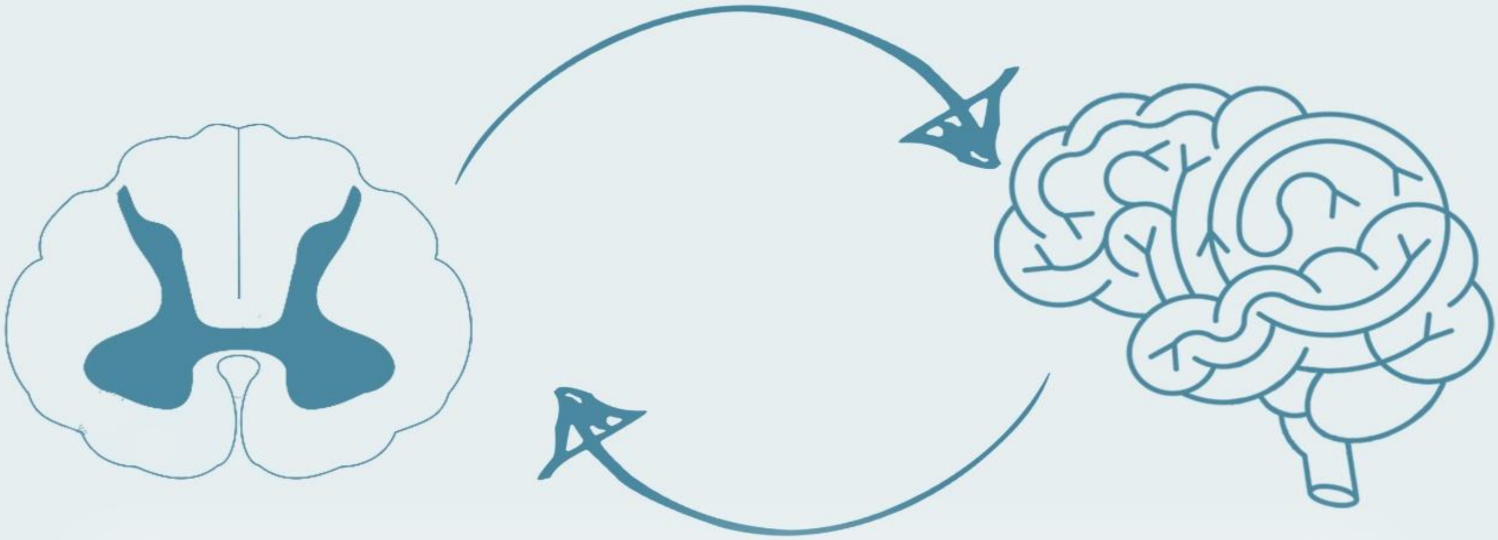

CNS

physiology

○ slides ● sheets

▶number	8
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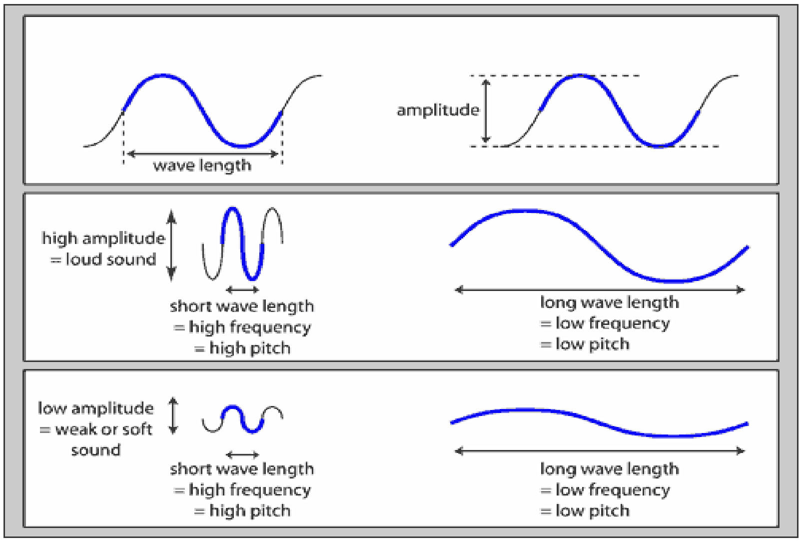
Auditory System

What is sound?

