Introduction to Brain & Behaviour
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Neuroscience of Sensation & Perception
Lecture 11

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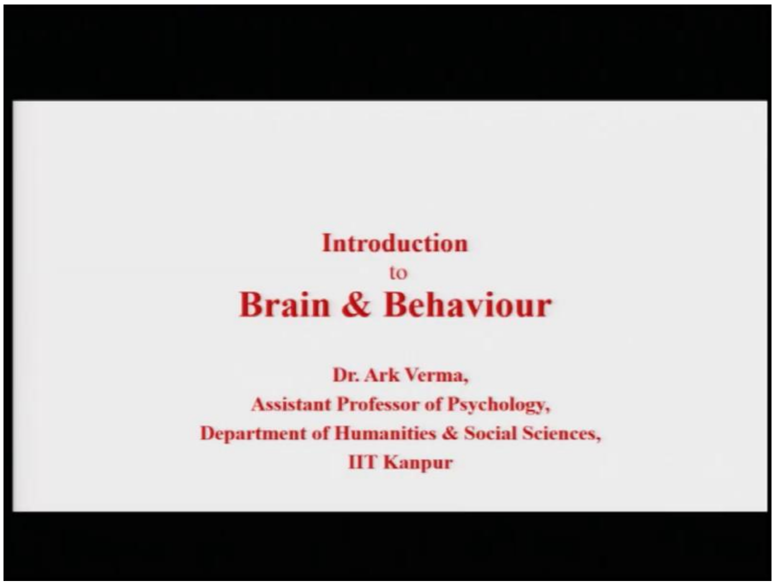

Hello, and welcome to the course Introduction to Brain and Behavior. I am Dr. Ark Verma from IIT Kanpur. I am working with the Department of Humanities and Social Sciences and also with the Program in Cognitive Sciences at the Institute. This is the third week.

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And today we will start talking about the neuroscience of sensation and perception.

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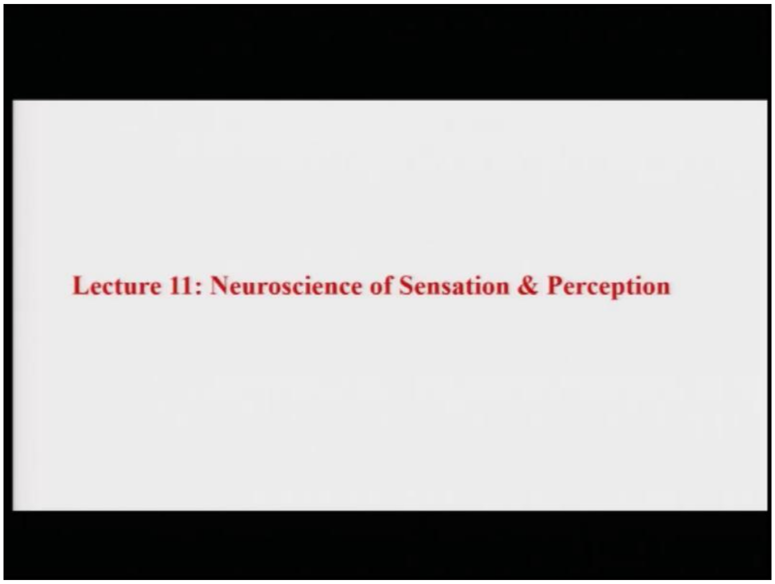

Now, sensation and perception are one of the most important, are basically the first mental functions that we can talk about, and which represent our interaction with the environment around us.

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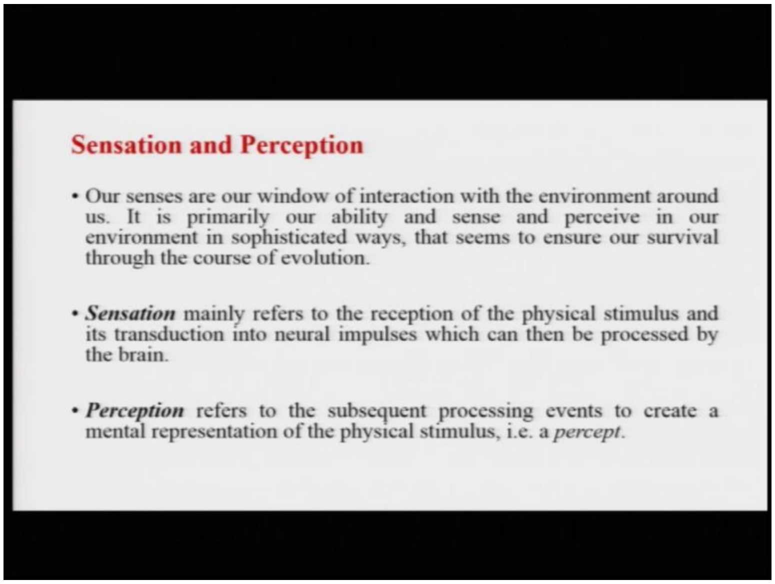

It is primarily our ability to sense and perceive the environment in sophisticated ways that seems to basically ensure our survival through the course of evolution. Basically, it is our ability to perceive, say, for example, the stimulation of temperature and the coldness or hotness of air and things like whether something is wet or it is dry or something like that. Or, say, for example, our ability to see clearly, hear clearly, all of that is what basically makes us the living organisms that we are and that is something that is very, very essential to us surviving as organisms or as species during the course of this evolution.

Now, I have discussed this at length in the course on advanced cognitive processes, actually basic cognitive process that I have taken earlier. But, researchers, scientists in cognitive psychology distinguish between sensation and perception, these two are different terms. So, let us try and be clear on them.

Sensation basically refers to the main act of receiving the stimulus from the environment and its transduction or conversion into neural impulses, which can then be processed by the brain. So, the idea is that all of these sensory organs that we have; the eyes, the ear, the tongue, the nose, and the skin as one of the sensory organs. Basically, they receive all the sensory stimuli that the environment has to present to us. And then they try and convert, they convert the sensory stimulation into neural impulses, which can then be communicated to the brain.

And then the brain can sort of process the stimulation and decide our next course of action. So, this is something that is very, very important. So as I was saying, sensation refers to the reception of this physical stimulus, and its transduction or conversion into neural impulses, which can then be processed by the brain.

Perception, on the other hand, refers to all what happens later. It basically refers to the subsequent processing events that create a mental representation of the stimulus or the percept. Now basically, whatever sensations you receive, or whatever sensations we receive, and we want to process them, that is not really the final form on which the brain takes a decision on whether to act in a particular manner on the stimulation. The brain actually sees, or say, for example, the brain actually works on the percept that is actually a mental representation of whatever stimulation has been received.

