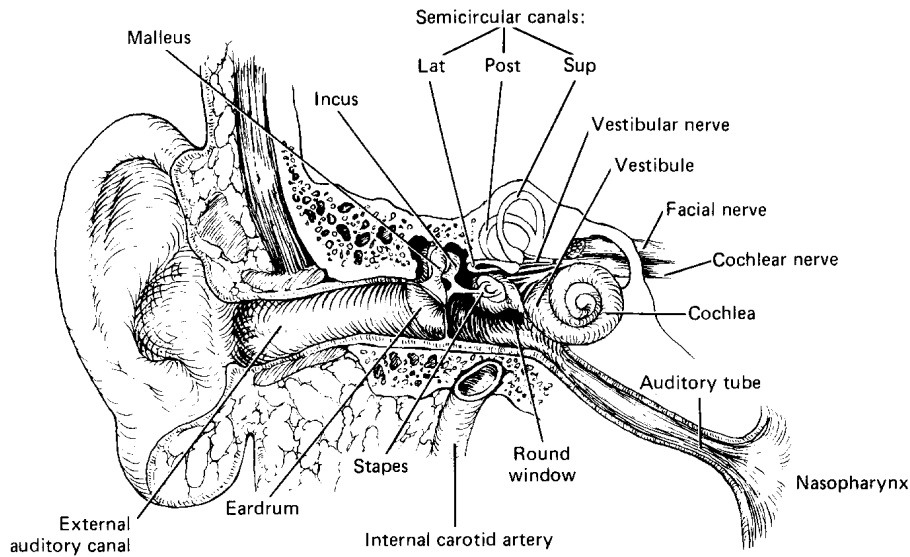
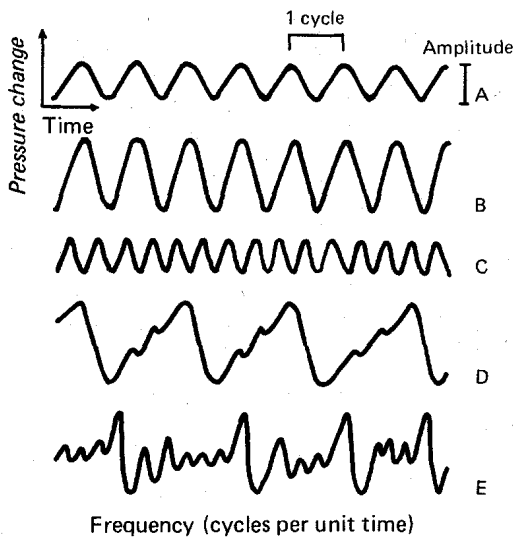


INTRODUCTION



Terms: external auditory canal = external auditory meatus
 eardrum = tympanic membrane
 auditory tube = Eustasian tube

- A. Transducer Function of Ear: to convert sound (pressure) waves in the range 20 - 20,000 hz (hertz, cycles/second) into action an action potential pattern that permits sensation of the incident sound and a recognition of its parameters
- B. Psychophysics of Sound
 - 1. Sound parameters



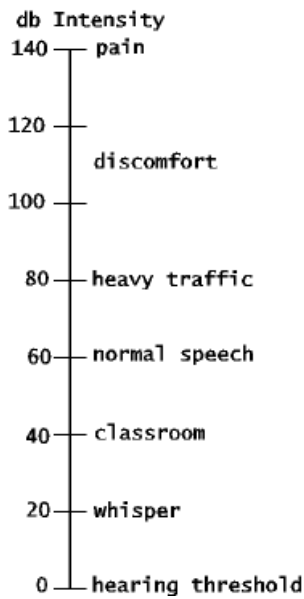
<u>Physical</u>	<u>Unit</u>	<u>Physiological</u>
Frequency	Hertz (hz, cycles/second)	Pitch
Power (or amplitude)	bel or decibel (db)	Loudness
Shape of wave	harmonic content (freq. spectrum)	Timbre

Note: "pure tone" = sine wave

INTRODUCTION (continued)

