The special senses (auditory)

Ear is composed of 3 parts:

1. external ear
2. middle ear
3. inner ear

\*\*\*the external ear starts with the auricle which has two main functions :

It can collect the sound as well as **helping** in the determination of the place and the direction of the incoming sound in the vertical dimension that enters our external ear.

**NOTE :** PAY ATTENTION TO THE WORD “HELPING”; IT’S NOT THE ONLY ONE WHO DO THIS JOB ,IT ASSIST IN DOING SUCH A JOB !!

Now we are going to talk more about the sound and the mechanism of hearing:

-the sound will first enter our external ear through the auricle ,then it will pass through the external auditory canal to finally reach the (ear drum ) tympanic membrane which marks the final part of the external ear .

-inside the canal there is a gland which specializes in the production of the cerumen (ear wax) which contains cell bodies.

\*\*\*I googled about the cerumen (ear wax) which is produced by the cerumen gland that is located in the external auditory canal, it serves as a self cleaning agent with protective, lubricating and anti bacterial properties, and the absence of this wax may result in a dry and itchy ears.

#remember that the sound move as vibrations in the air.

-tympanic membrane is a very thin membrane and can feel and sense the vibrations of the sound that enter the external ear and eventually **vibrate ,**and it will transmit and convey the resulting mechanical vibrations(vibration of the tympanic membrane)to the structures in the middle ear .

\*\*\*\* as a conclusion the main function of the tympanic membrane is to transform the vibrations in the air into vibrations that can be felt and sensed by this membrane and force it to vibrate according to these external vibrations and their frequency .

Now it’s time to talk about **the middle ear :**

**\***Middle ear is mainly composed by 3 bones:

1. malleus which is attatched to the tympanic membrane
2. incus
3. stapes which is the last bone that compress the oval window which is located in the cochlea (as if it’s attached to that place in the inner ear ).

-these 3 bones are connected together

-and they are stabilized and attatched to their places and thus conserving their relationship with each other by stabilizing ligaments .

\*\*\*it’s obvious that the main function of the middle ear (the 3 bones)is to transmit and transfer the vibrations from the external ear to the inner ear .

**But** the question is how does the ear permit and cause the amplification of the vibrations of the sound ??what are the main causes of this amplification ?

-First it’s because of the relationship between the 3 bones (because of **the lever** relationship in between them ).Second the fact that IS the tympanic membrane is much more larger and wider than the oval window .

FOR FURTHER EXPLANATION :

#logically the vibrations will be much more stronger and amplified if we move them from a larger area to a smaller area and this is exactly what happen when the vibrations of the sound is transmitted from the tympanic membrane (**wider area**), through the 3 bones (that have a **lever** relationship in between them) ,to the oval window (**smaller area** ) and this cause the amplification of the sound .

#ALWAYS KEEP IN MIND THAT THE AMPLIFICATION OF THE VIBRATIONS IS TO MAKE THEM MORE STRONGER AND LARGER !!!

\*\*\*but why do we need to amplify the sound ,or what are the benefits of doing this ?

-When the vibrations come from the air and enter through the thin tympanic membrane ;the tympanic membrane will start to vibrate against the air located in the middle ear which has a low density so we don’t need to amplify the incoming vibrations when reaching the tympanic membrane (because there will be no difficulty ).

-but when the vibrations try to enter the inner ear through the oval window it will have a difficulty to vibrate because of the presence of a fluid inside the cochlea (inner ear ) as if the vibrations will be against a fluid that has a higher density than that of the air; so we need to make the vibrations more stronger to enable them reaching the inner ear .

-so without the middle ear amplification we won’t be able to hear probably and this is because of the high resistance that the vibrations will face when reaching the cochlea because of the fluid that is located there ,and to get over this high resistance we need to amplify the vibrations and make them stronger thus be able to hear In a prober way.

\*\*\*PAY ATTENTION: that the AMPLIFICATION OF THE SOUND occurs in **the middle ear** by the 2 previous reasons I already mentioned them before .

