Hello. My name is Gonzalo Tassu, and today we'll talk about the anatomy and physiology of the auditory system. Today's objective is to describe the anatomy of the outer, middle, and inner ear. Then we will describe the principles of mechano transduction. Then we'll review the anatomy of the auditory pathway from the inner ear to the primary auditory cortex. We'll describe the physiology of the primary auditory cortex, and we'll look at the different type of auditory dysfunction, conductive versus sensory neural heating loss, and we'll give examples of both. This is the ear. W by the ear in tree part, there is the outer ear where that captures the sound pressure that's coming from outside and channels into the middle ear. Here, the sounds are traveling a. Now here, they are going to im onto the tympanic membrane. Now on the other side is the middle ear. Now these vibration, this air pressure vibration is going to convert it into vibrations through the ossicles that are going to propagate the wave, and this will be transmitted to the. Here, the sound wave is going to be traveling in liquid. And will be converted into nerve impulses. The sound pressure is very extremely low, is ten to the eight times weaker than the amosmtic pressure. There is a physical problem that the auditory system needs to solve, which is how to convert such small pressures into nerve impulses in a reliable manner. In the middle ear, we have the Tympanic membrane and the ticles. We have the ear canal where the sound pressures are going to make cause vibrations in the tympanic membrane. Now the bones of the middle ear, we have the, when they have the incus, and then we have the stats. These bones are the smallest bones in the human body. The vibration of the tympaic membrane first goes through the malleus. Then that vibration is transmitted to the incus, and finally, that gets transmitted through the states into the cochlea. And this is this pressure is going to apply on the val window. Now, this ticles, although the wave, the sound pressure is now going to be transmitted to the solid, this cavity needs to be filled with air. If liquid will appear here, the sound transmission will be impaired. The problem that the air needs to solve is that the sound we live in air and sound waves travel through air. Now, but our bodies are mostly formed with liquid, and the hair cells, the transduction of sounds of vibration to nerve impulses are in liquid. The airways do not penetrate well into liquid. You can next summer when you are at the pool, and you put your head under water. You'll notice that sounds get mitigated because the sound pressure the sound will not penetrate well into liquid. The reason is that the liquids are much less compressible than air. In order to transmit the vibration, do you need much higher pressure? You need to convert the low pressure sound wave into higher pressure, such s wave can be detected in liquid. The way that this is happening is that is by the difference in the area. You can compare here in the middle year the very large tympanic membrane and that that sound pressure is going to be applied to a much smaller area, which is the area of the oval window. The forces are going to be higher and the pressure will be increased. We have attached a conversion from low pressure in air to high pressure in liquid performed by the middle ear. In the middle ear, we could have conductive hearing losses. Conditions that affect the middle ear conduction could be damage to the tympanic membrane or we can have fluid in the tympanic cavity or damage to the occles. If the tympanic membrane would be perforated, then there's not going to be a pressure difference between the ear canal and and the tympanic cavity. The sound will just bypass the ossicle chain and will directly impede on the oval window, so there won't be any change. There will be no amplification in the pressure and the sound perception will be highly attenuate. Also, if liquid accumulates inside the tympanic cavity, the ossicles could not move well, their movement will be damped and will perceive a decrease in sound intensity. The transmission through the ossicles is not completely passive. There is a certain amount of control. There are two sets of muscles that serve to attenuate the intensity of the sound transmitted through this ossicle change. One of the muscles is the tensor tympanic muscle, which is innervated by canal nerve number five. You can see that if you contract this muscle, the malls will uncouple from the tympanic membrane and there'll be sound attenuation. The second muscle that could mitigate the transmission of sound is the small muscle, the spidous muscle, which is innervated by cranial nerve number seven. This muscle, you can see when it comtrat, this steps is going to decouple from the val window and will reduce the intensity of the transmitted sound. The purpose of this muscles is to protect the very fraile inner hair cells from high pressures produced by loud sounds. There are reflexes that when a strong sound is perceived, these muscles will contract and the amount of energy transmitted to the hair cells will be reduced. Still, sudden loud sounds can still damage the hairs. Now we'll describe the principles of mechanotransduction in the inner ear. Sound coms transmitted through the otic to the oval office, and it travels through the cochlea and then it's transmitted into nerve impulses. The cochlea is located in the pets portion of the temporal bone. It has 2.5 turns and is about the size of a chip. Also, the diameter decreases with each coil. In order to understand the structure of the cochlea, let's start with this simple dim. We have the oval window, and on the other side at the output of the cochlea, we'll have the round window. As we saw, the states couples to the oval window. Now, between the oval window and the round window, we can locate here the basilar membrane. The bacular membrane is going to be the place where you're going to find the hersal.