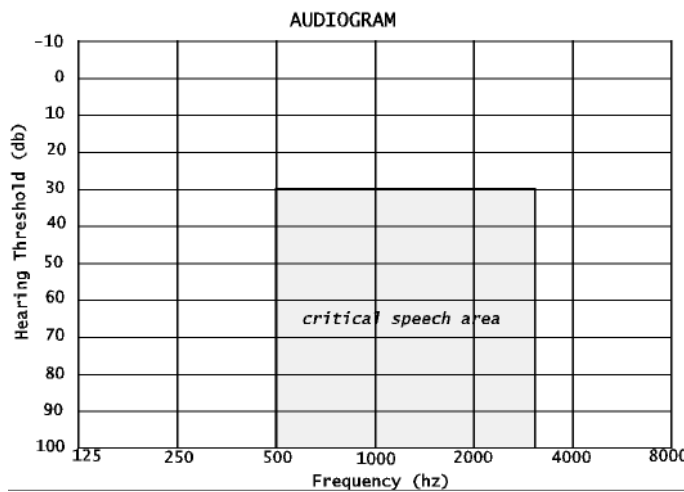
B. Psychophysics of Sound (continued)

2. Units of Power/Loudness/Intensity: decibels (db)



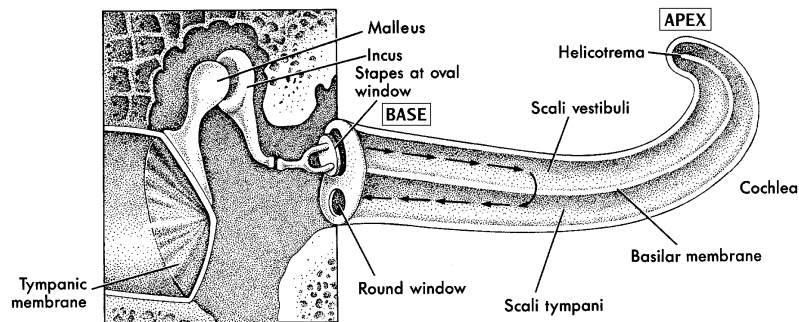
Note: when two sound sources are present simultaneously, the louder tends to mask (suppress perception of) the softer

3. Audibility Curve: the auditory system is most sensitive at the midrange of frequencies (500-3000 hz) and progressively less sensitive at higher and lower frequencies
4. Audiogram: Hearing threshold *compared to normal* as a function of frequency
 - a. determined by measuring hearing threshold compared to normal at several frequencies
 - b. on an audiogram, normal sensitivity at a given frequency is plotted as 0 db; degree of hearing loss at each frequency is noted by the distance below the 0 db line
 - c. each ear is tested separately



AUDITORY SYSTEM SOUND TRANSMISSION

A. Sequence for Sound Wave Transmission



1. Collection of sound waves in the external ear canal (external auditory meatus); concentrates sound waves
2. Vibration of the tympanic membrane (ear drum)
 - a. large area (relatively) so helps to amplify sound
 - b. transmits sound vibrations to middle ear ossicles
3. Conduction by ossicles through middle ear
 - a. ossicular function: sound transmission from tympanic membrane to oval window of the cochlea

- b. middle ear muscles (tensor tympani and stapedius): muscle contraction decreases efficiency of ossicular sound transmission

function: protect against cochlear damage due to excess sound energy; *tympanic reflex*

loud sound \Rightarrow muscle contraction

Note: cannot protect against very loud sound or sound of sudden onset because of response latency (0.25 sec) and limited attenuation (10db)

Note: decreased hearing sensitivity after exposure to loud sound; initially sensitivity recovered with time but with repeated exposure may become permanent

- c. Eustachian tube: equalizes pressure between middle ear and atmosphere to prevent stress on tympanic membrane by venting middle ear to nasopharynx

Note: Eustachian tube normally closed, but opened by swallowing, chewing, yawning, etc.; can be blocked by middle ear infection

4. Vibration of the oval window
5. Transmission through the cochlear fluid
6. Vibration of the basilar membrane and excitation of the hair cells of the Organ of Corti

AUDITORY SYSTEM SOUND TRANSMISSION (continued)

B. Normal and Abnormal Conduction

1. Ossicular conduction

tympnum ⇒ middle ear ossicles ⇒ oval window ⇒ basilar membrane

normal, highest sensitivity

2. Air conduction

tympnum ⇒ middle ear air ⇒ round window ⇒ basilar membrane

important if ossicular chain becomes broken or fixed (rigid)
30 db hearing loss (compared to normal)

