CENTRAL NERVOUS SYSTEM

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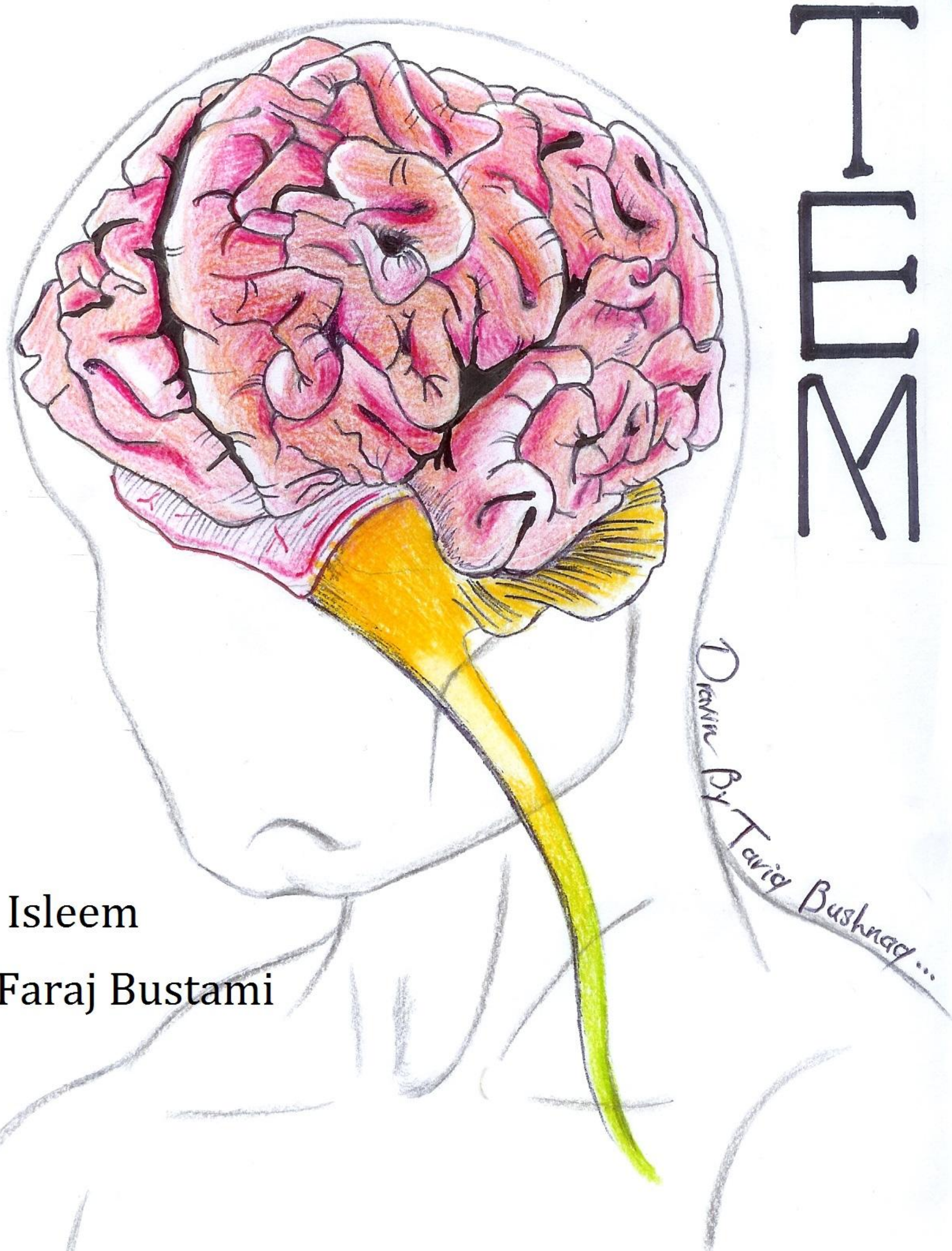

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The Auditory System

The ear is responsible for equilibrium and hearing. That's why the 8th cranial nerve is called the Vestibulo-cochlear nerve.

Vestibulo → Equilibrium

Cochlear → Hearing

When you look at the inner ear, what parts do you notice are responsible for maintaining equilibrium? These parts are the 3 semi-circular canals, the utricle, and the saccule.

