Audio for Virtual Reality
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Spatial Hearing

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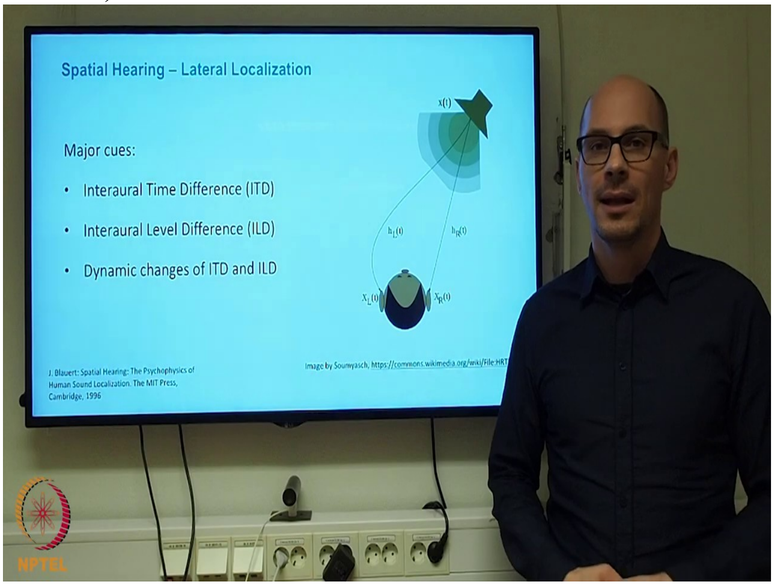

Let us start with looking at a very simple situation like a one that is sketched here. This is the listener with the left ear and the right ear. The listener is looking straight and the listener is exposed to the sound field of one sound source which is indicated with the loudspeaker symbol.

And if the sound source is not located inside the median plane which is this one then there will be some path length difference from the sound source to the ears.

So this case the path that the sound has to travel to the right ear of the user is shorter than the path that the sound has to travel to the left ear. And this causes the timing difference because the speed of sound is finite.

It is in the order of 300 meters per second, 340 meters per second or equivalently 30, 30 something centimeters per millisecond.

This causes this difference in path length, causes a timing difference and our auditory system is able to sense this. It is able to measure to sense that there is a timing difference and also it is able to measure how much of the timing difference is there.

And the difference that arise are in the order of maximally couple of microseconds so it is very short differences but our auditory system is able to sense this and this is how it knows that the sound source was located lateral if it was that.

Similarly in the same situation the head will also occult the sound that reaches the contralateral ear which would be the left one in this case. The ear this is directly illuminated by the sound source is called ipsilateral.

So the head is basically in the way so that it will attenuate the sound that reaches the contralateral ear. It will primarily do this for higher frequencies but still it will do this on dense peaks of the interaural level difference.

So these two cues, the interaural time difference ITD and the interaural level difference ILD are the major cues for lateralization.

And in static scenarios, if you allow the changes in the head orientation then the dynamic changes of these interaural difference, of the time and the level difference, they are also very strong cues for localization.

For example, for differentiating front and rear. Imagine a sound source is in front of me and I turn my head to the left

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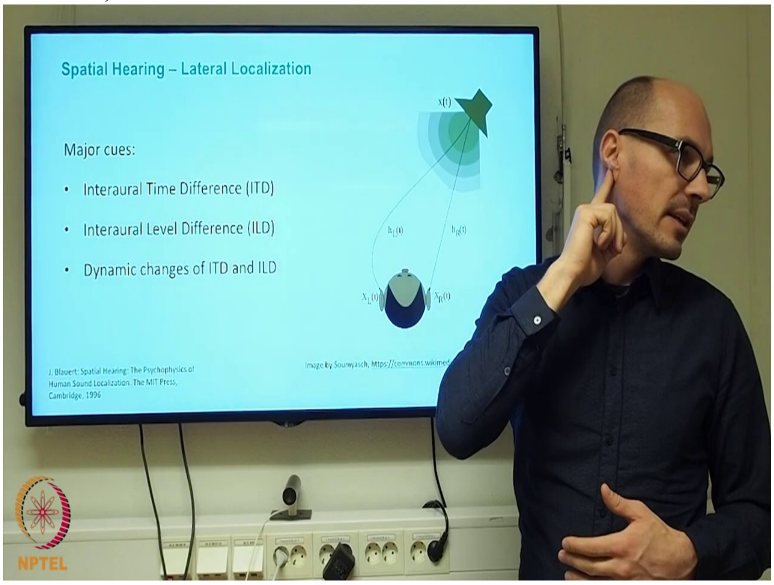

then this ear, the signal at this ear will be leading over the other one.

