

Physiology of Hearing

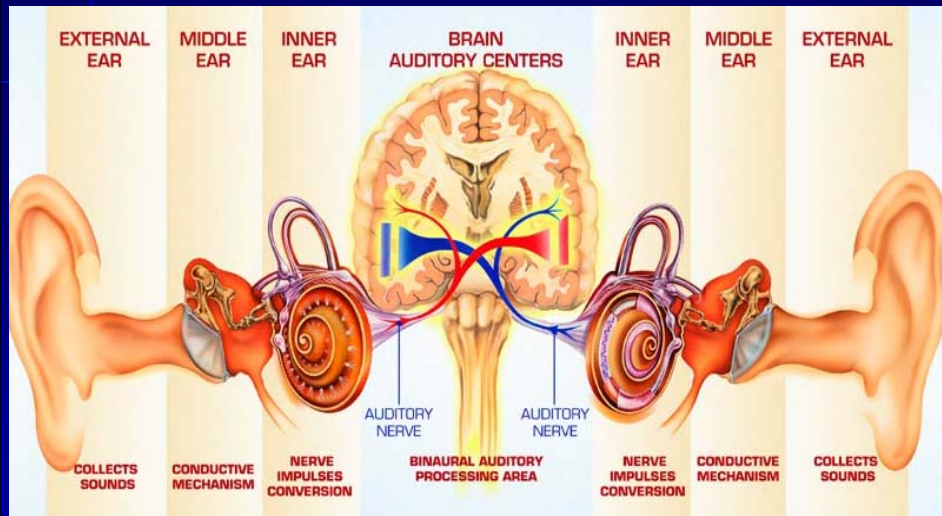
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Undergraduate Round Courses
2008-2009

Is hearing important?

- **Communication**
Hearing is essential to **Language**
- **Localization**
Determining the location of
unseen **sound sources**

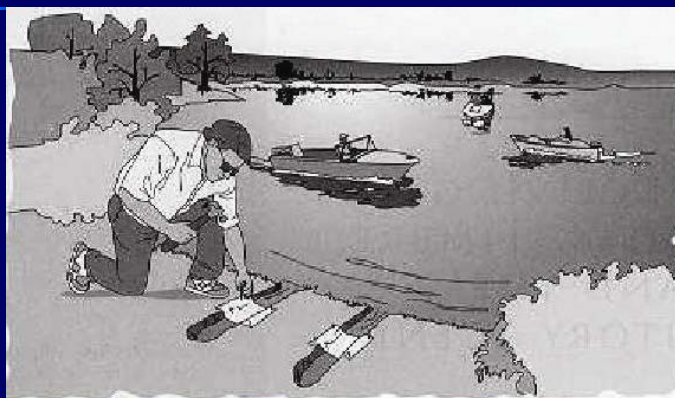
How do we hear?



Schematic representation of normal hearing mechanism

Hearing is not so simple!!

The ripples in a lake analogy



You have to tell what's in the lake by just seeing the ripples in the two pieces of paper in two channels at the lake's edge

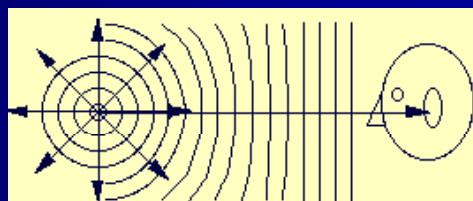
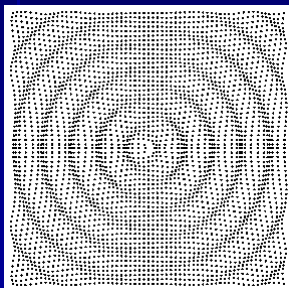
What needed for normal hearing?

- **Adequate stimulus (SOUND)**
- **Conduction** of stimulus to sensory organs of hearing
- **Sensory transduction** of stimulus at organs of hearing
- **Neural transmission** of the signal
- **Central auditory processing** of the signal at the brain

Normal hearing - Adequate stimulus

What is sound?

