بسم الله الرحمن الرحيم

Hearing

MID | Lecture 8

﴿إِنِّي تَوَكَّلْتُ عَلَى اللَّهِ رَبِّي وَرَبِّكُم ۚ مَّا مِن دَابَّةٍ إِلَّا هُوَ آخِذٌ بِنَاصِيَتِهَا ۚ إِنَّ رَبِّي عَلَىٰ صِرَاطٍ مُّسْتَقِيمٍ﴾

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PHYSIOLOGY

رحلة اليقين مع سورة يس

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

سُبۡحَٰنَ ٱلَّذِي خَلَقَ ٱلۡأَزۡوَٰجَ كُلَّهَا مِمَّا تُنۢبِتُ ٱلۡأَرۡضُ وَمِنۡ أَنفُسِهِمۡ وَمِمَّا لَا يَعۡلَمُونَ (٣٦)

{ سُبْحَانَ الَّذِي خَلَقَ الْأَزْوَاجَ كُلَّهَا } أي: الأصناف كلها، { مِمَّا تُنْبِتُ الْأَرْضُ } فنوع فيها من الأصناف ما يعسر تعداده. { وَمِنْ أَنْفُسِهِمْ } فنوعهم إلى ذكر وأنثى، وفاوت بين خلقهم وخُلُقِهِمْ، وأوصافهم الظاهرة والباطنة. { وَمِمَّا لَا يَعْلَمُونَ } من المخلوقات التي قد خلقت وغابت عن علمنا، والتي لم تخلق بعد، فسبحانه وتعالى أن يكون له شريك، أو ظهير، أو عوين، أو وزير، أو صاحبة، أو ولد، أو سَمِيٌّ، أو شبيه، أو مثيل في صفات كماله ونعوت جلاله، أو يعجزه شيء يريده.

بسم الله

Neurophysiology

Hearing

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Sound waves

- Sound waves (longitudinal waves) are alternating high- and low-pressure regions traveling in the same direction through a medium. They originate from a vibrating object.

- The higher the **frequency** of vibration (Hz), the higher is the pitch (tone).

Sound waves

- The larger the **intensity (or amplitude**) of the vibration, the louder is the sound. Sound intensity is measured in decibels (dB).

- An increase of one decibel represents a tenfold increase in sound intensity.

Sound waves

- The human ear is sensitive to tones with frequencies between 20 and 20,000 Hz (a cycle/sec) and is most sensitive between 2000 and 5000 Hz.

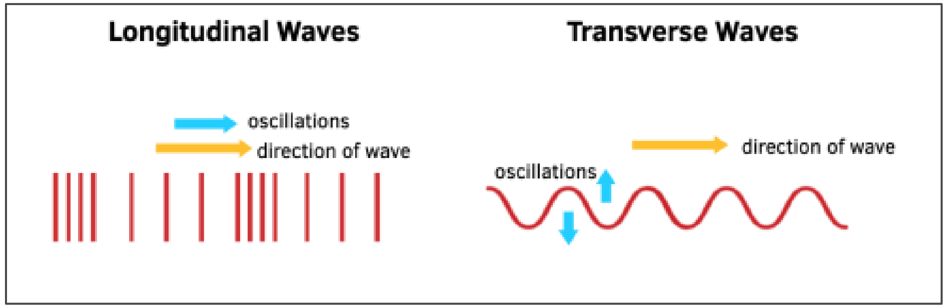
- The usual range of frequencies in human speech is between 300 and 3500 Hz, and the sound intensity is about 65 dB.

- Sound intensities greater than 100 dB can damage the auditory apparatus, and those greater than 120 dB can cause pain (see next slide)

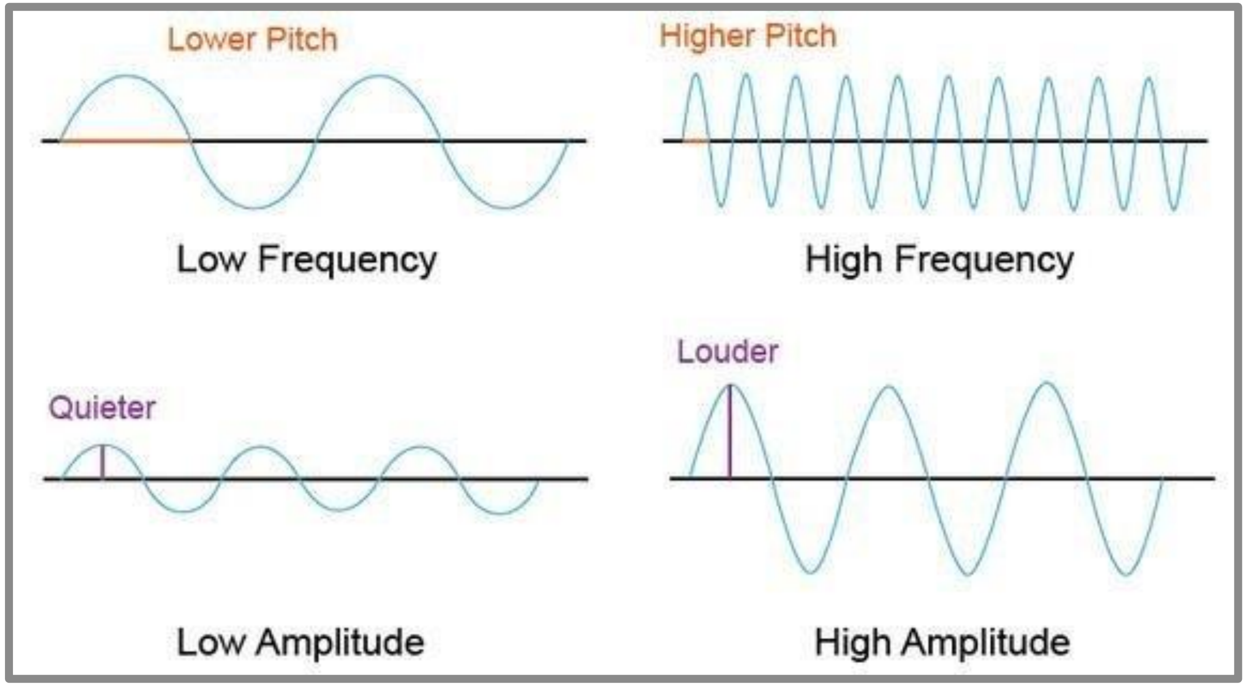
Frequency & amplitude

- Different **frequencies** produce different **pitches/tones.**
- At the same frequency, changing the **amplitude** will change the **intensity** which is perceived as **loudness.**

- The typical human hearing ranges between (0-100) dB:
  - The faintest sound intensity detectable by the average human ear is zero dB.
  - Greater than 100 dB is loud & noisy so that it produces intense stimulation of cochlear hair cells causing **discomfort.**
  - Greater than 120 dB will cause **pain** (due to damage in the hair cells that is detectable by nociceptors in the middle or inner ear).



Sound waves are longitudinal waves but for simplicity & visualization, they're often represented as transverse waves to illustrate amplitude & frequency

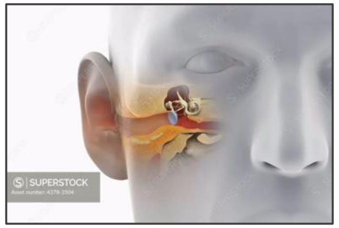


Frequency & amplitude

Sound	Loudness in Decibels (dB)	Comparison to Faintest Audible Sound (Hearing Threshold)
Rustle of leaves	10 dB	10 times louder
Ticking of watch	20 dB	100 times louder
Whispering	30 dB	1 thousand times louder
Normal conversation	60 dB	1 million times louder
Food blender, lawn mower, hair dryer	90 dB	1 billion times louder
Loud rock concert, ambulance siren	120 dB	1 trillion times louder
Takeoff of jet plane	150 dB	1 quadrillion times louder

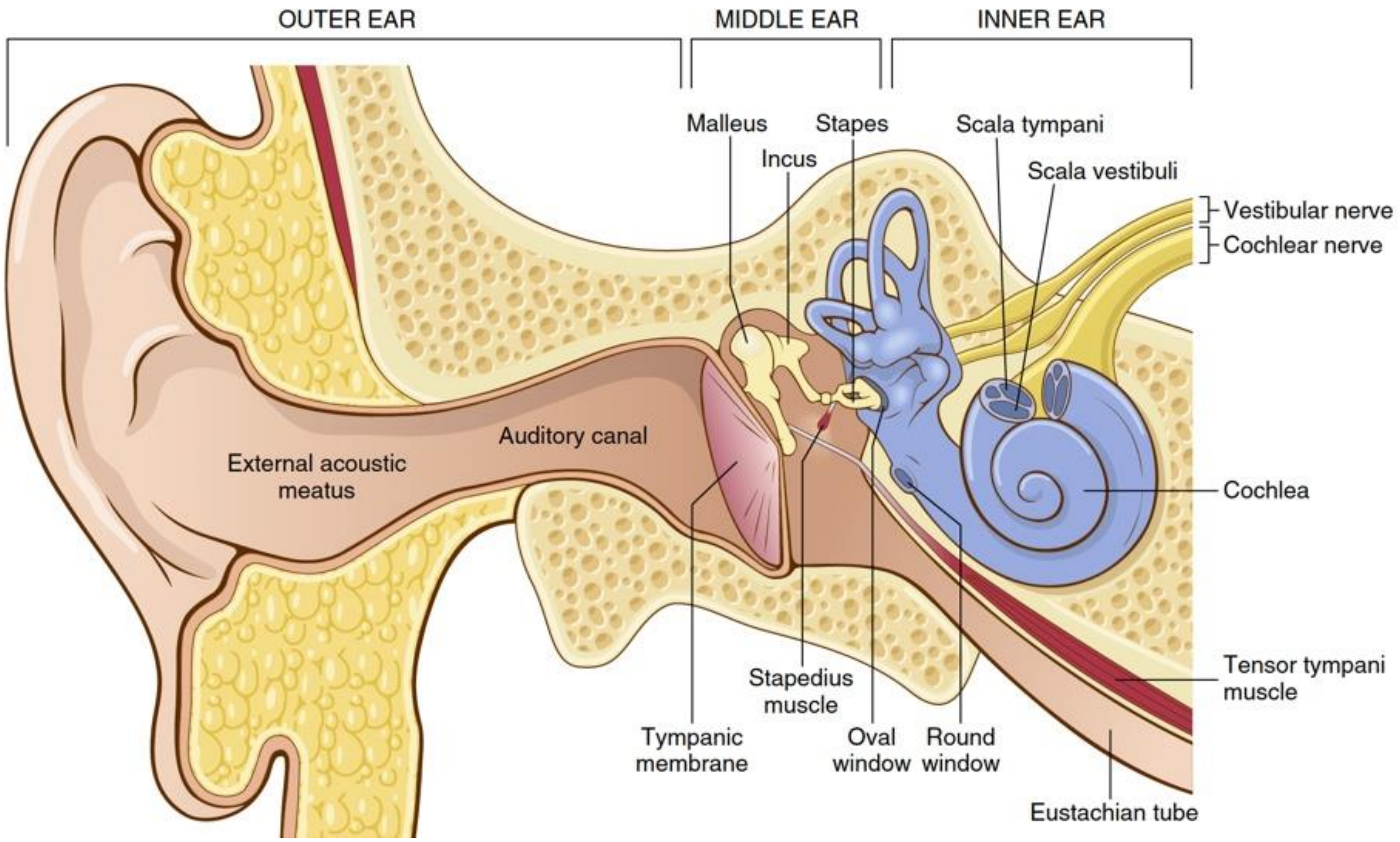
Hearing

- Hearing is the ability to perceive sounds.



