Multimodal Interaction
Technische Universitat Berlin
Lecture 1.2.2
Hearing Ear

Now that we have learnt how speech production works, let us come to the hearing systems. I will start with the ear.

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So, what is hearing? Hearing is actually the sensation of oscillations, in a physical medium for example the air molecules, but also this could work in water as well. The ear itself is a sensory organ that does not cover what we typically consider to be the ear but also the auditory nerve and the auditory cortex which is part of the brain.

Let us define what an auditory event actually is. So, an auditory event is a perception which is related to a sound event and this means we have a real distinction between the two. So, there could be sound events that are too low intensity or too different in the frequency spectrum so that humans can actually not perceive them and also the other way around. There might be auditory events that have no sound event beforehand for example when you have tinnitus. This is related to the capabilities of the human ear and the human sound perception. For example, typical healthy adults have a frequency range of 16 and 20 or let’s say rather 16 kilohertz but I will come to this a little bit later.

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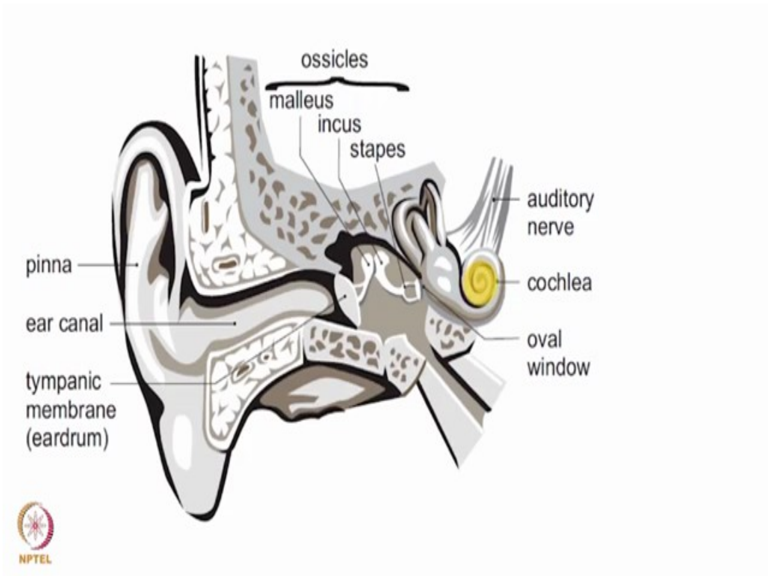

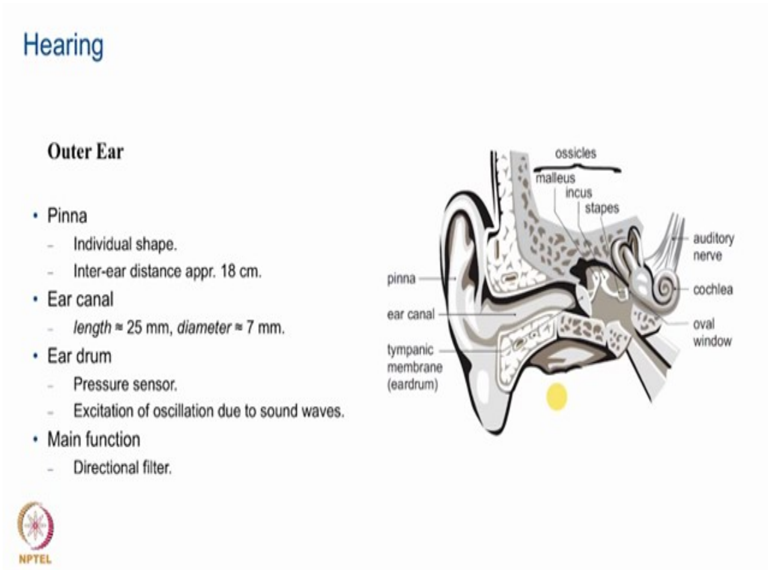

Here is a scheme of the ear and we have actually three parts that we can distinguish. So, there is the outer ear and the outer ear consists of the so called as the pinna that you can see here and the ear canal until the ear drum. The main function of this outer ear is to capture the sound information and carry them and transport them to the middle and inner ear and a really important function of this outer ear is directional hearing. I will talk about directional hearing at the end of this week’s content.

