and electrical synapses. The various functions of the brain are not enabled by just one or a few neurons. The brain is made up of many different modules or circuits, and each of these circuits involves thousands or millions of neurons that work together to enable various functionalities. In this series of videos, we will look at sensory systems, and that will also tell us how many neurons come together to perform a common task. Before we look at any sensory system in detail, we will try to understand the general principles of sensory processing.

So let's get started. For centuries, philosophers have debated whether the human mind is like a blank slate on which anything can be written. So some earlier philosophers in the category of empiricists like John Locke and David Hume believed that all knowledge is obtained through sensory experience. At birth, the human mind is like a blank slate on which experience leaves its mark.

In other words, they believe that when the brain is formed, there is no prior information in it, and everything that we perceive and we learn happens through experience. But now, there is more and more evidence that brains are pre-configured to respond to certain types of stimuli and in certain manners. Take an example from the sense of taste. We cannot detect the taste of every chemical equally. There are certain types of molecules whose tastes we can detect very well.

For example, various kinds of sugars or salts, and there are other chemicals that are relatively bland for us. And among the tastes that we can detect, there are certain tastes that we like and certain tastes that we dislike. So we have behaviors for them. Now, of course, some of these behaviors are learned. So you can learn to like the taste of a drink that you didn't like the first time.

But some of the preference for taste is inbuilt. So if you look at the taste preferences of children, you will find that most of them like sweet taste. And that has something to do with the revolutionary history because when humans lived in forests, a sweet tasting fruit was probably more nutritious than a bitter tasting fruit. And that information has gotten encoded our DNA and that determines how our brain is formed. And then it gets hardwired in our brains.

So our final perceptions and our behaviors are determined both by our nature, that is hardwired information in the brain, and nurture, that is the experiences that we have. One important thing to keep in mind about perception is that perception simply does not happen by passive encounters with the stimuli. So when we see colors, it's not that the colors are floating around in the environment and we just happen to encounter them and then we see them. There are actually no colors in the universe. What we see are electromagnetic waves and these electromagnetic waves strike our retina and from there, they generate some sensory input to the brain and the brain converts that information into colors that we see.

Now there is a very large range of colors that we can see. So if you look at the advertisements for monitors these days, they claim that they can show hundreds of millions or even billions of colors. But what I find most amazing is that this huge range of colors that we can see is a very very tiny range of electromagnetic waves actually. So here's a graphical representation of the same. On this axis here, we are looking at various electromagnetic frequencies.

The frequencies can vary on a very wide range and here we are only looking at a portion of it from 10 to the power 4 to 10 to power 18 hertz. And within this range, only a very tiny fraction between 10 to power 14 and 10 to power 15 hertz are all the electromagnetic waves that we can see. So on this end, the frequency is slightly above 10 to power 14 and that corresponds to the wavelength of 700 nanometers. So that is the shortest frequency or the maximum wavelength that we can see and that appears to us as dark red. And on the higher side of frequencies, the maximum frequency that we can see corresponds to the shortest wavelength of 400 nanometers that we see as violet.

So this 400 to 700 nanometers of wavelength range includes all the colors that we can see. If you go at higher frequencies on this side, that is lower wavelengths, those will appear dark to us, so we will not see anything. And similarly on this side, we will see nothing. But that's such a tiny range of all possible electromagnetic waves. Now it's not that these wavelengths are not present in the environment and that's why we are not seeing them.

They are present. So on this side, there are infrared rays that are present and on this side are ultraviolet rays that are there in the environment. It's just that we cannot see them. And that's because our brain has evolved to detect electromagnetic waves only in this narrow region of the spectrum. But there are other animals that can detect somewhat higher wavelengths or somewhat lower wavelengths.

So for them, these wavelengths have colors. So it's important to keep in mind that what we perceive as colors are ultimately a creation of our brains. There are no colors in the universe, just like there are no tastes in the universe. There are only chemicals whose encounters with the tongue are converted into tastes by our brain. The same thing is true for all sensory modalities.

In the case of sound, what we are really perceiving are pressure waves. You're hearing my voice right now because the diaphragm in your headphones or your speakers is vibrating and generating pressure waves that are traveling to your ear and activating receptor neurons that convey that information to the brain and the brain interprets that information as sound. And again, we can only detect a narrow range of frequencies of the pressure waves. Humans can detect pressure waves from 20 hertz to 20 kilohertz. And any frequencies that are beyond this range cannot be perceived by us.

So frequencies outside this range are not sounds for us, but they would be sounds for other animals that have evolved to detect those frequencies. Let's take a look at different senses that we have. And we are all familiar with these five major senses. Vision, that is things that we can see, hearing, touch, taste, and smell. But in addition to these five, we have some more senses.

Do you want to pause the video here for a moment and think about it before we discuss the other ones? So here are some more senses that we have. Some of these are classified as somatic senses because they are related to the physical body. One of them is pain, so you can feel the prick of a pin on your skin. Temperature, you can feel hot and cold. Itch, we all know that feeling when we really want to scratch our skin.