- The ear is divided into three main regions:
- (1) the external ear, which collects sound waves and channels them inward.
- (2) the middle ear, which conveys sound vibrations to the oval window.
- (3) the internal ear, which houses the receptors for hearing and equilibrium.

Structure of the ear



Details in the next slides

Structure of the ear

- The ear is located within specialized bony structure in the skull which is the petrous portion of temporal bone & it is divided into;

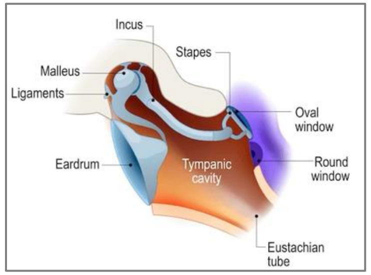
- **External ear** which is composed of;

- **Cartilaginous part called pinna** which functions in;

1. Collecting sound waves & transmitting them.
2. Localizing sounds (to know where sounds come from).

- **External acoustic/auditory canal** that has S-shape (not straight) to protect the tympanic membrane.

- **Middle ear;**



- It is separated from the external ear & inner ear by membranes;

1. It's separated from the external ear by the **tympanic membrane/eardrum.**
2. It's separated from the inner ear by the **oval window & round window.**

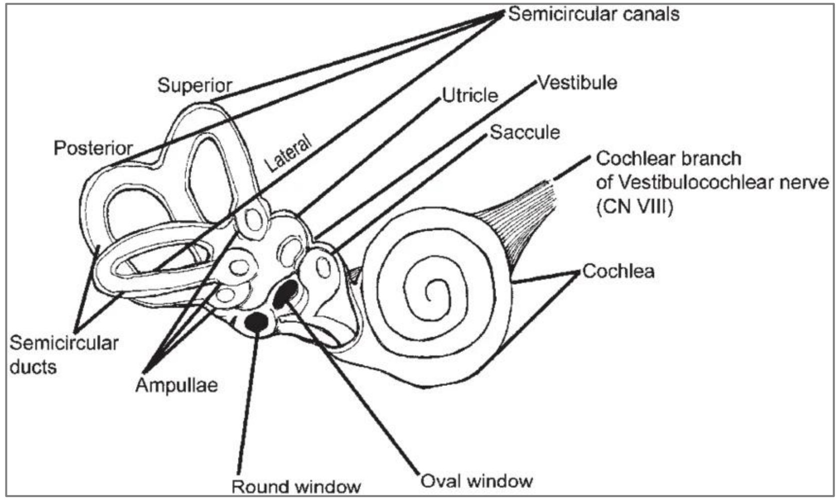
- **Two muscles; tensor tympani & stapedius muscle** (more details slides 18-21).
- **Bony structures (malleus, incus & stapes)**; which are the smallest bones in our body, they are attached to ligaments, to the tympanic membrane on one side & to the oval window on the other side.
- **Eustachian tube** for communication between the middle ear & the pharynx to equalize the pressure in the middle ear with the pressure in the external ear allowing the tympanic membrane to move freely (see the next slide).

Structure of the ear - con.

استغفر الله العظيم وأتوب إليه

❑ **Clinical relevance of the eustachian tube in pressure regulation & infections;**

- **Pressure regulation;** In areas of pressure differences (Dead Sea, planes….), the pressure in the external ear doesn't equal the pressure in the middle ear leading to discomfort, this can be minimized by mechanisms that open the eustachian tube (e.g.; chewing, swallowing, talking…) this will allow more air entry to the middle ear equalizing the pressure.
- **URT infections;** can cause inflammation & edema of the eustachian tube leading to its obstruction. This results in the accumulation of fluids & cellular secretions in the middle ear which impairs sound conduction & affects the hearing process.



○ **Inner ear** which is composed of two continuous components; bony labyrinth & membranous labyrinth (more in slide 24). Functionally it consists of;

- **Cochlea** is responsible for hearing & transmits auditory signals through the cochlear branch of the vestibulocochlear nerve.
- **Vestibular apparatus** responsible for balance & it's composed of two sac-like structures (urticle & saccule) & three semicircular canals. It detects changes in head position & movement, then transmits signals through the vestibular branch of the vestibulocochlear nerve.

Middle ear

- The middle ear is a small, air-filled cavity in the petrous portion of the temporal bone. It is separated from the external ear by the tympanic membrane and from the internal ear by a thin bony partition that contains two small openings: the oval window and the round window.

- Extending across the middle ear and attached to it by ligaments are the three smallest bones in the body, the auditory ossicles. The bones are the malleus, incus, and stapes.

Auditory transduction

- The external and middle ears are air filled, and the inner ear, which contains the organ of Corti, is fluid filled.
- Note that sound is easier conducted in air than in fluid.

- Thus before transduction can occur, sound waves traveling through air must be converted into pressure waves in fluid, the sound pressure should be amplified before it reaches the inner ear fluid to overcome the impedance between air & the inner ear fluid.

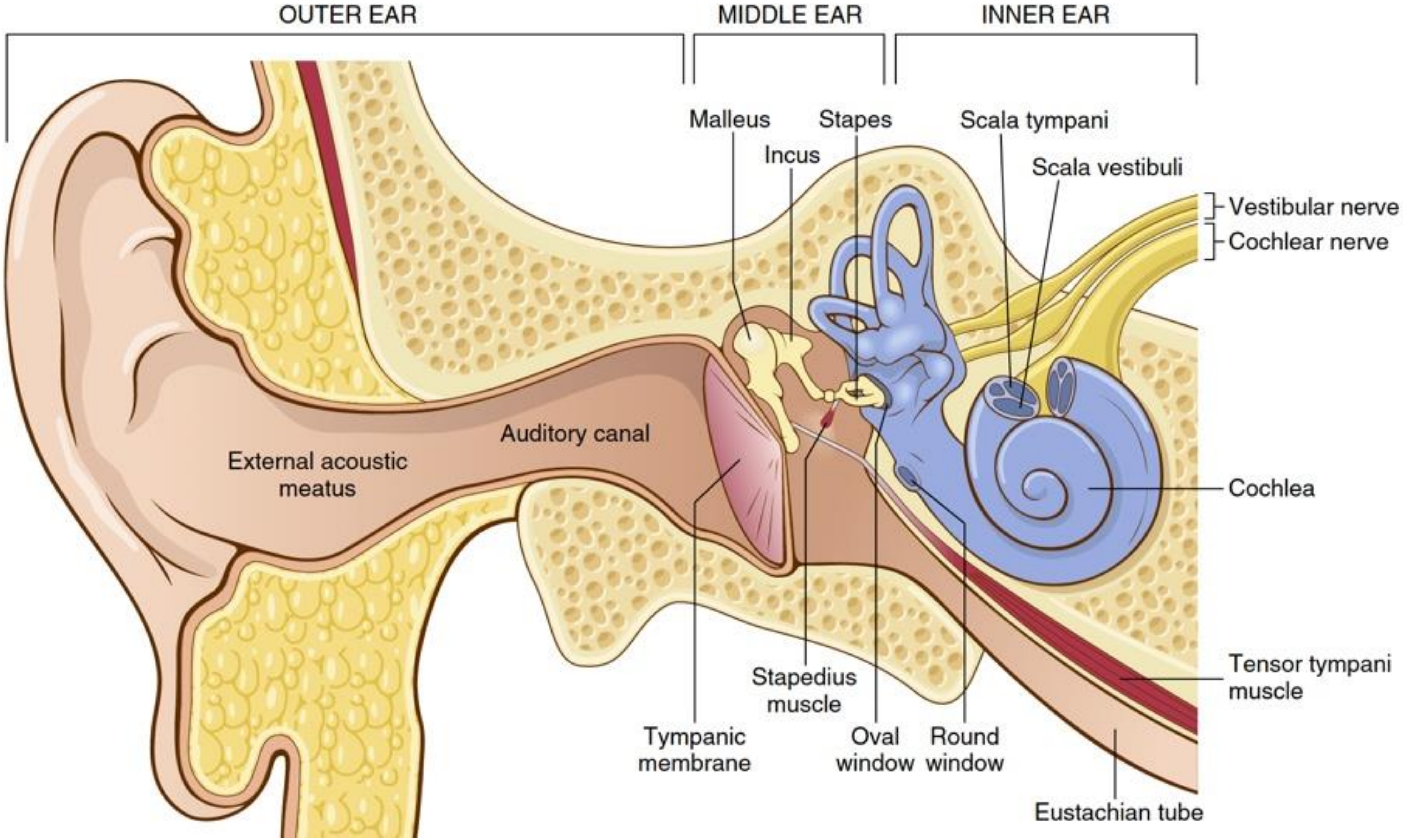
- The acoustic impedance of fluid is much greater than that of air.
- The combination of the tympanic membrane and the ossicles serves as an **impedance-matching device** that makes this conversion.

اللهم صلِّ على محمد وعلى آل
محمد كما صلّيت على إبراهيم
وعلى آل إبراهيم إنّك حميد مجيد

Impedance Matching & pressure amplification

- The receptor cells are located in the inner ear (cochlea). Therefore, the external & middle ear are mainly responsible for **conducting** sound waves to the cochlea. This **conduction isn't passive**, as both structures play other important roles in sound transmission.
- The sound waves pass through two different media in the ear; air in the external & middle ear, and fluid in the inner ear. If the conduction were purely passive, most of the sound energy would be dissipated when waves reach the fluid medium in the inner ear resulting in insufficient stimulation of the the receptors.
- The middle ear mainly functions in impedance matching to enhance sound transmission. Amplification is achieved through:
  - The lever system of the middle ear ossicles (bony structures).
  - The difference in surface area between the tympanic membrane (larger "a") & the oval window. According to the formula P = F / A → a decrease in the area (such in the oval window) increases the pressure, which amplifies the sound energy reaching the inner ear.

Impedance matching: reducing the loss of sound energy when sound waves pass from air to fluid, middle ear transforms sound vibrations from **air (low impedance/resistance)** into vibrations in the **cochlear fluid (high impedance/resistance)** efficiently.