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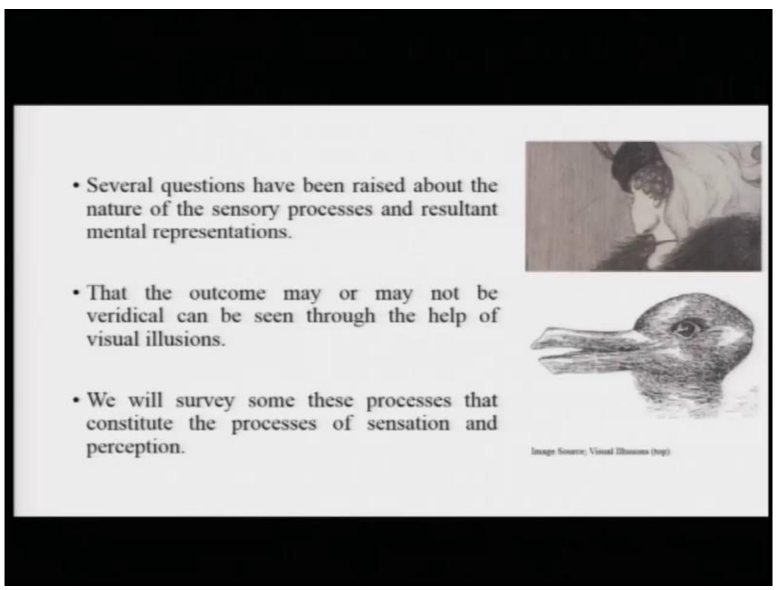

A very good example of what is the difference between the sensation that is falling upon our eyes, for example, let us take, versus the perception that we are actually getting is basically coming through these visual illusions. If you can see the figure on the right, figures on the right, you can see that both of these figures are actually by, are actually amenable to two kinds of perceptions.

You can see both a young woman and an old woman in this picture on the top and you can see actually a bird or a rabbit on the picture on the on the bottom. Even though the sensation that is being received from this stimulus is identical and it is not really changing with respect to what is happening on our eyes, but we can actually make two meanings out of it depending upon where actually we are focusing. So perception is basically a process that involves processing of these sensory stimulations on the five senses.

Now, several questions actually have been raised upon the nature of these, nature of how we sense or how we receive the inputs. And also how do we convert the sensory inputs into perceptual representations. So, there is a lot of theory in this regard. And if you want to have a more detailed discussion about it, I propose that you can go and see those lectures where I have discussed this in some detail. There is a lot of questions, say, for example, whether what we see or actually what we perceive is veridical or not, and some of that can be explained through the examples that I just gave.

Now, in this chapter, we will basically process some of these processes. We will survey some of these processes. We will see how sensations are received from the environment. What are the neural pathways that help us receive these sensations, convert them into neural signals that can then be processed by the brain and what is the processing that the brain eventually does on these sensory inputs and how does it kind of give us a sense of let us say how to act with respect to any of these particular stimuli.

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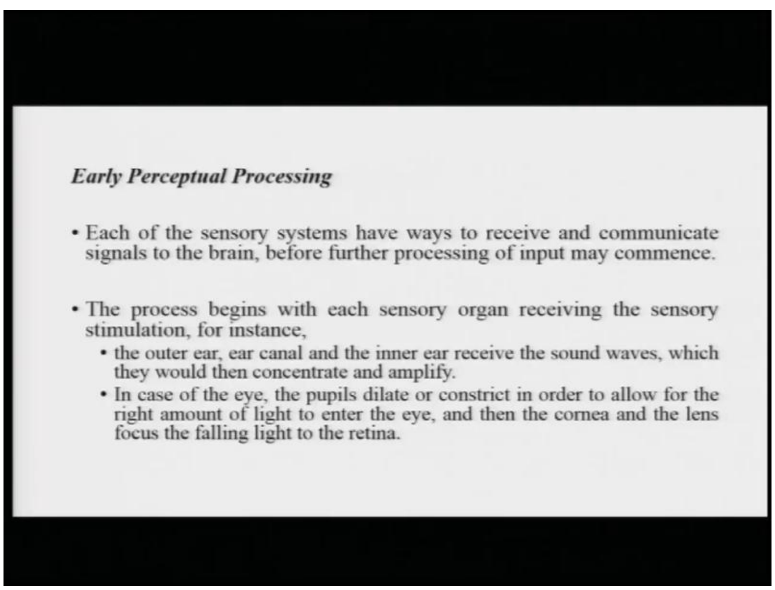

Now, early perceptual processing basically refers to the initial parts of the processing cycle, where in the stimulation has just been received by the sensory organs. And it basically refers to the process of after these stimulations have been received, how are they conveyed to the brain. Now, the process begins with each sensory organ. We talked about five sensory organs receiving the sensory stimulation, for instance, the outer ear, the ear canal, and the inner ear receive the sound waves.

They funnel it and they funnel the sound waves inside the ear and then they concentrate and amplify these sound waves which can then basically be transduced by the hair cells or the receptors in the inner ear and inside the basler membrane in the cochlea, and then how is that information conveyed to the primary and secondary auditory cortices. In case of the eye, the pupils dilate or constrict to allow less or more light entering the retina. And basically once the right amount of light is entered the retina, the cornea and the lens adjust to focus the falling light on the retina. We know that we will actually talk about this also.

We know that the retina contains these photoreceptor cells called rods and cones. And they are basically responsible for converting the ray of light or the physical stimulation from the light into neural impulses which can then be conveyed to the other parts of the brain. So, this is one of the things.