Sound is vibrations that travel through transmission medium (air, liquid...) as waves. These waves have different characteristics, which make the different sounds we hear.



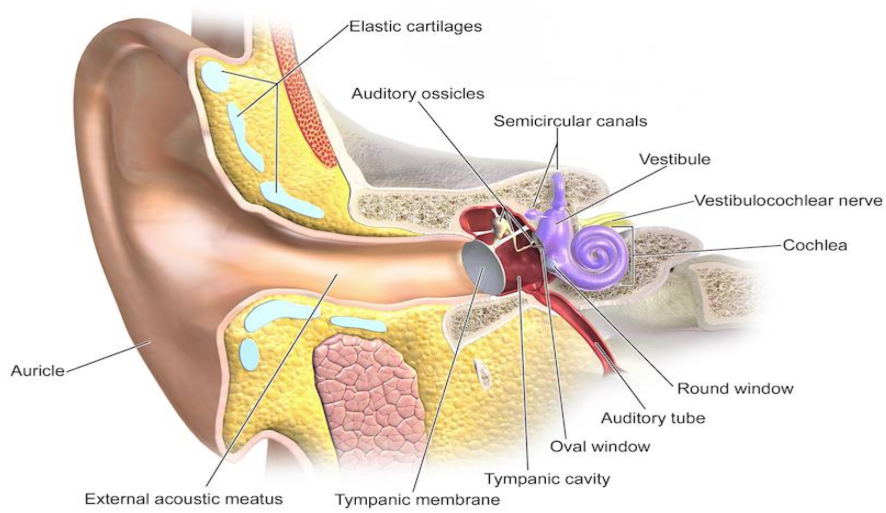
As the picture above shows; there are different characteristics for the waves:

1- **Frequency/wave length:** which determines the pitch of the voice (high frequency means higher pitch and vice versa). By this feature we can hear different sounds; we can differentiate between a bird and a bulldozer because they have different frequencies and pitches.
Note: higher pitch doesn't mean higher intensity. A sound with **low frequency and high amplitude** is a sound with **low pitch and high intensity.**

2- **Amplitude:** which determines the intensity of the sound "the strength/ if it's loud or weak". For example, the same pitch of the bird sound, you can hear it loud-if it's near you-or you can hear it weak-when it's far away from you-.

To sum up: difference in frequencies allows us to determine the TYPE of the sound, while difference in amplitudes allows us to determine the INTENSITY of the sound.

<u>Anatomy of the ear:</u>



The ear can be divided into three parts; external, middle and inner ear.

1- **External ear**
the sound is being collected in the auricle then it enters the external auditory canal (meatus) to reach the tympanic membrane and result in its vibration. The folds of the auricle help in localization of the sound especially in the vertical dimension. Moreover, the external auditory canal has **cerumen glands** (earwax glands) to help in protection, lubrication and cleaning.

2- **Middle ear**
it is composed of (I) the three bones of hearing (malleus, incus, and stapes), (II) two muscles and (III) the auditory tube. The auditory tube is a very important structure that connects the middle ear with the nasopharynx regulating the pressure at both sides of the tympanic membrane.

**When you go below the sea level where the atmospheric pressure is high you are advised to open your mouth or chew gums to regulate the pressure and relief the tension made on the tympanic membrane.*

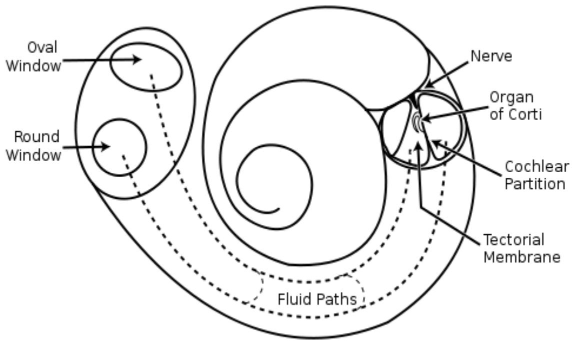
The two muscles in middle ear are Tensor tympani; which is supplied by the trigeminal nerve, and Stapedius; which is supplied by facial nerve.