OUTER EAR
MIDDLE EAR
INNER EAR
Malleus
Stapes
Incus
Scala tympani
Scala vestibuli
Vestibular nerve
Cochlear nerve
Auditory canal
External acoustic meatus
Cochlea
Stapedius muscle
Tympanic membrane
Oval window
Round window
Tensor tympani muscle
Eustachian tube

اللهم بارك على محمد وعلى آل
محمد كما باركت على إبراهيم
وعلى آل إبراهيم إنّك حميد مجيد

Middle ear

- Besides the ligaments, two tiny skeletal muscles also attach to the ossicles.
- The **tensor tympani muscle** which is attached to the tympanic membrane, & it is supplied by the mandibular branch of the trigeminal (V) nerve, limits movement and increases tension on the eardrum, so it cannot move freely, to prevent damage to the inner ear receptor cells from loud noises
- This tension allows sound vibrations on any portion of the tympanic membrane to be transmitted to the ossicles.
- The **stapedius muscle** which is attached to the stapes & is supplied by the facial (VII) nerve, is the smallest skeletal muscle in the human body. By dampening large vibrations of the stapes due to loud noises, it protects the oval window by increasing the tension on this membrane so its vibration is reduced in response to high-intensity sounds.

Acoustic (attenuation) reflex

- It's a Protective mechanism performed by the stapedius & tensor tympani muscles. These muscles contract in response to loud sounds to reduce the transmission of vibration to the inner ear;
  - The stapedius muscle decreases vibration transmission at the stapes-oval window interface.
  - The tensor tympani muscle decreases vibration transmission at the tympanic membrane.
- This reflex is beneficial during **continuous loud noises,** but it's not effective against sudden loud noises like explosions or sudden bomb blasts because the reflex cannot be activated fast enough.
- **Neural pathway** includes;
  - **Afferent limb:** Cochlear nerve → Cochlear nucleus → Superior olivary complex (for integration).
  - **Efferent limb:** (a) Facial nerve (CN VII) → Stapedius muscle **&** (b) Trigeminal nerve (CN V) → Tensor tympani muscle.

The activation of these muscles stiffens the ossicular chain & reduces sound transmission to the inner ear.

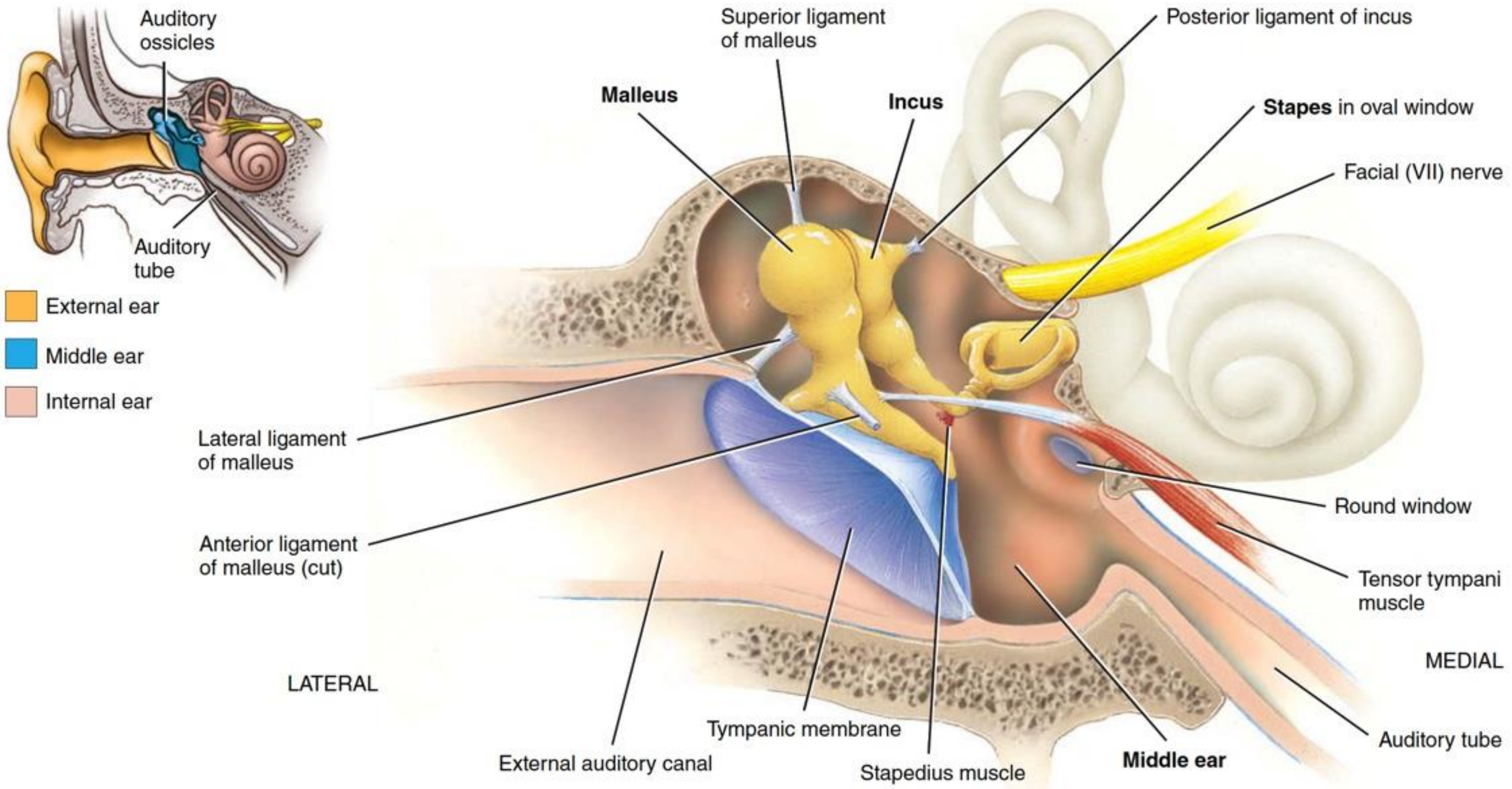
- **Practical Application;** In military systems, a pre-burst sound is sometimes used to activate the acoustic reflex before exposure to a high-intensity explosive sound. This pre-activation protects the inner ear.
- The stapedius muscle also contributes to the **attenuation of internal self-generated sounds** such as talking, chewing & swallowing.

Middle ear

- When loud sounds are transmitted through the ossicular system and from there into the central nervous system, a reflex occurs after a latent period of only 40 to 80 milliseconds to cause contraction of the stapedius muscle and, to a lesser extent, the tensor tympani muscle.
- The tensor tympani muscle pulls the handle of the malleus inward while the stapedius muscle pulls the stapes outward.
- These two forces cause the entire ossicular system to develop increased rigidity.

Attenuation reflex

- This reflex can reduce the intensity of lower frequency sound transmission by 30 to 40 decibels, which is about the same difference as that between a loud voice and a whisper.
- The function of this mechanism is:
- 1.to protect the cochlea from damaging vibrations caused by excessively loud sound and to mask low-frequency sounds in loud environments, and allows a person to concentrate on sounds above 1000 cycles/sec, where most of the pertinent information in voice communication is transmitted.
- 2.to decrease a person's hearing sensitivity to his or her own speech.

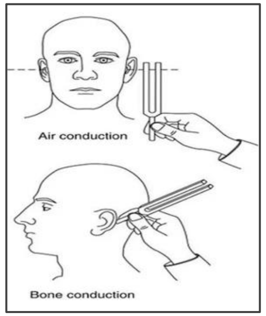

Auditory ossicles
Auditory tube
External ear
Middle ear
Internal ear
Superior ligament of malleus
Malleus
Incus
Posterior ligament of incus
Stapes in oval window
Facial (VII) nerve
Lateral ligament of malleus
Anterior ligament of malleus (cut)
Round window
Tensor tympani muscle
MEDIAL
LATERAL
Auditory tube
Tympanic membrane
External auditory canal
Stapedius muscle
Middle ear

سبحان الله وبحمده عدد خلقه ورضا
نفسه وزنة عرشه ومداد كلماته

Bone conductance

- Because the inner ear, the cochlea, is embedded in a bony cavity in the temporal bone, called the bony labyrinth, vibrations of the entire skull can cause fluid vibrations in the cochlea.

- Therefore, under appropriate conditions, a tuning fork or an electronic vibrator placed on any bony protuberance of the skull, but especially on the mastoid process near the ear, causes the person to hear the sound → **Rinne test.**



Inner ear

- The inner ear is also called the labyrinth. Structurally, it consists of two main divisions: an outer bony labyrinth that encloses an inner membranous labyrinth.

- The **bony labyrinth** is a series of cavities in the petrous portion of the temporal bone divided into three areas: (1) the semicircular canals, (2) the vestibule, and (3) the cochlea.

- The **membranous labyrinth**, a series of epithelial sacs and tubes inside the bony labyrinth that have the same general form as the bony labyrinth and house the receptors for hearing and equilibrium.

Inner ear

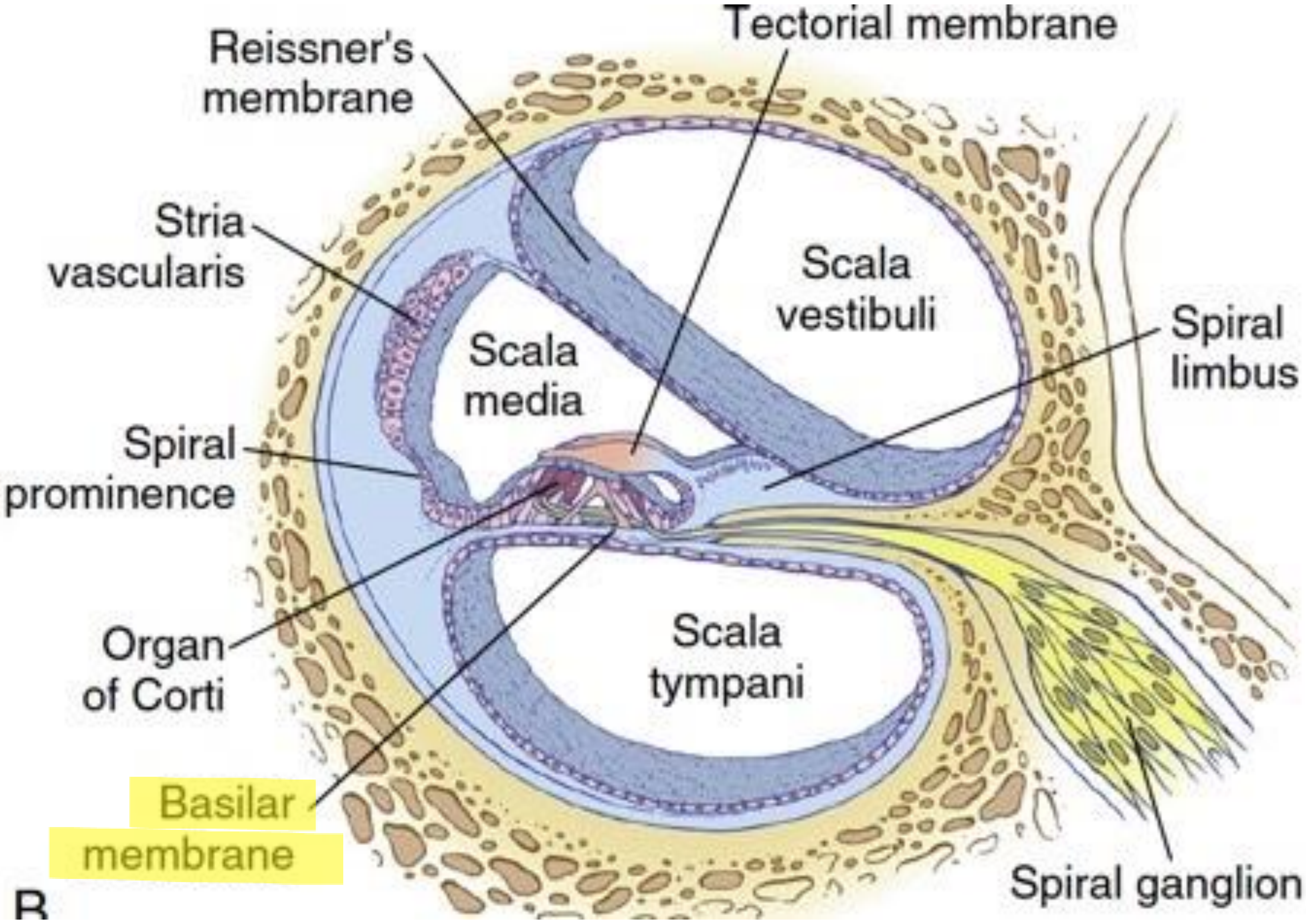
The cochlea can be imagined as a coiled structure similar to a snail shell. If it is uncoiled and straightened, it appears as two tubes positioned one inside the other, similar to two balloons placed concentrically. The inner tube is enclosed within a larger outer tube.