SOUND: (perception of) **pressure waves** generated by **vibrating** air molecules



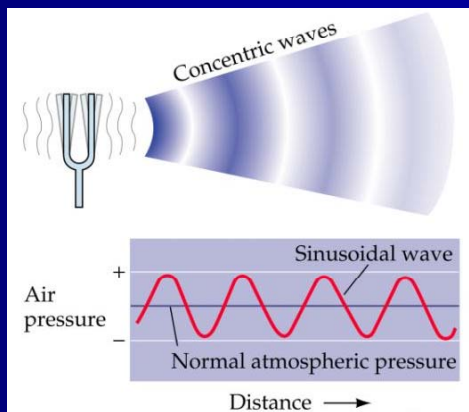
Sound source

Listener

Normal hearing - Adequate stimulus

Sound waves:

- Sound **travels in waves** through media
- Alternating **compression** (dense molecules) & **rarefaction** (loose molecules) waves
- The simple sound is the **sinusoidal wave** or **Pure tone**

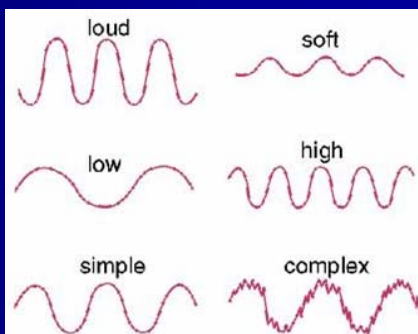


Normal hearing - Adequate stimulus

What properties of sound does the ear detect?

- 1- Pressure level (dB)
- 2- Frequency (cycle/sec = Hz)
- 3- Complexity

Physical Dimension	Perceptual Dimension
INTENSITY	Loudness
FREQUENCY	Pitch
COMPLEXITY	Timbre

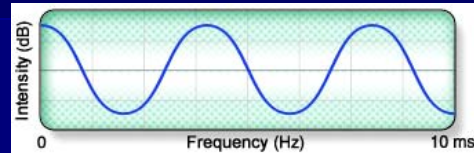


Normal hearing - Adequate stimulus

Frequency of sound:

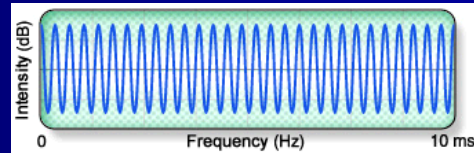
Low frequency tones

300 Hz tone

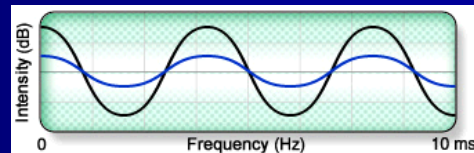


High frequency tones

3000 Hz tone



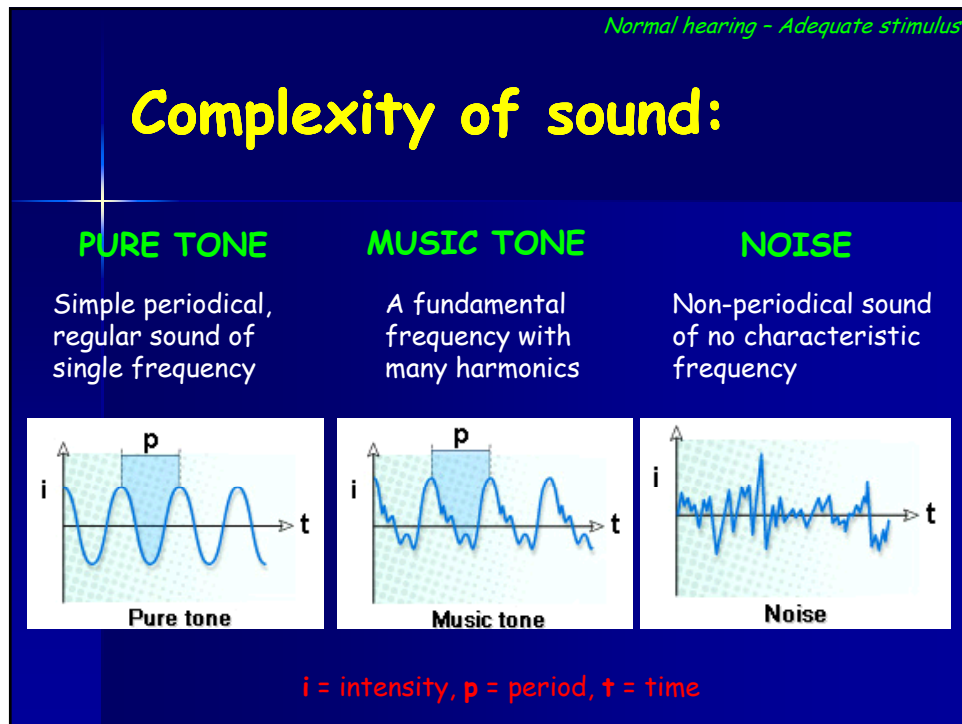
Tones may be of
different amplitudes
and same frequency