The second part is the so called middle ear and these are basically the three tiny bones that we have which we call as ossicles. They transport the sound wave from the ear drum, here over the three ossicles to the inner ear to the so called oval window. The main function of the middle ear is impedance matching. The problem is that in the outer ear we have air as the medium and this means that we have low pressure, but in the inner ear here we have a liquid as medium. And if we would have a direct connection between the outer ear and the inner ear without the middle ear then the sound wave would actually just reflect and come back and would not be transported any further.

So the inner ear is basically the so called cochlea and the auditory nerve until the auditory cortex. The main function of it is a kind of real like analysis of the frequency components of a sound. I will come to this in just a second.

So, let us start with the outer ear. The outer ear consists of the pinna and you can see there are some morphological aspects here. So we have some valleys and some mountains and all these different parts might resonate concerning or dependent on the direction of the sound source. The ear canal has a length of 25 millimetres and this is important because that is a quarter length of the resonance frequency of this ear canal. This means roughly a frequency of 3 1/2 kilohertz is the resonance frequency and we will encounter this resonance frequency a little bit later on. The main function of the outer ear of course is that it acts as a directional filter according to the special morphological aspects of the ear canal and the pinna we have a directional dependent resonances which filter actually the sound according to the source of the origin of the sound.

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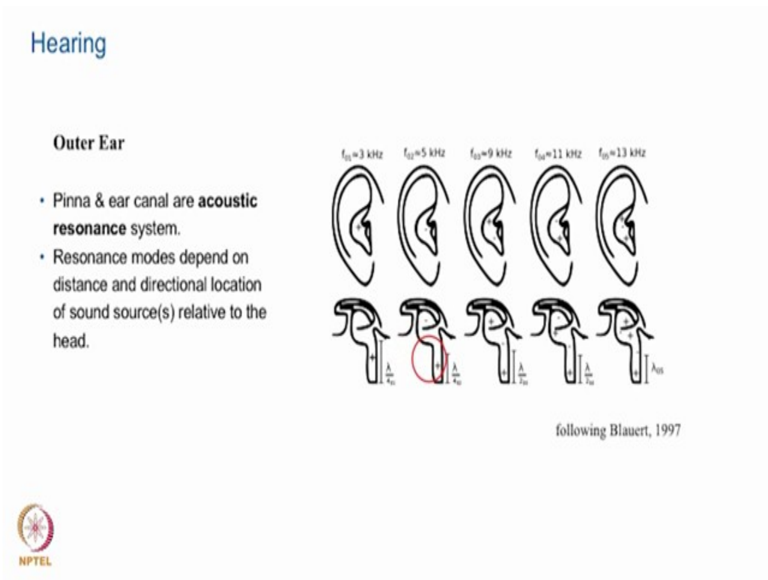

Here you can see for different frequencies the pinna here and the ear canal and whether there is a positive resonance or a damping of these frequency aspects and frequency components.

And as you can see according to the ear canal resonance between 3 and 5 kilohertz we have actually an amplification of these frequency components due to the length of the ear canal.

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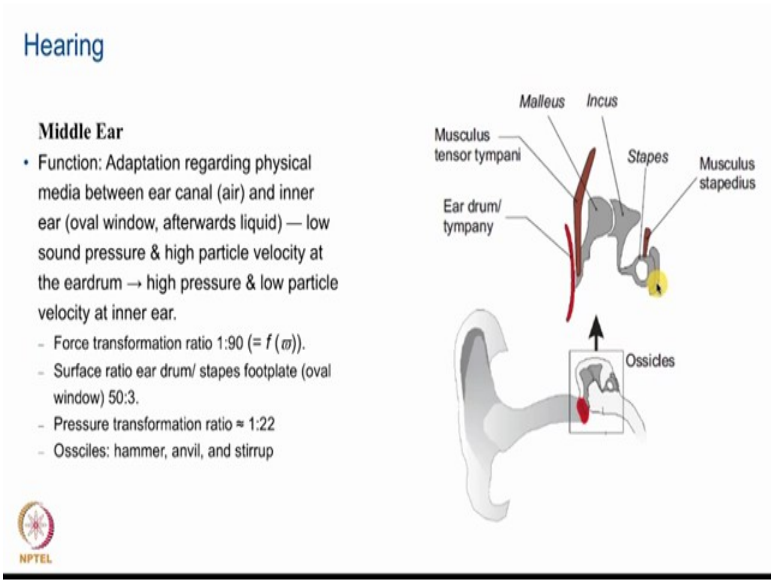