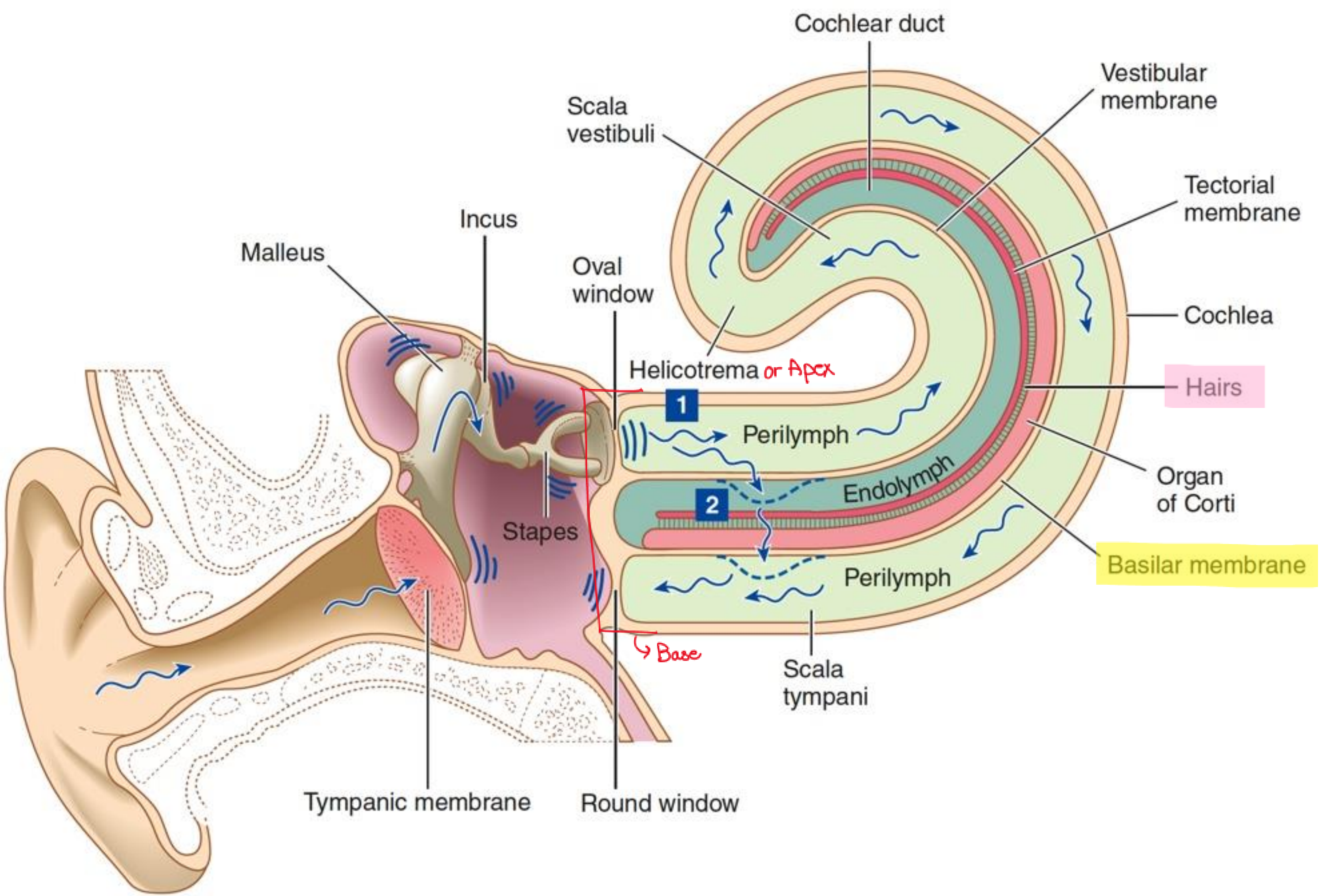
Perilymph fills the outer space and is **sodium-rich** (scala vestibuli + scala tympani) like typical extracellular fluid. **Endolymph** fills the inner tube (scala media) and is **potassium-rich**, making it **unique** among extracellular fluids. This difference in sodium and potassium concentrations is essential for normal hearing.

The cochlea contains three fluid-filled chambers known as scalae:

1. The upper chamber is called the scala vestibuli. This chamber receives vibrations from the oval window. Beneath it lies a very thin membrane called the vestibular membrane (Reissner's membrane).
2. The lower chamber is called the scala tympani.
3. Between the scala vestibuli and scala tympani lies the middle chamber, known as the scala media.

- The sensory receptor cells (hair cells) and endolymph are located within the scala media. **Receptors rest on the basilar membrane, which forms the base that supports them.** The basilar membrane separates the scala media from the scala tympani.


Reissner's membrane
Tectorial membrane
Stria vascularis
Scala vestibuli
Scala media
Spiral limbus
Spiral prominence
Organ of Corti
Scala tympani
Basilar membrane
Spiral ganglion
B


Cochlear duct
Vestibular membrane
Scala vestibuli
Tectorial membrane
Incus
Malleus
Oval window
Cochlea
Helicotrema or Apex
Hairs
1
Perilymph
Endolymph
2
Organ of Corti
Stapes
Basilar membrane
Perilymph
Base
Scala tympani
Tympanic membrane
Round window

Inner ear

- The **cochlea**, which is a spiral-shaped structure composed of three tubular canals or ducts, contains the organ of Corti.
- The **organ of Corti contains the receptor cells** and is the site of auditory transduction.
- The inner ear is **fluid filled**, and the fluid in each duct has a different composition.

Inner ear

- The fluid in the scala vestibuli and scala tympani is called **perilymph**, which is similar to extracellular fluid (CSF).
- The fluid in the scala media is called **endolymph**, which has a high potassium (K+) concentration.
- Thus endolymph is unusual in that its composition is similar to that of intracellular fluid, even though, technically, it is extracellular fluid.

Inner ear

- The lengths of the basilar fibers increase progressively, beginning at the oval window and going from the base of the cochlea to the apex.

- The diameter of the fibers, however, decrease from the oval window to the helicotrema, so their overall stiffness decreases more than 100-fold.

- As a result, the stiff, short fibers near the oval window of the cochlea vibrate best at a very high frequency, whereas the long, limber fibers near the tip of the cochlea vibrate best at a low frequency.

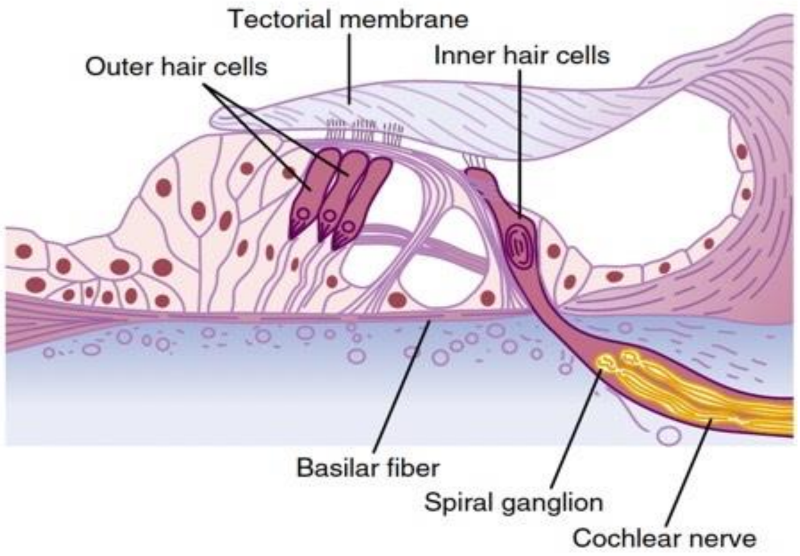
Mechanism of hearing/sound wave transmission:

1. (Air → external ear → tympanic membrane →Ossicles, stapes→oval window):
Sound waves enter the external ear and travel through the ear canal until they reach the **tympanic membrane**. The tympanic membrane vibrates, and this mechanical vibration is transmitted through the **ossicles**. The **stapes** then moves at the **oval window**.

2.(Oval Window → scala vestibuli →vestibular membrane →scala media→basilar membrane→ hair cells):
When the stapes pushes on the oval window, the mechanical vibration is transferred into the cochlear fluid. At this stage, vibration becomes a pressure wave inside fluid, and the pressure wave travels through the perilymph and **pushes** on the thin and flexible **vestibular membrane,** displacing the **endolymph** in the scala media. The movement of endolymph then causes displacement of the basilar membrane.**The basilar membrane supports the sensory receptor cells for hearing, known as hair cells. When the basilar membrane moves upward or downward, the hair cells move with it.**

3. Movement of the basilar membrane causes **bending** of the stereocilia against the **tectorial membrane**, converting mechanical energy into an electrical signal. **Inner** hair cells transmit this signal to the cochlear nerve (= signal transduction), outer hair cells fine-tune basilar membrane movement, **and the remaining pressure waves are dissipated at the round window** within scala tympani, allowing the system to reset and receive new sound vibrations -Details of this point will be discussed in the upcoming slides-

Mechanism of hearing/sound wave transmission:



- Above the hair cells lies a stiff structure called the **tectorial membrane.** Because the tectorial membrane does **not** move as freely as the basilar membrane, movement of the basilar membrane causes bending of the **stereocilia** on the hair cells. **This bending is the key step in mechanical-to-electrical transduction.**

- There are two types of hair cells:

1) **Inner hair cells** are responsible for signal transduction and are connected to the **cochlear branch of the vestibulocochlear nerve.**

2) **Outer hair cells** are arranged in three rows for each single row of inner hair cells. Their exact function is not fully understood but aren't primarily responsible for transmitting the signal but have a property called **electromotility**, so they can change length in response to stimulation, which helps in improving the process of hearing. (The doctor said not to worry about outer hair cells' function).

