Sensory 2

[00:00:00.00] Now we're going to a cover hearing. This is a general outline of ear anatomy. What I want you to notice here is that the ear is divided into two sections-- the outer ear and the inner ear. So, the outer ear consists of the fleshy part on the outside of your head and the ear canal. And the sound here is transmitted through air. But in the inner ear, past the tympanic membrane, or ear drum, the signal is transmitted through fluid.

[00:00:31.09] This diagram shows how sound is transmitted through the outer and the inner ear. So, step one is on the top left. You have a sound wave of alternating high and low pressure traveling through air. And this sound has a frequency, which is how often the cycles of high and low pressure travel through the air. And this diagram shows a simple sound that has just one frequency to it, but you could have a complex sound that represents the sum of multiple frequencies.

[00:01:06.64] Step two is the top-right part of this diagram. The air deflects the tympanic membrane, also called the ear drum, in response to these waves of pressure traveling through the air. And that causes vibrations in the ossicles, or the tiny inner ear bones, which are just past the tympanic membrane.

[00:01:27.76] And the ossicles deflect the oval window, which is another membrane. And that is transferring the sound from air to fluid. So, the oval window membrane then vibrates, and it causes vibrations in the fluid inside of the inner ear. And that happens at the base of the cochlea, which is the home of the sensory organ of hearing.

[00:01:56.02] So, step four, the bottom of this picture, is the fluid waves traveling through the cochlea. And inside of the cochlea, we have another membrane called the basilar membrane. The basilar membrane is sensitive to different frequencies at different points along its length.

[00:02:19.21] So, the sound enters the cochlea at the base, which is on the left side of this diagram. And depending on the frequency of the sound, which is the same as the frequency of the fluid moving inside of the ear, the basilar membrane moves.

[00:02:37.21] So, for a high frequency, the basilar membrane is sensitive near the base, near right where the sound is entering the spiral. And then the frequency that the basilar membrane is sensitive to decreases as you move along around the spiral until you get to the lowest frequencies that humans can hear at the apex, the inside of the spiral.

[00:03:00.75] The basilar membrane then pulls on layers of hair cells that are lining the cochlea, which together are called the organ of Corti. The cochlea represents the first step of tonotopic organization, or organization based on the frequency of sound.

[00:03:18.58] And as I'm describing this, remember also that most sounds in real life have a mixture of frequencies. So, the basilar membrane would be vibrating at multiple points along its length. The basilar membrane is what's sensitive to different frequencies, not the hair cells. So, a hair so corresponds to a specific frequency of sound based on its location along the basilar membrane, not because the hair cell itself is responsive to that specific frequency.

[00:03:49.99] Modern cochlear implants have, at most, a few dozen channels, where each channel corresponds to a small range of frequencies of sound, in contrast to the tens of thousands of different frequencies that people with typical hearing can detect.

[00:04:07.18] Users of cochlear implants often have trouble picking out one sound from many sounds. For example, trying to hear one person talking in a large group. And they can't hear the wide range of frequencies that a person with typical hearing can detect. Consequently, in addition to struggling to pick out a single sound from a crowd, users of cochlear implants often have trouble hearing music.

[00:04:37.23] So, this is what's happening inside of the cochlea. So, in the diagram, on the right, the blue layer along the bottom represents the basilar membrane. And that's what sensitive to different frequencies. So, as it vibrates, it moves these hair cells that are embedded on it. And as the hair cells move, they pull on the tectorial membrane, which gives those hair cells something to pull against. The tectorial membrane is not sensitive to different frequencies.

[00:05:12.30] You have three layers of outer hair cells, which are pink in this diagram, and one layer of inner hair cells, which are yellow. The inner hair cells are the ones that actually contribute to hearing. So, they're sensitive to sounds of different frequencies.

[00:05:27.99] The outer hair cells, you have three layers, and they dampen your hearing based on the amplitude, the loudness of the sound, and feedback from your brain in order to help prevent damage to the inner hair cells. These hair cells are not neurons, but they then stimulate neurons of the spiral ganglion. And those neurons lead to the vestibulocochlear nerve.

[00:05:56.08] So, the vestibulocochlear nerve is entering from the cochlea, which is marked in C on the lower left part of this diagram. The information travels through the vestibulocochlear nerve to the brain stem. It totally bypasses the spinal cord. And it travels through the medulla. And two-thirds of the sound content crosses to the opposite hemisphere in the superior olivary complex, marked as SOC in the middle of the dark gray area that's the medulla on this diagram.