3. Bone conduction

bone vibration ⇒ basilar membrane

inefficient, 50 db hearing loss
bypasses ear canal, tympanic membrane, middle ear, oval and round windows
useful with hearing aid if normal conduction pathways lost

C. Clinical Classification of Deafness

1. Conduction deafness: loss or reduction of ossicular conduction (but bone conduction remains)

examples: ear canal blockage, scarred or thickened tympanic membrane, otitis media, fixation of the ossicular chain (ankylosis, otosclerosis)

2. Nerve (or sensory neural) deafness: lesion in cochlear fibers of VIII nerve or Organ of Corti; loss or reduction of all three routes of conduction

examples: Organ of Corti damage by excess stimulation or certain antibiotics, tumor or trauma damaging VIII th nerve

3. Central deafness: intact ear and VIII th nerve but lesion in CNS pathway

Note use of sound source to diagnose cause of hearing loss; e.g. tuning fork in air vs. tuning fork on bone

Note: cause of deafness can be diagnosed in infants by the *Brainstem Auditory Evoked Potential* (electrical waves originating in the brain stem and recorded from the surface using a brief auditory stimulus), also called the Auditory Brainstem Response (ABR)

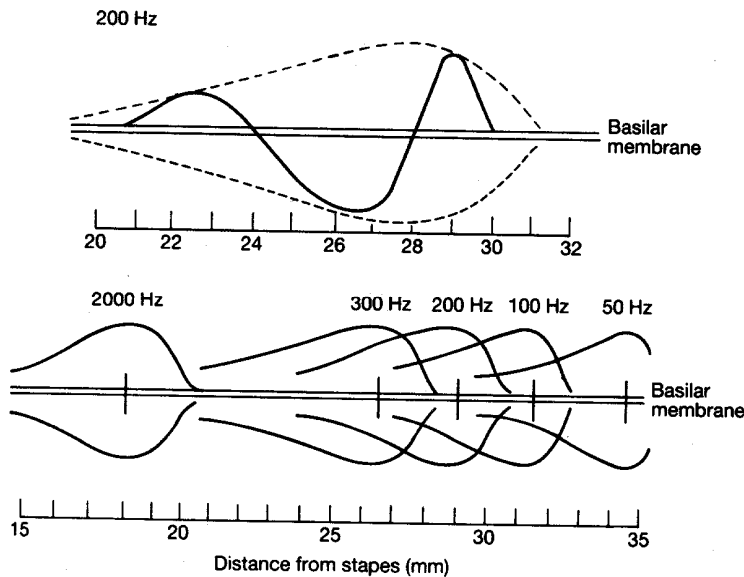
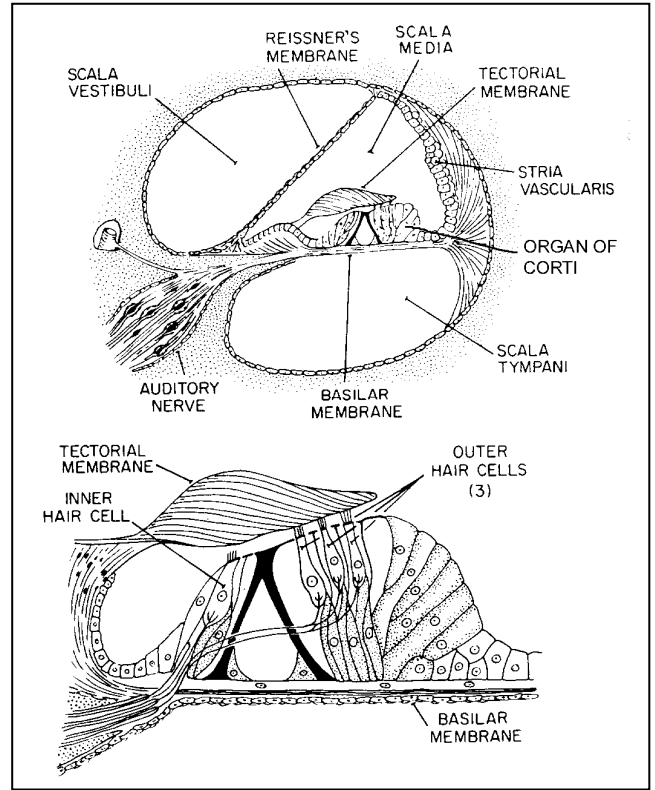
COCHLEAR PROCESSING