When you are hearing very loud sound, these muscles contract and prevent the tympanic membrane from rupture and protect the inner ear; as contraction of these muscles will cause damping of the sound "reduce it and change it from high to low".
However, the three bones carry the main function of the middle ear, which is amplification of the sound.

<u>HOW the amplification is done?</u>
Remember the lever system; Area1*Force1=Area2*Force2, which means a wider area will have less force than the small 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.
- The tympanic membrane: large membrane.
- The oval window "which is under stapes": small membrane.
So when the vibrations move from a larger area to a smaller one, amplification of the vibrations will occur.
**This concept has a huge value in hearing tests "will be mentioned later"*

3- **Inner ear**
It contains two structures; vestibular labyrinth "important in balance, we'll talk about it next lecture" and cochlea "the one that is important in hearing".

Cochlea is hard-shelled cavity filled with a "perilymph" fluid and contains two windows; oval window "under stapes" and round window "relief window/ for the vibration to exit the cochlea". And as you can see in the picture below, these two windows are anatomically beside each other; so in order to enforce the vibration to travel throughout the whole cochlear cavity, there must be separations to guide the vibrations.



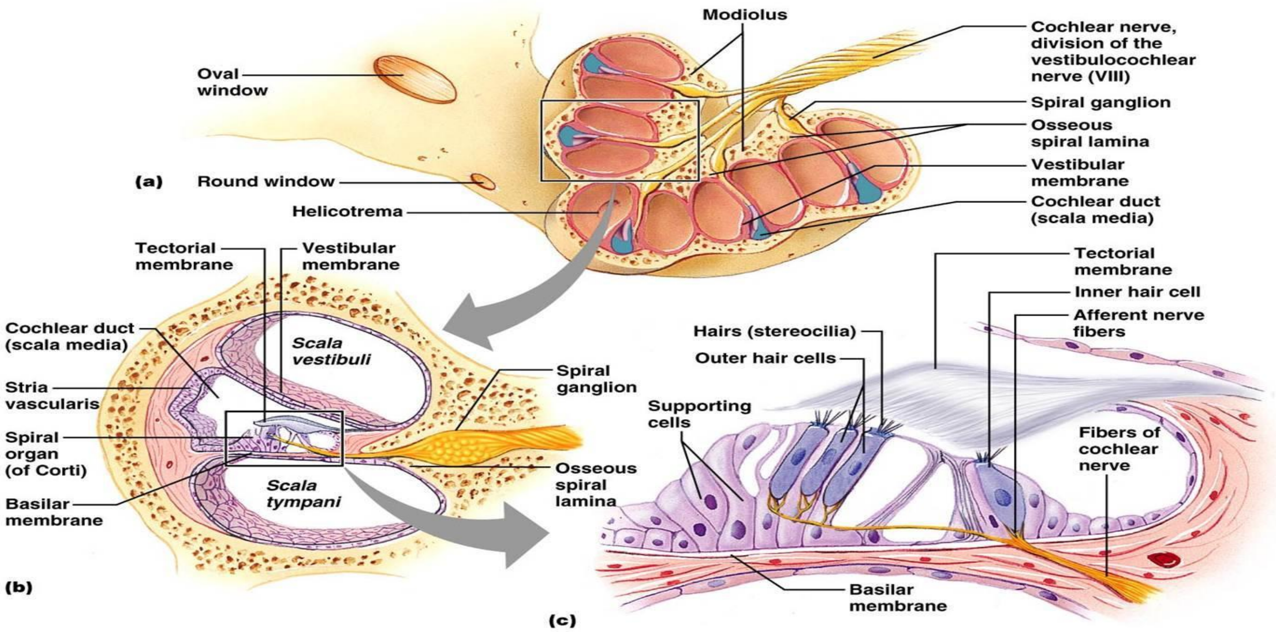
The separation wall is not simple and thin, instead it's a two-walled structure with a central canal in between called **cochlear duct**, which contains "endolymph" fluid.

