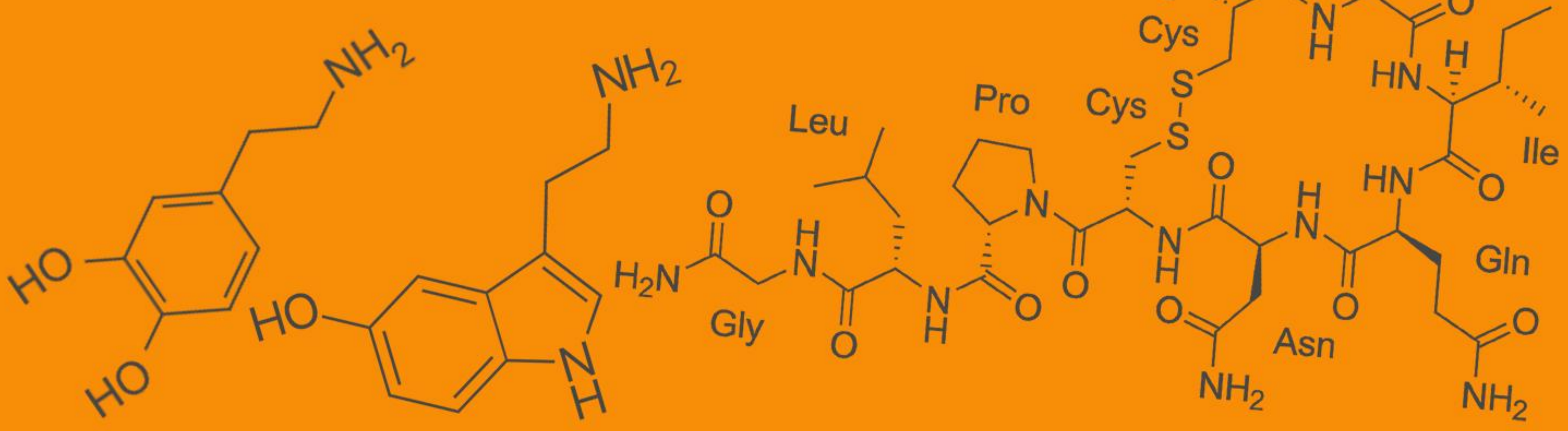
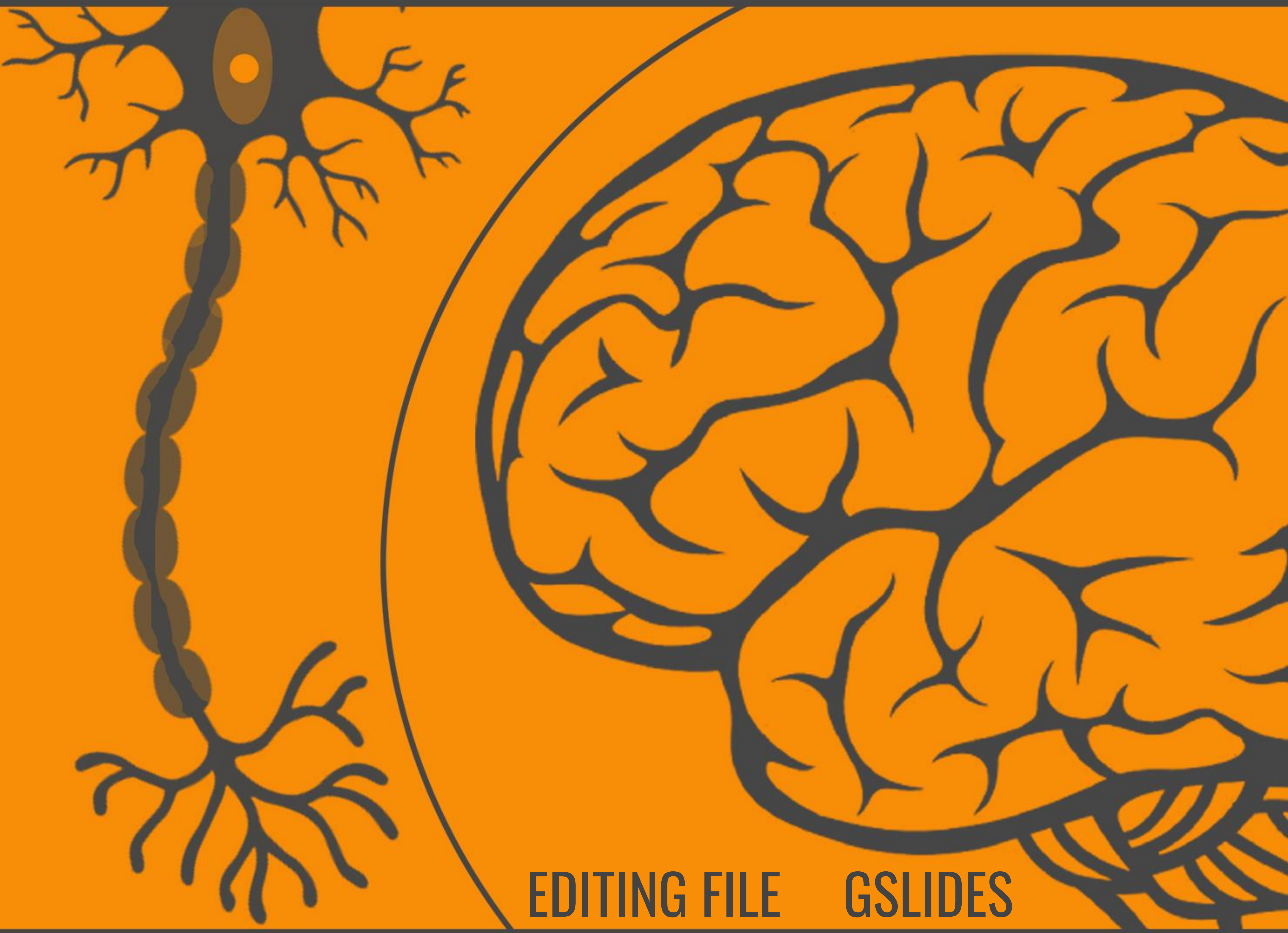


MEDICINE438's CNS PHYSIOLOGY

LECTURE VIII: Hearing Mechanisms



EDITING FILE GSLIDES

IMPORTANT | MALE SLIDES | EXTRA | FEMALE SLIDES | LECTURER'S NOTES

OBJECTIVES

- **Appreciate the functions of outer, middle and inner ear.**
- **Describe nature of sound & its characteristics.**
- **Function of semicircular canals & utricle & saccule.**
- **To understand the role of middle ear in sound transmission, magnification**
- **and tympanic reflex effect**
- **Recognize the function of hair cells of inner ear.**
- **Auditory pathway**
- **Differentiate between conductive and perceptive deafness.**
- **Hearing tests**

Ear: Receives sound waves, discriminates frequencies, and transmits auditory information into the CNS, where meaning is deciphered.