The middle ear consists solely of the three bones, these small bones called as ossicles or hammer-anvil and stirrup. These are the three ossicles. What you can see here is the ear drum of the outer ear which has a big surface area. And the function of the middle ear is to reduce the surface area, the pressure, to reduce the surface area, to a smaller surface area at the inner ear, at the so called oval window. This increases the intensity, the pressure and therefore adapts to the liquid that we have in the inner ear.

There are also two muscles and both muscles put a tension on the appropriate bones that are adapted or connected here, in this case the muscle tensor tympani actually puts tension on the ear drum which leads to a stronger reflection of the sound wave. So, this protects a little bit from high intensity noises. The same is true for Musculus Stapedius this one twists a little bit how the stirrup pushes or presses on the oval window also reducing the amount of intensity, and those protects the inner ear from too high intensities or too much noise. This is actually related or operated by reflex that means that if we encounter too high intensities too loud noise, then this happens automatically.

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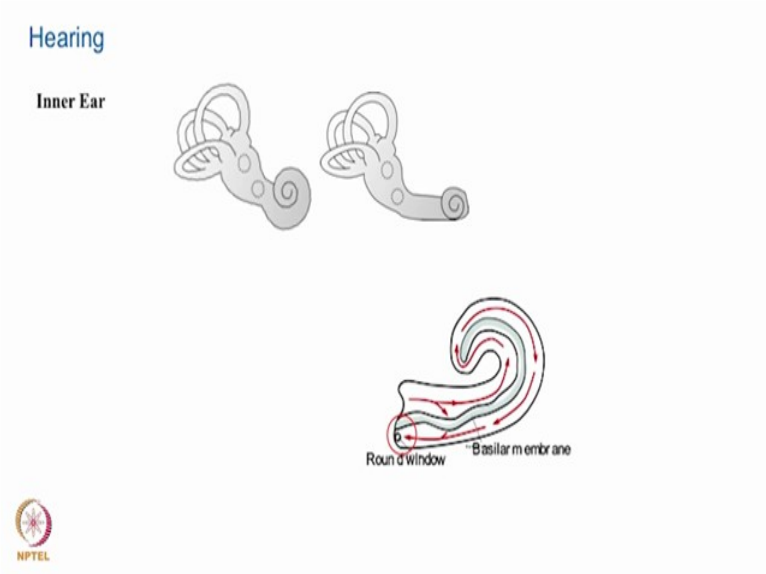

The inner ear is the cochlea this is only this one these other parts are related to the balance sense the balance modality. If we enrol this inner ear a little bit, then we see that it actually consists of three kinds of membranes. So, the first one is here, it is filled with liquid, and here, sound is like a wave in liquid a traveling wave passes through this part and at the apex it encounters entrances the second membrane here. And between the two there we have a third kind of membrane. I will talk about this in detail on the next slides.

So, we start at the oval window and we end up in the round window. And this round window is closed by a flexible membrane which acts to equalize the pressure of the liquid that we have.