The perilymph and endolymph are two fluids that differ in their composition and the way of synthesis; perilymph as example is very similar to CSF.

So all in all, the vibration start from tympanic membrane, get amplified in the middle ear through malleus, incus and stapes. The later will press on the oval window, which causes the vibrations to reach the cochlear cavity and move through it until they reach the relief window "round window".

11:20

The physiology of the auditory system:



Look at picture (B), where you can see the cochlear duct clearly, and zooming in as in picture (C), you can see that this duct is composed of two walls separated by a space.

The two walls are the following:

1- The superior/upper wall and it is called **Tectorial membrane**, which is a hard gelatinous membrane; thus it's unable to move by vibration.
2- The lower part, which is the Basilar membrane, is elastic and contains the hearing receptors/receptor cells.

Receptor cells -aka receptor neurons or hairy cells- have cilia that made them look like hairs, since their name "hairy cells" appear!

The two membranes (basilar and tectorial) including the receptor neurons/receptor cells all together are called **Organ of Corti**. You can see in picture (C) the arrangement of organ of corti; the hairy cells are on the basilar membrane and the tectorial membrane stands on the cilia of those hairy cells.

How the energy is transmitted from sound to action potential?

The sound causes a vibration in the tympanic membrane which results in the movement of the malleus, incus and stapes in the middle ear for amplification. Stapes pulls 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 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 action potential and neuronal signal!

Since we can change the sound signal to neuronal one by the ciliary movement, why we need to have the whole cochlea with its complexity?

To give specification for the sound; in other words, to be able to detect not only if there is a sound or not, but also to know (I) which sound I'm hearing right now, (II) if it's high or low, (III) from which side…etc.

REMEMBER: in somatosensory, we have different types of receptors to enable us to detect different sensations to identify the objects we touch (their temp, texture…). And by stimulating the receptor more, you will have a higher frequency of action potential which means stronger stimulus.

Furthermore, in smell we have chemical receptors, each one for a group of chemicals, and by combining between them along the pathway we can differentiate different smells.

The same idea is here, we want a system that enables us to detect different sounds!

HOW we can differentiate between different amplitudes, frequencies, and different locations of the voice?

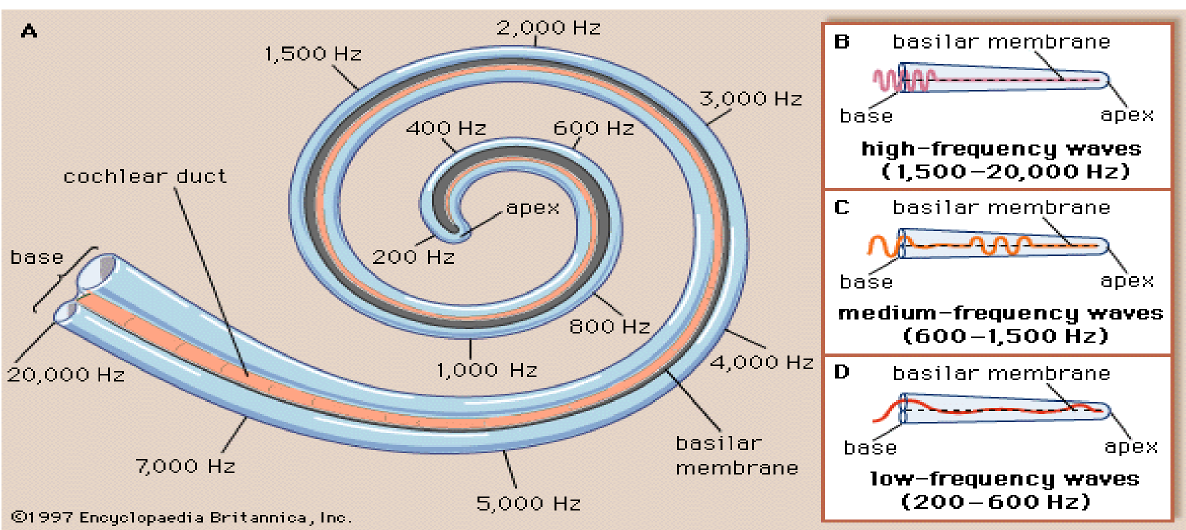
1- **Amplitude**

The higher amplitude means the wave is higher (you can check the picture on the 1st page) and vibrations are stronger; thus the basilar membrane will move to a higher level causing more bending of cilia on the hair cells. Consequently, more ion channels will open and the depolarization for the receptor potential will be higher and finally more frequency of action potential.

