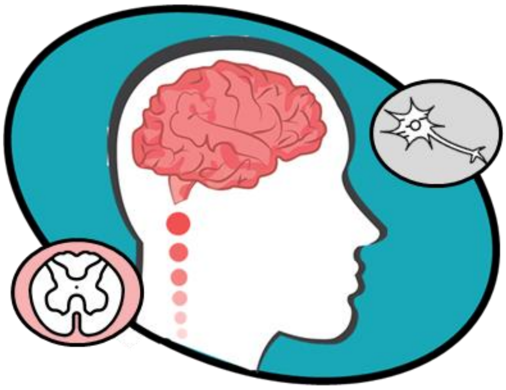

CNS

Physiology

Sheet ● Slide ○

Number

-3

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- Today we are going to talk about **<u>hearing (the auditory pathway)</u>** and we will cover these concepts :
    - The nature of sound
    - Revision of the anatomy of the ear
    - The physiology of the auditory system and auditory pathway
    - Types of deafness

    Corrector's note: It's so much better to listen to the records while studying physiology sheets; we tried to clarify everything as much as possible. If you find any scientific mistake, contact Amani Nofal as soon as you can to correct it. Good luck!

- **<u>The nature of sound :</u>**

    - Sound is basically vibrations that travel as waves in a medium like air. Different Sounds (different vibrations) have **<u>specific characteristics</u>** which are *(Amplitude, Frequency and Wavelength*)

        ➔ **Amplitude:** is a characteristic represented by <u>intensity</u> of voice (loudness of voice) which means that the voice is either weak or strong (عالي او واطي). So, the louder the voice, the higher the amplitude and the lower the voice, the lower amplitude.

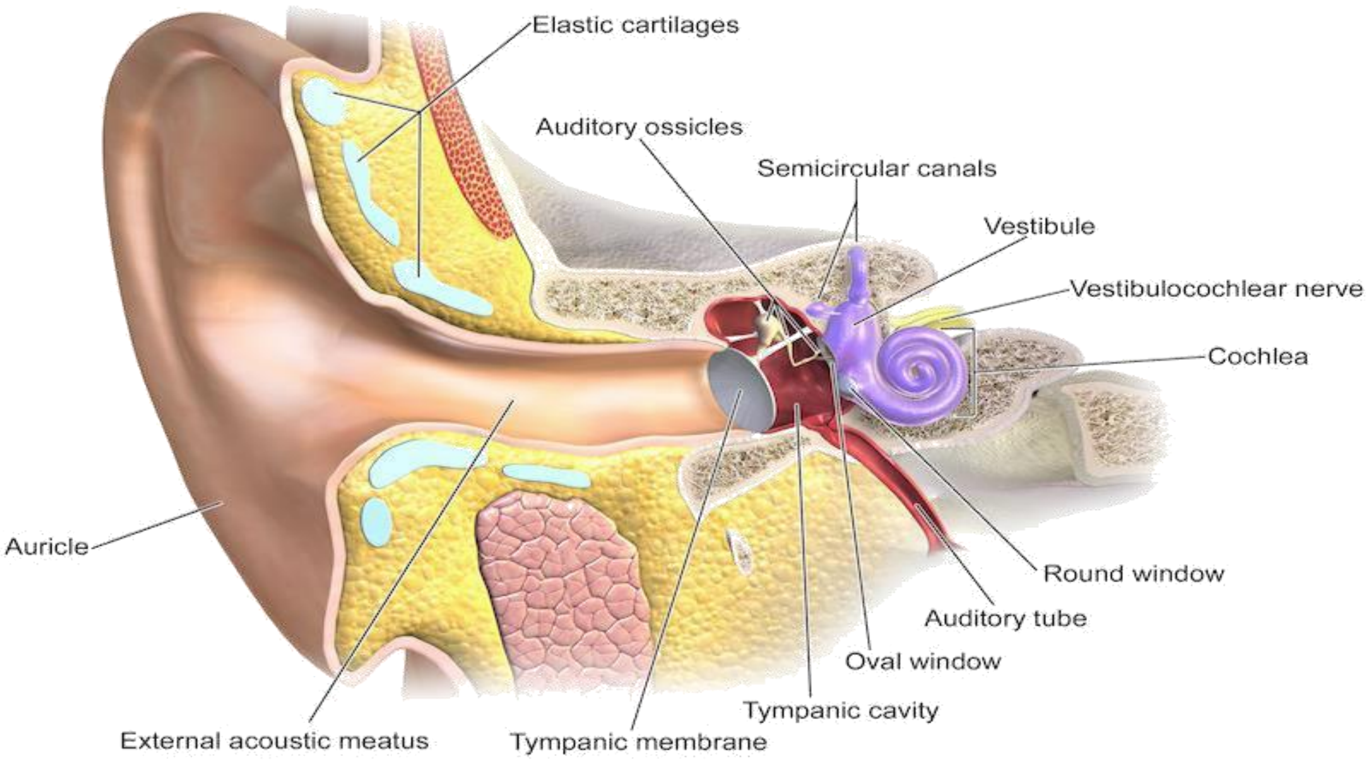
        ➔ **Frequency:** is a characteristic that distinguishes different types of sounds (different pitches). For example, a bird's sound or a dog's sound and even sounds of letters are all different because they have different frequencies. So, each sound has a specific frequency thus a specific pitch, meaning that high frequency means high pitch and vice versa.