Functions of The Ear

- **Equilibrium sense (Parts involved):**
  - Internal ear
- **Hearing (Parts involved):**
  - External ear
  - Middle ear
  - Internal ear

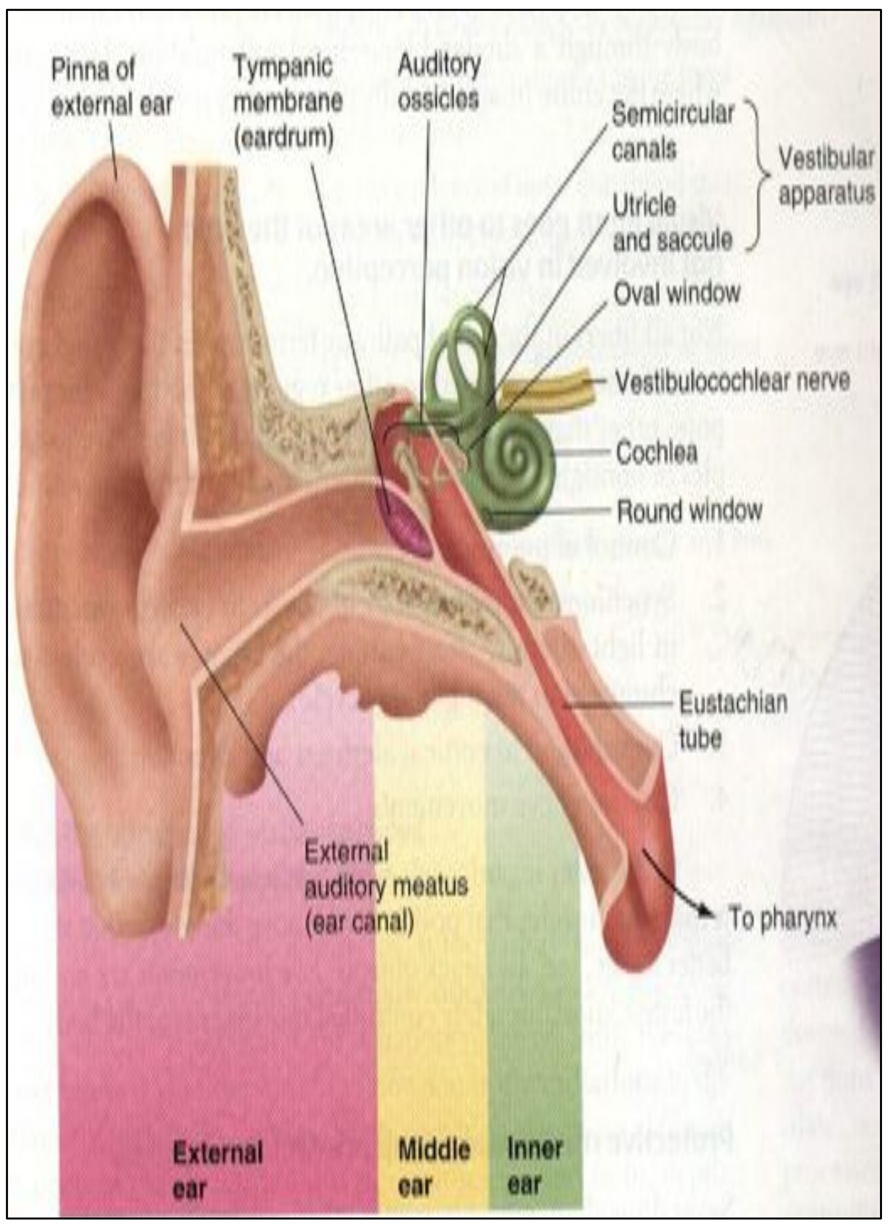


Figure 8-1

Anatomical Consideration

Outer ear	Middle ear	Inner ear
• Pinna • External canal • Tympanic Membrane (funnel shaped, pointing inward)	• Air filled cavity • Three bones: 1- Malleus 2- Incus 3- Stapes (with its foot sitting on the oval window of the inner ear)	• Bony and membranous labyrinth

Table 8-1

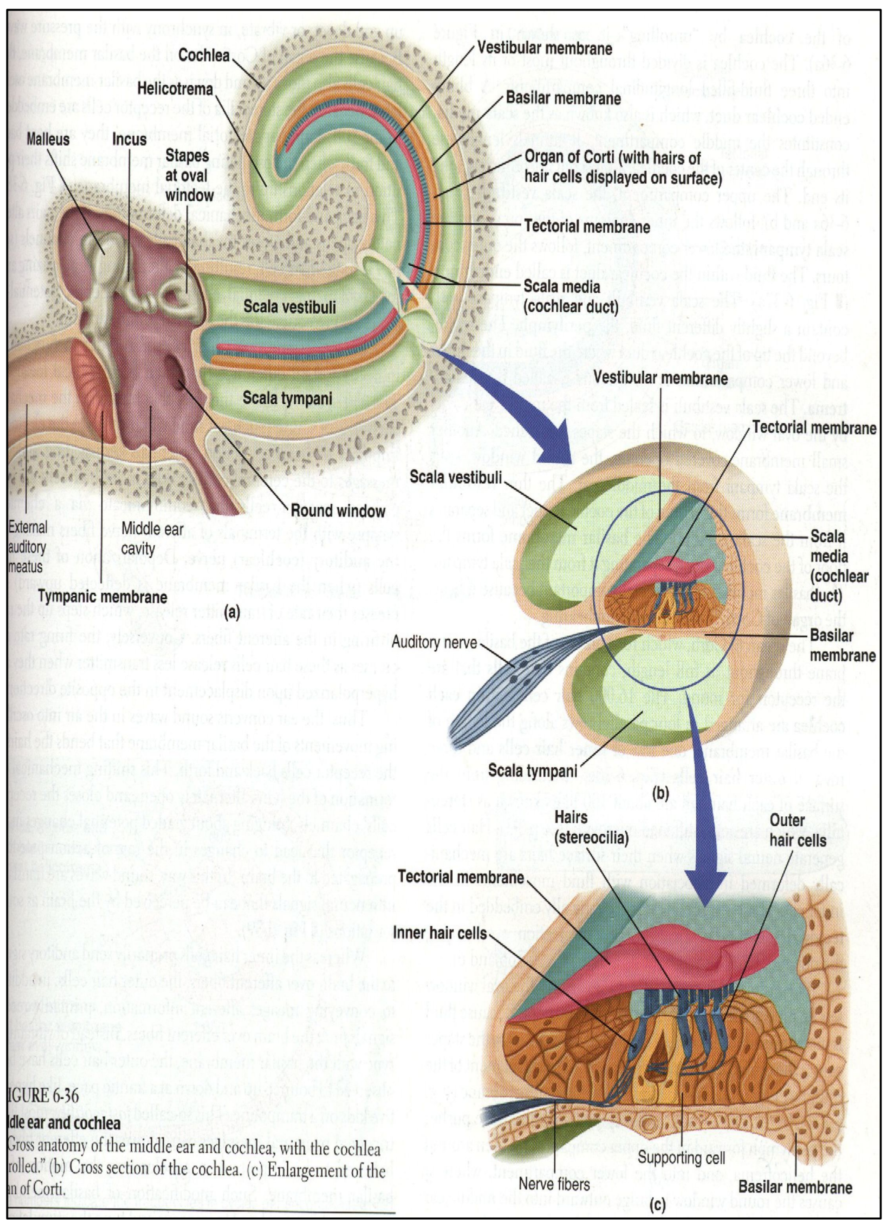


Figure 8-2

Nature of Sound

Sound is a vibration that propagates as an audible wave of the pressure, through a transmission medium such as gas, liquid or solid. Sound is produced from alternate compression and rarefaction of air molecules by a vibrating body.