So, higher amplitude will lead to more frequency of action potential.

2- **Frequency**

The differentiation between a bird sound and a bulldozer, or between a high pitch letter "R" and a low pitch letter "B" is the function of cochlea and the basilar membrane inside it.



The base of the basilar membrane is **narrow** and attached near the oval and round windows, while its apex is **wide** and free (not attached). This characteristic along with the unique shape of cochlea determine which part of the basilar membrane will respond to a certain frequency. Low frequency waves will move the free end (apex), whereas high frequency waves will move the attached end (base).

So normally, **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**. With experience, activation of hair cells on site X will generate an action potential that means the sound I'm hearing has a frequency of 40 Hz, while activation of site Y means I'm hearing a 15 Hz-frequency sound. This organization of the basilar membrane is called **tonotopic organization**.

Normal person can distinguish frequencies from 20-20,000 Hz; this depends on the design of the cochlea and the basilar membrane as each part of the basilar membrane is designed to a specific frequency. However, this range might differ a little bit and reach 21 or 19 Hz instead of 20 Hz in some people. Furthermore, babies during development could have different shapes for cochlea; that's why they have different range of frequencies heard "but not that different".

**Note: different shapes of cochlea mean different frequencies range. This is clearly seen in animals and their ability to detect different sounds because their cochlea is different in shape.*

23:18

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 that voice because there isn't any part of the basilar membrane designed for this frequency, BUT this voice will lead to vibration in the tympanic membrane, movement of malleus; incus; and stapes, vibration of the fluid and finally the relief of those vibrations from the round window WITHOUT any movement in the basilar membrane.

The frequency of the sound determines which part of the basilar membrane will be activated and the amplitude determines the degree of ciliary bending. Keeping in mind that the site of activation is the type of the sound (bird or bulldozer) while the degree of bending is the intensity of the sound (high or low). For example, let's assume that the frequency of the letter R is 15 KHz, if you hear it from a close distance to its source, it will activate site X with 70% bending of the cilia, but if you hear it from far away, it will activate the same site (site X) but with 20% bending of the cilia.

3- localization: will be discussed later in this sheet.

The auditory pathway:

The sound waves are transmitted through a medium, enter the external auditory meatus and lead to vibrations in the tympanic membrane, 3 bones of hearing and the perilymph in the cochlea. As the fluid moves, the basilar membrane with hairy cells on it will also move. This mechanical change of the cilia will open ion channels and lead to action potential in the hairy cells "receptor neurons". The axons of these hairy cells (which are found in the spiral organ of corti and considered the 1^{st} order neuron) will be collected together to transmit the information to CNS through cochlear nerve.