A. Sequence in Cochlea

vibration of basilar memb. \Rightarrow bending of hair cells \Rightarrow depol. of hair cell \Rightarrow transmitter release from hair cell soma \Rightarrow APs on auditory nerve axon

1. Pressure is transmitted through the oval window to cochlear fluid
2. Pressure wave moves through the cochlea from the base to the apex
3. This sets up a traveling wave in the basilar membrane, beginning at the base of the cochlea. This wave travels down the basilar membrane, first increasing and then decreasing in amplitude (depends on mechanical characteristics of cochlea). The site of maximum displacement depends upon frequency. The high frequencies are rapidly damped, so their peak amplitude is near the base; the low frequencies travel further toward the apex. Lowest frequency waves cause vibration along whole length of basilar membrane

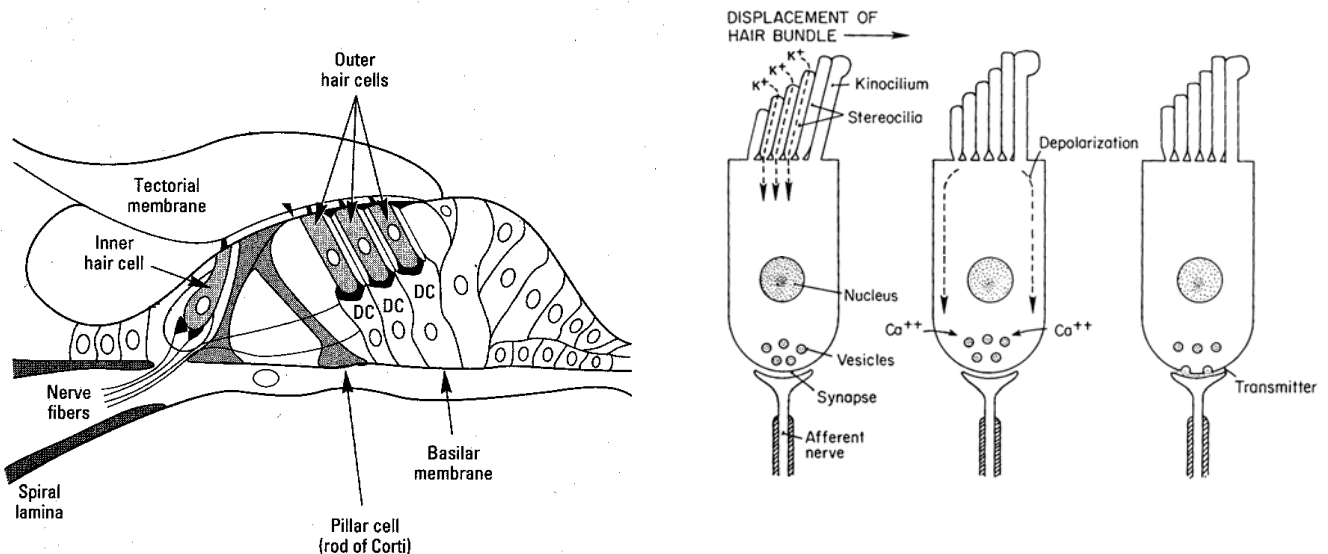
Note: In the illustration to the right, the cilia of the inner hair cells should contact the tectorial membrane



COCHLEAR PROCESSING

A. Sequence in Cochlea (continued)

4. Vibration of the basilar membrane causes bending of the hair cells. This causes inner hair cell depolarization due to cation (mainly K^+) influx (generator potential), followed by Ca^{2+} influx (due to opening of voltage-dependent Ca channels), leading to release of excitatory transmitter, causing action potentials to be developed on auditory nerve axons.
 - a. inner hair cells and primary auditory afferent neurons are separate cells. Hair cells depolarize and release transmitter but do not generate action potentials. Primary auditory afferent neurons generate action potentials when excited neurotransmitter released from hair cells.
 - b. influx of K^+ into inner hair cell is due to K^+ channel opening, which occurs when the cilia flex toward the stria vascularis. K^+ influx is made possible by the high concentration of K^+ in the scala media fluid, due to K^+ secretion by the stria vascularis.
 - c. hair cell flexing is promoted by the tectorial membrane, which contacts the hair cell cilia
 - d. influx of Ca^{2+} into the soma also causes opening of soma K^+ channels, terminating the depolarization