Notice: the same pitch of the bird's sound can be heard as **loud and weak so high amplitude and low amplitude respectively of the same frequency because it is the same pitch.**

Notice: frequency means the number of waves with the same length in a specific time interval, usually one second.

Notice: again differences in **frequencies** allow us to determine the **TYPE** of the sound, while differences in **amplitudes** allow us to determine the **INTENSITY** of the sound**.**

- **<u>Revision of the anatomy of the ear & physiology of the auditory system</u>**



- The ear is divided into three parts :

    - ***External ear***; which consists of the auricle, and an external auditory meatus, and ends at the tympanic membrane.
        - ➔ **Sound pathway here:** the sound is collected in the auricle then it enters the external auditory meatus to reach the tympanic membrane and results in its vibration.

Functions of the auricle:

1- Collecting sounds and passing them to the auditory canal.
2- Helping the CNS to distinguish between the different origins of certain sounds by **the folds** of auricle

    - ***Middle ear;*** which consists of three ossicles (the bones of hearing); the malleus, incus and stapes. Also, there are two muscles; tensor tympani and stapedius. In addition to the auditory tube.

➔ **Sound pathway here:** After vibration of the tympanic membrane, these vibrations are transmitted to the middle ear and result in vibration of the the 3 bones of hearing then these vibrations will be transmitted to the inner ear.

Notice: the main function of the middle ear is controlling the intensity of vibration by either amplifying or dampening the intensity of sound.

- ➔ Three bones of hearing perform sound amplification
- ➔ Two muscles of hearing perform sound dampening by their contraction and thus protect the ear from damage caused by the high intensity of voice

So, when the sound intensity is high, dampening will happen and when sound intensity is low, amplification will happen.

Example: when you go to a party, at the beginning the sound is too intense and strong so dampening happens by the contraction of the two muscles of hearing.

Notice also that the main function occurring in the middle ear is **amplification** of sound and this is not only achieved by the **3 bones of hearing,** but also by something called the **lever system.**

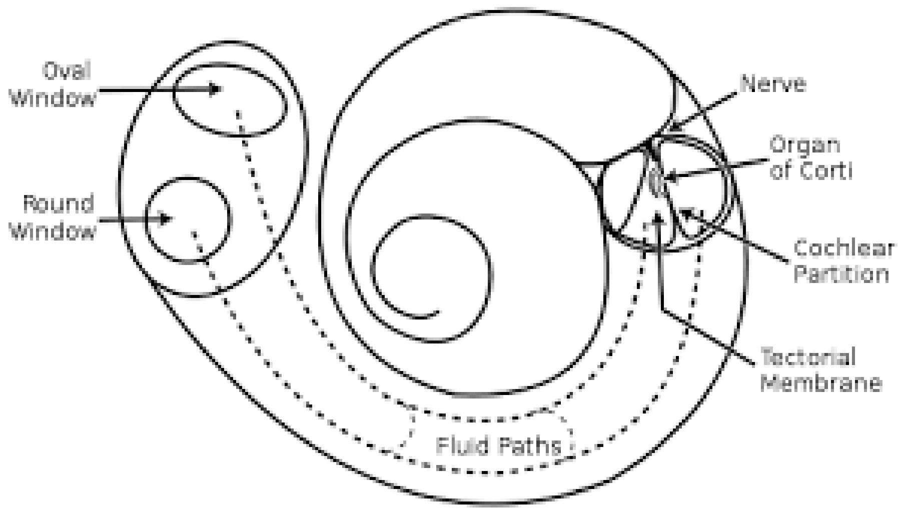
Remember: the lever system; Area1*Force1=Area2*Force2, which means a wider area, will have less force than a smaller area. The same idea works here with sounds, as the middle ear is the lever system. The vibrations will pass through two membranes with different areas (sizes) and this will cause the amplification and these are:

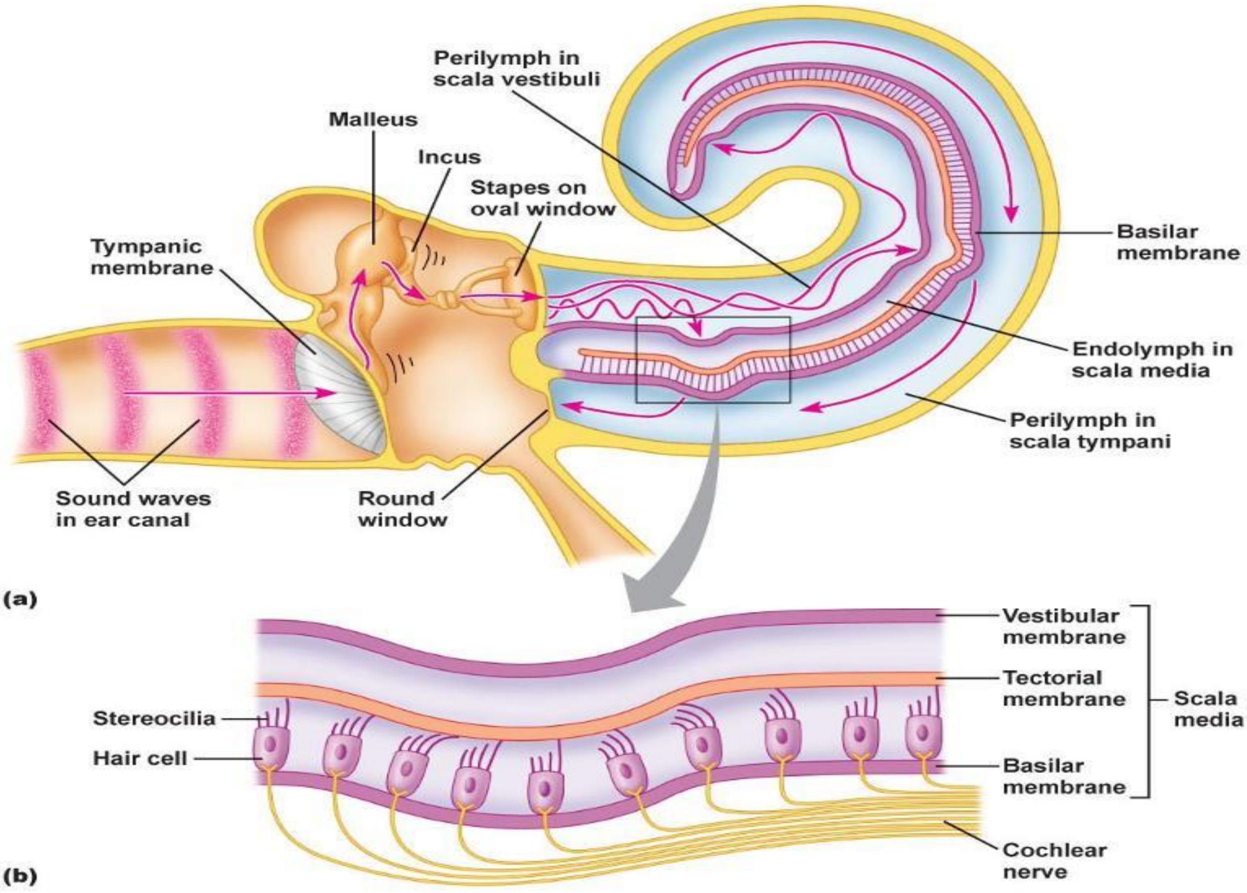
-The tympanic membrane: large membrane.