Now, we have the structure, and now imagine that you elongate this middle U This middle cavity elongated and twisted and we have a cochle. The reason that we have this elongation is to have different resonant mechanical resonant frequencies of the cochlea. There's differences between the apex and the base of the co. The base is closer to where the stapes brings the vibrations into the oval window, and the apex is the more distal part. The basilar membrane is white, in floppy at the apex of the cochlea, but it is narrow thicker, and more tout towards the base. The base responses to high frequencies, and the apex is going to be respondent to lower frequencies. You might think that as a guitar, where you have high tension, that is going to be resonating at higher frequencies, and lower tension is going to cause resonance at lower frequencies. The role of the cochlea is to decompose the vibration into its frequency components. As you are aware, sound is composed can be decomposed into a sum of side waves of different frequencies. Human dar range is between 20 hers and 16-20 kilohers, depending on your age. And the stiffness of the basilar membrane, determining the location of which frequency does the asilar membrane is going to oculate to. You are converting, so you get a continuous wave and you are going to decompose it mechanically in through the different frequencies. Depending which part of the asular membrane, the oscilation is going to be largest. Notice also that the diameter of the cochlea is reverse to that of the basilar membrane. At the oval window, the cochl is broadens and the basilar membrane is at its narrow. And the opposite is true at the apex. Let's look at the anatomy of the cochle. The air impinges onto the tympanic membrane, that vibration is transmitted to the ossicles, the force is applied on the val window. Now we are on the cochle. Here the wave is going to travel liquid. In this case, the pen limbs This first chamber is the scalab stable, the so make the turn, and now we are going to be into the scala te panic. The wave will come out through the round wind. That's the pathway of the vibration traveling to liquid. This liquid is going to be the perilymph. Here in the middle, we have the organ of corti, which have sectorial membrane, and here the liquid is not going to be peronph, and it's going to be the endolymph, which has different properties. If we now cut through the cochlear transversal section, we can see the scala sibule and the scalar tympanic. Here there is the cochlear d where the endolymph is located. What is important is here surrounded by this endolymph, we have the tectorial membrane. There is the pasilar membrane and the organ of corti, and here very small, you can see the hair cells, and here is where the hair cells send their output through the clear nerve. Now, the endoln has hypothasm concentration in the extracellular medium. This is very unique. In most of the nervous system, the concentration of potassium is low extracellarly. But here in the endolymph, surrounding the hair cell tips, the concentration of potassium is high. The lymph, the concentration of potassium is close to what you are used to low potassium. This is a picture of the organ of corti. We have the tectorial membrane, and there are two types of hair cell. They are the inner hair cells and the outer hair cells. The outer hair cells are not coupled to the tectorial membrane and they are the actual sensory receptors. And 95% of the fibers of the auditory nerve that project to the brain arises from this population. The outer hair cells actually make contact with the tectorial membrane and they receive efferent terminals. There's a feedback look here where there's movement of the tectorial membrane and also the hair cell, the outer hair cell are producing movement as well. The stereo cilia are where the sound mechano electrical transducers are located and are in here on the top of the inner hersel. There are three outer hair cell. This is an electron microscope image showing the outer hair cells and here the inner hair cells. There is one row of inner hair cells and there are three rows of outer hair cells. What is important and really something to remember is that the number of inner hair cells is very small, is only inner hair cells total. Each one counts and death of the inner hair cells can affect hearing and they do not regenerate. This is a very small number. In the brain, neocen we're used to hundreds of thousands, but for air cel, the number is rea. The ster cilia are connected through these structures called tilings. These tilings functional couple, they are functionally coupled to mechano electrical transduction channel. When they move, the channels open. Stretch of this ricila causes the opening of the mechano electric transduction channel, MET channels. What hair cells actually do is to detect the flexions of the vascular membrane. The outer hair cells The tips of the sero cilia are embedded in the