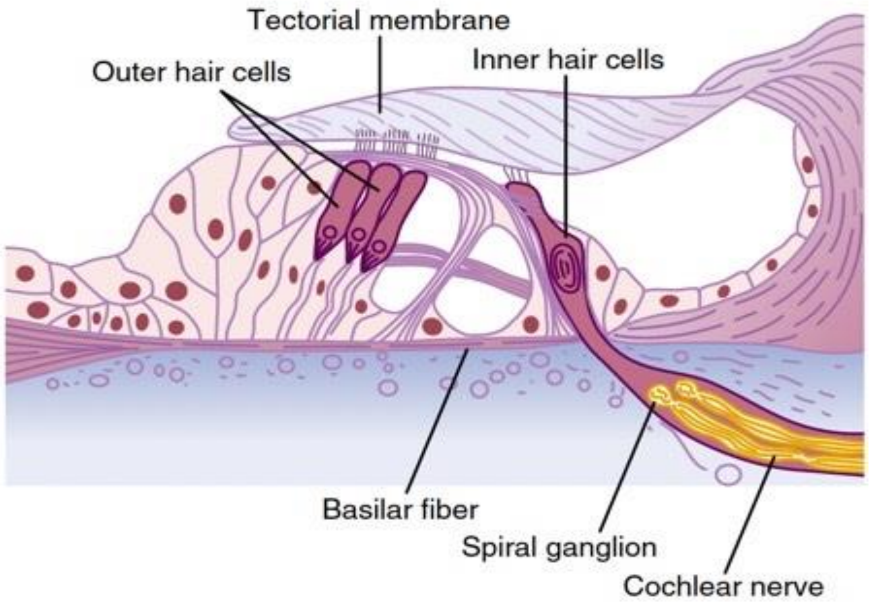
- **Note: The hair cells, along with the basilar membrane and tectorial membrane, form the Organ of Corti**

Organ of Corti

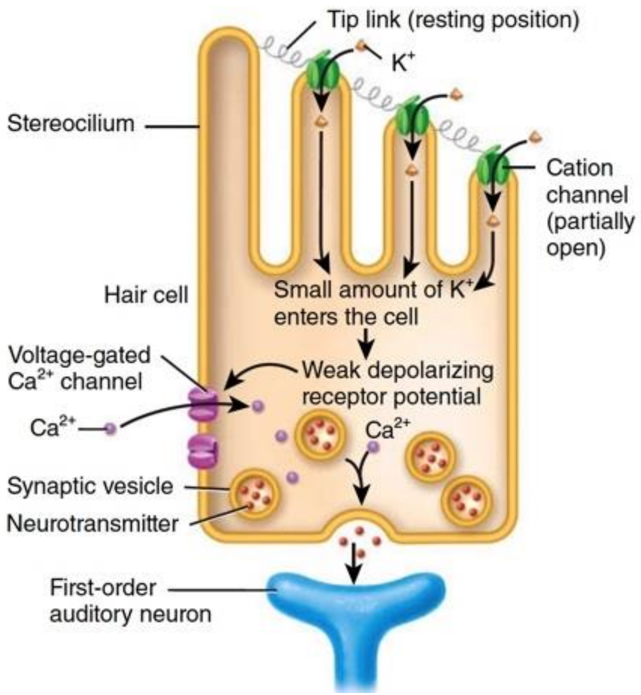
- The organ of Corti lies on the basilar membrane of the cochlea and is bathed in the endolymph contained in the scala media.
- Auditory hair cells in the organ of Corti are the sites of auditory transduction.
- The organ of Corti contains two types of receptor cells: **inner hair cells and outer hair cells.**
- There are fewer inner hair cells, which are arranged in single rows. Outer hair cells are arranged in parallel rows and are more numerous.

Organ of Corti

- Cilia, protruding from the hair cells, are touching/embedded in the tectorial membrane.
- Thus the bodies of the hair cells are in contact with the basilar membrane, and the cilia of the hair cells are in contact with the tectorial membrane.
- The nerves that serve the organ of Corti are contained in the vestibulocochlear nerve (CN VIII). The cell bodies of these nerves are located in spiral ganglia, and their axons synapse at the base of the hair cells.



Mechanism of sound transduction:



- Structure of hair cells:
Hair cells in the organ of Corti have **stereocilia** on their apical surface. These stereocilia are arranged in rows of gradually increasing length, with the tallest one called the **kinocilium**. **This orderly difference in length is very important for the process of mechanotransduction.**

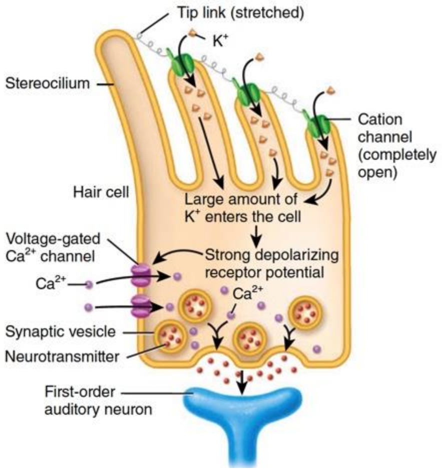
- Between each shorter stereocilium and the adjacent taller one, there are **tip-linked proteins** that connect to mechanically gated cation channels. These tip links act like springs and control the opening of the channels when the stereocilia move.

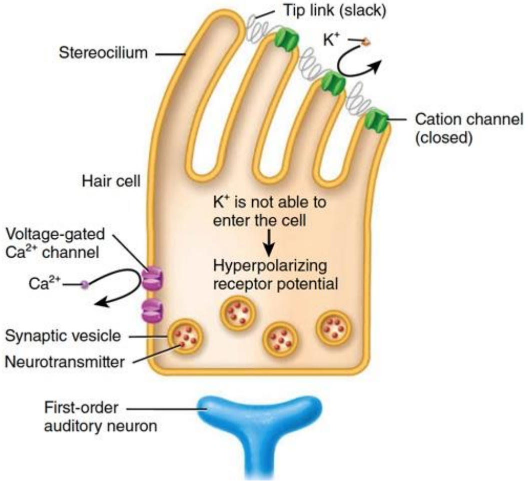
- In resting state (no sound waves), the **cation** channels are **partially** open. This allows **potassium** (K^+), which is abundant in the endolymph, to enter the hair cell. The influx of potassium causes **partial depolarization** of the cell membrane. This depolarization **opens voltage gated calcium channels,** allowing calcium to enter. Calcium triggers **exocytosis** of vesicles containing neurotransmitters (**glutamate**),which stimulate the first-order auditory neuron.

- As a result, the first-order neuron **generates AP at a certain baseline frequency**, even in the absence of sound. These action potentials travel along the auditory pathway until they reach the **auditory cortex,** and because the firing rate remains at this baseline level when no sound is present, the cortex interprets this steady activity as silence.

Mechanism of sound transduction:

The stereocilia can bend in one of two directions: either toward the longest stereocilium (toward the kinocilium) or away from it:

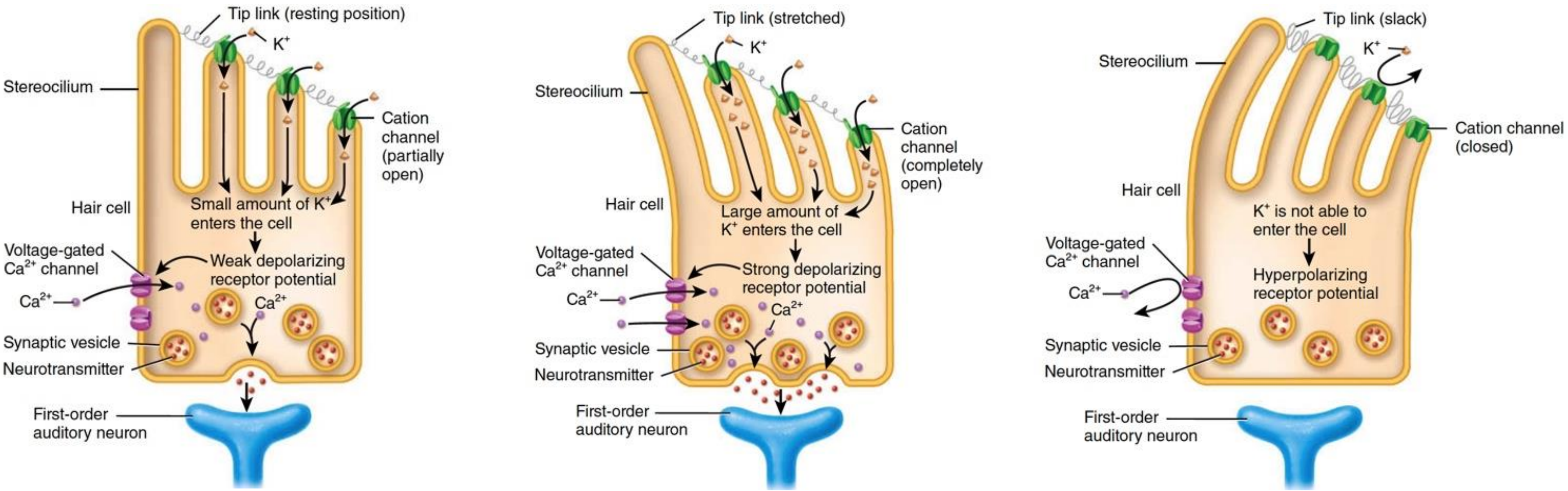




- If the stereocilia bend **toward** the kinocilium, the tip-link proteins become stretched and pull mechanically gated ion channels until they **fully open**. As a result, there's an **increased influx** of potassium ions (K^+) into the hair cell from the endolymph.
- The entry of potassium makes the inside of the hair cell more positive, causing a **strong depolarization** of the membrane , which **opens voltage gated calcium channels** at the base of the cell, leading to increased release of **glutamate** onto the auditory nerve fibers. Consequently, the auditory nerve fires action potentials at a **higher frequency**, which the brain interprets as a **stronger sound.**

- If the stereocilia bend **away** from the kinocilium, the tip links relax and the mechanically gated channels **close more than they are at rest**. Potassium influx **decreases** below the resting level. As a result, the membrane becomes **more negative than its resting state (hyperpolarization).**
- Because **less** calcium enters the cell, **glutamate** release **decreases**, and the auditory nerve fires at **a lower frequency than baseline** and brain interprets this decrease from baseline as **reduced sound intensity.**

Mechanism of sound transduction:



Encoding of frequency **(tone)**

- Encoding of sound frequencies occurs because different auditory hair cells are activated by different frequencies.
- The frequency that activates a particular hair cell depends on the position of that hair cell along the basilar membrane.
- The base of the basilar membrane is nearest the stapes and is narrow and stiff. Hair cells located at the base respond best to high frequencies.