- The oval window "which is under the stapes": small membrane.

So, when the vibrations move from a larger area to a smaller one, amplification of the vibrations will occur.

- ***Inner ear;*** which consists of the vestibular labyrinth and cochlea. **Cochlea** is hard-shelled from the outside and contains an inner cavity filled with a **perilymph fluid**. Cochlea has **two gates (windows)**; **oval window** "under stapes" which is the gate of which vibrations pass through to reach the cochlea. The other one is a **round window** "relief window/exit gate" and it is for the vibrations to exit the cochlea".
- ***Anatomically;*** the two gates are located next to each other. However, from the inside they are separated by the cochlear duct to allow the vibrations to move along the duct and the entire cochlea and then to the exit gate. Imagine that there are no separations in the cochlear cavity. In this case, the vibrations will enter through the oval window and go directly to the round window without passing through many parts of the cochlea that are enough to achieve the proper function. Accordingly, we notice the presence of **a structure-function relationship.**





- Now look at the picture above where we will study the anatomical structure of these separations.
    - This separation is called the **cochlear duct** and it is a two-walled structure with a central canal in between called the cochlear canal which contains "**endolymph" fluid.**
    - The two walls are :
        - ➔ ***One of them is HARD and gelatinous; called Tectorial Membrane***
        - ➔ ***The other one is ELASTIC and called Basilar membrane*** that contains hairy cells as you can see in the picture. These cells are called hairy cells because they resemble hair due to their ciliary projections. These cells also contain ***hearing receptors.***
    - **Notice** that the two membranes (basilar and tectorial) including the hairy cells and their receptors all together are called ***Organ of Corti.***

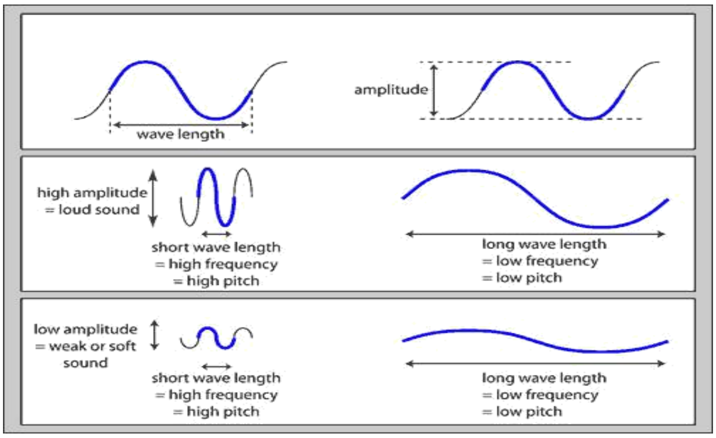
- **Sound pathway here:** When the ossicles vibrate, they cause the oval window to move back and forth to transmit vibrations to the basilar membrane – it will vibrate in the same manner as well- leading to the upward, downward movements and bending of hair cells. Hair cells have a **base tone firing rate**; meaning that bending of hairs in one direction opens the ion channels and depolarizes the hair cells (this is what we will focus on), and bending in the opposite direction closes the ion channels and hyperpolarizes them.
- **So what is the main function of the cochlea?**
  As you notice, ***cochlea transforms vibrations of sound waves to neuronal signals***.Notice these vibrations represented as a type of ENERGY that is translated as neuronal signals by hairy cell receptors.

A summary of the whole pathway we discussed: Sound causes vibration of the tympanic membrane which results in the vibration of the malleus, incus and stapes in the middle ear for amplification. Stapes pushes forward the oval membrane of cochlea which leads to transmission of vibrations through the fluid "perilymph". The vibrations in the fluid will cause the basilar membrane to move upward and downward with the receptor cells on it, but this movement is restricted because of the presence of the tectorial membrane "which is hard as we said". So as a result, the cilia will bend against the tectorial membrane in a specific direction and go back with each vibration. The cilia have mechanical gated ion channels which open when the cilia bend to one side and close when the cilia bend to the other side. Bending of the cilia to a specific side, will lead to the opening of those mechanical gated ion channels and depolarization follows. This will result in neurotransmitter release and action potential generation. By this, we changed the sound waves in air to vibrations then to mechanical changes in the cilia, which resulted in an action potential and an actual neuronal signal!