Whereas if the sound source is behind me and I turn my head to the left then it will be the other ear that will be leading. And this is a very strong cue that allows the auditory system to differentiate whether a sound source was in front or behind the listener.

Similarly a sound source above or straight below the listener will not cause any changes in interaural differences when rotating the head above the vertical axis. This is one means how we can localize sound sources above and below us.

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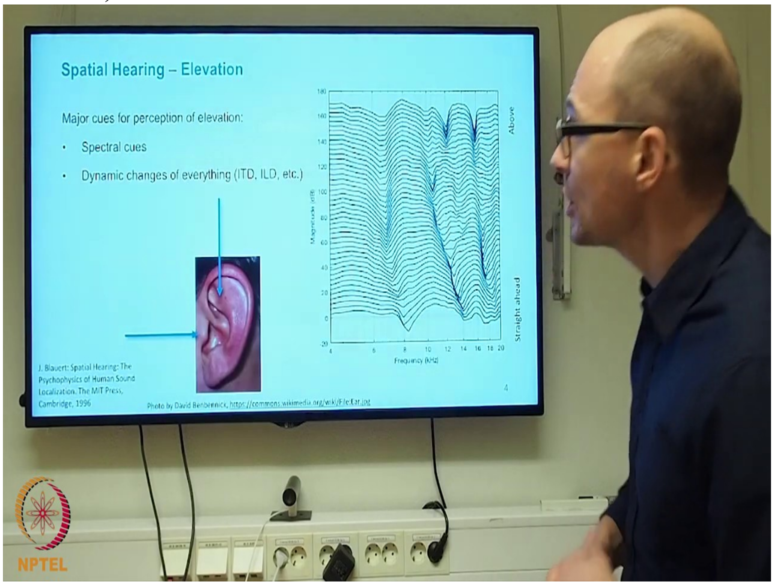

Additional to these interaural differences are the so-called monologue cues. If you look at the shape of the outer ear, so the outer ear

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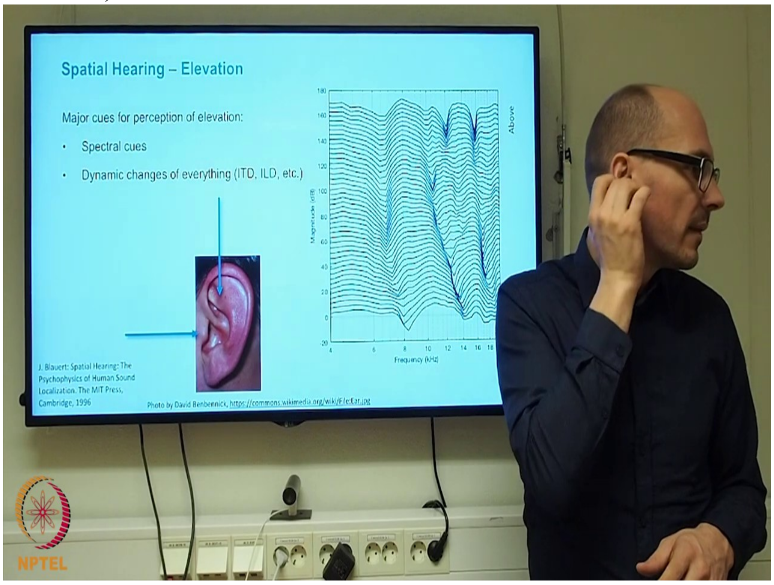

includes everything that you see including the shape of the head and the shoulders and all these parts of the body will have an influence on the signal that reaches the eardrum of a listener.

And the influence of the signal is dependent on the angle of incidence, on the direction of incidence.

We can imagine a sound source, a sound signal that arrives from the front will be guided differently into the ear canal compared to the sound from above, for example because our ears are not symmetric. So the changes, the effect of the inner, the outer ear will be different depending on the angle.