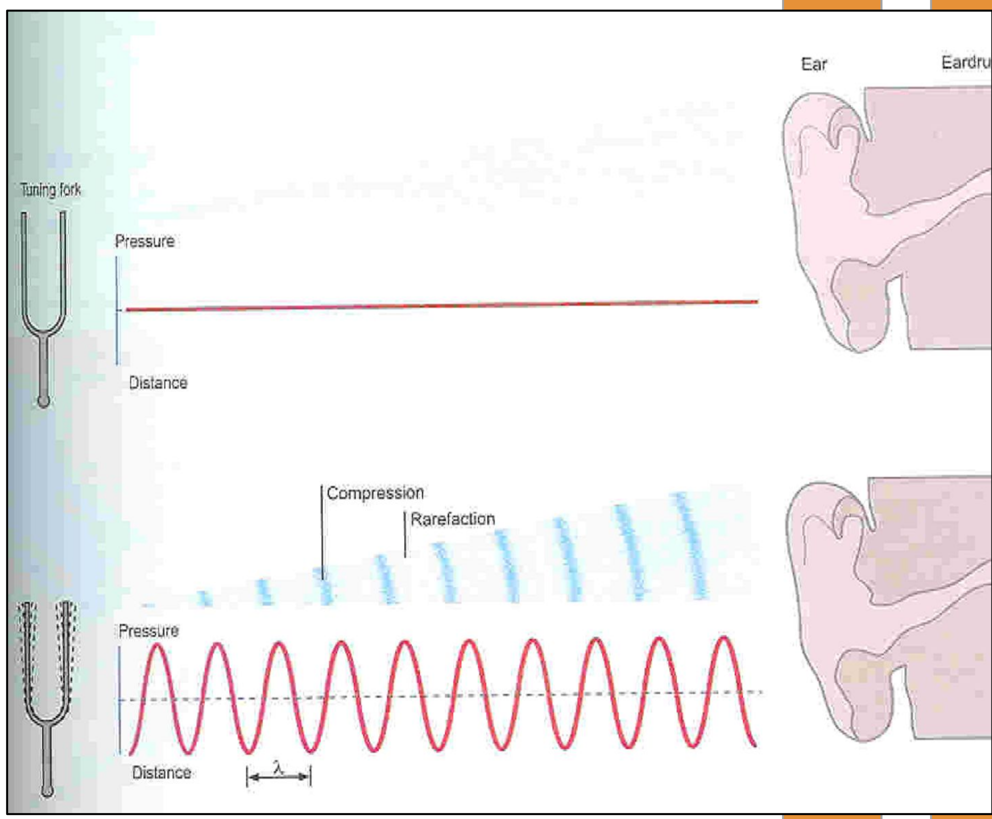


Figure 8-3

Characteristics of Sound

- **Quality**: depend on the overtone or interference.
- **Intensity (Loudness)**: Depend on amplitude[1]
- **Pitch (Tone)**: depend on No. of cycle/sec. (Human ear can detect sound waves with freq.. 20-20000 cycle /sec)[1] Old age: Frequency range is shortened to 50 to 8000 cycles/ sec or less

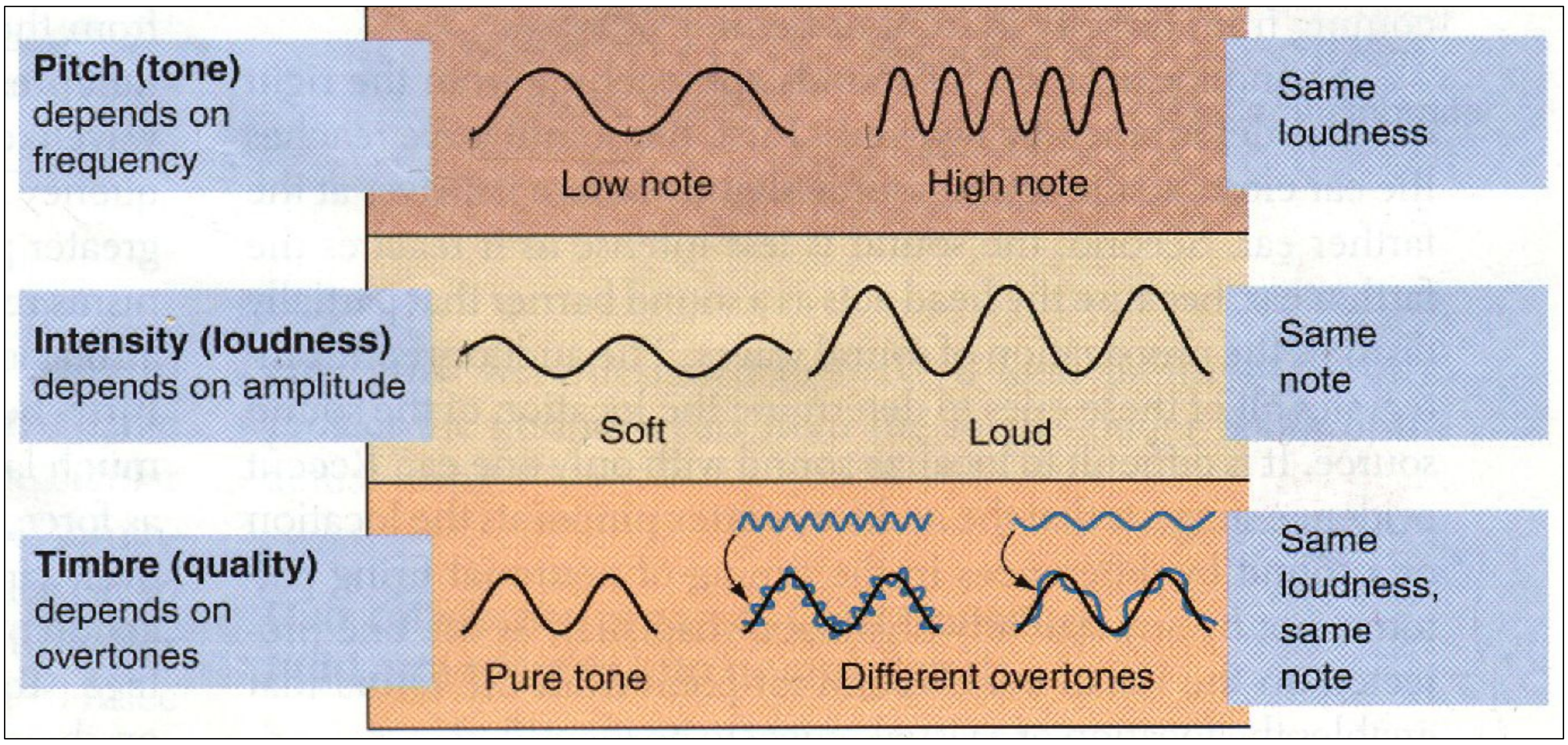


Figure 8-4

FOOTNOTES

1. Distance from the baseline of a wave to a successive peak, in simple terms, can be calculated by measuring the distance to a peak from the baseline, or measuring the distance between a peak and a trough and dividing by 2.
2. Cycles/seconds, also referred to as Hz, which is basically the frequency (amount of occurence) of a wave. Equal to 1/s.

Functions of The Ear

External ear

- Act as **funnel** to collect sound
- Protection Filtration by hair
- Sound localisation (front, back, high, low)
- Alter amplitude (Pinna)
- Wax
- Humidification and warming the air entering the ear

Middle ear

It is a space between tympanic membrane and the inner ear (opens via Eustachian tube into nasopharynx) Content:

Air	Ossicles	Muscles
Connected to the atmospheric pressure	Malleus Incus Stapes • Magnify the sound waves • Manubrium of the malleus is attached to the back of the tympanic membrane and its short process is attached to the incus. • The incus then articulates with the head of the stapes, and its foot plate is attached to the oval window - Malleus and Incus act as a single lever - Tympanic membrane (Eardrum) and ossicles, conduct sound from the tympanic membrane through the middle ear to cochlea (the inner ear). - In the absence of the ossicular system and tympanic membrane: Sound waves can still travel directly through the air of middle ear and enter the cochlea at the oval window. However, the sensitivity for hearing is 15 to 20 decibels less than for ossicular transmission.	**1. Tensor tympani** **2. Stapedius** • These muscles contract reflexly in response to constant loud sounds (over 70 dB) • Contraction of the tensor tympani pulls the manubrium inward and tenses the tympanic membrane. Thus, it decreases the vibrations. • Contraction of the stapedius pulls the footplate outward from the oval window and thereby reduces the intensity of sound reaching the cochlea. • Protection from constant loud noise, but not sudden intense noise, with a latency of 40-80 msec.