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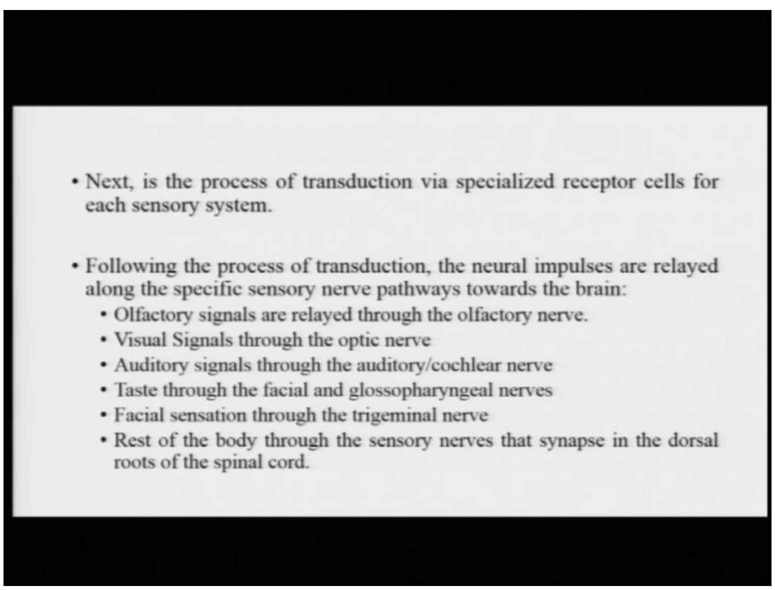

Now, next is this process of transduction. Once the stimulation has been received, and it has been transduced by these specialized receptor cells into neural impulses. However, these neural impulses conveyed to different areas of the brain. Now, say for example, let us try and understand that in detail. Olfactory signals are relayed to the primary olfactory cortex through the olfactory nerve. Visual signals through the optic nerve, auditory signals through the auditory or cochlear nerve, taste signals through the facial and the glossopharyngeal nerves, facial sensation, say for example, touch sensations of the face through the trigeminal nerve.

The rest of the body sends its sensory signals through the sensory nerves that synapse at the dorsal roots of the spinal cord and enters the brainstem through there. So, this is one of the, this is basically the ways how the sensory stimulation received on these sensory organs is can be conveyed to the different regions of the brain.

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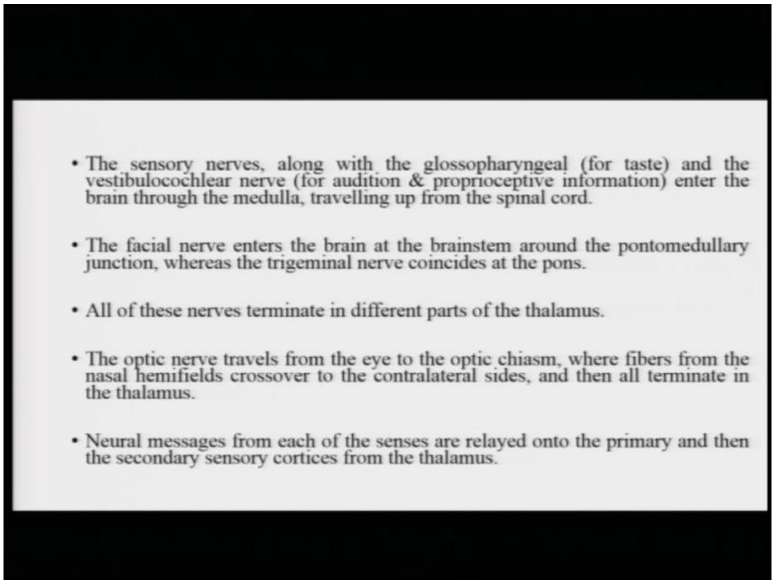

Now, the sensory nerves, along with the glossopharyngeal nerves, which are responsible for taste and the vestibulocochlear nerve, which is basically responsible for auditory, processing auditory information, and proprioceptive information about the body balance, etcetera, enter the brain through the medulla and then travel up the spinal cord. The facial nerve enters the brainstem around the pontomedullary junction, whereas the trigeminal nerve basically coincides at the pons.

This is, these are the ways how these very important sensory nerves are coinciding or connecting with the brain. All of these nerves terminate in different parts of the thalamus. So thalamus basically, as we have discussed earlier, acts as a relay station that conveys all of this incoming sensory information to different parts of the brain to the different cortices that processes these bits of information.

Now, the optic nerve basically travels from the eye socket to the optic chiasm, where there is this crossover of part of the optic nerve happening, actually crossover to project information, the contralateral size, which is basically from the coming from the two nasal hemifields. And part of them basically go directly through the ipsilateral cortex. Now, neural messages from each of these senses are really down to a primary and secondary sensory cortices from the thalamus.

So the primary sensory cortices are basically, let us say the primary visual cortex or the primary auditory cortex, which receive the sensation firsthand and then they can, after initial processing convey the information to the secondary auditory cortices where this (info) sensory information is integrated with information from the other senses and processes like evaluation of emotion, consulting the memory, etcetera, can take place.

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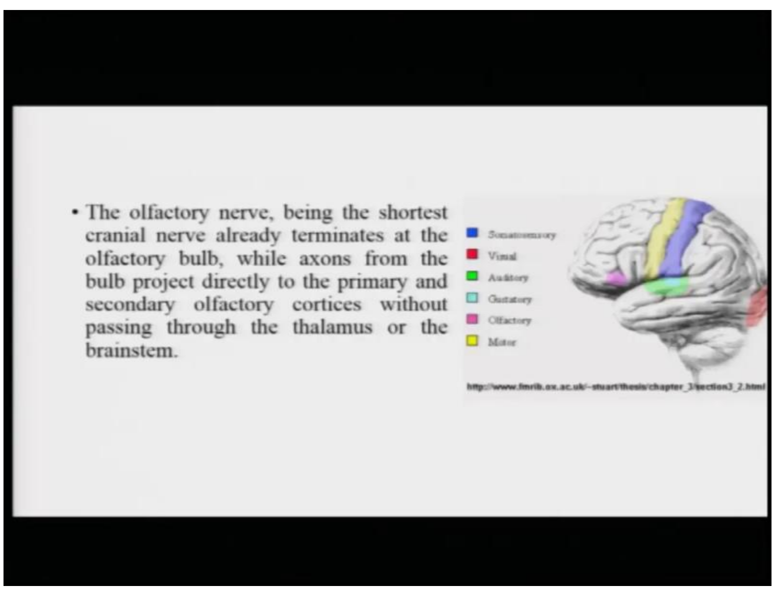

Now, the olfactory nerve, being the shortest cranial nerve, it already terminates at around the olfactory bulb, while the axons from this olfactory bulb actually project directly to the primary and the secondary olfactory cortices, without passing through the thalamus or the brainstem. So, the olfactory is slightly unique in a sense that the information from the olfactory nerve does not really relay through the thalamus but directly connects to the primary and the secondary olfactory cortices. So, this is also something that you will need to remember.