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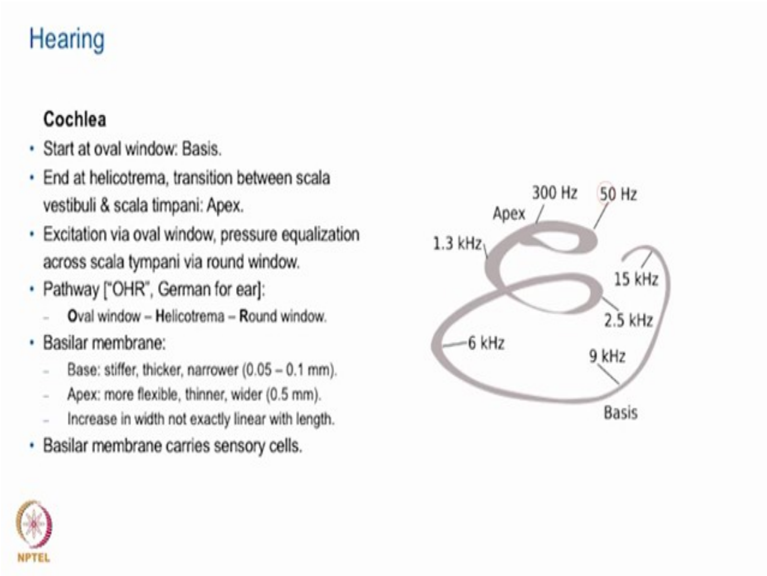

Functionally this cochlea or the middle membrane has does something like a locational place transformation, so it means we have frequency component in the sound which is now a travelling wave in water and this frequency information is transformed to a place information on the so called Basilar membrane. And the green scheme you see here is the basilar membrane and as you can see it has a different shapes and widths and stiffnesses. And this is the beginning of the oval window and this is changing in its characteristics to the apex and then back of course. And this is where the basilar membrane is sensitive to different frequency components that means that at the beginning of the cochlea, at the oval window, the basilar membrane is very sensitive to very high frequency components and the closer we get to the apex the sensitivity reduces to lower frequencies.

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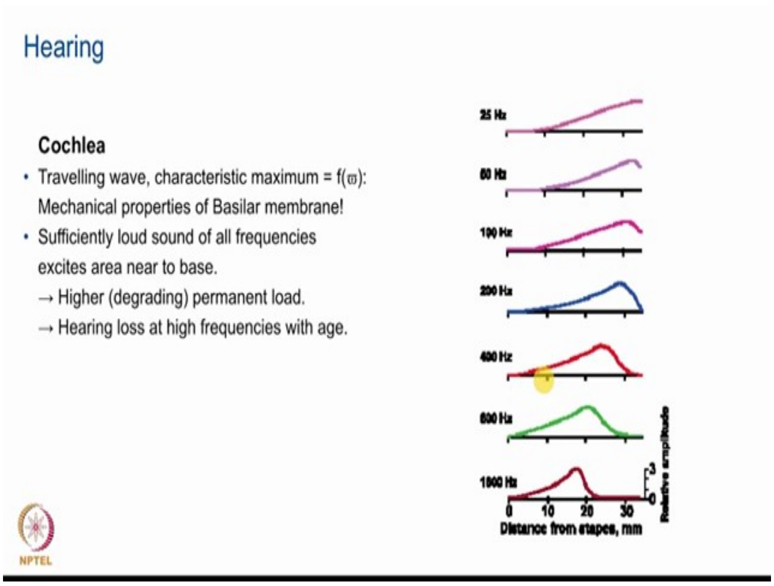

This is also illustrated on the next slide where we have the distance from the oval window in stapes as a function of the frequency of a sound and as you can see lower frequency components or lower frequency sounds are exciting the far end to the apex and higher the frequency becomes the closer it is to the oval window. This actually means that high frequency components and complex sounds with high intensity are all stimulating the basilar membrane at the oval window at the beginning of the pathway and this is the reason why over age or a lot of noise that we encounter our sensitivity to the higher frequency regions decreases after a while.