Table 8-2

BOX 8-1: CLINICAL RELEVANCE

What is meant by decibels?

1 decibel represents the lowest sound intensity (amplitude) that can be heard by an undamaged human ear, and it is considered as a baseline to measure the intensity of sound with reference to the lowest sound possible that can be heard by a human ear, decibel unit is derived from bel, a unit named after Sir Alexander Graham Bell, the deci prefix indicates 10^{-1}, since one bel is always too big, we use decibels, which is equal to 10^{-1} multiplied by 1 bel. Just like 10^{-2} multiplied by a meter gives a centimeter.

Transmission of Sound Through The Middle Ear:

1. Sound waves vibrate the tympanic membrane
2. Tympanic membrane moves the handle of malleus
3. Incus moves
4. Stapes move in & out of the oval window. The pressure transmitted through cochlea cause stimulation of hair cells in the organ of corti, which will stimulate the auditory nerve

Middle Ear Magnifying

1. The surface area of the oval window is smaller than that of the tympanic membrane. Therefore, the sound wave pressure is concentrated on a smaller area. The ratio is 17=1
2. The lever action of the ossicles, caused by the fact that the long process of the incus is shorter than that of the manubrium, increases the force of the incoming sound waves 1.3 times .
3. The total increase: 17 X 1.3 = 22 times

BOX 8-2: GUYTON AND HALL

The Ossicular System

- The amplitude of movement of the stapes faceplate with each sound vibration is only three fourths as much as the amplitude of the handle of the malleus. Therefore, the ossicular lever system does not increase the movement distance of the stapes, as is commonly believed. Instead, the system actually reduces the distance but increases the force of movement about 1.3 times. In addition, the surface area of the tympanic membrane is about 55 square millimeters, whereas the surface area of the stapes averages 3.2 square millimeters. This 17-fold difference times the 1.3-fold ratio of the lever system causes about 22 times as much total force to be exerted on the fluid of the cochlea as is exerted by the sound waves against the tympanic membrane.

Inner ear

- **Cochlea** (snail like, coiled tubular system laying deep in the temporal bone)
- Bony labyrinth
- Membranous labyrinth

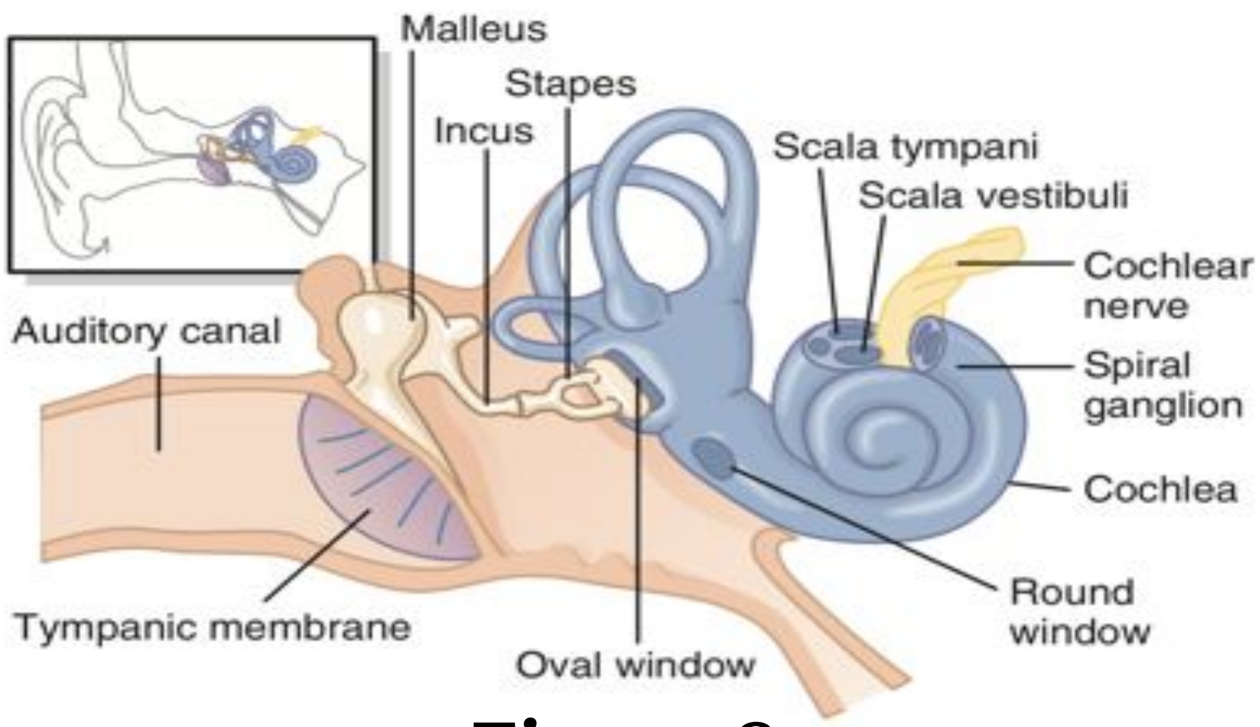


Figure 8-5

Cochlea

- It is a system of three coiled tubes through its length
- The basilar membrane and the reissner's (vestibular) membrane Divide it into three canals:

Composition		
Scala Vestibuli	Na high	K low
Scala Tympani	Na high	K low
Scala Media	Na **low**	K **high**

Table 8-3

- The middle chamber of the cochlea, SM, contains endolymph, whereas the outer chambers, ST and SV, are filled with perilymph. Endolymph contains a high concentration of potassium and a low concentration of sodium, which is exactly opposite to the contents of perilymph.

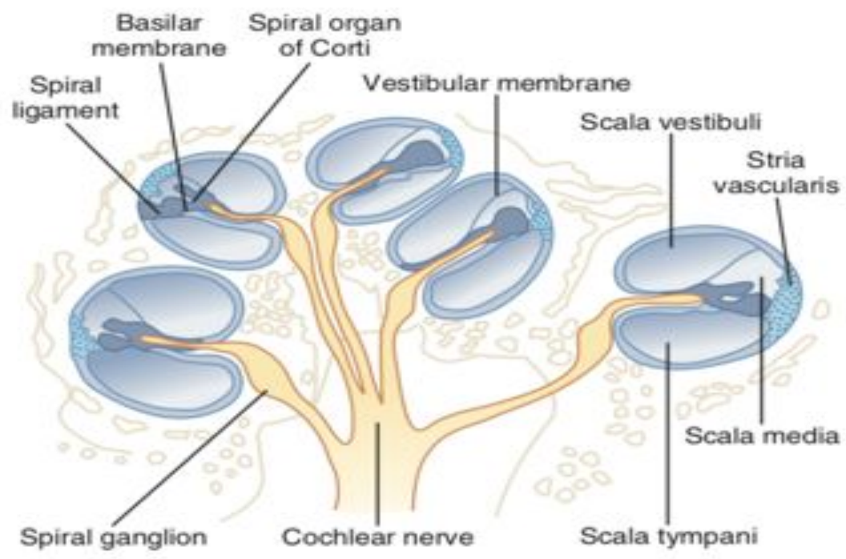


Figure 53-2. The cochlea. *(Modified from Drake RL, Vogl AW, Mitchell AWM: Gray's Anatomy for Students, ed 2, Philadelphia, 2010, Elsevier.)*

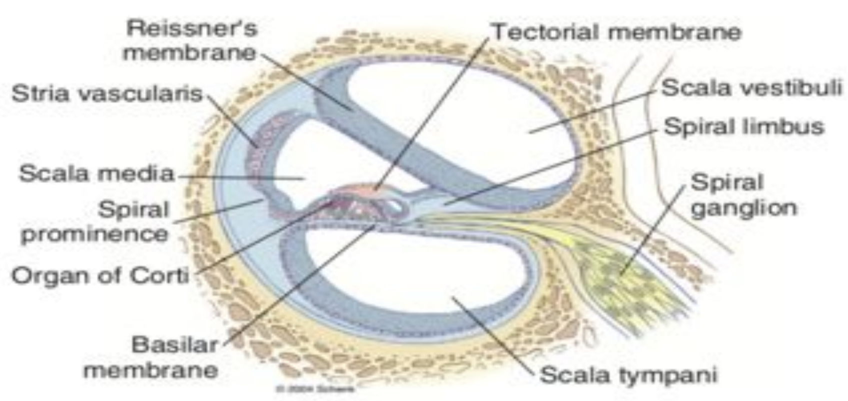


Figure 53-3. Section through one of the turns of the cochlea.