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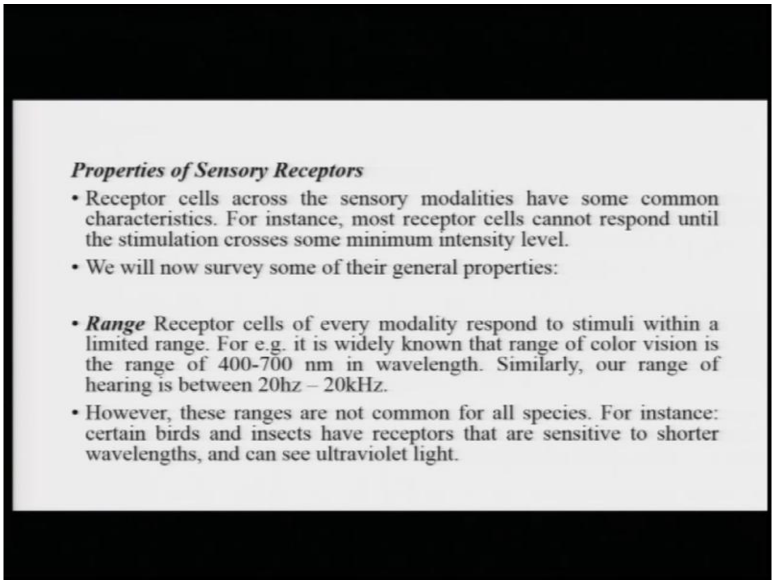

Now, let us look in at, in more general about the properties of these sensory receptors. Now, these receptor cells across these different sensory modalities have some common characteristics. For example, the receptor cells cannot respond until the stimulation has (be) that is being received crosses a minimum intensity level or a minimum threshold. Until then, there will be no firing of action potentials in these receptor cells.

Let us talk about some generic properties of these receptor cells. Say for example, range. The receptor cells of every modality such as vision, audition, touch, taste, etcetera, respond to stimuli within a limited range only. For example, I am sure it is known to all of you from class sixth physics is, that the range of our coloured vision is (any) is between 400 to 700 nanometers. Similarly, our range of hearing is between 20 hertz and 20,000 hertz. Now, these ranges are typical for humans, but are not common or shared across all species. For example, certain birds and insects actually have receptors that allow them to see ultraviolet light.

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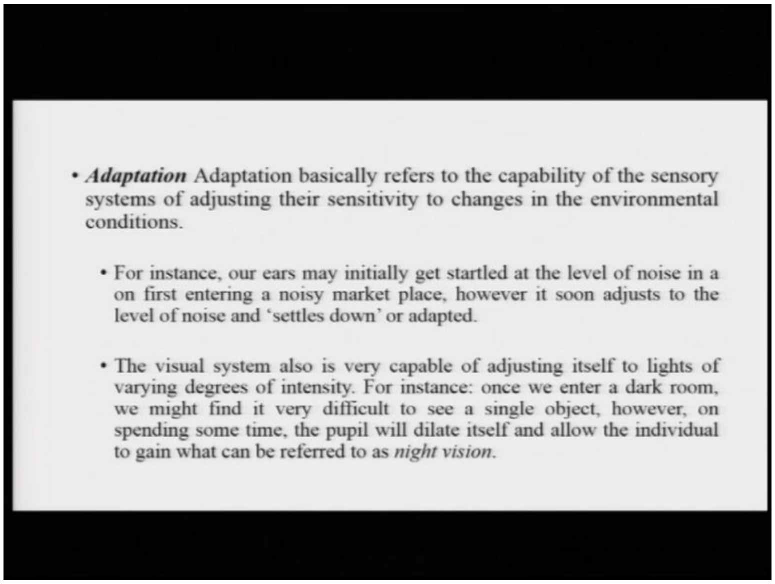

Another property is adaptation. Now, all of these sensory receptors can adapt to the dynamicity of the environment, can adapt to the changing levels of stimulation within the environment. Say for example, our ears, when you enter a very noisy place initially, your ears will initially get startled and you will be very sensitive to the sound. But if you spend enough time in that room, gradually the ears adapt to that level of noise and you start feeling the sound much less intensely.

Similarly, say for example, if you walk directly into a dark room from while you are coming from an area of adequate light. Initially, it is a bit difficult to spot even your hands, for example, but if you have spent 5 minutes, 10 minutes into the room, your eyes sort of adjust, the pupil dilates to allow more light inside. And therefore, you can sort of start seeing a little bit at least as much as possible with respect to that level of illumination. So this is basically a demonstration of the fact that the receptor cells are very capable of adapting to different kinds of stimulation situations.

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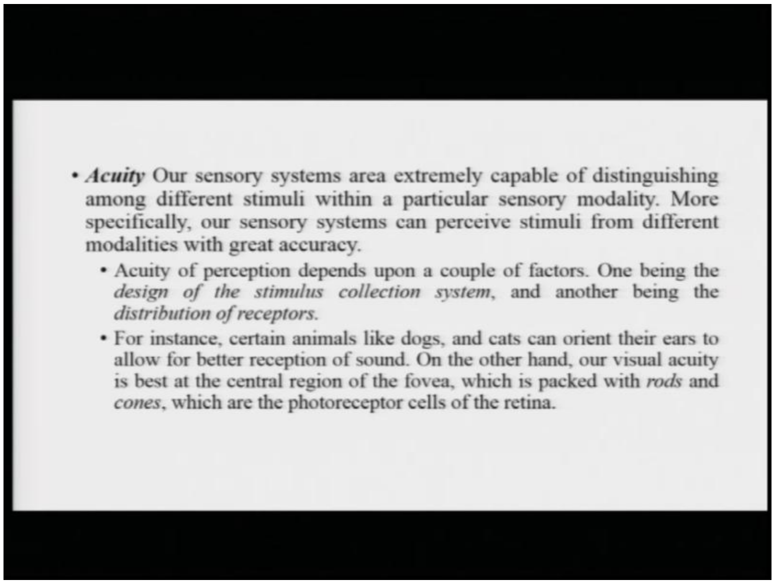

As far as acuity is concerned, acuity basically refers to the capability of the receptor cells of being able to distinguishing different stimuli within each modality. Basically, it refers to the accuracy of perception of each of these different kinds of stimulation. Now, acuity of perception may depend upon a variety of factors. Say for example, one could be the design of the stimulus collections. Say for example, our ears are designed in such a way that they can allow the concentration or the funneling of sounds towards the inside of the ear, in the inner ear and so on.

The other could be the distribution of receptors. Say for example, we know certain dogs and cats. Say for example, they can actually orient their ears to the source of sound so as to allow more a clear perception of that kind of sound. Similarly, say for example, if you talk about visual acuity or the clarity of visual perception, the visual acuity is basically based at the central regions of the retina, where there is this fovea, which is a small region, which is packed with these photoreceptor cells called rods and cones and which allow for, allow us to see whatever stimulus is out there with absolute and maximum clarity.