IMPORTANT NOTE : never confuse between the oval and the round window ;THEY ARE DIFFERENT , pay attention to this !

>>>continuation about the middle ear:

-Auditory tube> is the one that connect the middle ear to the larynx and it’s main function is to make the pressure on both sides of the tympanic membrane balanced .

>> you may wonder what do I mean about making the pressure balanced ?

-as we know that the tympanic membrane is very thin and is going to be affected by the pressure exerted on it EASILY .Try to understand the next example from our daily life :

What really happen when we go to the dead sea is that the atmospheric pressure (the external pressure) will be higher than the normal ,as a consequence the pressure that affect the tympanic membrane will be higher as well, causing compression on it ,force it to move toward the middle ear and to be more tense and not easy to vibrate in comparison to it when exerting a normal pressure, and because of all these reasons we will start to feel as if our ears are blocked and we are not hearing efficiently.(because of the pressure exerted on the tympanic membrane the vibrations wont be able to reach the other parts of the ear easily).

>>SO ,what shall we do to compensate for this difficulty in vibrating the tympanic membrane ,thus hearing ??

-we need to make the pressure on both sides of the tympanic membrane equal and balanced to let it vibrate and function , and to accomplish that we need to let the atmospheric pressure enter the middle ear to exert pressure against that on the opposite side of the tympanic membrane , and this is done through **the auditory tube. (remember that this atmospheric pressure that enters through the auditory tube is coming from the mouth ).**

-so as a reflex we will start in an automatic way to open our mouth widely by yawning (التثاؤب (and chewing gums in order to permit the atmospheric pressure to enter through the mouth >to the auditory tube> to finally reach the middle ear and make the tympanic membrane back to its normal state ;(less tense ,more relieved from the stresses and easy to vibrate) by balancing the pressure on both sides of it, so we can hear better.

>>CONCLUSION :THE PRESSURE ON BOTH SIDES OF THE TYMPANIC MEMBRANE MUST BE EQUAL FOR APPROPRIATE HEARING !!

###there is 2 muscles attached to the bones of the middle ear :

* the 1st one is tensor tympani muscle
* the 2nd one is called stapedus muscle

**\*both muscles** are **skeletal !!**

**>>>** WHY DO WE NEED THEM ?

-when the ear is exposed to loud noises and high volumes of sounds during parties for ex. , the tympanic membrane as well as the inner ear are now in threat and must be protected .AND to accomplish that ;those two muscles must be contracted so  **that we can make**

1. the tympanic membrane more stretched and tensed to minimize the vibrations and the movement of this membrane thus decrease the possibility of getting this membrane damaged .
2. and to protect the inner ear and it’s associated neurons from these high vibrations that could at any time lead to the damage of the inner ear as well.
3. We finally need either one of these two muscles to contract so that we can accommodate and get use to the high sounds during parties “for example “,by decreasing the vibrations and consequently decrease the damage and make the ear and us comfortable while hearing this sound.

\***VERY IMPORTANT NOTE** BEFORE TALKING ABOUT THE COCHLEA IN MORE SPECIFIC:

**-The hard shell of the cochlea contains two windows:**

**1.** The oval window, through which the vibrations enter the inner ear. (the stapes will be attached to it )

**2.**The round window

\* So what is the principle of the oval window? Why do we need it ?

-IMAGINE that the cochlea is only having one window which is the oval window , so in this case the pressure needed to compress the fluid and cause the entrance and the process of transmitting the vibrations "creating what we called vesto??!" from an air media to a fluid media so hard and not easy to accomplish unless exerting a very huge and large pressure ; so what really occurs is that the cochlea created another window which is called the **ROUND WINDOW** which act as a reliving point that contains a membrane such as a balloon that can vibrate and inflate when exerting a pressure, thus minimize the pressure needed to compress the fluid and permit the entrance and the transmission of the vibrations inside the inner ear through the fluid .