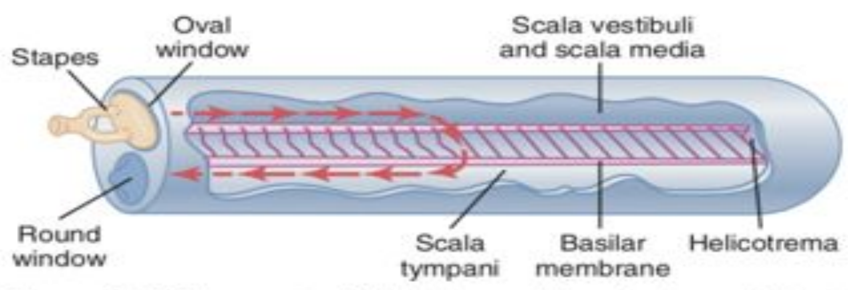


Figure 8-6

Continued

BOX 8-3: GUYTON AND HALL

- The scala vestibuli and scala media are separated from each other by Reissner's membrane (also called the vestibular membrane), the scala tympani and scala media are separated from each other by the basilar membrane. The Reissner's membrane is so thin and so easily moved that it does not obstruct the passage of sound vibrations from the scala vestibuli into the scala media. Therefore, as far as fluid conduction of sound is concerned, the scala vestibuli and scala media are considered to be a single chamber.
- An electrical potential of about +80 millivolts exists all the time between endolymph and perilymph, with positivity inside the scala media and negativity outside. This is called the endocochlear potential, and it is generated by continual secretion of positive potassium ions into the scala media by the stria vascularis.

IMPORTANT: Each **frequency** will be received by **special area** in the cochlea.

- **High** frequency is likely to stimulate the organ of corti in the **base** of cochlea.
- **Lower** frequency sound waves stimulates the area on the **apex**.

BOX8-4: GUYTON AND HALL

- **The basilar membrane** is a fibrous membrane that separates the scala media from the scala tympani.
- It contains basilar fibers that project from the bony center of the cochlea toward the outer wall. These fibers are stiff and elastic structures that are fixed at their basal ends in the central bony structure of the cochlea.
- 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 diameters of the fibers, however, decrease from the oval window to the tip of cochlea. 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.
- Thus, high-frequency resonance of the basilar membrane occurs near the base, where the sound waves enter the cochlea through the oval window (beginning of cochlea). However, low- frequency resonance occurs near the tip, mainly because of the less stiff fibers but also because of increased "loading" with extra masses of fluid that must vibrate along the cochlear tubules.

Organ of corti

- Located (resting) on the basilar membrane within the cochlea
- Contain inner & outer hair cells (Hearing receptors)
- Extend from base to apex
- Gel-like tectorial membrane capable of bending hair cells
- Cochlear nerve attached to hair cells transmits nerve impulses to auditory cortex on temporal lobe
- Stereocilia extend from the top
- Arrangement:
- Three rows of outer hair cells (attached to the reticular lamina or tectorial membrane)
- One row of inner hair cells (not attached to tectorial membrane)

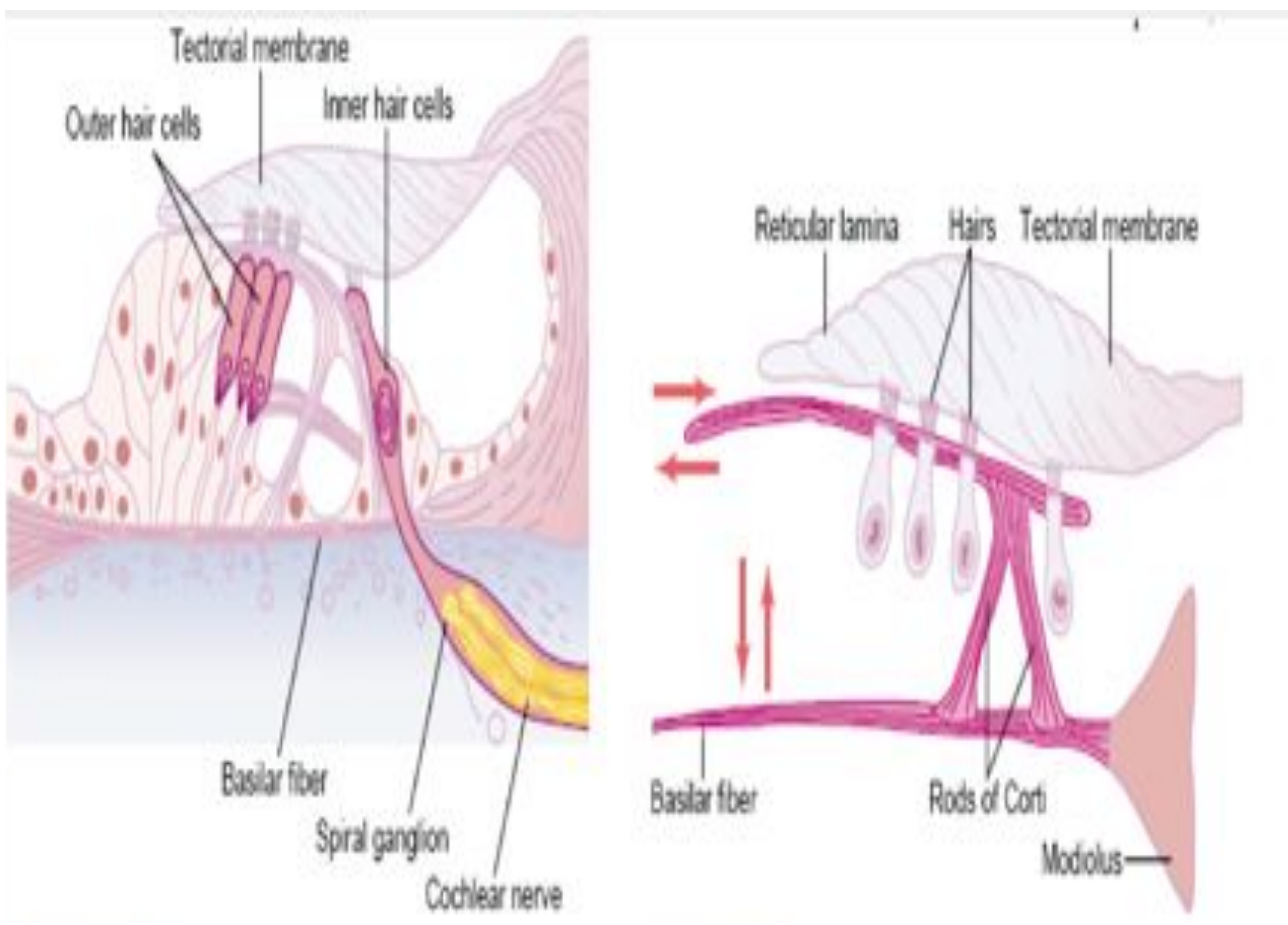


Figure 8-7

Continued

Function of Inner Hair Cells	Function of Outer Hair Cells
Stereocilia are not embedded in the tectorial membrane, but bent by fluid movement under the tectorial membrane.	Large number, but stimulate only small fraction of nerve fibres in the cochlear nerve.
They are primary receptors for sound, transducing fluid movement in cochlea into action potential in the auditory nerve.	Damage to these hair cells results in significant loss of hearing (they control the sensitivity of inner hair cells to particular sound frequency).