tectorial membrane. When the tectorial membrane is move because of the vibrations in the cochlea, that movement is going to be transmitted through the inner hair cells. That vibration is what causes the inner hair cells to move in this diagonal manner. The inner hair cells are not coupled and not directly mechanically connected to the tectorial membrane, but the movement of the serocila is induced by movement of this endlef. Now, the hair cells synapse onto the spiral gangln cells, one spiral gangln cell, connects to one inner hair cell. The ha cells depolarize when they are activated, but they do not fire action potential, the as release glutamine, which is which is going to be affecting the spiral gangurt. The action of the spiral gngonin, for nal nerve number eight. There are also different axons innervating the hair cell. If we now look at an individual inner hair cell, S on the seroclla, they are surrounded by the endolymph and there is high potassium. When the mechanosensory trigger channels, when the hell the sterc

move, this movement causes the opening of these potassium channels and potassium flows in. Which is very unique. Mostly, remember, potassium usually flows out of the cell. In this case in this particular case, because of the characteristic of the endolymph, the potassium flows into the cell and causes the polarization. Now, toward the cell body of the inner hair cell, that's the parent lymph and Here, The the polarization produced by potassium in the stocllu, closes causes inflow of calcium. This inflow of calcium is going to cause the opening of calcium activated potassium channels, and here the potassium will flow outside of the cell to bring back the potassium down to rest. Very important is how the potassium concentration is regulated for hearing. Now let's look at the anatomy of the auditory pathway. The ascending auditory pathway starts in the cochlea in the neons in the spiral ganglion that are going to receive input from the inner hair cells and send the axons into the psi lateral cochlar nucleus in the rostral medula. Here. The axons of the cochlar nucleus are the neurons here are going to ascend to the mid pons. Here's the mid ponds where the fibers are going to decosate and continue their trip towards the Talmus. So it's important to notice that some fibers are going to make synapses in the superior body complex, in the mid ponds. Some other fibers are going to You have inputs from one ear, you have fibers that are going deting here at the mid ponds, and there are structures there that are going to have information coming from both ears. By comparing the different subtle difference and intensity and timing of the input from both years, that's going to help us for sound localization. The circitry for that sound localization is located here in the superior vary complex in the mid pot. The fibers are going to ascend through the lateral lemniscus. After the decsation in the midpons, this information is going to reach the inferior colliculus. From the inferior colliculus, there are going to be projections to the medial genicular body, the MGP of the talus, bilaterally, and this is going to be the auditory talus. From there, the talaic neurons are going to project to the auditory cortex in the temporal lobe. Besides this ascending pathway, there is also olvo cochlear descending pathways, and there are two major subsystems. The medial component is made of melanated axons of the medial superior olive projecting to the cochlear outer hair cells. There is also a lateral component made up of millinated axons of neurons of the lateral superior olive projecting to the cochlar nerve fiber near the afferencpss with the CClar inner hair cell. The outer hair cells are going to receive milnated feedback, fast feedback, the inner hair cells, that feedback signals lower traveling elated axis. Let's now describe the basic physiology of the nucleo central auditory as well as of the primary auditory cortex. We thought that the cochlea mechanically is going to divide the different components, low frequencies and high frequencies depending on which part of the cochlea is going to resonate. And that tonotopy is actually preserved also in the in the primary auditory cortex in the temporal lobe. The more rostral part of the auditory cortex is going to represent the lower frequencies, and the more caudal part is going to represent higher frequencies. Here, this is a very unique example of recordings of single cortical neurons in a human person. As you are aware, there are several types of epilepsy that originate in the temporal lobe. People when the sergeans want to find the location of the ppi that is originating that epilepsy, sometimes the implant electrodes into the temporal lobe. Some of those electors are going to be in the auditory cortex. These researchers were able to record cortical neurons in humans. What was noticeable is they play different frequencies. What you can see is the exquisite frequency tuning. These