# A CONCLUSION: the reliving point (round window) facilitates the entrance of the vibrations to the inner ear because it decreases the pressure that must be exerted on the fluid to cause its compression .

#NOW WE WILL START TALKING ABOUT THE INNER EAR (which contains 2 important things: the cochlea and the vestibular system that we will be discussed later, but now let’s talk in more specific about the cochlea ) !

-cochlea is resembling a shell, so it’s a hard shell from outside and a space containing fluid from inside.

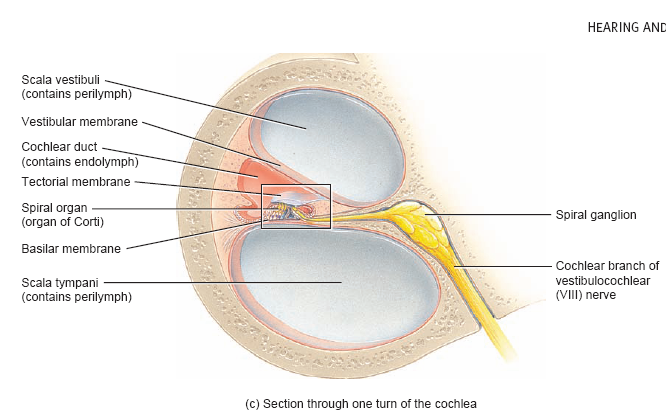
To understand the cochlea you must pay attention to the next slide and the notes corresponding to it:



Note 1 : one space for the cochlea is not enough so if we take a cross section through the cochlea we will notice the presence of 3 compartments (spaces) so from where did they come ?

>>> from the formation of what is called the cochlear duct (the red one ) which resembles a separate compartment (space) that is located **in the middle of the cochlea** (in the middle of the original space of the cochlea ,the gray one ) and thus separate the ordinary or the preexisting space inside the cochlea into two spaces (parts ,or compartments) ,so part of the cochlear space will be located above it and the other part is going to be below it ( the gray ones) .

* And we can see these 3 compartments obvious in this corresponding slide :



>>> you should pay attention to 2 important things :

The 1st one :is that the extension of this duct inside the cochlea will be from the beginning of the cochlea to finally reach a point just before the end of it .

The 2nd one : is that this duct (with the fluid contained in it ) will twist with the cochlea and is going to be separated from the original cochlear space (the gray in color) and the fluid that is contained within it .

\*\*SO as a conclusion we can realize that the fluid that is contained inside the original compartment (the gray one ) is different from that which is contained inside the cochlear duct ( the red one ) and this is the purpose of forming such a duct .

NOTE 2 : the cochlea itself contains a fluid that resembles that in the CSF and the external tissue fluid (they all have a high **sodium** concentrations) and we call this fluid the **PERILYMPH (in the gray** **compartment )** , whereas the fluid that is inside the cochlear duct is going to be different than these fluids because it contains high concentrations of **POTASSIUM** instead ( in the red color compartment ) and we call it THE ENDOLYMPH ; and that’s why we separated it alone inside the cochlear duct .

**#REMEMBER that the duct is not continuous all along the length of the cochlea ,it terminates just before the ending of the cochlea thus allowing a continuation between the upper and the lower compartments , so the fluid that is contained in the upper compartment is the same as that contained in the lower part which is the perilymph .**

>>> when the vibration reach the inner ear it will enter the oval window and pass through the perilymph to finally reach the round window.