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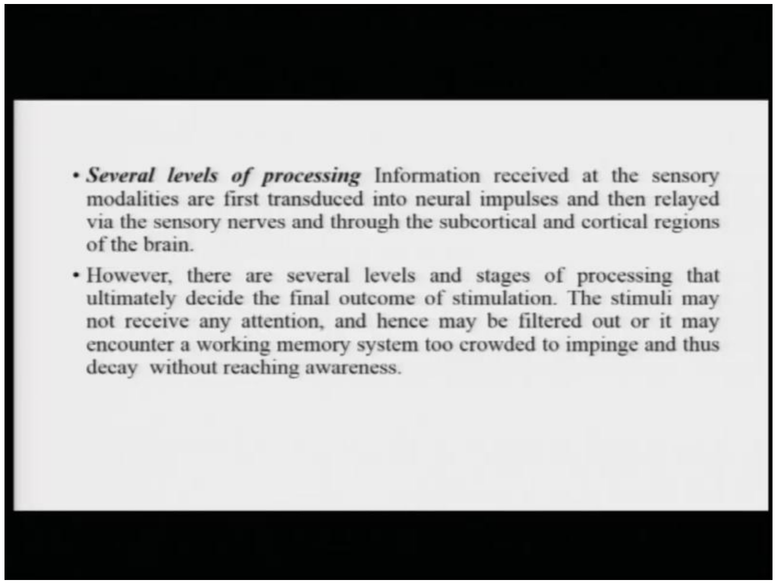

Apart from the range, adaptation and acuity, there are actually several levels of processing that each stimulus has to go through before it can be processed by the brain. Information that is received at the sensory modalities are first transduced into neural impulses and then they are relayed via the sensory nerves through and towards the subcortical and cortical regions of the brain. But during this journey, there can be many instances or there can be several factors that affect whether this information is going to reach conscious awareness or whether the brain is going to be allowed to act as per this particular stimulation.

For example, a particular kind of stimuli may not receive any attention and therefore, may be filtered out or say for example, if a certain kind of stimulation enters your brain where the working memory is crowded up, because you are processing other stimuli or doing other tasks. So, basically, it may decay very quickly over time and it may not really reach awareness or conscious processing at all.

So, this is sort of and therefore, it can be said that out of the hundreds and thousands of stimuli that one is processing at all times, only a very small section of the stimuli actually receive active processing or reach conscious processing where the brain is sort of decides as to what action needs to be taken in order to process these stimuli.

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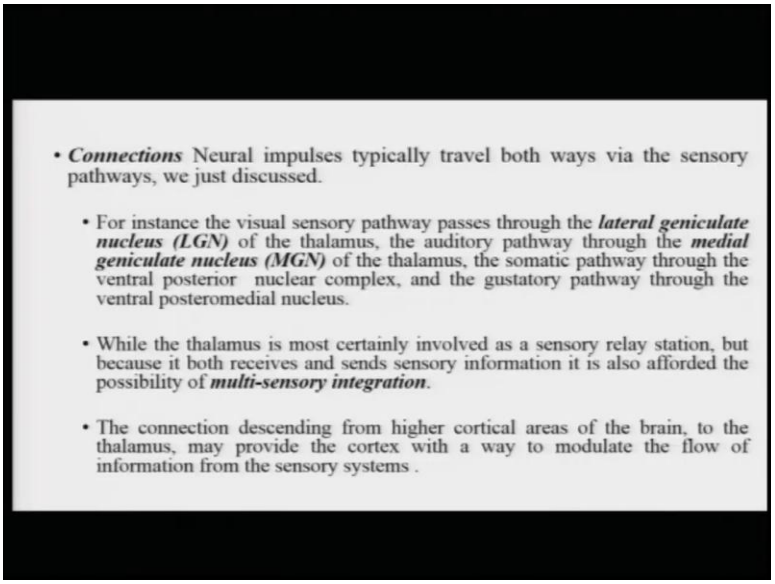

Another thing that we can talk about with respect to these receptors is basically the kind of connections that they have. Now, neural impulses typically travel both ways via the sensory pathways as we were just talking about. For instance, say for example, let us take the example of vision. (Sens) visual sensory pathway passes through the lateral geniculate nucleus of the thalamus, the auditory pathway passes through the medial geniculate nucleus of the thalamus. Similarly, a somatic pathway passes through the ventral posterior nuclear complex, and the gustatory pathway passes through the ventral posteromedial nucleus.

Now, these are the different junctions in the brain where these sensory pathways actually converge. And then relay the information via regions of the brain. Now, while the thalamus is most certainly involved as a sensory relay station, it basically, it is not clear as to what is it, what is the kind of processing that really happens with respect to information that is descending from the higher areas of the brain, towards the thalamus.

One of the options or one of the alternatives that researchers have proposed is that the thalamus basically participates in what is called multisensory integration, where it basically tries to combine together information from these different senses and be able to deduce or say, for example, form a holistic impressions of the percept. Now, the connections descending from higher cortical areas of the brain towards the thalamus, therefore may provide the cortex with a way to modulate the flow of information from the sensory systems and as I said, integrate them if the need be.

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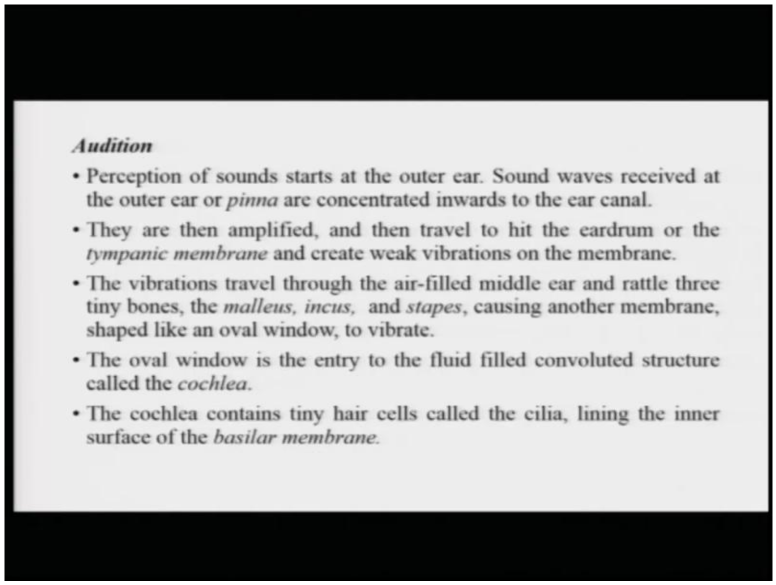

Now, we have talked about the general properties of the receptors across modalities. Now in this section, we will start considering a specific sensory modalities and try and discuss what happens with respect to them in some detail. Now, we will first take up the sense of audition. Now, perception of sounds actually starts at the outer ear, so this is where the perception of sound actually starts. Now sound waves received at the outer ear or pinna are concentrated inwards towards the ear canal. They are then amplified and they travel inwards to hit the eardrum or the tympanic membrane, wherein they create weak vibrations on the membrane.