[00:06:30.03] After the sound has mostly crossed to the opposite side of the brain from the ear where it was detected, then some sound localization processing happens in parallel on both sides of the medulla. You need information from both ears in order to localize the sounds. You have two sensors, left and right ear, which is why some of the information doesn't cross over.

[00:06:53.49] You have two different processes for determining the location of a sound in the environment. The first one is the interaural time difference. And this is used for frequencies under about 1,000 Hertz. So, this is most sounds, like human voices and most muzak-- most of them are below 1,000 Hertz.

[00:07:15.66] And the interaural time difference measures how far apart in time did it take for the signal to reach your left ear and your right ear. And that difference in time tells you where in the environment the sound came from. And this information processing happens in the medial olive, which is marked on this diagram.

[00:07:37.29] Higher frequencies over 1,000 Hertz are measured using interaural level differences. Is the signal significantly louder in one ear than the other? And this happens in the lateral olive. The interaural level difference specifically depends on the fact that for high frequency sounds, that the frequency of the sound is blocked by your head. So, there will be a difference in the level at your left and right ear because your own head reduces the volume of the sound.

[00:08:14.75] Finally, all of this information reaches the brain. The auditory cortex is located in the superior or higher up part of the temporal lobe on both the left and right sides of the brain. The organization in the brain of the auditory cortex is also tonotopic. So, the information all the way from the cochlea to the first parts of processing in the brain is organized by frequency.

[00:08:40.76] The primary auditory cortex then assembles all of those frequencies back into a coherent sound. So what's marked on this diagram is all of the individual frequencies. And you can see that they're aligned in order. And then it gets put together into a single signal. And that's then processed as a whole for the meaning of the sound.

[00:09:05.06] Language information is processed exclusively by the left hemisphere in the vast majority of people. About 95% of right-handed individuals and about 75% of left-handed individuals have all of their language function on the left side of the brain.

[00:09:23.87] And in those people, the left auditory cortex, and by extension the left temporal lobe, is significantly larger than the equivalent areas on the right side. For people who have their language regions mirrored on the right side of the brain, or in rare cases who have their language functions distributed in the hemispheres, the size changes accordingly.

[00:09:48.65] Now we're going to cover the vestibular sense. Your inner ear does double duty. The cochlea detects sound information that's coming in from the outer ear. But the vestibular system also is located in the same part of the ear, just next door in the semicircular canals and the utricle.

[00:10:11.28] The utricle contributes information about the position of your head. It consists of the macula, which is the hair cell layer located inside of the utricle. And it's filled with gelatinous fluid. And inside of this fluid are otoliths, which are little blobs of mineral that push on the hair cells as the otoliths move. And they respond to gravity, and they pull the hair cells in whatever direction your head is tilted.

[00:10:46.73] The hair cells are only each sensitive to one direction of movement. So, you have collections of hair cells that are sensitive to different directions to signify what direction your head is pointing. This information then gets transmitted to the vestibulocochlear nerve.

[00:11:08.39] Rotation information is handled by the three semicircular canals-- the anterior, posterior, and horizontal semi-circular canals. Each of these is filled with fluid and has hair cells embedded in groups called cupulas. The cupula functions like the tectorial membrane does for hearing, and it gives something for these hair cells to bend against.

[00:11:34.19] As your head moves, the fluid seems to move in the opposite direction of your head movement. But what's really happening is that the fluid holds still as your head rotates. So, it moves the cupula in the opposite direction of whatever way your head is rotating.

[00:11:54.68] This movement then also gets translated to the vestibulocochlear nerve as these hair cells fire and stimulate neurons. Vestibular information primarily gets passed to non-cortical destinations, where it's used in controlling eye movements and balance. This includes the cerebellum, which is involved in both balance and eye movements, the thalamus, which is involved more in eye movements, the reticular formation, which is part of the brain stem and the spinal cord, both of which pass information directly out to the body to do balance-related movement adjustments without the involvement of the brain.

[00:12:36.17] Vestibular disorders are relatively rare and cause symptoms like vertigo and poor balance. Although the vestibular system is not an obvious sense, it is absolutely necessary to typical motor function, especially walking. An individual might want to use a vestibular implant to alleviate the symptoms of a severe vestibular disorder for which there are a few other treatment options.