The part of the inner ear responsible for hearing is the cochlea. The cochlea is a tube with 2.5 turns. There is a basal turn of cochlea and an apical turn. The basal turn is closer to the turn and the apical turn is slightly higher than the basal turn.

Sound has the following features:

1) **Pitch/Tone**-Depends on frequency of waves. The greater the frequency of the waves, the greater the pitch.

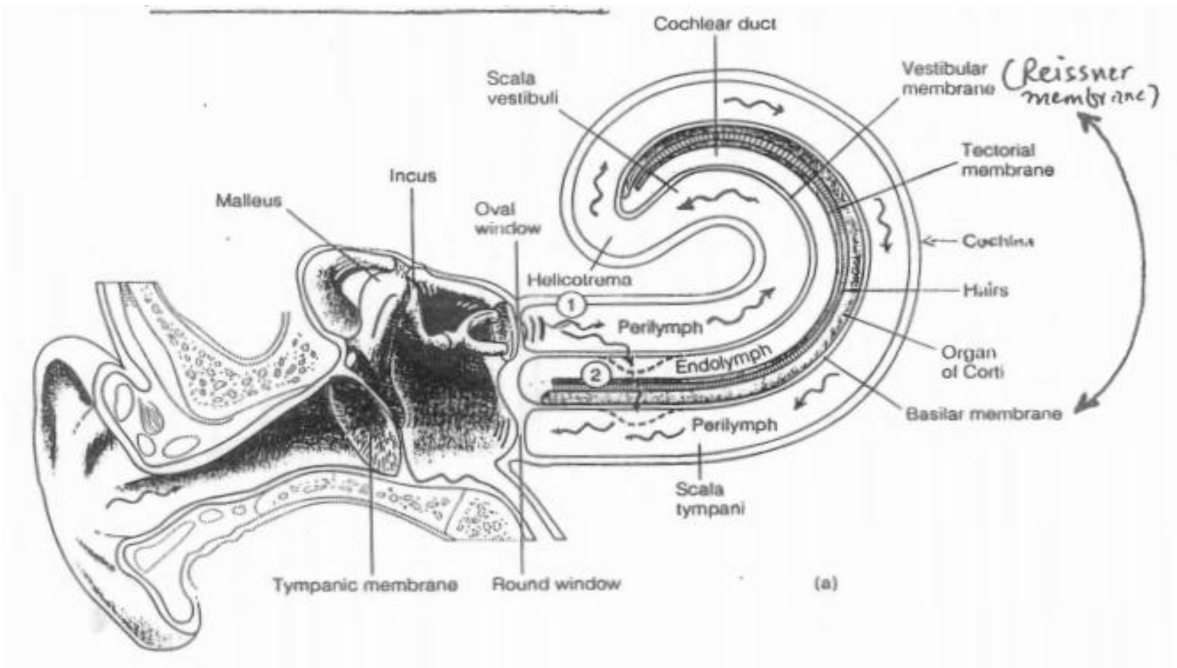
2) **Intensity/Loudness**- Depends on the amplitude of the waves. Higher amplitude means greater intensity.

-If 2 sound waves have the same amplitude, but different frequency, they have the same intensity, but at a different pitch.

-If 2 sound waves have the same frequency, but different amplitude, they have the same pitch, but different intensity/loudness.

3) **Timbre/Quality**- The individual overtones that differentiate each person's voice, which is why you can recognize a specific person on the phone.

This is the external ear



At the base of the external ear is the eardrum. The eardrum/tympanic membrane conducts vibrations of sound to the middle ear. In the middle ear, we have three ear ossicles. These ossicles are the malleus, the incus, and the stapes. These ossicles further conduct sound vibration to the inner ear.

The gate to the inner ear is the oval window. The oval window opens into the cochlea. In the above picture, the cochlea is unraveled, forming an ear shaped tube, rather than its structure which contains 2 and a half turns. This is a cross sectional section. The parts of the cochlea in cross section are 3 compartments. The upper compartment is the scala vestibuli. The lower compartment is the scala tympani. The middle compartment is the scala media/cochlear duct.