The weak vibrations on the membrane basically travel through the air-filled middle ear, the inside of the ear, and they are basically, they rattle three very tiny bones that are there, which are called the malleus, incus and the stapes. The vibration of these three tiny bones causes another membrane, which is shaped like an oval window to start vibrating. Now, this oval window is basically the beginning point of this coiled tubular structure called the cochlea, which is a fluid filled convoluted structure. This cochlea basically contains tiny hair cells called the cilia lining the inner surface of this cochlea, which is called the basilar membrane.

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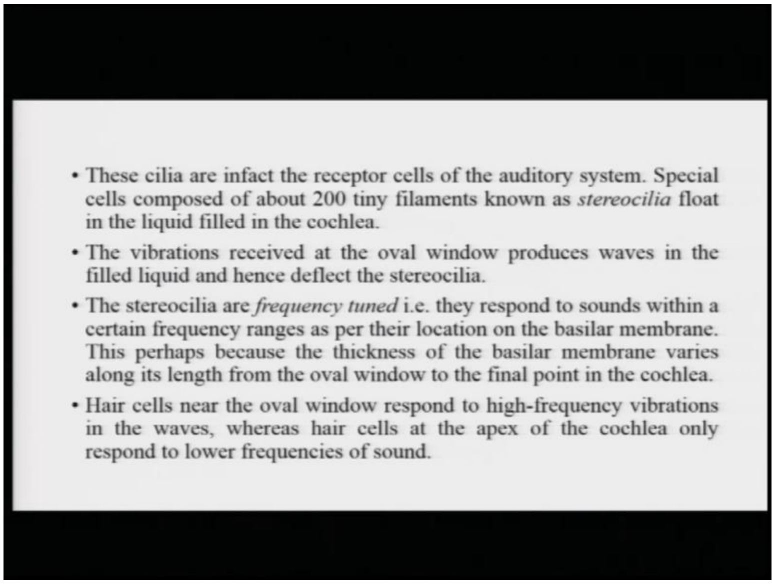

These cilia are basically the actual receptor cells in the auditory system and they are special cells composed of 200 tiny filaments known as stereocilia and these are what are floating inside the liquid filled cochlea. The vibrations at the oval window actually produces waves in this liquid which is filled in the cochlea and hence they start deflecting these stereocilia. The stereocilia are basically frequency tuned that is, they respond to sounds within a particular range of frequency as per their location in the basilar membrane.

This is probably because the basilar membrane is the thickness of this basilar membrane varies from the point at where it is connected with the oval window till the final point where it is sort of coiled up. Now the hair cells or the cilia near the oval window typically respond to higher frequency vibrations in the waves, whereas the hair cells towards the apex of the cilia, apex of the cochlea actually respond to lowest frequencies of sound. So this is basically how the process of receiving the sound is actually happening.

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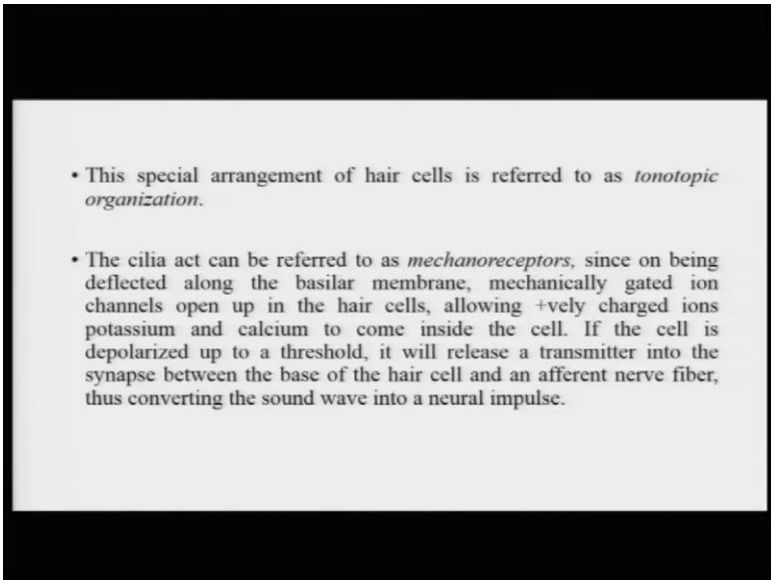

Now, this a special rearrangement with respect to frequency of the cilia is called tonotopic organization. And these cilia basically are referred to as mechanoreceptors because as soon as they start vibrating or as soon as their deflection is received on the along the basilar membrane, mechanically gated ion channels open up in these hair cells allowing more positively charged ions to get inside of potassium and calcium to get inside hence depolarizing these cells.

Once these cells are depolarized they generate an action potential, which can then basically lead to the appearance of this nerve impulse which has to then be conveyed towards the higher areas of the brain.

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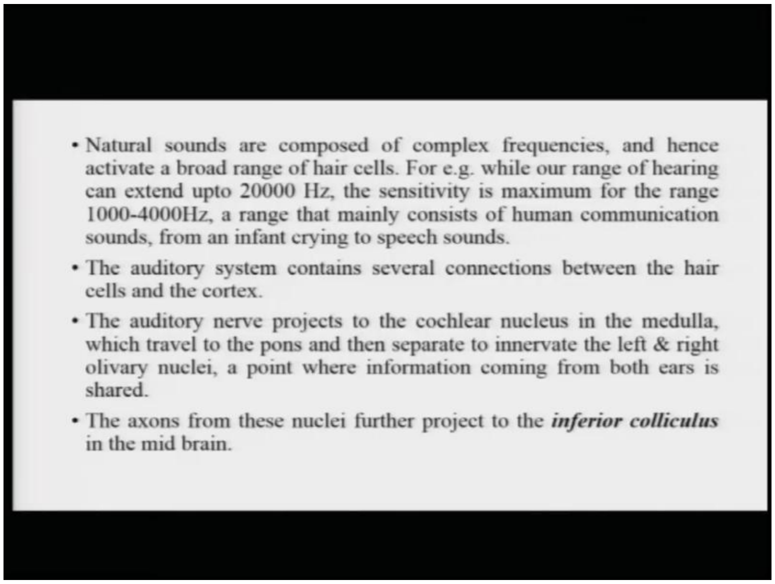

Now, we know that natural sounds are composed of very complex frequencies hence, basically they activate a wide range of these hair cells. So, for example, our range of hearing is, as I said, up to 20,000 hertz, the sensitivity is maximum within this range. However the sensitivity, we have enhanced sensitivity of receiving sounds between 1000 to 4000 hertz, which is basically the range of human communication, starting from a particular conversation somebody is having to a child crying.