Normal hearing - Adequate stimulus

Intensity of sound:

SOUND	dB SPL
Rocket Launching pad	180
Jet plane	140
Gunshot blast	130
Car horn	120
Pneumatic drill	110
Power tools	100
Subway	90
Noisy restaurant	80
Busy traffic	75
Conversational speech	66
Average home	55
Library	40
Soft whisper	30



Normal hearing - Adequate stimulus

How sensitive the ear to sounds?

- The Human ear is sensitive to sounds over a **wide range** of:
 - **Frequencies:** 20 - 20,000 Hz
 - **Amplitudes:** 0.0002 - 200 dyne/cm²
- The human ear can detect the **difference** between two sounds occurring 10 μsec apart in **time**

Note: The wide sensitivity range of human hearing necessitates the use of **Logarithmic (Ratio) scales** rather than **Linear (Numerical) scales**

Normal hearing - Adequate stimulus

Logarithmic scales:

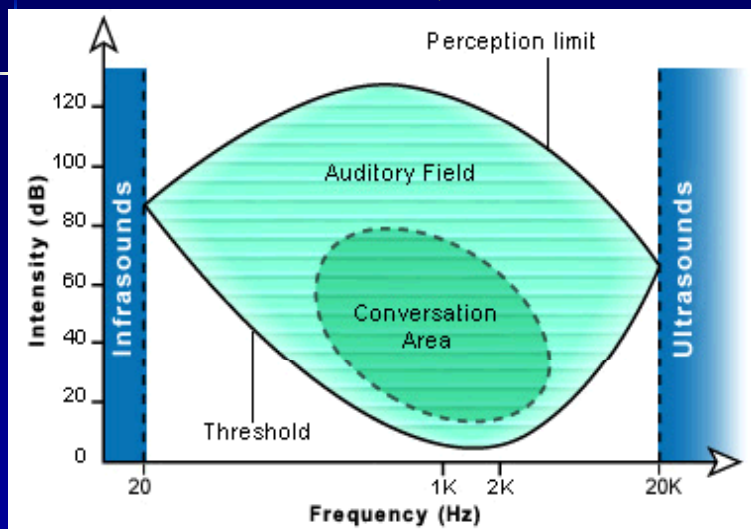
- **Decibel (dB) scale** for sound pressure levels:
 - **0 dB** = 0.0002 dyne/cm² (threshold)
 - **120 dB** = 200 dyne/cm² (limit)

So, the range of hearing is reduced to only 120 units of measurement (instead of (10)⁶ units)
- **Octave scale** for sound frequency in Hz:

frequency range is measured in **octave bands** i.e. each frequency is double the previous one e.g. 250, 500, 1000, 2000, 4000 Hz, ...etc.