Table 8-4

BOX8-5: GUYTON AND HALL

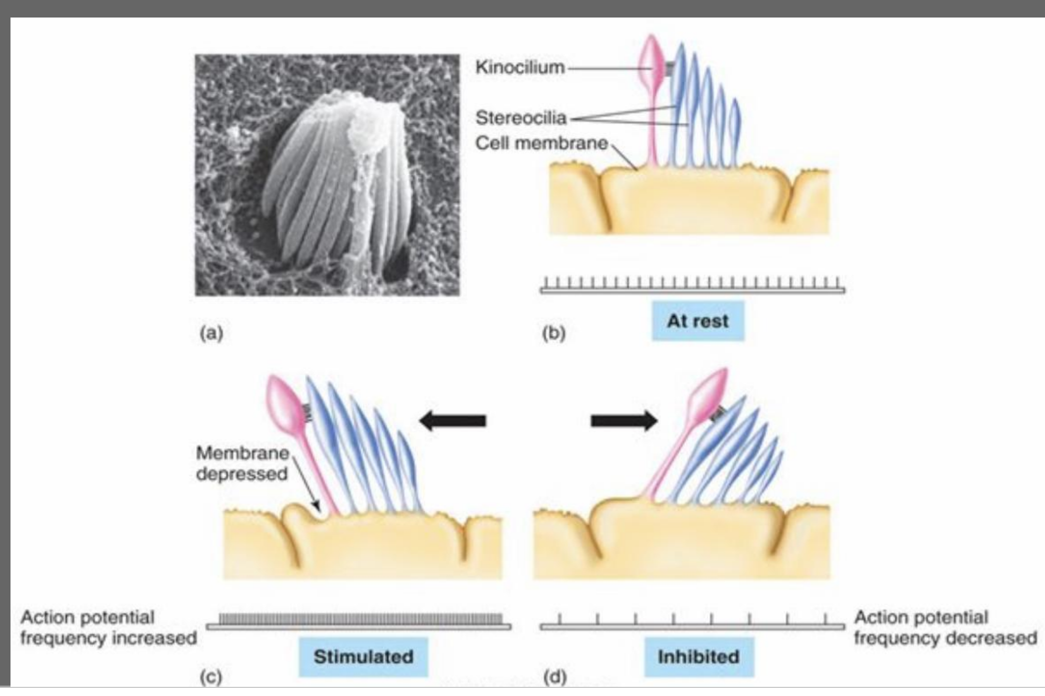
- The bases and sides of the hair cells synapse with a network of cochlear nerve endings. Between 90 and 95 percent of these endings terminate on the inner hair cells, emphasizing their special importance for the detection of sound.
- The nerve fibers stimulated by the hair cells lead to the spiral ganglion of Corti, which lies in the center of the cochlea.
- The hair cells endings are excited by the vibration of the basilar membrane
- The outer ends of the hair cells are fixed tightly in a rigid structure composed of a flat plate, called the reticular lamina, supported by rods of Corti, which are attached tightly to the basilar membrane. The basilar membrane, the rods of Corti, and the reticular lamina move as a rigid unit.
- Upward movement of the basilar membrane rocks the reticular lamina upward and inward toward the modiolus (the central bony part of cochlea around which the tubes loop). Then, when the basilar membrane moves downward, the reticular lamina rocks downward and outward. The inward and outward motion causes the hairs on the hair cells to shear back and forth against the tectorial membrane. Thus, the hair cells are excited whenever the basilar membrane vibrates.
- The Auditory Signals Are Transmitted Mainly by the **Inner Hair Cells.** Even though there are three to four times as many outer hair cells as inner hair cells, about 90 percent of the auditory nerve fibers are stimulated by the inner cells rather than by the outer cells. Nonetheless, if the outer cells are damaged while the inner cells remain fully functional, a large amount of hearing loss occurs. Therefore, it has been proposed that the outer hair cells in some way control the sensitivity of the inner hair cells at different sound pitches, a phenomenon called "tuning" of the receptor system.

Receptors & Endocochlear Potentials:

- Sound transmission into the inner ear cause upper & lower movements of the reticular membrane (tectorial membrane)
- Produce bending of stereocilia of the hair cells alternatively open & close cation channels at the tip of the stereocilia
- Inward current → depolarization
- Outward current → hyperpolarization
- The net results is depolarization
- Production of cells receptors potentials
- Release of neurotransmitter
- Production of action potentials

BOX8-6: Stereocilia and Kinocilia

- Hair cells in the **vestibular system** are slightly different from those in the auditory system, in that vestibular hair cells have one tallest cilium, termed the **kinocilium.** Hair cells (receptors for equilibrium) each contains 20-50 stereocilia. One of these is Kinocilium, a true cilium. Stereocilia bend toward Kinocilium causing hair cells depolarization. When bent away from Kinocilium, hair cells hyperpolarize.



The Central Auditory Pathway

- This pathway begins in the *organ of corti.*
- End in the primary auditory cortex (area 41 & 42, *superior temporal gyrus* in the temporal lobe of the brain)
- Fibres end in the auditory area, where it is heard, then **interpretation** occurs in the auditory association areas ***(wernicke area)***
- There is a bilateral cortical connection of auditory area
- Thus destruction of one side slightly reduces hearing in the opposite ear
- Destruction of both primary auditory cortices greatly reduces sensitivity for hearing.
- 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 ability to localize the source of a sound.