Now, the auditory system contains several connection between the hair cells that is the cilia and the cortex. The auditory nerve projects to the cochlea and nuclear in the medulla, which travel to the pons and then separate to innervate the left and the right olivary nuclei, which is a point where information from both ears is shared. The axons from these olivary nuclei, actually further project to the inferior colliculus in the midbrain.

So, you have to sort of remember the pathways as to how the sound waves were first received at the outer ear, how are they converted into neural impulses at the cochlea using these hair cells or cilia and how are they then further kind of conveyed to the (in) till the inferior colliculi in the midbrain.

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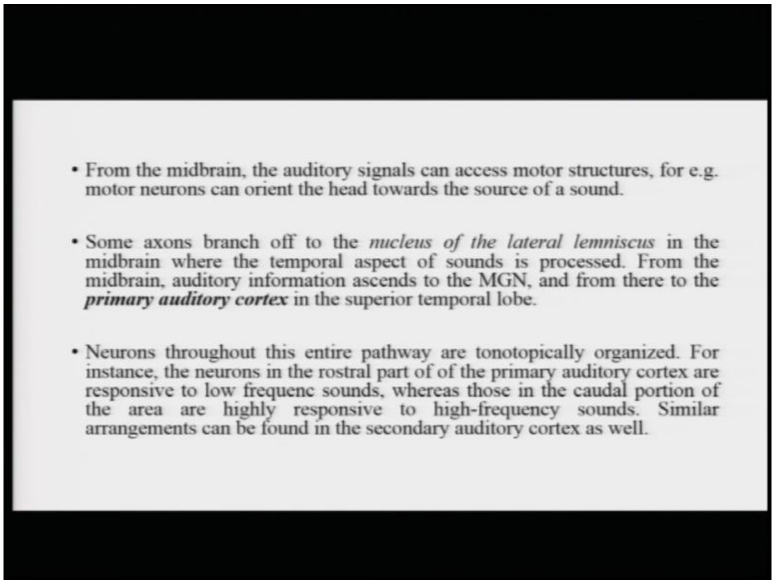

Now from the midbrain, basically, the auditory signals can access what are called motor structures. Say, for example, at this level, motor neurons can actually orient the head towards the source of sound in order to enhance the perception or clarity of sound. Now, some axons around this region branch off to the nucleus of the lateral lemniscus in the midbrain where the temporal aspects of sound is processed. Basically, from the midbrain auditory information ascends to the medial geniculate nucleus, and from there to the primary auditory cortex which lies in the superior temporal. We have seen where these regions lie typically.

Now, neurons throughout this entire pathway are actually tonotopically organized. So starting from the cilia in the cochlea, which are which were tonotopically organized to each of the neurons in the in these regions of the cortex are actually tonotopically organized, which means that neurons in the prime rostral part of the or rostral part or the bottom part of the primary auditory cortex will respond to lower frequency sounds, whereas neurons in the caudal part is the upper part of the auditory cortex will (high) will be highly responsive to high frequency sounds.

Similar arrangements can also be found in the secondary auditory cortex as well. So something that is very clear is that frequencies play a very, very important role in determining how the sounds will actually be perceived not only inside the brain, but also not only inside the ears, but also in the brain as well.

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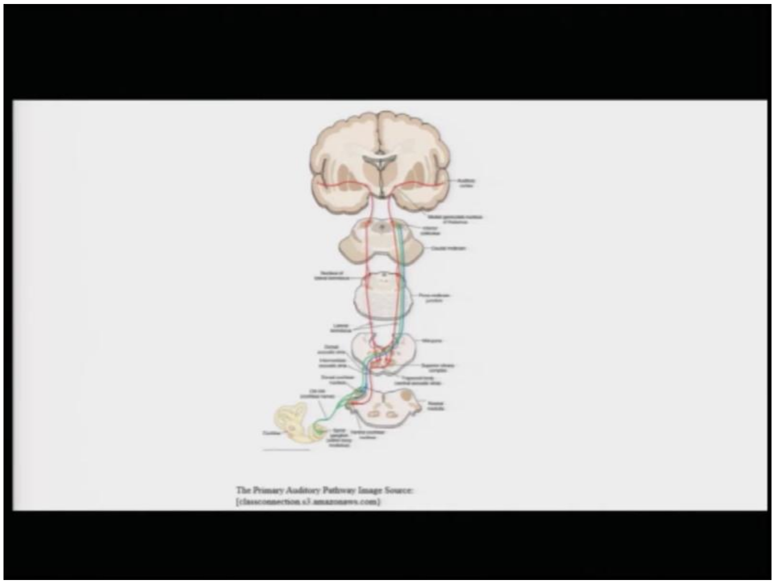

Now this is basically a graph which actually shows how the informations or how the projections from the cochlea reach the rostral medulla, these ventral cochlear nuclei, and then to the mid bonds and then the lateral lemniscus and upwards till the auditory cortices. So this is something that you will probably need to remember.