- **NOTICE:** The whole pathway we have discussed terminates by the generation of a neuronal signal, where we are only able to detect if there is a sound or not**. However, the cochlea cannot only detect if there is a sound or not, but also, it can detect all of the characteristics of sounds like:**

- ➔ **Type of sound** (the pitch; if I am pronouncing the B or C letter for example. In other words; the frequencies of sounds) .
- ➔ **The intensity** of sound (the amplitude) and whether it's high or low. In other words, if the sound is weak or strong for the same pitch). **Remember**: we said in the first page that the intensity of sound is represented as amplitude.
- ➔ **The direction of** sound (if it's from the right or left side and the angle of which it is coming from. For example, it could be on the right from 90 degrees away or at 45° degrees**).**

- ***<u>How to know the intensity of sound?</u>*** The higher the intensity, the higher the amplitude and the stronger the vibrations are. In case of transmitting a high-intensity sound wave, the basilar membrane moves further causing more bending of cilia on the hair cells so more ion channels will open and the generated potential will be higher and more frequent. So, higher intensity= higher amplitude, which leads to a higher frequency of action potentials.



<u>How to know the type of sound (the pitch)?</u>

- In other words, we want to differentiate between different frequencies of different sounds. The frequency of sounds is determined by the <u>activated part of the basilar membrane</u>.
- Notice that the basilar membrane is narrow at the base near the oval and round windows, while its apex is wide and free. This characteristic along with the unique rounded shape of the cochlea determine which part of the basilar membrane will respond to a certain frequency. Each frequency will move a **specific** part of the basilar membrane and consequently activate the corresponding small number of hair cells found on that part only. So, these hair cells on that specific part only will generate action potentials that will be transmitted to the brain by neurons attached to theses hair cells. So, the brain determines the frequency of a certain sound by detecting the pathway of the neuronal signals it receives and the location of hair cells on the basilar membrane that were activated in the process.

<u>Example</u>: Assume that we have a sound frequency of about 1000 Hz that activates the "X" portion on the basilar membrane. This means that whenever we hear that sound only this portion "X" will be activated and it then sends neuronal signals to the CNS.

- Humans can distinguish frequencies as high as 20,000Hz and as low as 20 Hz; this depends on the design of the cochlea and the basilar membrane as each part of the basilar membrane is activated by a specific frequency.

Question: if there is a voice with frequency of 25,000 Hz, will you be able to hear it? No, you won't be able to hear it because there isn't any part of the basilar membrane designed for this frequency, BUT this voice will lead to the vibration of the tympanic membrane, movement of malleus, incus and stapes, vibration of the fluid, where the vibrations will finally terminate as they pass across the round window WITHOUT any movement in the basilar membrane**.**

Note: different shapes of cochlea lead to different ranges of frequencies. For example, animals’ cochlea differs in shape from humans so they can hear a different range of frequencies**.**

- **How to know the side which sounds are coming from?** We will discuss it later in this sheet.

- <u>**The auditory pathway**</u>
  - Before we start with the auditory pathway, we will talk about general information about sensation and the cortex:
    - ➔ We said previously that there are many sensory pathways, and each one ends in a distinct destination. Nonetheless, all information should go at the end to the cortex so that we can become familiar with it (conscious about it). Each part of the cortex has three names; ***the physiologic name*** depending on the information it processes, for example the part in the cortex that receives auditory information is called the primary auditory cortex, the part that receives visual information is called primary visual cortex and so on. The other two names are the ***anatomic name*** according to the location and the shape of the cortical part, and the **Brodmann name (**which is the oldest one) which represents the number of areas. We have about 50 areas in the cortex, so each area has one specific number.

The Brodmann nomenclature divides the human cortex into about 50 distinct areas based on the histological structural differences.