neuron doesn't respond to 900 hairs doesn't respond to 1,130, but it only responds to 1,110 heirs. There's a very high precision in the human auditory cortex for frequency representations. Now we will look at the different type of conductive versus snural healing loss, and we'll provide some examples of how audition can be affected in different conditions and how the auditory function is tested by clinicians. Hearing loss is divided generally by it can be conductive, which will be anything that blocks the conduction of sound from the external and Mar ear. This is a mechanical problem that is often correctable. Sensorineural, which involves the inner ear cochlea or the auditory nerve and is usually caused by her cell pathology. Now, in general, there's no treatment, but in recent years, for this sensorineural, cochlear implant have been used in this. Cochlear implant is an array of electrodes is in implanted in the cochlea, and there is an external microphone, an electronic device converts the sound captured by the microphone into divided according to the frequency, depending on the location on the cochlea and converts that into electrical impulse. It bypasses the middle ear and bypasses the transduction in the cochln, directl is going to stimulate the cochln nerve. But several of them have been used, and technology is improving, increasing the density of electros and so. Now, there's also mixed loss, which is a combination of sensory neural and conductive hear loss. What are the causes of conductive hearing los? It could be congenital atria or malformation of the external auditory canal. In this, for example, in this example, the external ear is probably form, but this person, it's a ear canals it's block. Congenitally. It's unilateral in the minority of cases and children with unilateral oral trical typically have normal speech as long as the other ear is unaffected. There's also the possibility that this could be also associated with malformation of the occle, but other surgical treatments available. There's a possibility that there's an increased width of delay language

development due to the functional mon hearing. A identification is Another cause of conductive hearing loss loss would be scan cell carcinoma that blocks the ear canal here is an otoscopic image. You can see here the tumor. Here in a cat scan, you can see that the ear canal is completely blocked. There will be a hearing loss, conductive hearing loss in this ear. Another cause of conductive healing loss could be chin tube dysfunction. You have an infection, viral, upper respiratory or sects. The taken tube can get blocked. Tin tube provides the drainage of the middle ear. Without if that drainage is blocked, then liquid can accumulate. In the middle ear, and if there is liquid accumulation, the vibrations transmitted to the ossicles will be affected. Also the middle ear barotrauma could also cause this chamber to fill with theirs fluid or blood, which also is going to affect hear. Other causes of conductive healing loads include osteoma, malformation of the ossicles, otosclerosis, benign polyp and castma or cerumen. Sensorineural loss refers to hearing loss in the CoCl and above. It could be congenital. It can be hereditary autosomal dominant or or ressive, like char syndrome, or it could be no hereditary caused by infection, recreational drug use, alcohol, or and retinoid acid. Precipicss is the age related healing loss, especially high frequencies. Remember there's only a discrete amount of inner hair cells and as they die as we age, we lose hearing specifically in the high frequencies. There's also meningitis and methyls can destroy inner hair cells and cause deafness. Very important noise exposure. It also can damage the cocar structures. Also for the high frequencies. To more, most commonly these neuromas could also cause could affect the cochlear nerve and produce hearing loss. Another cause could be alcali maal formation where the tonsil of the cebolon impinge on renal nerve number eight producing hearin loss. Also there's ceral medications, antibiotics, and chemotherapetic, hydrose aspirin, antimalarial agents that could also lead to hearin loss. Azure syndrome is a editory form of hearing a vision loss. The most serious type is type one. From bird, there is profound deafness on both ears, and vision is also affected, decreased vision before each ten and vestibular function, the balance are also problems with it since birth. The type two and type three are less severe. Asure syndrome can be produced by several mutations that are going to be affecting the tiplings from the stereo cilia. There could be several genes like my07 A, sh1c, CD 23, PCH D 15 and SANs These genes create this wonderful mechanical transduction system. As you can see, the silks are very delicate, and these genes this molecular machinery is very unique. There's not much redundancy. You have a mutation, let's say of caring 23, this template is going to affect it, it's