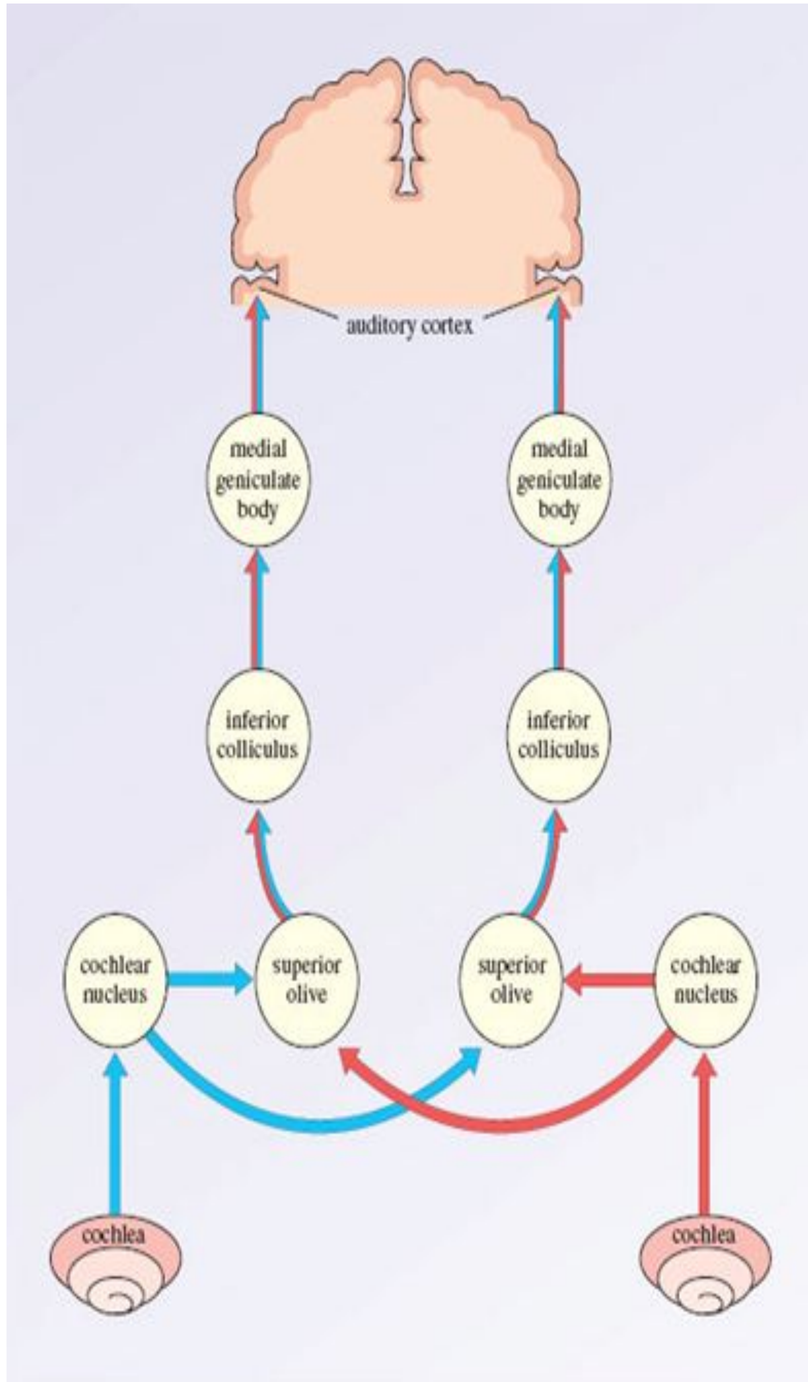


Figure 8-8

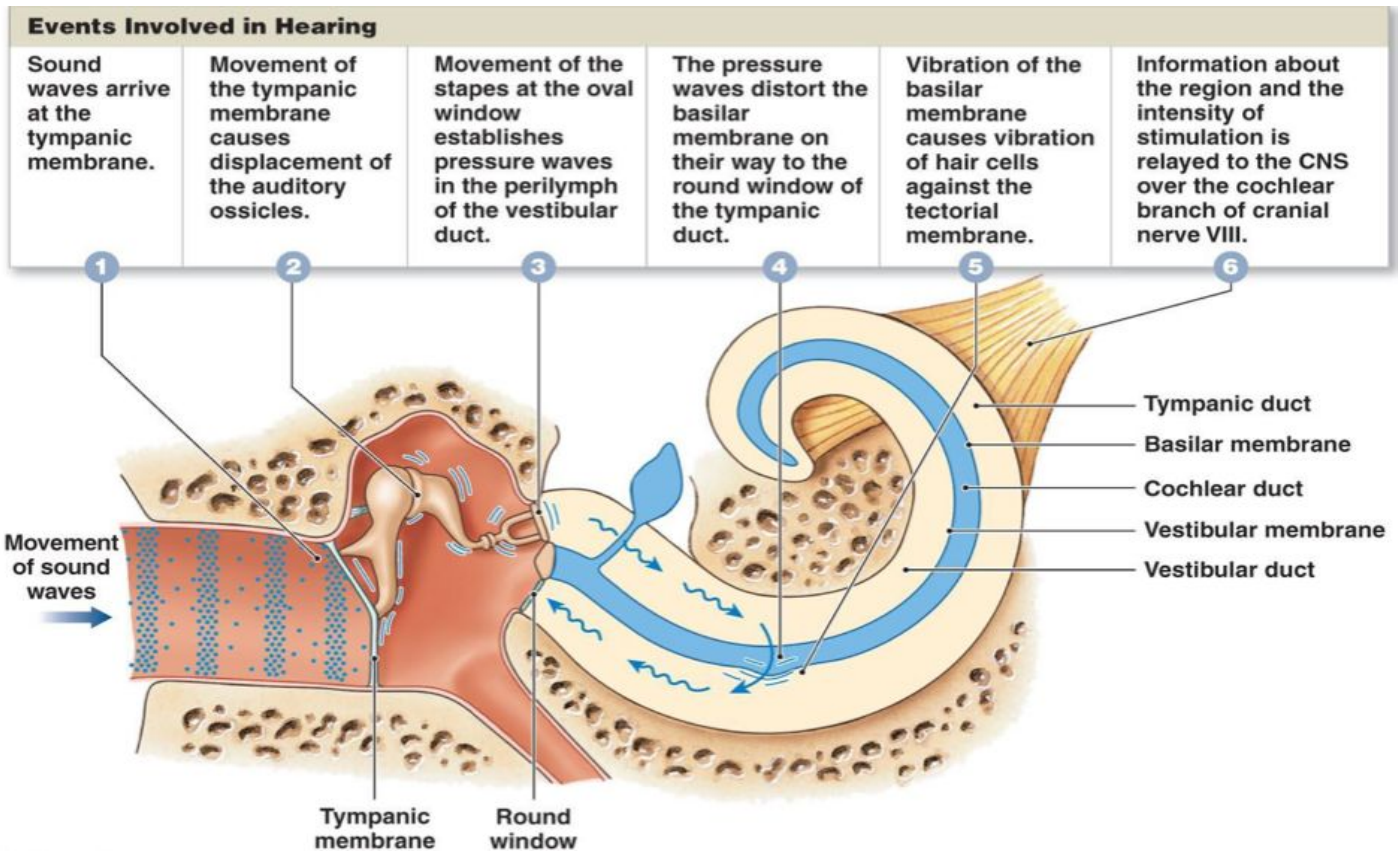


Figure 8-9

Sound Localization

- Differences in the **time arrival** of the sound wave at the ears (time-lag)
- Differences in the **loudness**

Masking Effect

- Presence of one sound decreases an individual's ability to hear other sounds. This phenomenon is known as *Masking.*
- Presence of background noise affect the ability to hear another sound, **due to some receptors being in a refractory period.**
- Masking is more clear if **two sound** are having the **same frequencies.**

Noise pollution

- Noise pollution is an environmental hazard.
- Exposure to sound intensity above 80 db may damage outer hair cells.

It’s uncomfortable at 120 db and painful at 140 db

Figure 8-10

Conduction of Sound Wave	
Air conduction	Bone conduction
Normal situation of hearing, sound travel in air causes vibration of **Tympanic membrane,** transmitted by **ossicles** to the **oval window**	Sound cause vibration of skull bones **directly** transmitting the sound vibration to the cochlea (eg. when placing tuning fork on the head or mastoid process)

Table 8-5

Deafness

Conductive Deafness

Impairment of sound transmission through **external** or **middle ear** due to:

- **Wax**
- **Repeated infection**
- **Perforated drum**
- **Destruction of ossicles**
- **Osteosclerosis** (pathological fixation of stapes on the oval window)

- All sound frequencies are equally affected
- Bone conduction is better than air conduction

Perceptive Deafness

Due to congenital or damage to **cochlea** or **auditory nerve** pathway due to:

- **Toxins** (antibiotics, gentamicin)
- **Inflammation**
- **Vascular**
- **Tumor**