Similarly the sound source that

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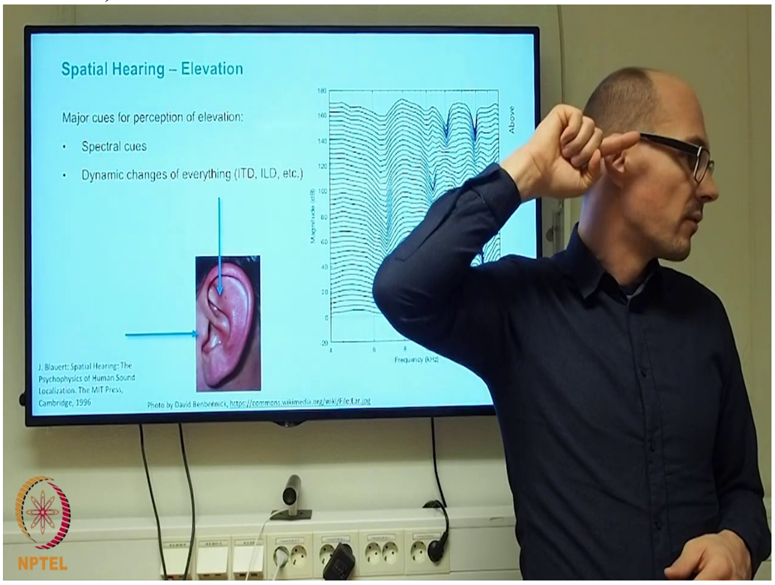

enters from rear will be guided differently into the ear canal compared to sounds of the, compared to sounds signal from the front.

This causes a subtle but still detectable spectral differences which our auditory system also recognizes and this is another way how we can differentiate front and rear.

But these cues are not as strong, they are not as reliable as these, as the interaural differences and also the dynamic changes of the interaural differences.

The fact that the acoustic influence of the body on the signal that arrives at the ears is systematic and this fact is illustrated in this chart. On the horizontal axis you see the frequency

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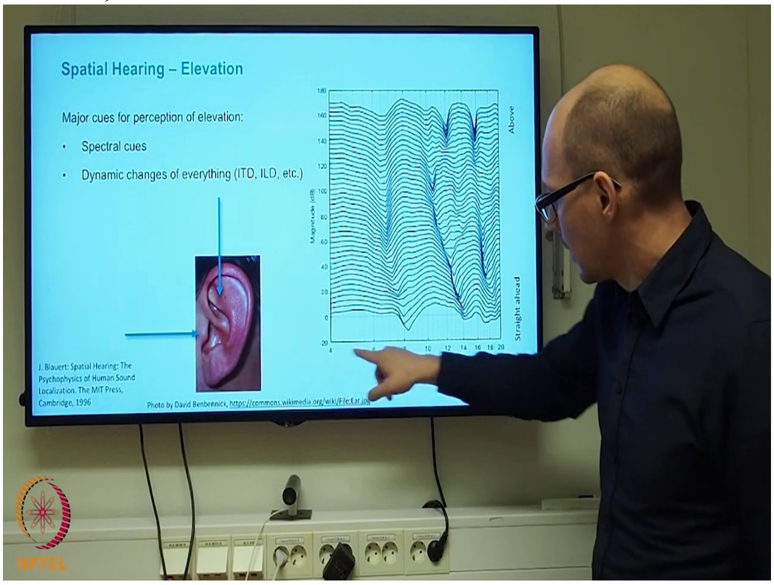

and the range is 4 kilo Hertz to 20 kilo Hertz. So we are looking at the higher part of the audible frequency range.

And the vertical axis shows the magnitude of the transfer function from a sound source location to the ear of the, ear canal entrance of the listener and this is plotted for different positions of the sound source. And each position is offset slightly so that the crests do not overlap and we can read them easier.

So the positions we are looking at, so the lowest graph is the magnitude of the transfer path from a sound source in front of the listener to the ear. And then as we are moving up on the plot, also the sound source moves up and the top graph will show the transfer path from a sound source straight above the listener.

So if you are changing the elevation of that sound source we can, so first of all we see that this transfer curve is not flat, so different, so some frequencies are boosted and other frequencies are attenuated. This is because of interference that is taking place in the outer ear.