What do we have in the cochlear duct? We have the organ of Corti. The organ of Corti contains the receptors for sound; called hair cells. These cells have appendages like cilia and are arranged into two groups; outer and inner hair cells. The outer hair cells are arranged as 3 layers (less important). The inner hair cells are arranged as a single layer (more important). These hair cells rest on the basilar membrane. The hair cell appendages/cilia on the upper layer rest on something called the tectorial membrane. Any vibration of the basilar membrane causes movement of the hair cells on the tectorial membrane.

The scala media has the organ of Corti and around them is the endolymph. In the scala vestibuli and tympani, there is perilymph, instead. What is the difference between endolymph and perilymph? The endolymph is richer in potassium, while the perilymph is richer in sodium.

Once the sound vibrations reach the oval window, the vibrations are translated into liquid/fluid movement, because these vibrations move the fluid of the scala vestibule and tympani, which is the perilymph. These fluid movements end in the round window.

The fluid movement pushes the vestibular membrane and causes movement of the endolymph.

Basically, sound vibrations move along this pathway:

Eardrum → Middle ear → perilymph of scala vestibule and tympani→ pushes vestibular membrane downward → endolymph → basilar membrane

Vibration of basilar membrane causes up and down movement of the hair cells and is our final goal in the pathway of vibration. The basilar membrane has a narrow, stiff end and a wide, flexible end. The narrow end is near the Oval Window and it responds to high frequency sounds of 20,000 Hz. The wide, flexible end responds to low frequency sounds of 20 Hz. This indicates that different areas on the basilar membrane respond to different frequencies from a range of 20-20,000 Hz.

Inner hair cells have a more important role than outer ear cells in producing sounds. They are the cells which transmit action potential. If there is upward movement of the basilar membrane, this leads to depolarization of hair cells. If the movement of the basilar membrane is downward, this will lead to hyperpolarization of the hair cells. Depolarization induces action potential which will be transmitted to the nerves in charge of hearing. In hyperpolarization, there will be no induction of action potential.

In depolarization, the potassium ion channels in the apex of the inner hair cells will open, causing potassium ions to enter the cell down an electrical gradient (keeping in mind that the endolymph is rich in potassium). Once these cells are depolarized to around -60mV, the voltage-gated calcium channels at the base of the cell will open, causing calcium influx (potassium enters at the apex and calcium enters at the base). Increase of calcium in the cell will stimulate neurotransmitter release. Neurotransmitters cause action potential at the beginning of the nerve and this action potential will ascend until it reaches the auditory cortex.

<u>The Auditory Pathway</u>

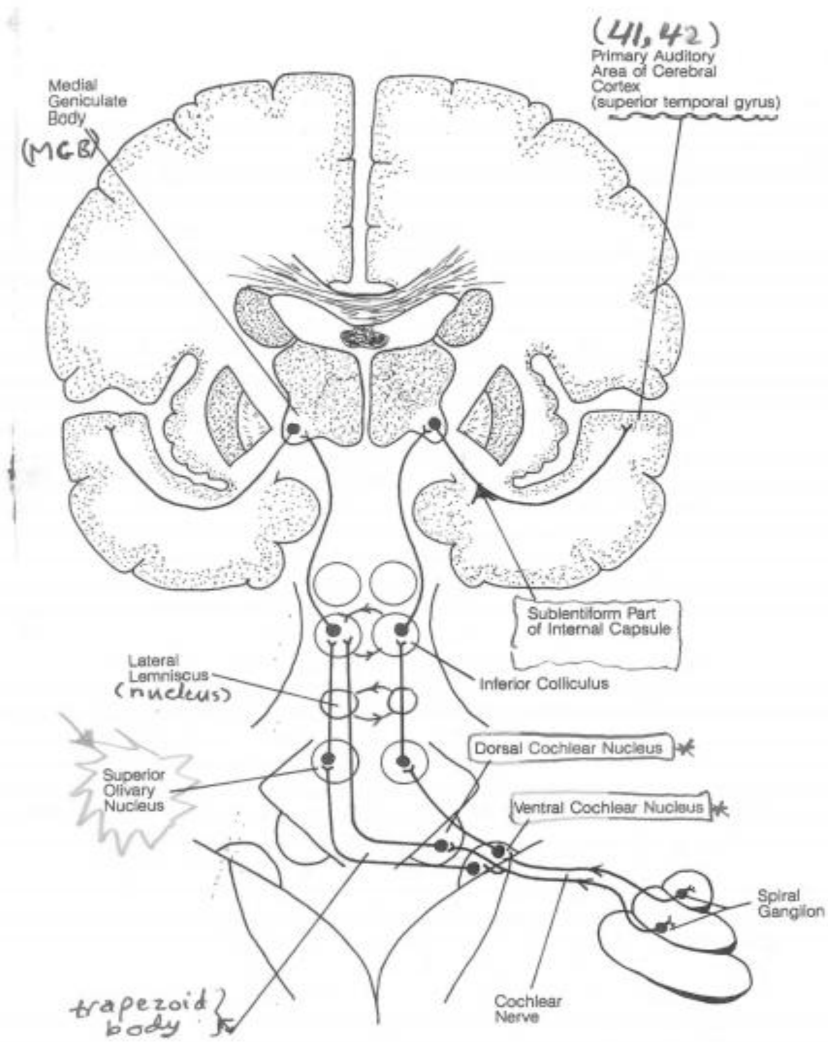
In all sensory pathways, the first order neuron is the ganglion. The ganglion in the auditory pathway is the spiral ganglion (not to be confused with spinal), which is found in the inner ear. This ganglion contains pseudounipolar and bipolar neurons. The main neuron here is the pseudounipolar neurons. The pseudounipolar neurons contain peripheral processes on the receptors. The receptors in the ear are, once again, the hair cells within the organ of Corti. The central processes enter at the junction of the pons and medulla and synapse at the 2nd order neurons. The 2nd order neurons are the dorsal/posterior cochlear nucleus and the ventral/anterior cochlear nucleus.