\*IMPORTANT THING TO KNOW **: the cochlear duct** contains the sensory receptors and compartments that permit the process of hearing and they are located specifically inside something called **(ORGAN OF CORTI ).**

#High magnification at this area of the cochlear duct that contains organ of corti and regarding to the previous picture illustrated above we can realize number of important things :

1. The organ of corti that is located inside the cochlear duct is composed of 3 main parts arranged from down to up :
2. The basilar membrane(which separate the duct from the whole cochlea and is going to be vibrated easily according to the vibrations that reach the cochlea so it’s not hard ;it’s flexible )and it was named so ,because it is located at the base.
3. Hair cells (hearing neurons that are responsible of hearing) which are attached to and sitting on the basilar membrane.
4. Techtorial membrane ( is located above the hair cells ).
5. And because these hearing neuronal cells have a spiky hair appearance on their surface we called them HAIR CELLS !, and these hairy projections (bundles) is touching and can enter another gelatinous heavy membrane which is called the tectorial membrane .so the hair cells are located between the tectorial membrane (at the side of the hair projections ) and the basilar membrane that lays beneath these cells (at their the base ).
6. as we said the basilar membrane is not hard >>easy to vibrate >>and it can move up and down during vibration.
7. So what really happen if the basilar membrane moves up during vibration the hair bundles located on the hair cells will touch the tectorial membrane and try to push it upward , but unfortunately this wont happen because this membrane is hard and gelatinous and will cause bending of these hair bundles instead .
8. Notice the arrangement of the hair on the neuronal cells (long and short hairs).
9. we know that there is 3 types of gated channels : the lighted gated ion channel, the voltage gated and the mechanical gated ion channels.
10. On the hair cells (specifically on the hair projections itself) there is mechanical gated potassium channels located on it ,so when the hair cell bends during vibration they will open and stretch those channels mechanically .

\*\*if we bend the hair cell toward the long hair located on it, the mechanical gated potassium channels will open , and they will close if we bend the hair cell toward the short hair projection .

So what will happen if these gated channels are open ??(refer to slide 8 )

-when it is open the potassium will enter (not exiting) the hair cell because it’s located inside the cochlear duct which as we mentioned before contains endolymph (high [k]);so the potassium will move from the higher potassium concentration area toward the lower k concentration area (inside the hair cell) causing depolarization (because we raised the positivity of the potential inside the cell ), and when the depolarization occurs and the membrane potential increases( due to the entrance of the positively charged k) , another gated channels will open which is the VOLTAGE GATED Ca channels , so calcium will enter >>entrance of **Ca** cause vesicle release of neurotransmitters that will be attached to a special receptors located on the 1st order neuron in the hearing pathway >>causing action potential .

- pay attention to the synapse between the hair cell and the 1st order neuron of the hearing pathway.

-voltage gated ca channels they open at specific voltage.

- note: the hair cells **don’t** have the property of creating ***an action potential*** (the action potential will take a place in the first order neuron of the hearing pathway).

- **Important note:** when the hair cell is not bent (straight ) the potassium channels will be half an open and half a closed so there will be leakage of potassium(little amounts) ,there for entrance of little amount of calcium and neurotransmitter will be released in small amount as well , causing little action potential in the 1st order neuron that is called ( base line action potential ), but when the hair cell is bent and the channels are open more potassium and calcium will enters so the frequency of the action potential will increase .

# The vibration of the basilar membrane will cause it to move and vibrate not only upward but also it will move down causing the hair to bend on both sides so usually vibrations will move and transmitted according to the increase and decrease of the action potential during time .

For further explanation :

A knocking sound that will cause vibration of the basilar membrane that will move upward and downward causing the hair cell to bend on both sides ( the Long hair side and toward the short hair side ), so the action potential will increase when moving upward then it will decrease when moving downward thus getting the action potential into its normal value .

# As a revision we said that the part of the ear that is responsible for hearing is the organ of corti and the hair cells that lays on the basilar membrane.

>>>and of course while we are hearing the ear should differentiate between different voices and sounds .

A VERY IMPORTANT NOTE : The sound as a wave has two properties :

1. The frequency property
2. The intensity property

-the frequency is going to be determined according to the speed of sound and vibrations , and is represented by the wave length or its frequency (so if the wave length or the wave frequency is high this means that the frequency of the sound is high as well).

-Whereas the intensity means whether the sound is low or high ,and is going to be represented by the amplitude.

>>>important note to keep in mind: it’s not necessary for a sound having a high intensity (high amplitude) to have a high frequency as well.