  - **Let's start with the auditory pathway: the neurons** that transmit information from hair cells have cell bodies in the spinal ganglia and their axons together form the cochlear part of the vestibulocochlear nerve and this cranial nerve is responsible for transmission of information to the CNS. Firstly, the information goes from the cochlear branch of the vestibulocochlear nerve to the **cochlear nucleus** in the brain stem. The fibres of the 1st order neurons of the cochlear nerve enter the brainstem where they synapse with 2nd order neurons in the cochlear nucleus**.**

- Notice that neurons transmit different frequencies so neuron fibres of the cochlear branch of the vestibulocochlear nerve will synapse at a distinct site at the cochlear nucleus in order to preserve the frequency. So there are different sites to synapse at according to frequencies; the higher frequency will synapse medially in this nucleus, while the lower frequency will synapse outside laterally "at the edges of this nucleus". This designation mainly preserves the labelled line principle and the ability of detecting different frequencies.
- Now after synapse at the cochlear nucleus occurs, information goes to the second order neuron then the information should go to the cortex but before that ***remember*** **that any information that enters the cortex or leaves, should pass through the thalamus. So, the thalamus is considered as a gateway to the cortex**.
- So the 2nd order neurons from the cochlear nucleus will synapse with a 3rd order neuron in the **medial geniculate nucleus** in the thalamus (notice that also there are different sites to synapse according to the information transmitted by the neurons) **Then the 3rd order neurons go to the primary auditory cortex (area 41) in the temporal lobe of the cortex.**

So, the frequency of the sound is preserved in a certain line (pathway), as neurons synapse at different sites in the cochlear nucleus and in the thalamus. Also, in the primary auditory cortex there are sites for different frequencies, usually neurons transmitting high-frequency sounds synapse at the medial side of the cochlear nucleus while those transmitting low-frequency sounds synapse at the lateral side of it!

- SO THE FREQUENCY IS PRESEVED.

- **Now, let's talk about *<u>how to know the side the sound is coming from (localization)?</u>***

  - When the sound for example originates from the right side, it reaches the right ear with stronger INTENSITY than the left ear and it reaches the right ear in shorter TIME than the left ear.
    - ➔ So CNS needs two things to determine at which side the sound is; **intensity of the sound in each ear** and **the time** that sound spent to reach each ear. So these two characteristics are important in localization of the sound.

    - ➔ Localization of the sound is important for the **conscious** cortex and also for **unconscious** reflexes (it's important to have such reflexes as mentiond in the paragraph below). In the subcortex for example, when someone calls you suddenly; you will respond quickly by turning your head towards the side the voice is coming from.

    - ➔ But as we took previously when the information reaches the cortex it stops many times at many stations and undergoes processing that leads to **ALTERATION** of the intensity and time of the sound and loss of auditory information. So, it's important to determine the side of sound early in the pathway to preserve the intensity and time of the sound. **REMEMBER**, frequency is always preserved in any pathway.

    - ➔ How does that happen? Part of the cochlear nucleus will send neurons in another pathway to synapse at a nucleus called **the superior olive nucleus /complex** (we have two on both sides; right and left)**.** These nuclei receive information from both sides. In other words, **the right superior olive nucleus** receives information from both right and left cochlea, and **left superior olive nucleus** receives information from both right and left cochlea. Note that there is a pathway by ***<u>trapezoid body</u>***

that connect auditory fibers from ventral cochlear nucleus from one side to the superior olive nucleus in the opposite side. By comparing information from both sides, superior olive nuclei determine the location of the sound.

- We took the general auditory pathway but there are two ***specific pathways*** that we have to cover :

  - ***Monaural pathway*** : This pathway as the name implies, receives information from one ear only and ends at the opposite side of the cortex; so the right ear will terminate in the left cortex and vice versa.

    ➔ The 1st order neuron synapses with a 2nd order neuron at the **dorsal cochlear nucleus**, which crosses the midline and passes through the inferior colliculi of the midbrain; where they synapse with another neuron which in turn will synapse again at the medial geniculate nucleus of the thalamus to reach the cortex. Thus there are a few stops in this pathway and the processing mechanisms are less, so there will be minimal changes on intensity and time and the sound is transmitted with discrete quality. It has a great importance in preservation of the amplitude and time. This is important in hearing words arranged in a pattern (sound resolution) وضوح الصوت.

    (يعني الصوت بيصل بهاي الطريقة بجودة عالية فبنقدر نسمع كلمات الجملة الواحدة بطريقة مرتبة لأنه صار في حفظ للصوت زمناً وشدةً)

  - ***Binaural pathway:*** it starts from the **anterior cochlear nucleus** and ends **at both sides** of the cortex***. For example;*** the sound from the right cochlea will go to the right and left hemispheres of the cortex and this applies to the sound coming from the left cochlea.