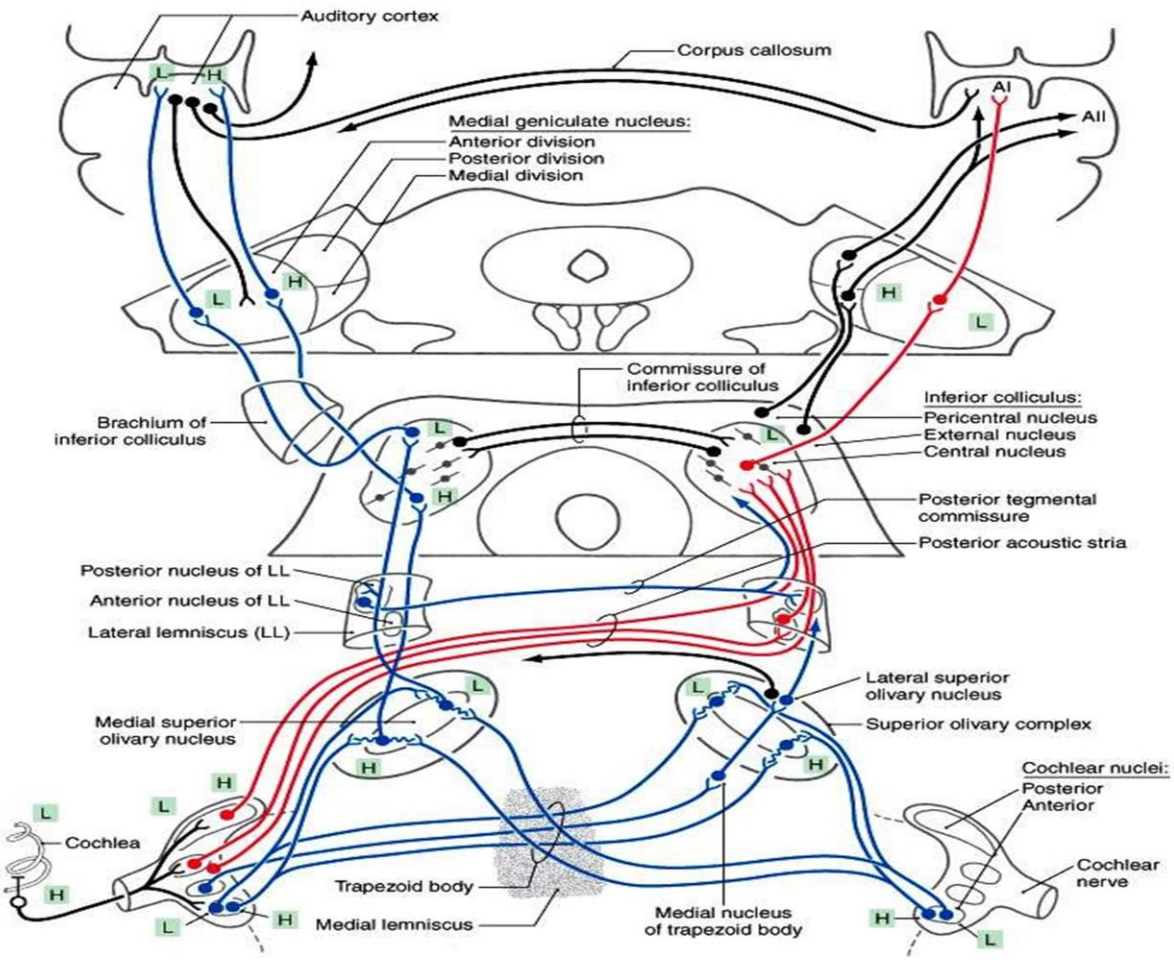
The fibers of the 1^{st} order neurons of the cochlear nerve enter the brainstem (upper part of medulla) directly; where they synapse with 2^{nd} order neurons in the cochlear nucleus.

The cochlear nucleus itself is arranged in a way that different frequencies will have different organizations there; the higher frequency will synapse inside "in the middle" of this nucleus, while the lower frequency will synapse outside "at the edges of this nucleus". This designation mainly preserves the labeled line principle and the ability of detecting different frequencies (the fibers of a specific group of hair cells should not converge together until their destinations).

Note: The cochlear nucleus is a complex of two nuclei; ventral/anterior one and dorsal/posterior one.

As we took earlier, for most fibers to reach the cortex they must pass through the thalamus. The auditory pathway is not an exception; the 2^{nd} order neurons from cochlear nucleus will synapse with a 3^{rd} order neuron in the **medial geniculate nucleus** in the thalamus. Then the 3^{rd} order neurons go to the **1ry auditory cortex** (area 41 and 42) in the temporal lobe of the cortex.
**Note:1ry auditory cortex is mainly 41, we'll talk about 42 later*

That was a general overview of the pathway. But as you can see there are two different pathways in the picture below and we'll discuss each one of them.