-we usually correlate the calm and loud sounds with **the frequency** of the sound not **the intensity** , so for someone has a quiet calm sound or voice >>>the frequency of the sound will be low , and for another that is having a loud sharp sound >>the frequency of the sound will be high.

#SO AS A CONCLUISION >>> whenever we are talking about loud voices and sounds remember that they are having high frequency whereas low frequency will be associated with quiet and calm sounds and voices , and try not to confuse between the frequency and the intensity that is talking about the strength of the sound whether it is high or low .

>>> so **high** sounds and voices high intensity.

>>>**low** sound and voices low intensity.

# we can also classify the sounds into two categories:

-One that is discussing the type and the nature of the sound , whether if it was loud or quiet and is going to be represented by the frequency .

-and the second is discussing the strength of the sound , whether if it was high or low , and this is further represented by the intensity .

\*FOR FURTHERE EXPLANATION :

You as a person has a specific nature/ type of voice and sound. So your sound either to be quiet , or to be moderate or it may be loud and sharp and thus having a specific frequency. And you as a person can also increase your tone of sound (make it higher ) or decrease it (make it lower ).

So according to the previous information the sound can have :

1. High frequency (sharp and loud voices and sounds )
2. Mid frequency . (the voice and sound is moderate between loudness and quietness )
3. Low frequency (your voice and sound is calm and quite )

**And each of these frequencies illustrated above could be having either high or low intensity according to the strength of the sound. (this means that you can raise your voice or make it lower )**

# note : the frequency depends on the nature of the letter and the person . so different letters may require different frequencies ( some letters either require high / low frequencies as well as different intensity depending on the strength of the voice needed ).

#according to the frequencies I can differentiate between different voices and different sounds and letters , but notice that the hair cells they are not able to distinguish between different frequencies, so how the ear is going to have the ability of differentiation between the different voices ,sounds and letters? How the ear is going to distinguish and differentiate between the different sounds ?

The answer is by the basilar membrane which extends and twists almost all over the length of the cochlea and terminates just before the ending point of it, and to understand more you should read the whole information below.

#referring to slide number 9 , two things must be considered regarding the basilar membrane :

1. –it has a base which is going to be attached (and thus hard to move and vibrate )

-it has an apex which is going to be free (and thus easy to move and vibrate)

2. – the base is going to be narrow, whereas the apex is going to be wide .

\*So as a conclusion: it’s easier to move and vibrate the apex of the basilar membrane than its base .

\*So the base will be moved only at high frequency ,whereas the apex will move at lower frequencies (because it’s not attached and wider).

\*So if the basilar membrane is exposed to a voice or sound having low frequency it will only cause the movement of the apex and not the base ,and in the case of exposing to high frequency the movement will be to the base not the apex ,and finally when exposed to a mid frequency the middle portion of the basilar membrane will be vibrated .

\*so what will happen after the vibration of the basilar membrane ??

-if the basilar membrane for example was exposed to a sound having mid frequency this will cause the vibration and movement of the middle portion and therefore the movement of the hair cells that are attached to this portion causing entrance of the potassium ,eventually the releasing of the neurotransmitter that will cause the firing stage in the 1st order neuron ,so that the fact that we were exposed to a mid voice frequency will be understood .

#Regarding to slide number 10 :

-Remember that near the oval window the basilar membrane is going to be narrow and stiff (the basilar portion), whereas near the helictrema (the end of the cochlea) the basilar membrane is going to be flexible and wide.

-we can hear sounds at frequencies extend from 20 HZ -20 Kilo HZ .

-SO according to the vibrations of different regions of the basilar membrane we can assume the magnitude of the frequency coming to the ear .

-and then according to the vibrations of any specific area on the basilar membrane ,that will vibrate only according to a specific frequency , there will be firing of the neurons that synapse with the hair cells specifically located at this area ,and thus giving information to the brain telling it the frequency of this sound.