- Frequency is determined by the location of maximal vibration (tonotopic organization).

- High frequency sound→ Vibrates base → Signal sent from base region→ Cortex identifies location→ Interpreted as high pitch

- Medium frequency→ Middle region activated

- Low frequency sound→ Vibrates apex → Signal sent from apex region→ Cortex identifies location→ Interpreted as low pitch

"لا إله إلّا أنت سبحانك
إنّي كنت من الظالمين"

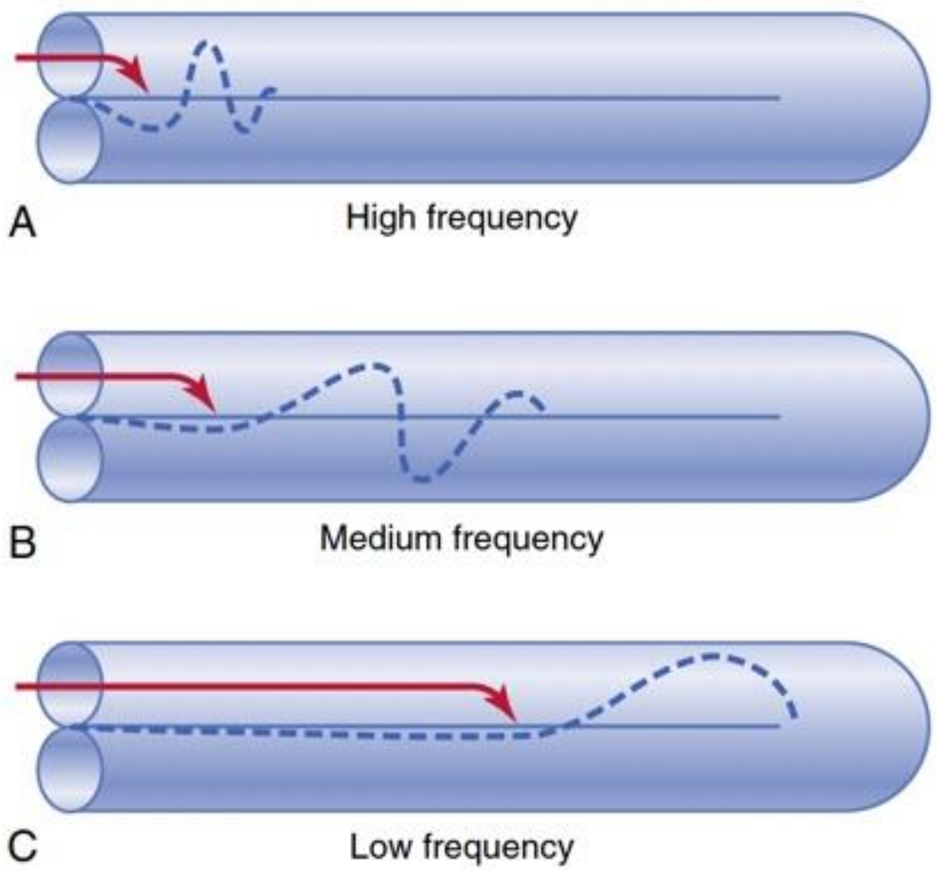
Encoding of frequency

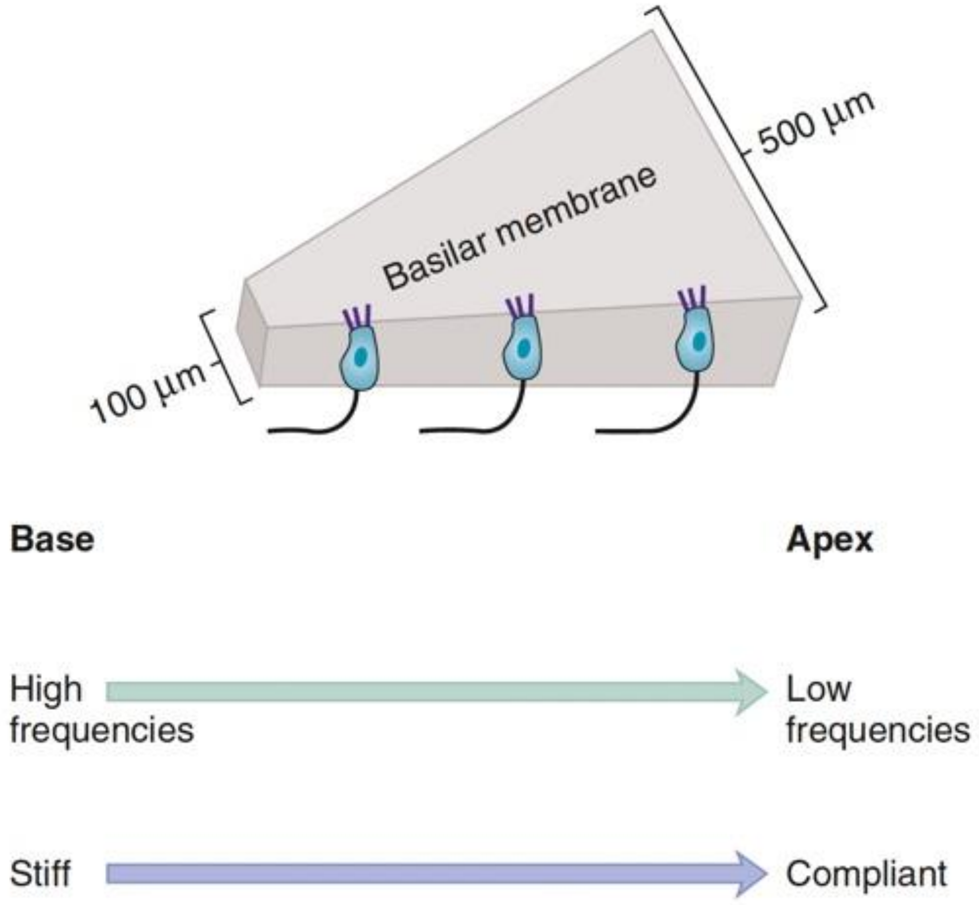
- The **apex of the basilar membrane is wide and compliant**. Hair cells located at the apex respond best to low frequencies.

- Thus the **basilar membrane acts as a sound frequency analyzer**, with hair cells positioned along the basilar membrane responding to different frequencies.

- This **spatial mapping of frequencies generates a tonotopic map**, which then is transmitted to higher levels of the auditory system.

Encoding of frequency





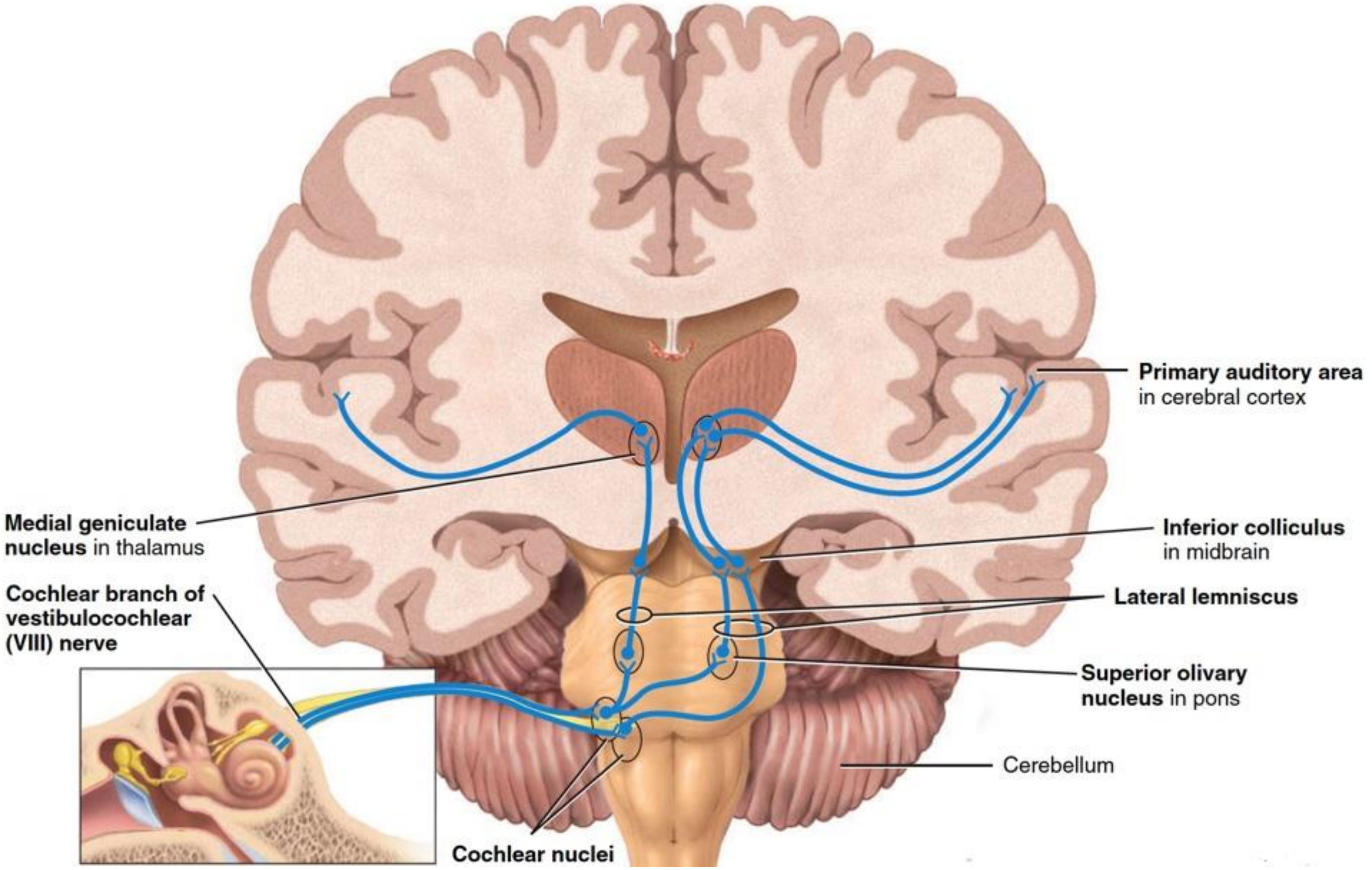
Encoding of loudness **(intensity)**

- First, as the sound becomes louder, the amplitude of vibration of the basilar membrane and hair cells also increases so that the hair cells excite the nerve endings at **more rapid rates.** (increased depolarization → higher frequency of action potentials in auditory nerve fibers)
- Second, as the amplitude of vibration increases, it causes more and more of the hair cells on the fringes of the resonating portion of the basilar membrane to become stimulated, thus causing **spatial summation** of impulses. (Number of hair cells)

  – Note: excessive bending in extreme sounds may lead to hair cell damage and degeneration.