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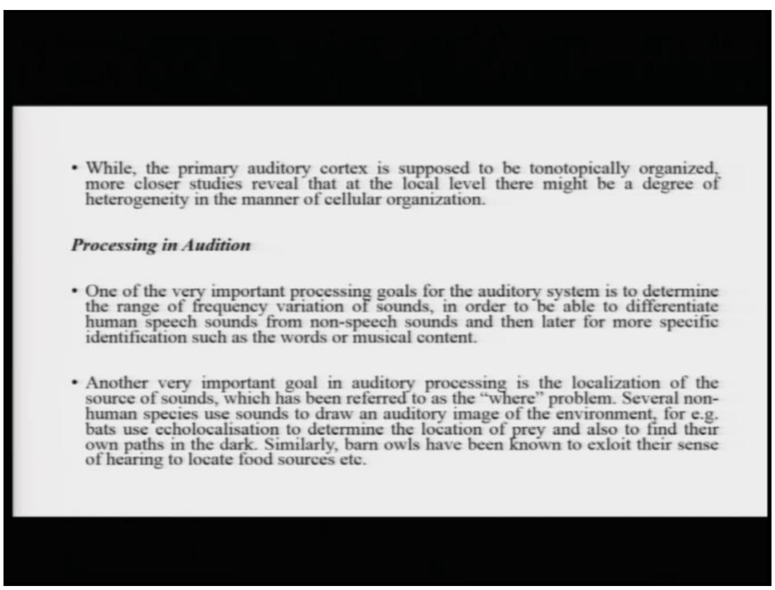

Now, while the primary auditory cortex is supposed to be tonotopically organized at the grass level, a closer look at these, at the experimental studies, actually reveal that at the local level, there might be degree of heterogeneity or a mix of neurons which are receptive to other kinds of frequencies. Because as you know, (comple) natural sounds, so the sounds that we typically hear are sometimes not really just having containing one kind of frequencies, but actually containing a mix of different kinds of frequencies.

Now, let us talk a little bit about what is the processing that goes on with respect to audition. One of the very, very important processing goals for the auditory system is to determine the range of frequency variation of sounds in order to be able to differentiate, let us say, things like human speech sounds, from non-speech sounds and then later, a more specific identification as to determining the voice of a person or the words or the content. Another very important goal in auditory processing refers to the localization of the source of the sounds where are the sounds actually coming from.

Another very important goal in auditory processing refers to localization of the source of the sound, which has been referred to as the where problem. It is very, very useful. Say, for example, in order to avoid predators, or in order to locate preys when you are sort of looking for something, if you can identify where the source of a sound is actually located. And this is something not only limited to humans, but is used extensively by several other species.

Say, for example, you might be aware that bats' technique, bats use a technique called echolocalization, wherein they use basically the sounds being created by, where they used sounds to determine the location of the prey and also to find their own paths in the dark. In a similar manner, barn owls have been known to exploit their sense of hearing to locate food sources, etcetera.

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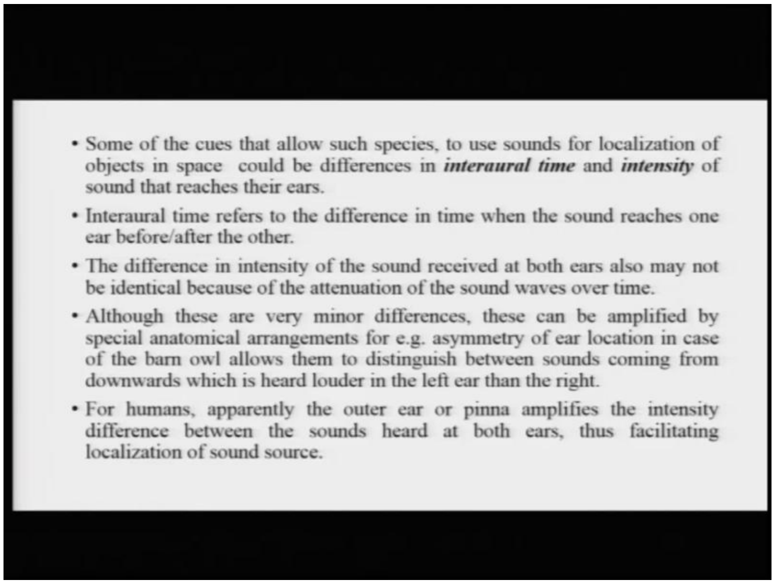

Now, some of the cues that could help us localize objects in space on the basis of sound could be differences in two things. One is the interaural time and the other is the intensity of sound that reaches the ears. Now, interaural time typically just refers to the difference of time in which the sound reaches your ears. So the difference in intensity of the sound received at both ears may not be constant or may not be identical, because of the attenuation of the sound waves over time. So both of these things, the difference in time at which the sound reaches the left ear versus the right ear, and the intensity of the sound that is registered at the left ear versus right ear.

These two cues act as very important sources of information, which help not only humans but other species also to identify the source of the sound. Say for example, although there are very minor differences, although there are very minor differences with respect to the interaural time or the intensity of the sound, these minor differences can be amplified by specialized anatomical arrangements. Say for example, in case of barn owls, it is seen that the ear are located asymmetrically. And therefore, what happens is that for a barn owl, the sounds coming from bottom are sort of received more intensely, or they appear louder in the left ear than the right.

So that sort of helps the barn owl actually locate where the sound is coming from, is it coming from the down, or is it coming from the upwards direction. For humans, apparently the outer ear or pinna amplifies the intensity of the sound difference and intensity of the difference between the sounds received at both ears, thus facilitating localization of the sound source. So, these are some of the cues that sort of help in identifying where so each of the sounds are being received at. This is all about the audition that I want you to see.

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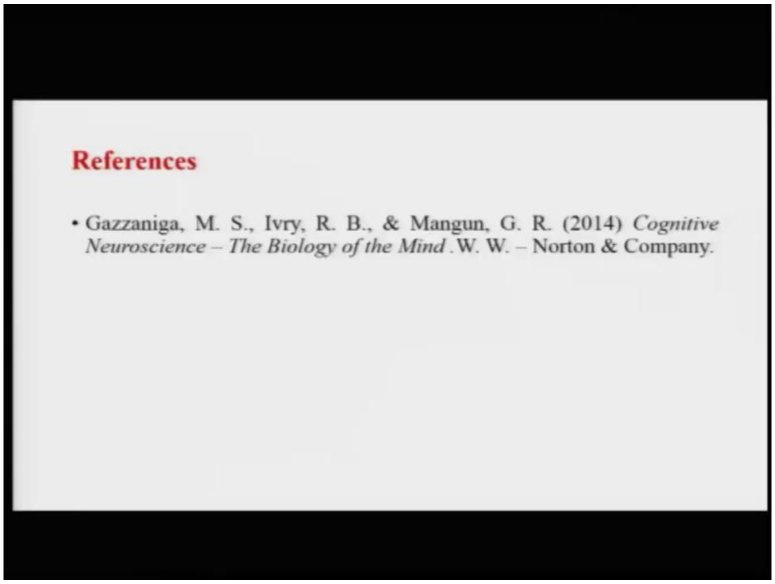

In the next lecture, I will talk about some of the other senses. Thank you.