An important conclusion: **Differentiation of the frequencies of sounds will be according to the hair cells and the synaptic 1st order neurons that were involved in the region of the basilar membrane that was vibrated” according to a specific frequency.**

**And this resembles what happen when something touches our hand each at different site (or finger) so according to the neurons that has been fired when this thing touches our hand , the brain can assume and differentiate and know what part has exactly been touched.(according to the neurons that have been fired and stimulated and transmitted the information to the brain)**

**#**Usually the words , the things we speak ,and sounds they wont **be purely** having high or low frequencies ( because words have multiple letters and each letter has a different frequency ),so normally the ear will be exposed to a complex sound (having multiple frequencies) and thus multiple regions will be vibrated in the basilar membrane at the same time >>causing firing of different multiple neurons that synapse with hair cells located at different regions >>so the brain will analyze the frequencies and the word that we were exposed to and understand it as well ,according to the regions and the frequencies that are taking place .

Hope you have understood how the ear can differentiate between different voices and sounds .

\*AND NOW AFTER WE HAVE TALKED ABOUT THE FREQUENCY ,IT’S TIME FOR DISCUSSING THE INTENSITY :

>>> example : for a sound with a frequency of about 1 kilo HZ ,specific area located on the basilar membrane will vibrate . Assuming that the sound was high (high intensity) the vibrations of the basilar membrane will be higher >causing more ion channels to be opened >the number of the action potentials that will be produced is going to be higher or the frequency of the action potential will be higher .

And if the sound was low (low intensity and strength of the sound ) >it will cause less vibrations of the basilar membrane >the number of ion channels that will open will be less >thus less production of action potential or the frequency of the action potential will be low .

**#TRY not to confuse between the frequency of the sound and the frequency of the action potential :the frequency of the sound is encoded by the location at the basilar membrane , whereas the intensity is going to be coded by the frequency of the action potential that will be transmitted .**

**(so the higher the intensity “stronger and higher sound” the more the frequency of the action potential ,and vice versa .**

##IT’S TIME TO GIVE SOME PREIF INFORMATION ABOUT THE 1ST ORDER NEURON AND THE AUDITORY PATHWAY WHICH WILL BE FURTHER DISCUSED IN THE NEXT LECTURE !

\*note 1 :the 1st order neuron is considered as a pseudo polar(not sure )neuron , though there is other references that classify it as a bipolar neuron .

\*note 2 : and as any other normal neuron it has a cell body (that is going to be located in the spinal ganglia ) and an axon that will travel through the 8th cranial nerve which is the “vestibulocochlear nerve “.

- it will go to the cochlear system (the axons of the 1st order neuron that is transferred by the vestibulocochlear nerve) and the reach the brain stem , where they synapse with the cell bodies of the 2nd order neurons located in the cochlear nucleus . Then the axons of the 2nd order neurons will travel through the brain stem to finally reach the thalamus , and from the thalamus to the cortex of the brain .

**NOTE: the** auditory pathway is complicated because there will be more than one route (path, track) and they will overlap with each other.

What overlapping means that there will be crossing between the routes that is coming from two sides ;so the left route that can go to the right side and vice versa.

**\*REGARDING to slide number 15 ,** there will be two pathways one is colored blue and the other one is colored red.

-the red pathway when collects the information from oneear  **it will not do crossing between the route** , thus is called **mono** auditory or **mono** naural pathway ." but we can get input from both ears"

-whereas the blue pathway is highly overlapped and usually collects and takes the information from **TWO** ears and is called **bi** auditory or **bi** naural pathway .

**\*FINALLY**: why do we need to obtain the information from two ears? And what is the difference between the information that is coming from one ear and that which is coming from both ears?

- we need the bi auditory pathway (the blue one ) to determine the direction and the place from where the voice is coming . (to determine the source of the sound ), whereas the mono auditory pathway will take care of distinguishing the meaning of the voice ,sounds and words ,and other functions that the bi auditory pathway can’t do .

Sorry for being late , hope you understand everything .

Good luck everyone ☺