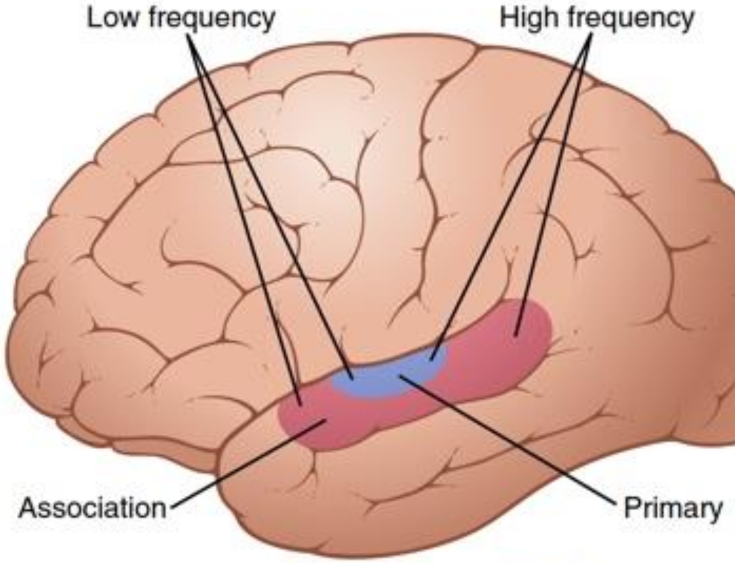
Auditory pathway

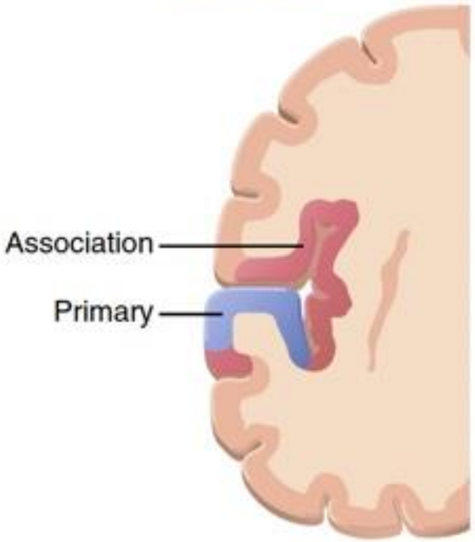
- Nerve fibers from the spiral ganglion of Corti enter the **dorsal and ventral cochlear nuclei** located in the medulla.
- At this point, all the fibers synapse, and second-order neurons pass mainly to the opposite side of the brain stem to terminate in the **superior olivary nucleus**.
- A few second-order fibers also pass to the superior olivary nucleus on the same side.

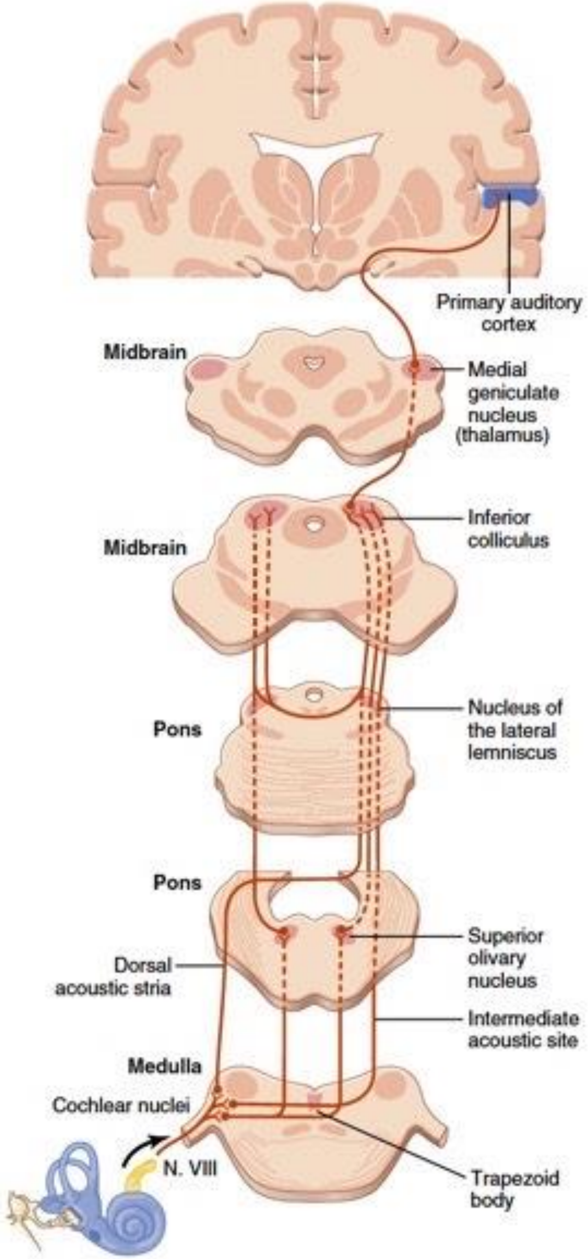


لا إله إلّا الله وحده لا شريك له

Auditory pathway







Auditory pathway

- Most of the auditory signals cross to the opposite side of the brainstem, while some fibers remain ipsilateral. These fibers reach an important nucleus called the **superior olivary nucleus.**
At this level, integration occurs. The superior olivary nucleus plays a key role in the **acoustic reflex** and helps in determining the location of sound. Sound localization processing continues at higher levels until it is finally completed in the cortex.

- Sound localization begins even before the cortex. For example, time lag and intensity differences between the ears, whereas front-back and up-down discrimination depends mainly on the pinnae; therefore, pinna deformities can impair accurate localization.

- Fibers continue ascending to the **inferior colliculus, which mediates reflex responses to sudden loud sounds.** Along the pathway, collaterals project to the **reticular activating system** (causing generalized arousal with loud sounds) and to the **cerebellar vermis, which is activated instantly by sudden noise.** Tonotopic organization is preserved from the cochlea to the cortex.

- Signals relay through the **thalamus to the primary auditory cortex, which analyzes frequency and intensity,** while auditory association areas interpret sound meaning (e.g., lesions impair understanding without reducing hearing). Because of **multiple** crossings and bilateral cortical representation, unilateral cortical lesions do **not** cause deafness but impair sound localization; even bilateral lesions do not produce complete deafness due to preserved subcortical processing remains intact.

Auditory pathway

- **Signals from both ears are transmitted through the pathways of both sides of the brain**, with a preponderance of transmission in the contralateral pathway.

- Many **collateral fibers** from the auditory tracts pass directly into the **reticular activating system** of the brain stem. This system projects diffusely upward in the **brain stem** and downward into the **spinal cord** and activates the entire nervous system in response to loud sounds.

- Other **collaterals** go to the vermis of the c**erebellum**, which is also activated instantaneously in the event of a sudden noise.

- A high degree of spatial orientation is maintained in the fiber tracts from the cochlea all the way to the cortex.

Auditory cortex

- **Destruction of both primary auditory cortices** in the human being greatly reduces one's sensitivity for hearing.
- **Destruction of one side** only slightly reduces hearing in the opposite ear; it does not cause deafness in the ear because of many crossover connections from side to side in the auditory neural pathway.
- However, it does affect one's ability to localize the source of a sound because comparative signals in both cortices are required for sound localization.

Auditory cortex

- **Lesions that affect the auditory association are**as but not the primary auditory cortex do not decrease a person's ability to hear and differentiate sound tones.

- However, the person is often **unable to interpret the meaning** of the sound heard (ex. Wernicke's area).

Determination of the direction of sound

- A person determines the horizontal direction from which sound comes by two principal means:

- (1) the **time lag** between the entry of sound into one ear and its entry into the opposite ear.

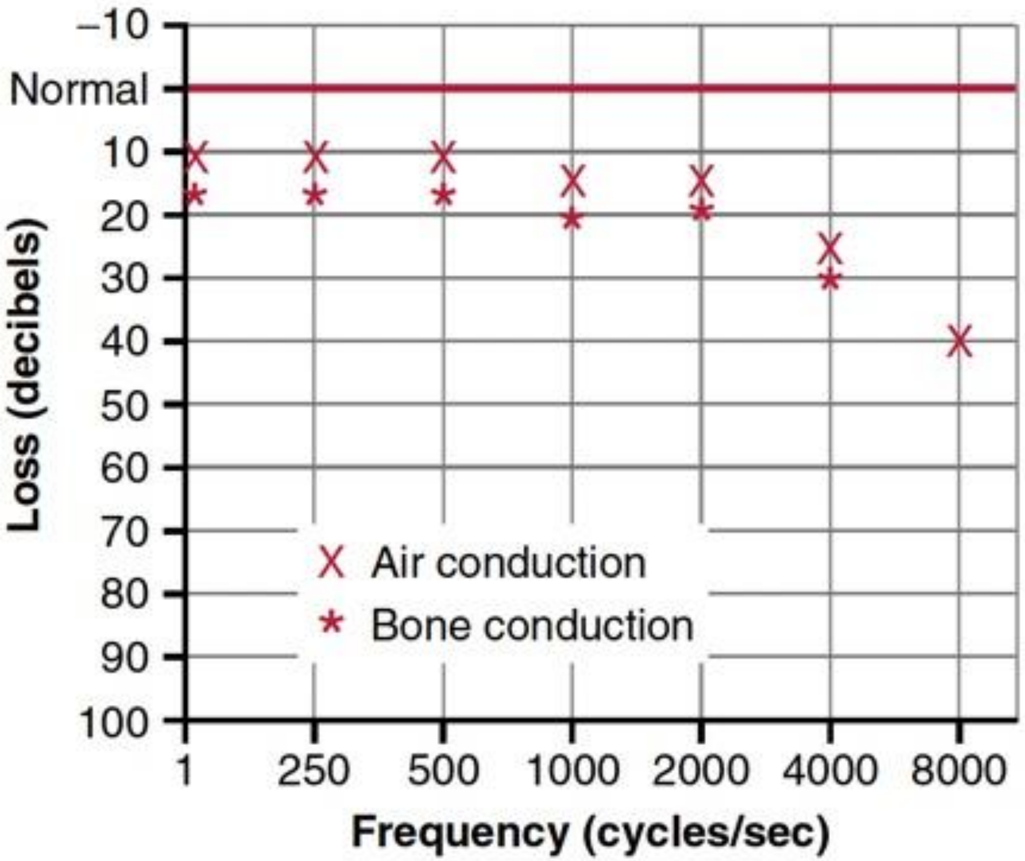
- (2) the difference between the **intensities** of the sounds in the two ears.