The central process of the pseudounipolar neurons of the spiral ganglion approaches the ponto-medullary junction and immediately bifurcates. Some nerves synapse on the ventral cochlear nucleus and other synapse on the dorsal cochlear nucleus.

The ventral cochlear nucleus projects both ipsilaterally and contralaterally. Ipsilaterally, the ventral cochlear nucleus projects to the superior olivary nucleus which is found in the pons. Contralaterally, it also projects to the superior olivary nucleus.

Impulses in the right ear supply both right and left auditory cortexes. However, most of the impulse supplies the left auditory cortex. It is important to remember that though the fibers on one side supply both sides, they mainly supply the contralateral, or opposite side.

Assume the superior olivary nucleus is the third order neuron. The impulse goes from the olivary nucleus along the lateral leminiscus. The 4th order neurons will be present in a structure called the inferior colliculus. The inferior colliculus will transmit the signal to the thalamus(MGB). The thalamus will then transmit the signal to the auditory cortex.



Remember: The auditory cortex is present in the superior temporal gyrus (deep to the lateral fissure) AKA areas 41 and 42

Finally, the impulse goes from the auditory cortex to the association cortex.

The dorsal cochlear nucleus follows the same rule as the ventral cochlear nucleus. Most of the fibers on one side supply the opposite side. Its fibers also follow the same pathway (**Dorsal cochlear nucleus →Superior olivary nucleus → Lateral leminiscus → inferior colliculus → MGB → auditory cortex**)

The ventral cochlear nucleus receives impulses from the cochlear nerve. It sends/projects impulses to the superior olive (some fibers to the ipsilateral olive, but most fibers to the contralateral side)

The dorsal cochlear nucleus receives impulses from the cochlear nerve. It sends/projects impulses to the superior olive (sends fibers ONLY to the contralateral olive).

The Superior olive is an important stage of the auditory pathway. Every cell at the level of and above the superior olive accepts fibers from both sides. Every neuron receives bilateral innervation. If we were to cut the lateral leminiscus on one side, there would be impaired hearing, more obvious on the contralateral side.

This rule of receiving fibers mainly from the contralateral side, with some from the same side applies to the MGB (Medial Geniculate Body), lateral leminiscus, superior olive, and inferior colliculus.

Once the fibers have synapsed in the MGB of the thalamus, they ascend to the primary auditory cortex as the auditory radiation. It passes in the sub-lentiform part of the internal capsule. At the upper surface of the superior temporal gyrus, we have an area which we sometimes call the transverse gyri of Heschl, or primary auditory cortex (Area 41 and 42). Once we've reached this level, this is where the brain starts to process words, but not compose full sentences. For us to be able to do this, the impulse must project to the association auditory cortex on the outer surface of the superior temporal gyrus (Area 22). We can now compare sounds to previous memory.