- Both air and bone conduction are affected

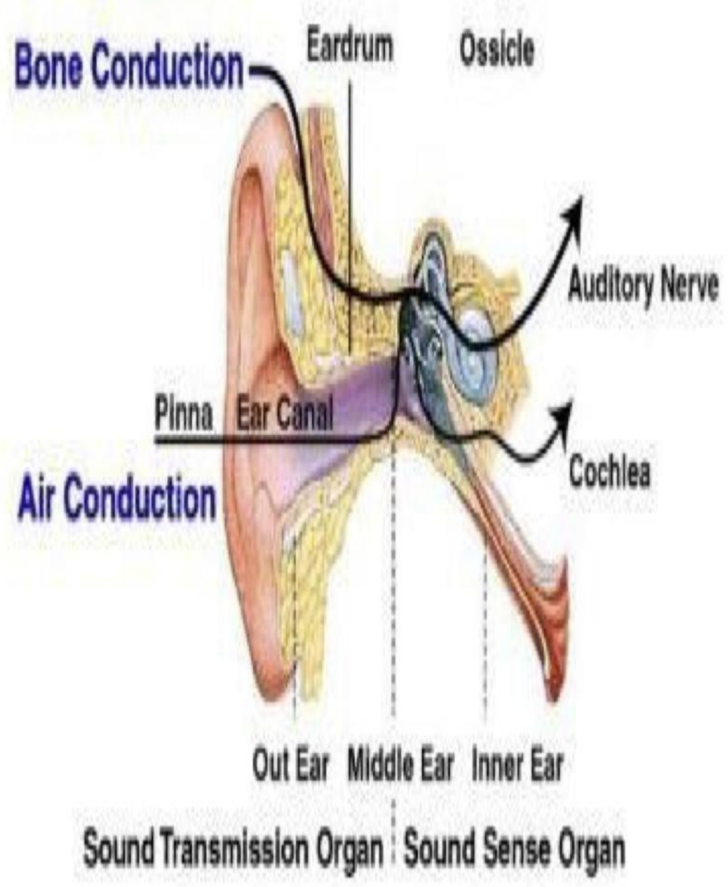


Figure 8-11

Hearing tests

- **Audiometer:**

a machine used for evaluating hearing acuity.

- **Weber Test:**

Tuning fork is placed on the patient's forehead (or in the middle line)

- **Rinnes Test:**

The base of the tuning fork placed on **mastoid process** until the sound is not heard

- Then the prongs of the fork held in air near the ear
- Normal subject continue to hear near ear (**positive test**)
- If not reveres the test (if heard near the mastoid process, **negative test**)

Figure 8-12

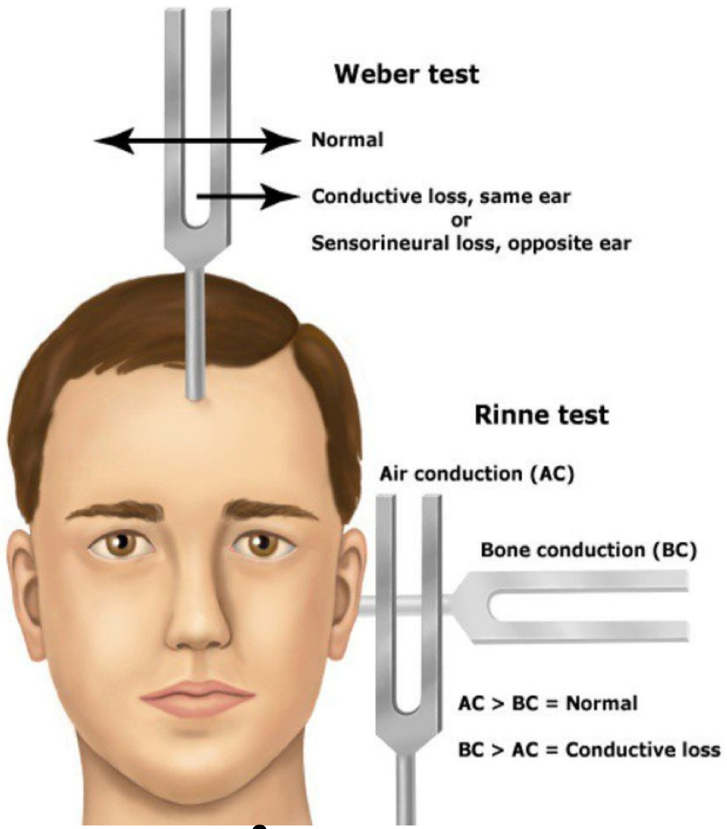


Figure 8-13

Common tests with a tuning fork to distinguish between nerve and conduction deafness.			
	Weber	Rinne	Schwabach
Method	Base of vibrating tuning fork placed on the vertex of skull	Base of vibrating tuning fork placed on mastoid process until subject no longer hears it, then held in air next to ear	Bone conduction of patient compared with that of normal subject
Normal	Hears equally on both sides	Hears vibration in air after bone conduction is over	
Conduction deafness (one ear)	Sound louder in diseased ear because masking effect of environment noise is absent on diseased side	Vibrations in air not heard after bone conduction is over	Bone conduction better than normal (conduction defect excludes masking noise)
Nerve deafness (one ear)	Sound louder in normal ear	Vibration heard in air after bone conduction is over, as long as nerve deafness is partial	Bone conduction worse than normal

Table 8-6

QUIZ

MEDICINE438's CNSPHYSIOLOGY

1. The central auditory pathway begins in which of the following:

A) organ of corti
B) Superior temporal gyrus
C) Wernickes area

2. Higher frequency sound waves stimulate which area in the cochlea?

A) organ of corti of in the base of cochlea
B) organ of corti of in the apex of cochlea
C) Both A & B

3. Muscles of the middle ear contract reflexly in response to:

A) Sudden loud voice
B) Constant loud voice
C) Whispers

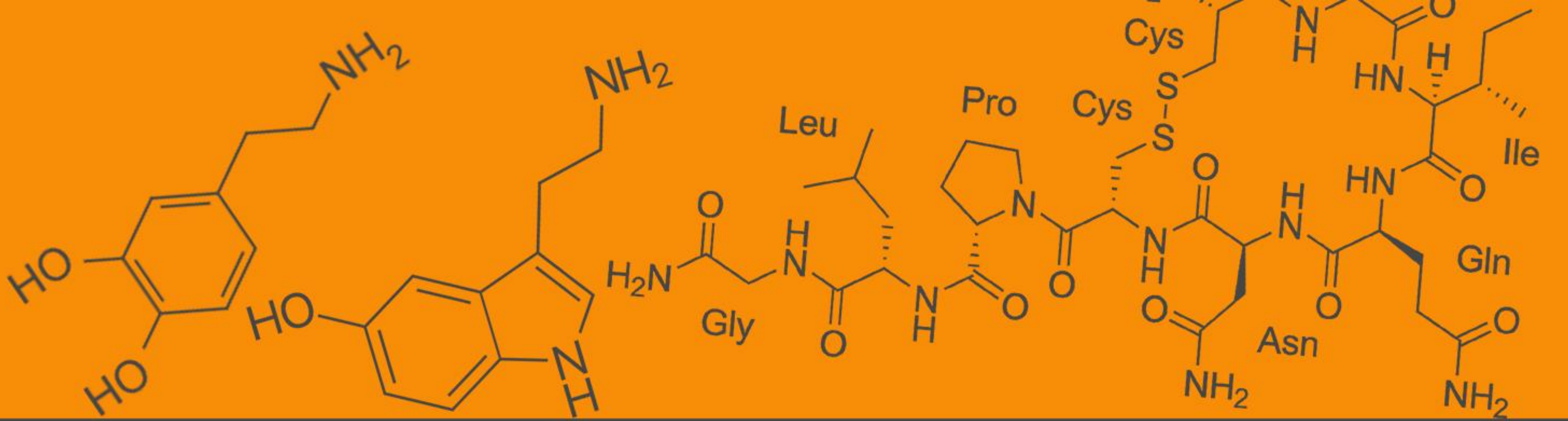
4. If the cochlea is damaged, which of the following will be affected?

A) Air conduction
B) Bone conduction
C) Both

5. The quality of sound depends on:

A) No. of cycle/sec
B) Overtone
C) Amplitude

ANSWER KEY: A, A, B, C, B



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REFERENCES

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