1- **<u>The monaural pathway</u>**

the 1st order neuron synapse with a 2nd order neuron in the dorsal cochlear nucleus, cross the midline and pass through inferior colliculi of the midbrain; where they synapse with other neuron which in turn will synapse again in the medial geniculate nucleus of the thalamus to reach the cortex.
<u>There aren't multiple stops in this pathway and the processing mechanisms are less,</u> **so** it has a great importance in preservation of the amplitude, time and order of the sound being heard. It specializes in transmitting high-resolution sounds.
Monaural pathway (monoaurical), as the name implies, receives information from one ear only; so the right ear will terminate in the left cortex and vice versa.

34:37

2- The bi-auricle pathway

It's opposite to the first pathway; it starts from the anterior cochlear nucleus and the fibers coming out from the nucleus will go to **both sides** of the cortex; the sound from the right cochlea will go to the right and left hemispheres of the cortex.

How these fibers reach the cortex?

Neurons from one side of **ventral cochlear nucleus** will go and synapse with both **superior olives** (right and left), then ascend up as **lateral lmeniscus** to synapse in the **inferior colliculi** of the midbrain. Finally from the **medial geniculate nucleus** in the thalamus fibers ascend up to the **1ry auditory cortex**.

Note: Superior Olives/ superior olivary complex is a group of nuclei in brainstem that have an important role in hearing and processing of the sound. They determine the command after a sensory input is received; if there is a need for a quick reflex or this info must be sent to the brain. they can be divided into two parts; medial (measures the time difference and the angle of the sound) and lateral (employs intensity to localize the sound).

Obviously there are many stops along this pathway so the resolution of the sound will be less but this pathway has an advantage in **localization of the sound**.

It's important for the brain to receive information from both ears to be able to detect the location of the sound. This is achieved by comparing the amplitude (in which ear it was higher) and the time (which ear delivered the sound faster). Then we can know from which side the sound is coming.

So, to determine the location of the sound we must compare the differences in inputs from both ears.
Difference in input includes two factors: (A) difference in delivery time, and (B) difference in amplitude.

Clinical cases

1- If the left ear or left cochlear nerve or left cochlear nucleus was injured, the patient will completely lose hearing on the left side. This patient will be able to hear from his right ear and both sides of the cortex will be activated.

2- If the left medial geniculate was injured, the right medial geniculate will compensate and this patient will hear from both ears.

*Any damage before the superior olive "from outside", the hearing will be lost on the side of damage. But if the injury is at or after the level of the superior olive, both ears will be able to detect sounds.

* In the 2nd case, where the injury is in or after the superior olive, there will be a loss of some aspects of discrimination of the sound or the localization "but not that significant"

*In any damage, the localization will be affected a little bit.

*Localization will be mostly affected if the injury is in the superior olives (they are the parts responsible for measuring the differences in input) or before.

*Medial geniculate nucleus injuries will affect the resolution on the contralateral ear not the localization. (It doesn’t have a significant role in localization)

*We'll talk about the sides of the cortex activated when we reach the cortex.

Auditory Reflexes:

- **Middle ear reflex (important)**

  Involuntary contraction of the middle ear muscles (extensor tympani; innervated by trigeminal and Stapedius; innervated by facial nerve) as a result of reflexes that activate facial and trigeminal nerves. This contraction tenses the tympanic membrane and cause sounds desensitization. "The same sound will lead to less vibrations than before, thus you won't hear it as loud as before"

  If you were in a party and you heard high intensity sound (loud), the auditory system will try to protect itself. At the beginning of hearing that sound you will feel some pain, but after a while, desensitization for the sound occurs.

- **Acoustic startle reflex**

  Involuntary response -carried by tectospinal tract- towards a sudden high sound, which makes you unconsciously look at the location of the sound.

  “ Remember when the doctor broke the table trying to illustrate this concept ;)”

  When there is a sudden sound from X side, afferent fibers from cochlea reach the inferior colliculi, which then go to the superior colliculi. And finally, through the tectospinal tract you will turn your vision to that side.

***Tectospinal tract is responsible for sudden visual or auditory stimuli and changing them to movement*
***Tectospinal tract either starts from superior colliculi in tectum (for vision) or from inferior colliculi (for auditory).*

“You don’t drown by falling in the water, you drown by staying there.”

Good luck *_*