And proprioception, that is the sense that tells you where your body parts are in a space and what is your posture or whether your body parts are moving. For example, you can tell whether you are facing up or facing down without having to look at your face. And you can tell whether your hand is stretched or it is in a relaxed position. And you can do it even if your eyes are closed. So that is the sense of proprioception.

We also have a vestibular sense, that is the sense of balance. So you know when you're falling down or you know if you're sitting in a car and the car is accelerating without additional visual input. In addition to these, we also have some senses that are more internal. For example, you know when your bladder is full or you're eating and your stomach is full or your throat is dry and many more such internal senses are present. The process of sensory perception begins with the sensory neurons that are present in the sensory organs.

For example, the photoreceptors in the retina. And within the sensory neurons, there are usually specialized proteins that function as sensory receptors. These proteins have unique structures that are sensitive to the particular kind of stimulus. So the options that are present on the photoreceptors are sensitive to light. And similarly, there are other kinds of proteins that may be sensitive to certain chemicals or sensitive to mechanical stimulus.

And when the physical stimulus is received, the structure of the proteins change and that may result in the opening of some ion channels. So the physical stimulus input is basically converted into the electrical activity inside the sensory neurons. And this process is known as stimulus transduction. And then this electrical activity that is generated in the sensory neurons can be transferred to other neurons that are connected to the sensory neurons through various synapses. So overall, we can say that the sensory modality is represented by an ensemble of neurons that are connected to the specific class of the receptors.

And this whole set of neurons that are connected to the receptors of a certain kind can be called the sensory system. So we have the visual system, auditory system, vestibular system, olfactory system, gustatory or taste system. Each of these systems would involve the corresponding sensory receptors on the sensory neurons and then the subsequent stages of various other neurons. And all that the sensory system cares about is the activity of the sensory neurons. So if one could artificially generate this activity in the sensory neurons, then that would also result in the same kind of perception.

So if the photoreceptors can be artificially stimulated by, say, injecting some current in the photoreceptors instead of light input, the brain would still feel that it is seeing things in the normal way. Similarly, if I could stimulate your olfactory neurons, you may feel like you're smelling something while your olfactory neurons are just being activated by some artificial current. Let's take a look at various sensory systems. The kind of stimuli that are involved, the types of receptors that detect those stimuli, and the type of cells on which these receptors are present. In the case of vision, of course, the stimulus is light.

That is, these are photons of different wavelengths. Which are detected by the photoreceptors that are present on rods and cone cells in the retina. Hearing is enabled by sound, which are pressure waves, and they involve mechanoreceptors, which are present in the hair cells inside the cochlea. The vestibular system involves sensation of gravity, acceleration, etc. And these also involve mechanoreceptors that are present inside the vestibular labyrinth.

So, these are structures that are present deep inside our ears. Then coming to the somatosensory systems, these involve various sensations that happen throughout the body. Touch is, of course, enabled by mechanoreceptors that are present on our skin. In addition to touch, we also have proprioception that allows us to feel where our body parts are in space and how we stretched various muscles are. So, they also involve mechanoreceptors that are present on the muscles or the joints.

We have already seen an example of this in the case of the knee jerk reflex, where the sensory neurons detect the stretch of the muscle and enable the reflex. So, pain is an interesting one. Pain can involve various kinds of stimuli. This can be thermal pain. So, if you come in contact with very high temperature object, that would be a thermal stimulus that would be detected by thermoreceptors.

It can be a mechanical stimulus such as the pin trick, which would involve mechanoreceptors. And it can also involve chemical stimuli. So, if you come in contact with some acid or even eating of chili peppers, so the sensation that you have is not really a taste, but it's a pain sensation and that involves chemoreceptors that detect certain chemicals inside the mouth. And if you eat a lot of chili peppers, then you can also realize the presence of these receptors in other parts of your digestive system. Itch, although it feels like a mechanical sensation, it is actually enabled by the presence of a chemical histamine and that is detected by certain chemoreceptors that are sensitive to histamine.

These are present on the skin. When we scratch the itchy surface, that response is mechanical, but the sensation itself involves this chemical sensation. Then we also have various visceral or internal body sensations such as the sensations inside our digestive system or bladder or lungs. And this can involve again mechanoreceptors and also thermoreceptors and chemoreceptors. The sense of taste, also known as the gustatory system, is of course made possible by the detection of chemicals that come in the mouth. These are detected by chemoreceptors present on the taste buds.

And the sense of smell, the olfactory system, is enabled by odorants. These are volatile chemicals that are again detected by chemoreceptors present inside the nose on the olfactory sensory neurons. So, this is a glimpse of various senses and the kinds of receptors that are involved. Each of these broad classes of receptors may involve many subclasses, which would include different types of proteins. Thank you.