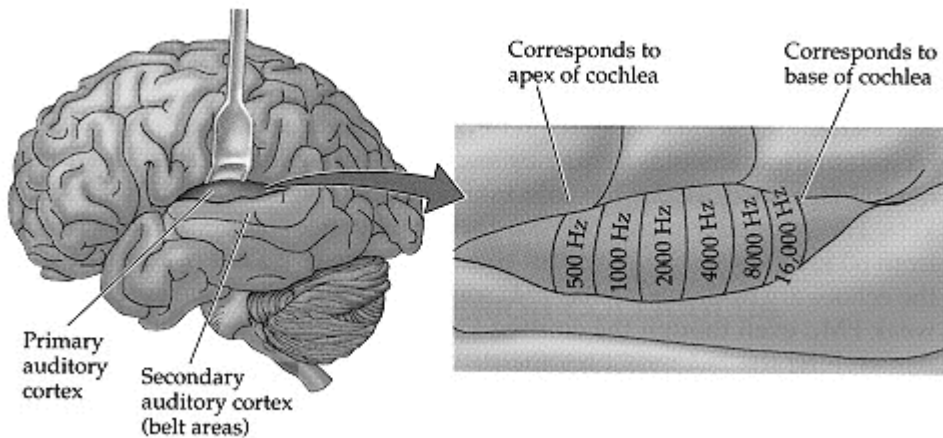


B. Determination of Pitch and Loudness

1. Pitch sensation is mediated by two mechanisms
 - a. place mechanism: which region of the basilar membrane is maximally excited; e.g. high frequencies near base, lower frequencies toward apex (main mechanism)
 - b. volley mechanism: at lower frequencies, a volley of APs is generated at the same frequency as the sound wave
2. Loudness depends on
 - a. how strongly individual hair cells are stimulated
 - b. how many hair cell axons are recruited

AUDITORY CORTEX

- A. Action potentials from the cochlea are transmitted through several synapses in the brain, finally reaching the auditory cortex



B. Primary Auditory Cortex (A1)

1. Located in the Temporal lobe
2. Organized as columns perpendicular to the cortical surface
3. Columns are frequency-specific (cochlear map)
4. Although some frequency discrimination is possible even with bilateral injury to A1, discrimination of complex sounds, such as speech, requires the auditory cortex

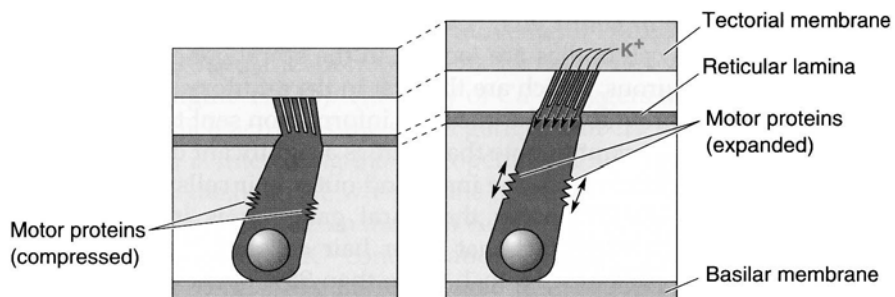
C. Auditory Cortex Projections

1. A1 projects to adjacent areas such as A2 (secondary auditory cortex, which also gets input from the thalamus) and speech processing areas
2. Projection areas associated with identifying significance of sounds, language, etc.

EFFERENT CONNECTIONS TO THE COCHLEA

A. Efferent innervation

1. Axons originate in the brain
2. Some axons terminate on the outer hair cells
 - a. outer hair cells are motor; can lengthen or shorten
 - b. length change alters the position of the tectorial membrane, thus changing the sensitivity of the inner hair cells and also can cause the cochlear fluid to vibrate



- c. postulated functions
 - 1) amplification to increase hearing sensitivity (replace some of the sound energy lost through viscous damping)
 - 2) attenuation to protect inner hair cells from excess displacement
 - 3) sharpening of frequency discrimination

Note: When functioning as an acoustic amplifier, the outer hair cells generate sound wave that can be detected by a microphone placed in the ear; this forms the basis of the otoacoustic test often used in assessing hearing in newborns

3. Some axons terminate on inner hair cell axon endings
 - a. postulated function: help control hearing sensitivity