Determination of the direction of sound

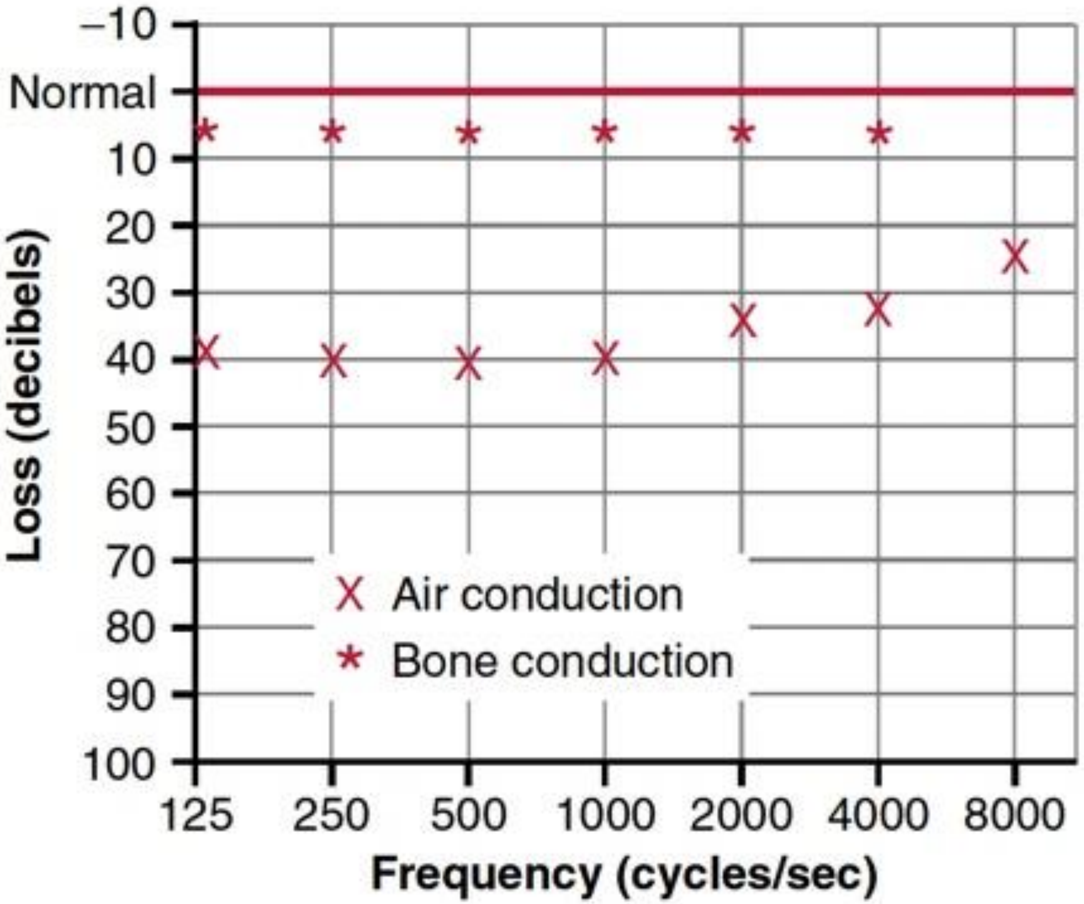
- These two mechanisms cannot tell whether the sound is emanating from in front of or behind the person or from above or below.
- This discrimination is achieved mainly by the **pinnae**, which act as funnels to direct the sound into the two ears.
- The shape of the pinna changes the quality of the sound entering the ear, depending on the direction from which the sound comes.
- The neural analyses for the direction detection process begin in the **superior olivary nuclei** in the brain stem, even though the neural pathways all the way from these nuclei to the cortex are required for interpretation of the signals.

Audiogram results of **Pure Tone Audiometry (PTA)**

Case 1



Case 2



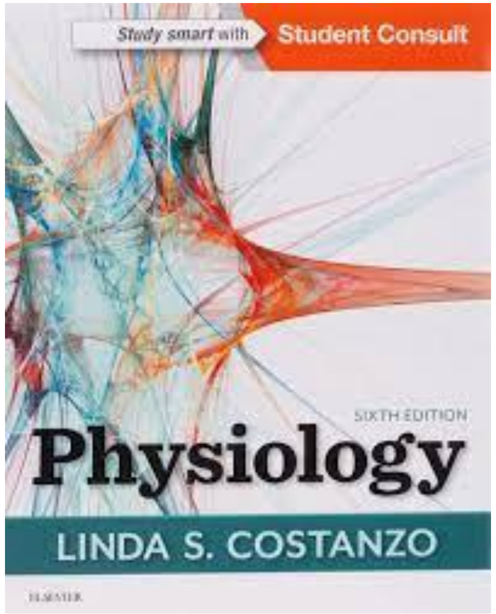
Audiogram

- Hearing is assessed using an audiogram, which **differentiates between conductive and sensorineural hearing loss.** Conductive loss results from problems in the external or middle ear, while sensorineural loss is due to damage to the hair cells, auditory nerve, or central pathways.

- The audiogram measures air conduction (normal pathway through external → middle → inner ear) and bone conduction (skull vibrations directly stimulate the inner ear). Normally, air conduction is better than bone conduction.

- If both air and bone conduction are reduced with no gap, this indicates sensorineural hearing loss (e.g., aging, ototoxic drugs, prolonged noise exposure) **-case 1.** If air conduction is worse than bone conduction, producing an air-bone gap, this indicates conductive hearing loss **-case 2.**

References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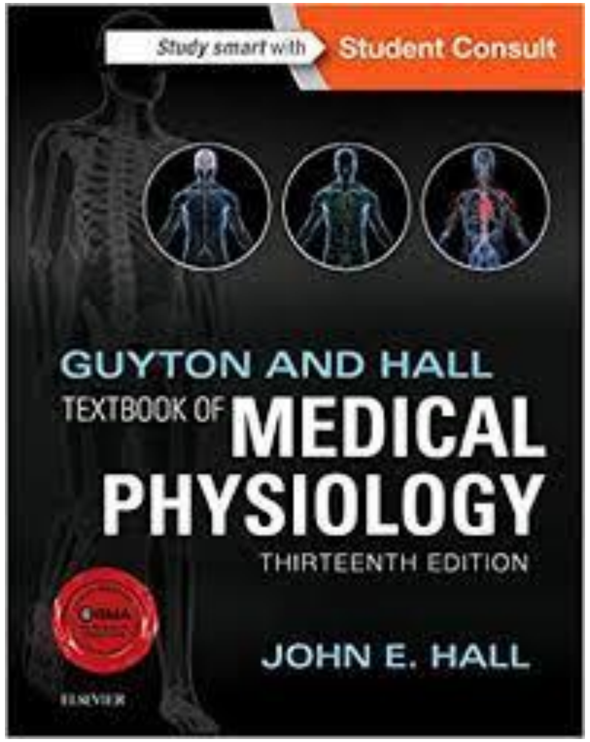
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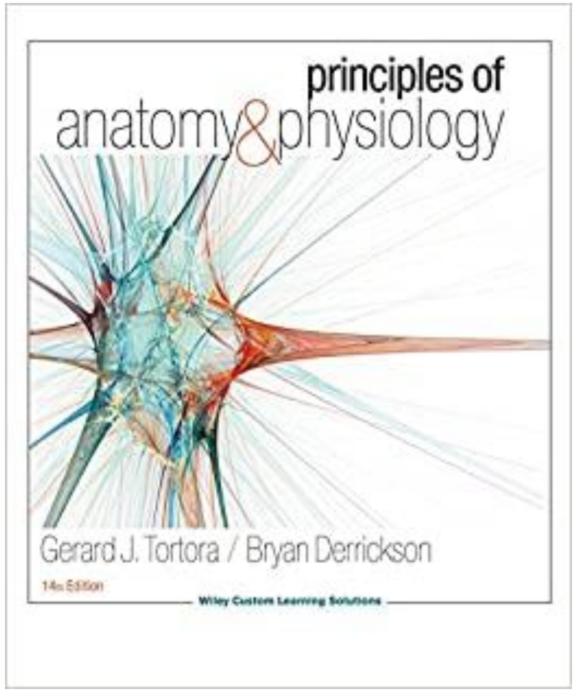
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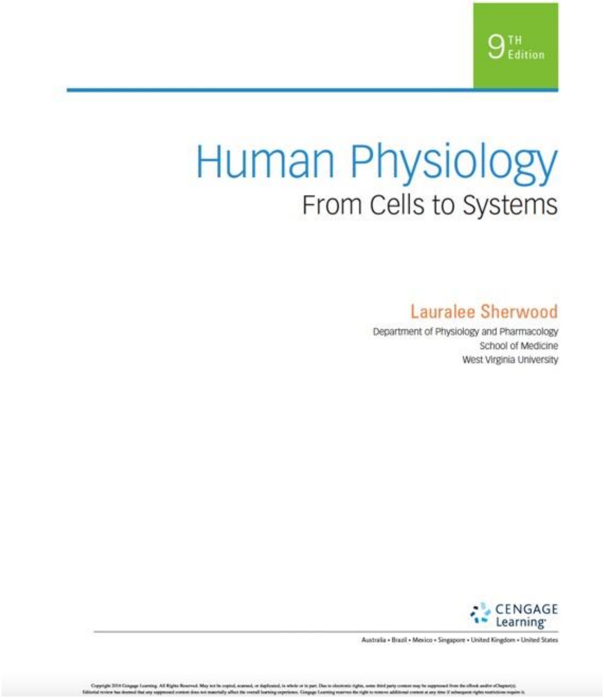
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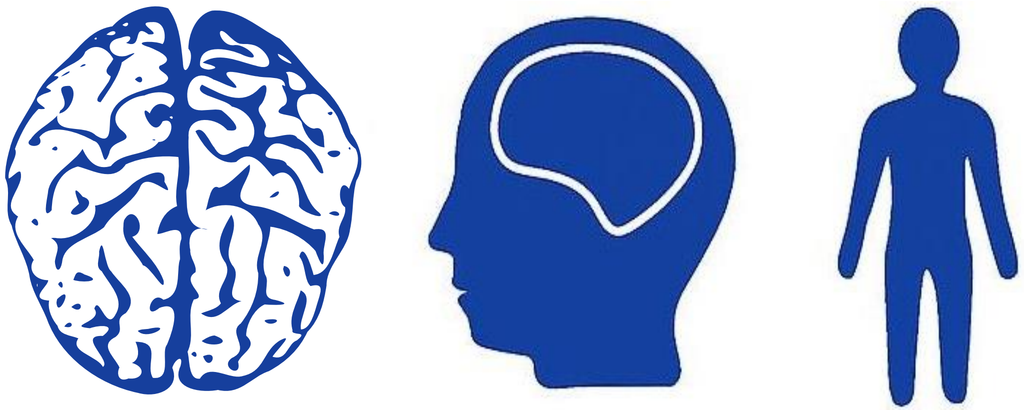

PHYSIOLOGY QUIZ
LECTURE 8

External Resources

Additional sources:

1. Guyton and Hall Textbook of Medical Physiology, 15th Edition. Pages (675 – 686)

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