Information from both ears converges on each superior olive. At the levels above the superior olive, the neurons respond to inputs from both sides. The cochlear nuclei receive input from only their adjacent ear, making them the only auditory nuclei which do not receive input from both ears. This means that damage to the cochlear nucleus on one side results in unilateral deafness. If there is damage in the hair cells on one side, due to lesion, damage due to large doses of certain drugs, or Schwannoma (tumor of the Schwann cells), this will lead to ipsilateral deafness.

This is unlike the effect on the Superior olivary nucleus, lateral leminiscus, inferior colliculus, MGB, and other structures rostral to, or at the level of the superior olive. In lesion of these areas, hearing will be impaired in both ears, affecting the contralateral side more. Once again, hearing is impaired because fibers are received from both ears.

Remember: The first site where fibers from both ear converge is at the level of the superior olive, which explains the lesions and their signs.

The superior olivary nucleus is located at the level of the facial nucleus. It receives input from the ventral cochlear nuclei. The superior olivary nucleus projects impulses, bilaterally, to the lateral leminiscus. For the millionth time, most fibers project to the contralateral side. It also plays a role in binaural hearing, which means hearing from both ears. Another role it has is sound localization. This means being able to identify the source of the sound. Finally, there are efferent fibers from the superior olivary nucleus called the olivocochlear bundle, which leaves the olive and goes to the cochlea. It's argued about whether or not this bundle suppresses or stimulates auditory activity when stimulated, but in this course, we will say that it suppresses auditory activity (the activity of the hair cells).

The lateral leminiscus is a very important pathway. First, let's remember the other leminisci, of which they are 4. We have the spinal leminiscus, which is the spinothalamic tract (ALS). It ends on the VPL of the thalamus. Another leminiscus is the middle leminiscus (DCML) which transmits vibration, 2-point discrimination, and stereognosis. The 3rd leminiscus is the trigeminal leminiscus. The 4th and final is the lateral leminiscus, which ends at the inferior colliculus.

The inferior colliculus is part of the tectum of midbrain. Unlike, the superior colliculus, it is an important component of the auditory pathway. The superior colliculus is an important reflex center, like in the movement of the eye. Inferior colliculus lesions lead to bilateral impaired hearing, with the ear contralateral to the lesion being the most affected. The inferior colliculus is found in the lowest level of the midbrain. So if we took a section at the upper part of midbrain, we'll find superior colliculus but the lateral lemniscus won't be found as it synapsed at the inferior colliculus inferiorly.

The nucleus of inferior colliculus projects its impulse to the MGB of the thalamus (thalamic center for hearing) via the brachium of the inferior colliculus.

The MGB will project the auditory radiation through the sublentiform part of the internal capsule to the primary auditory cortex (area 41, 42) and eventually to association auditory cortex (area 22).

The fibers that carry the auditory input decussate. There are extensive decussations from the level of the superior olivary nucleus to the inferior colliculus. These decussations allow us to receive information about sounds from a single ear (Monaural information). Monaural information is conducted from the contralateral side. Binaural information allows us to receive information from both ears and compare them. We can determine the direction and nature of the sound received. The superior olive usually determines the source of the sound. → The doctor said that none of this is as important as knowing the lesions relative to the superior olive.

<u>Remember:</u>

-Many drugs have toxic effects on the inner ear and damage the hair cells. This will result in unilateral/Monaural deafness at the damaged side. This applies to all structures up to the cochlear nucleus/ before the superior olive.

-Lesions from the level of the superior olive onward result in impaired hearing affecting, mostly, the contralateral ear.

The cells in the auditory cortex are arranged as columns. The posterior columns receive high frequency sounds. The anterior columns receive low frequency sounds. Some books say that the basilar membrane determines the frequency of sound. It is theorized that different areas of the different components of the auditory system respond to different frequencies of sound.