    ➔ Neurons from one ventral cochlear nucleus will go and synapse with both superior olives (right and left), then ascend up as lateral meniscus to synapse at the inferior colliculi of the midbrain. Finally, from the medial geniculate nucleus in the thalamus to the primary auditory cortex.

➔ As you notice there are many stops in this pathway; so the preservation of sound will be less but this pathway has an **advantage in localization of sound because** the monoaurual pathway does not include the olive complex as part of its pathway.

➔ **So this pathway is important also in unconscious reflexes as we said previously.**

- **Clinical case: If there is a lesion in the auditory pathway <u>above the right superior olive nucleus</u>, from which ear will the patient hear?**

  ➔ From both ears because as we said in the bi-auricular pathway each pathway (right and left) transmits information from both ears. So if the right one is interrupted, the left one still transmits information from both ears.

Any lesion above the cochlea will not lead to loss of hearing. However, if the lesion occurs before the cochlea and more to the periphery, it will lead to loss of sensation at the area of lesion and may result in loss of hearing at this side.

- **Auditory reflexes :**
  - **Middle ear reflex:** we talked about it previously that two things may happen to the sound which **are amplification or dampening.** If you were at a party and you heard a high-intensity sound (loud sound), contraction of the 2 muscles of hearing in the middle ear happens resulting in a more tense tympanic membrane. As a result, fewer vibrations will be transmitted through the ossicular system from the tympanic membrane to the basilar membrane and you will not hear the sound as intense as it is. In constrast, if the intensity of the sound that you hear is suddenly low, it will be amplified**. How?**

For example: imagine yourself sitting in the hall of the faculty and there are noisy sounds around you, then you hear someone calling your name with a very low voice. Within milliseconds; that specific sound will become more intense than before although there is noise around you. How come? Different sounds will go to the basilar membrane to different areas but we have to lower all vibrations at the level of the middle ear .However, we have the ability to raise the vibration tones selectively and increase the intensity (selective **amplification**).

To understand the way of selective amplification, you should know that we have two types of hair cells; **inner cells** which are large cells arranged in a single row and each cell is connected to 1- 3 neurons. So inner cells give good representation to the CNS and **they are important in sound resolution**وضوح الصوت

The other cells are **outer hair cells** which are small cells arranged together مدحوشين مع بعض and every 5 to 6 cells are connected to 1 neuron. They also contain motor units so these cells don't give good representation to the CNS and they are not important in sound resolution but they have **a role in changing the intensity of the sound**.

Let's come back to the example about when you hear something important with low intensity and you want to hear it with more intensity. In this case, there is a certain stimulus that will be sent to the cortex and it, in response, sends a motor order to the motor neurons of the cochlear branch of the vestibulocochlear nerve to reach motor units of the outer cells causing their bending, resulting in the movement of the tectorial membrane towards the inner cells that are slightly bended. This causes more vibrations at the basilar membrane, thus intensifying the sound (the amplitude becomes higher).

- This reflex (selective amplification or activation) happens also in many conditions of the ear, for example if there are antibodies generated against many hair cells with different frequencies, the cells will not be able to transmit the sound, so the cortex – in this case- sends signals to the cochlea to bring the two membranes (the tectorial and the basilar) closer to cause hair cells to develop more bending. However, they're already damaged, increasing their bending will not increase the intensity of sound, and instead **tinnitus occurs**.

Tinnitus can happen in many ear problems due to activation of this reflex and it is hard to control it!

- Tinnitus can happen also when you go outside the party, because the muscles of hearing that were contracted will relax suddenly and the sensitivity of hair cells to vibrations remains high resulting in tinnitus.

- **Types of deafness:** If there is a problem in the ear that leads to hearing loss, this results in deafness.

  ➔ **Neuronal deafness** happens when there is damage in the neuronal part including degeneration of hair cells and demyelination of any nerve in the auditory pathway from the cochlea to the primary auditory cortex.

  ➔ **Conduction deafness:** when the sound wave fails to activate hair cells due to many causes such as; damaged tympanic membrane, an abnormally large amount of wax in the auditory canal, and calcification of the ossicles.