So if you are looking for example

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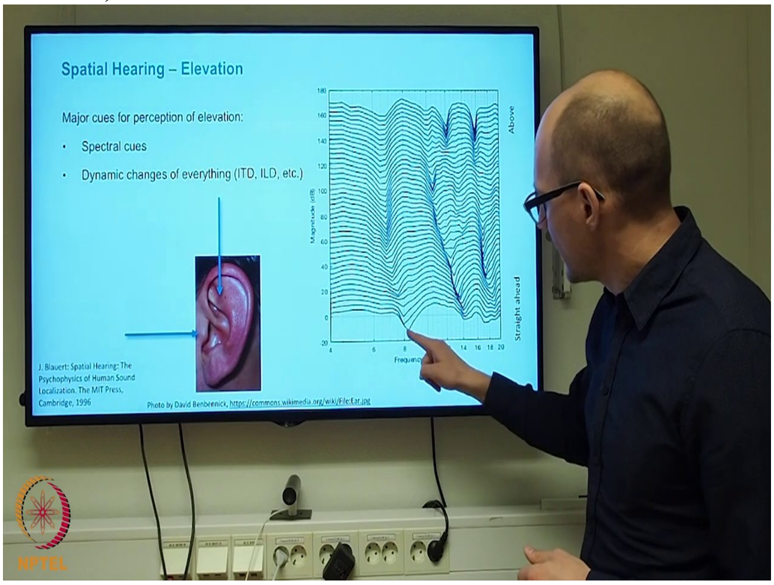

at this dip, we have this tip of couple of ten-ish decibels, around 8 kilo Hertz. If this elevation of the sound source increases then this tip moves down in frequencies slightly.

Similarly this tip moves down with frequency also very strongly with changing elevation and for certain elevations

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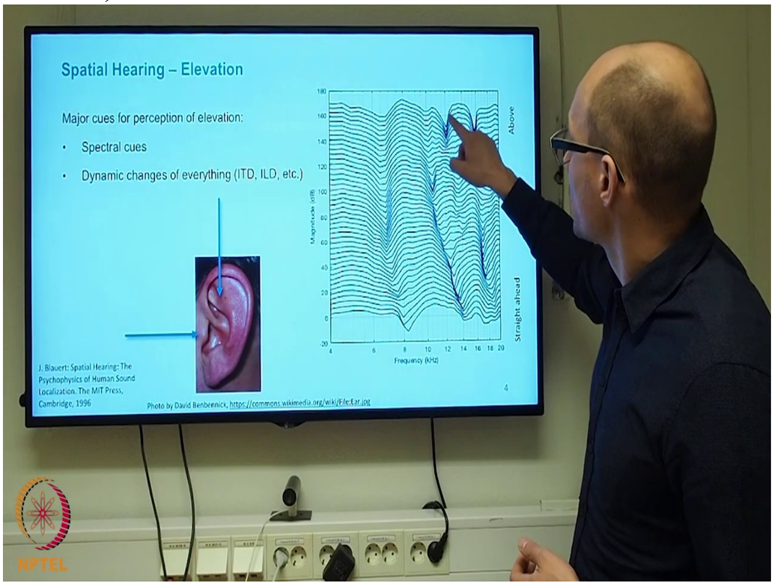

there is even another dip that did not exist before for other elevations. So there is a lot of systematic differences that occur as a function of the source angle.

And our auditory system has learnt this and it is aware of what spectral transfer or what transfer path belongs to what sound source location so that this is, so that it can recognize if a sound source is elevated. It can recognize all the interferences and all the acoustic influence of the outer ear on the signal that reaches the eardrum.

And of course, so these are so-called monologue cues and they are evaluated additionally to the interaural timing and level differences, excuse me, so and all the cues they are evaluated at any moment in time.

And the, the whole of the acoustic cues that a signal has as it reaches the eardrum is called head related transfer function, or HRTF.

That incorporates also, they basically represent the transfer path from a sound source location to the ear canal entrance and they include all the cues such as interaural time difference, interaural level difference, the spectral cues and technically also the dynamic changes of each of these cues because we can certainly include different head orientations in the definition of what is a H R T F what is head related transfer function.