The main function of the association cortex is that it integrates incoming sounds with auditory memory stores

<u>There are 2 types of Deafness</u>

1) **Sensory Neural Deafness**- in the receptor or nerve

2) **Conduction Deafness** – blockage of the ear by excessive wax accumulation or otosclerosis (defect in the middle ear- most commonly, hardening of joints between the oscicles, so there is no movement)

You can differentiate between these 2 types of deafness with the following tests:

<u>1) Weber Test</u>

Strike a tuning fork on the patient's head. If the vibrations are hear equally in both ears, that means that there is equal hearing OR equal loss in hearing. This depends on how strongly you hear the vibration.

If you have nerve deafness in one ear → you will only hear tone in the other ear

If you have conduction deafness in one ear → the vibration will be LOUDER in the affected ear because the sound will be conducted by bone.

2) Rinne Test

This test is used to compare Bone and Air conduction hearing

Strike the tuning fork and place it on the mastoid process of the patient, until the patient can no longer hear the vibrations. Move the fork toward his ear and if the patient can hear the vibration again, then this indicates that air conduction is stronger than bone conduction and the patient does not have impaired hearing.

Try it another time, but start from the ear, and then go to the mastoid process. If the patient could NOT hear it in front of the ear, but could hear it at the mastoid process, then the patient has conduction deafness.

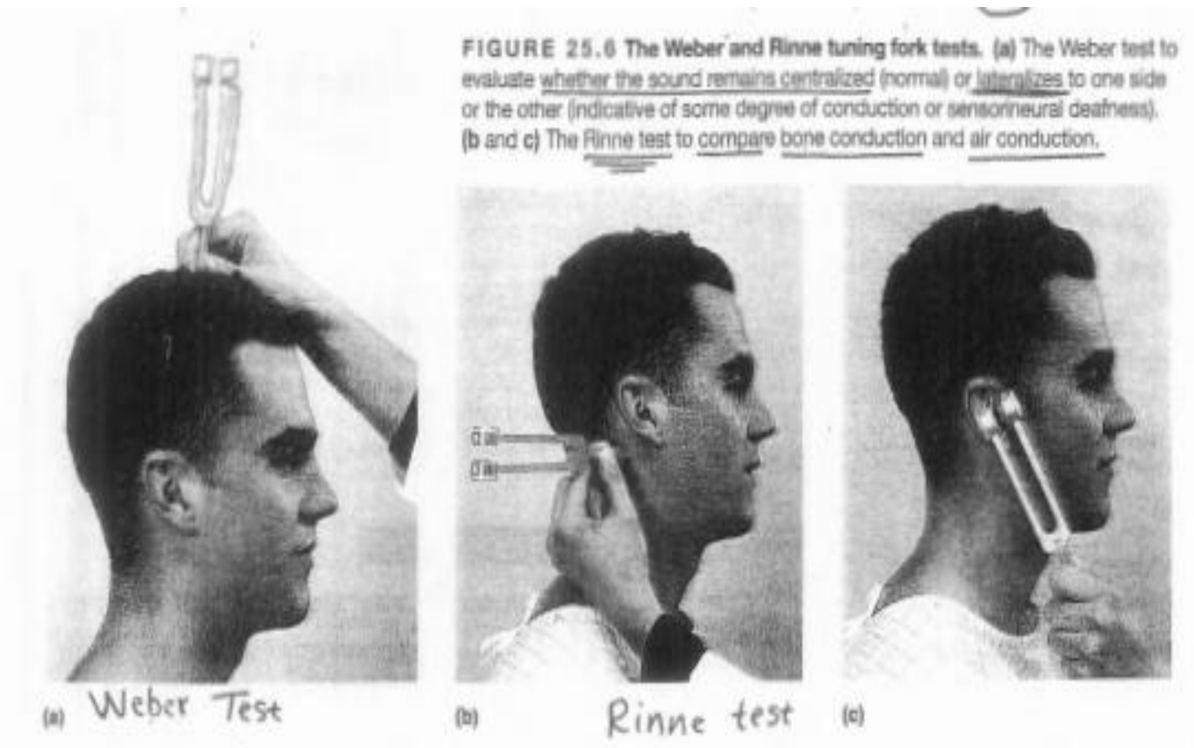


FIGURE 25.6 The Weber and Rinne tuning fork tests. (a) The Weber test to evaluate whether the sound remains centralized (normal) or lateralizes to one side or the other (indicative of some degree of conduction or sensorineural deafness). (b and c) The Rinne test to compare bone conduction and air conduction.

Anatomy of the Central Nervous System
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