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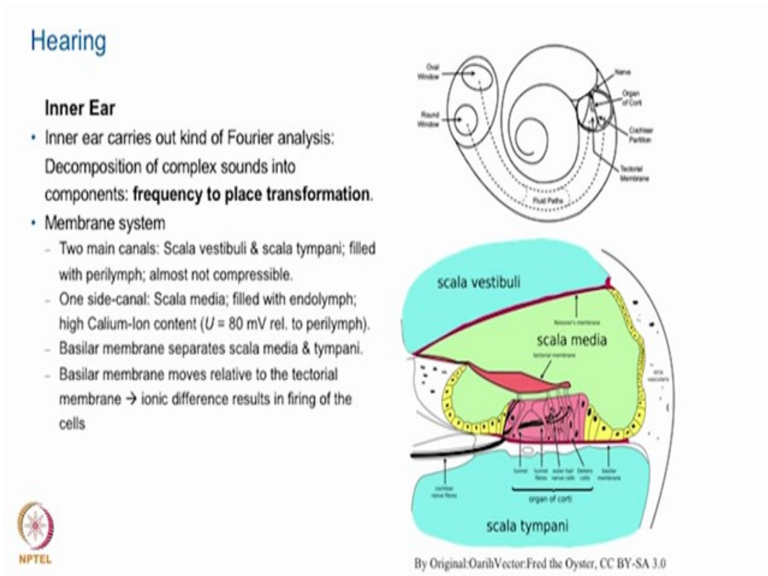

Now let us come to the details of the actually sensory organ in around the basilar membrane and in the cochlea. So, we have what we call Scala vestibuli which is from the oval window to the apex and then coming back, the Scala tympani from the apex to the round window. And the second membrane, if we call this in between, is the scala media and actually this tiny membrane here is called the basilar membrane and this moves according to the frequency of the traveling wave and it is connected to the nerve, the auditory nerve.

What we have here are inner hair cells and outer hair cells. The main idea of how this auditory perception now works is that the tectorial membrane is rather fixed and in relation to the tectorial membrane, the inner hair cells and outer hair cells move caused by movements of the basilar membrane. And because this area here is filled with ions, we have a chemical stimulation of the cells, which then send information or which then trigger information to the brain.

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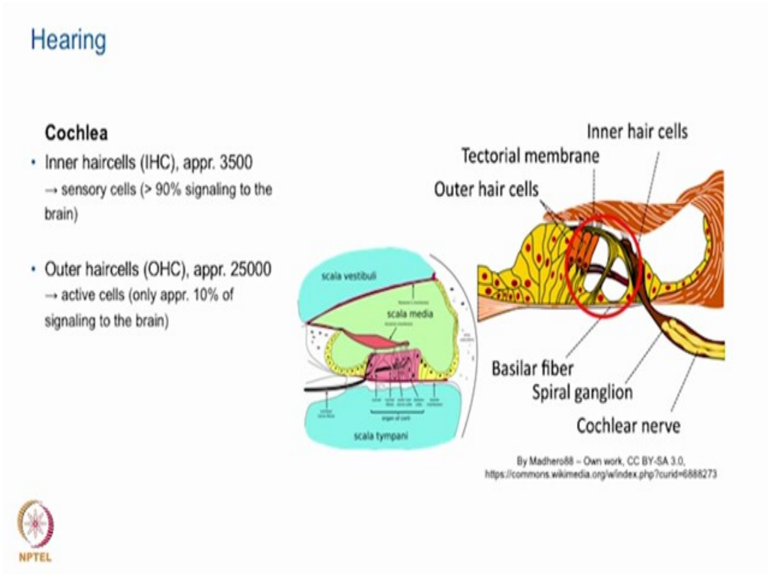

So how do these hair cells fire and when do they do that? Again, we have the and Scala vestibuli and the Scala tympani and this membrane, the basilar membrane. So this is scala media which is the part in the middle. And if we look, if you have a look here so we have outer hair cells, and inner hair cells. The inner hair cells we do not have many of them but they are the important ones who actually fire towards the brain when there is at this location a stimulation of the basilar membrane that means if there are frequency components which are related to these hair cells.

So about 90% of these hair cells are sending information to the brain and the other 10% and espically the 90%, roughly 90%, of the outer hair cells are receiving information. So, they are not sending them. This is an active amplification mechanism because they receive information and amplify mechanically by movements the stimulation of this whole area which is related to a certain frequency.