going to be affected, and the MED channel will not open when the ster cilia are vibrating due to the vibrations in the coche These genes play a role in the development and maintenance of the stereocilia for Azure syndrome, type one. Second type of Hearing sensory neural hearing loss is the epilepsia ataxia, sensory neural deafness and tubulopaty, E syndrome, EAST, which is produced by mutation in K N ten, which is this gene codes for the e 4.1 potassium channel. As you remember, the regulation of potassium is very important for normal hearing. And also for in the kidney and in the brain that with mutations in the Kear 4.1 potassium channel, we are going to have the epilepsy when it's affecting the brain and a taxi as well. Sensural deafness because it's roll in the inner ear, and the tubopaty, because of the role in the kidney. Here, for this lecture, we'll focus in on what happens in the hair cell. Remember the endof has to have high potassium concentrations to go introu the sterclia. Kar 4.1 participates in the generation and maintenance of high potassium concentrations in the endof Without high potassium concentrations, the inner hair cells will not depolarize. This is a recessive genetic disorder. You can see here that in this familly pedigree, it only appear at the end on these patients. There's also this hearing loss in this Tenets is most commonly described as a high pitch continuous stone, is caused by hyperactivity of the cochlear amplification produced by the outer hair cells, and frequency frequently, this is the first sign of lesion that is causing he los, especially sensory neural. Another cause for sensory neural healing loss is a vestibular snoma. This is a slow growing tumor of the vestibular cochlear nerve. Here you can see an image of it. This benign tumor, but it can cause damage to surrounding structures as it grows, including the facial nerve. Remember, and then this is something to watch during your neur anatomy lab, you should see that the cochlear nerve and the facial nerve run very close to each other. Tumor that is growing in the in the vestibular cochlear nerve will also cause pressure into the facial nerve, and there will be some facial nerve associated pathologies. The symptoms of the vestibular anoma are vertical, healing loss and tinits. It's usually diagnosed using an MRI of the brain and the treatment is surgical. But given its location, the possibility of the complication could include healing loss and paralysis of the facial muscles. The ear and auditory testing could be done through autoscopic exam. Pure tones are played to see in which part of the cochlea might be affected. There's also testing for speech comprehension. There are tests of the middle ear to measure the tympanometry and the acoustic reflect testing. We can also directly measure auditory brainstem responses. This is, for example, in little babies, where we cannot estimate the hear sound. However, we can still measure the electrical evoke potential in the brainstem. We can also directly measure the acoustic emission. When the efferent copies or efferent signals cause the basilar membrane,

the membrane to vibrate, then that can be heard, and there's also the weather and rn. For the ring test, these tests are designed to determine if it's a hearing loss in an ear is sensory neural of it's conductive. For the ring test, will have a tuning fork, which is placed against the mastoid bone. So in that case, as this tuning for is pressed to the tough the mastoid bod. There's going to be conduction through the ear canal, but through the bone. On the the amplitude produced by the tu form will be reduced. In time at some point, the subject will not hear any sound anymore. At that point, the tuning fork is moved away and close to the hear. Now we are not using bone conduction. We are using air conduction, and then because air conduction is more efficient than bone conduction, then the subject should report that the sound has restarted again. If it does not restart, this would indicate conductive hearing loss in that ear. For the weather test, the tuning fold is located here on the top of the head. And the subject should indicate that and this person has some complaint of hearing loss. I should say that the tuning f is localized to the affected ear. This would mean that the bone conduction is able to create vibrations in the cochlea of the affected ear, so the cochle is intact, and this person has conductive hearing loss. However, if the sound is localized to the non affected ear, then that means that there is a sensor sensory neural hearing loss in that. So the anatomy of the auditory system includes the ear, outer, middle, and inner, as well as diverse central nucle of the brainste and Talmu and finally the neocortex. Audition emerged from mechanotransduction and synaptic transmission along the auditory pathway, and this function of mechanotransduction or synaptic trans probably causes he. And thank you very much for your attention.