Normal hearing - Adequate stimulus

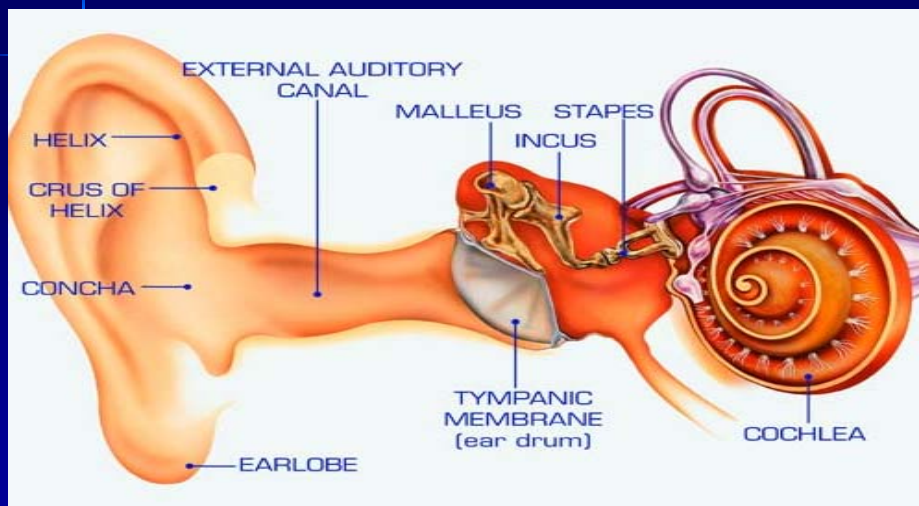
Human auditory field:



Note: The human ear is **not equally sensitive** across frequency range

Normal hearing - Conduction mechanism

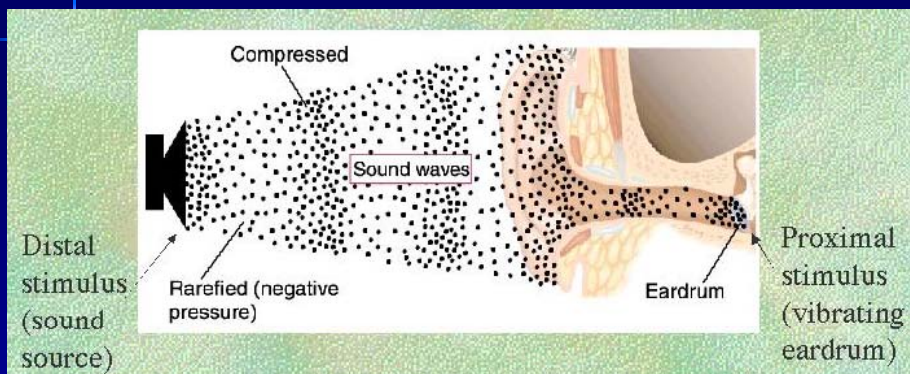
Sound conduction in the ear:



Structure of the human ear

Normal hearing - Conduction mechanism

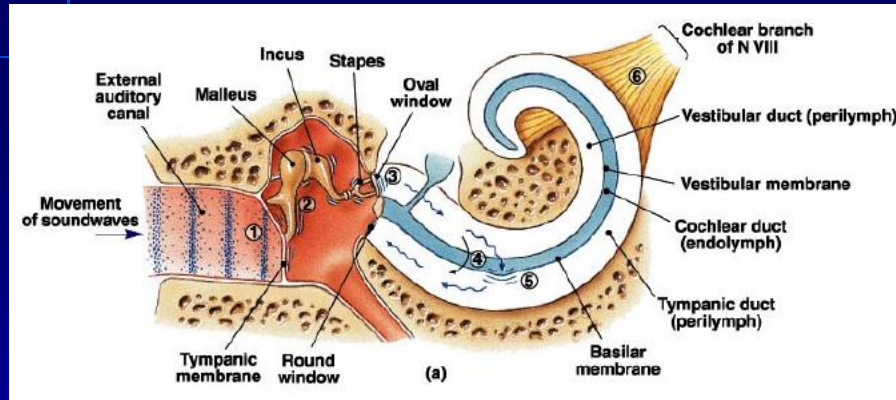
Sound conduction in the ear:



- Sound waves are collected by the **pinna** and focused into the **EAC**
- The vibration pass down the EAC and strike the **TM**

Normal hearing - Conduction mechanism

Sound conduction in the ear:

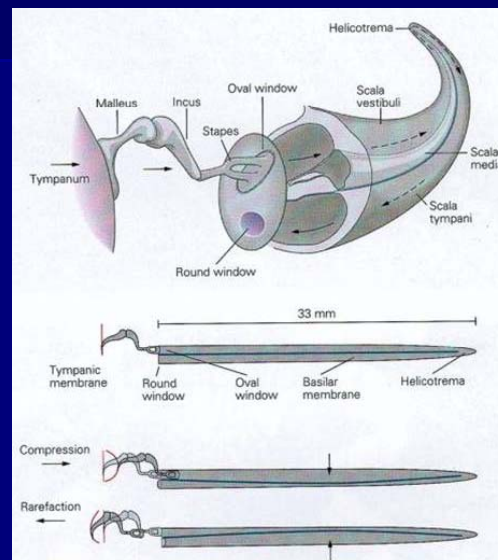


- **TM** vibrates in response to sound and moves the ossicles
- The **ossicles** vibrate the OW membrane

Normal hearing - Conduction mechanism

Sound conduction in the ear:

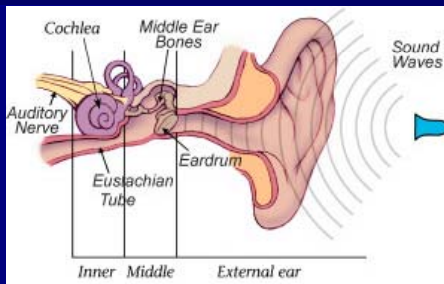
The **OW membrane** vibrations are transmitted to the **inner ear fluids** in scala vestibuli, scala tympani and scala media (cochlear duct) where the **organ of Corti** vibrates in turn



Normal hearing - Conduction mechanism

External ear functions:

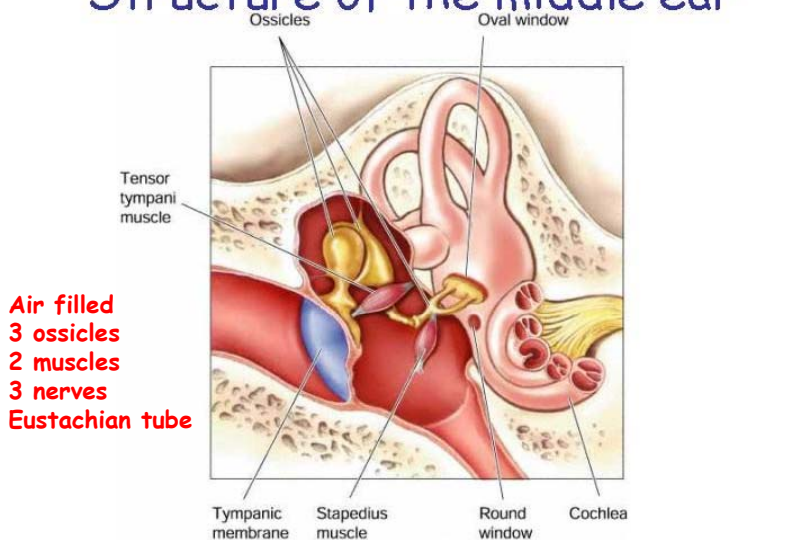
- **Collecting** sound waves
- **Amplification** of frequencies 2000 - 4000 Hz (resonant frequency of EAC)
- Providing cues about the vertical **localization** of a sound source (by the degree of sound waves reflection over the pinna)



Normal hearing - Conduction mechanism

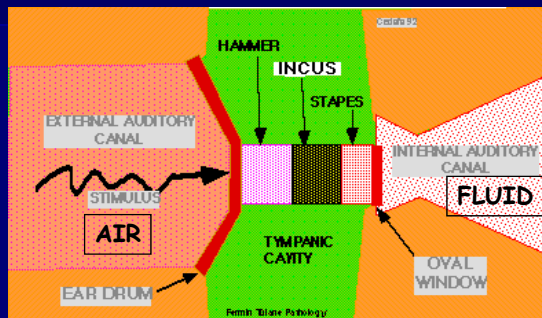
Middle ear functions:

Structure of the middle ear



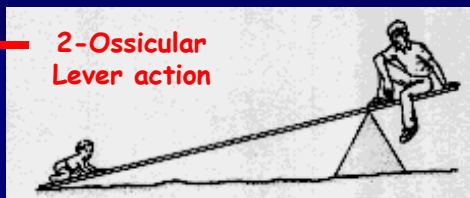
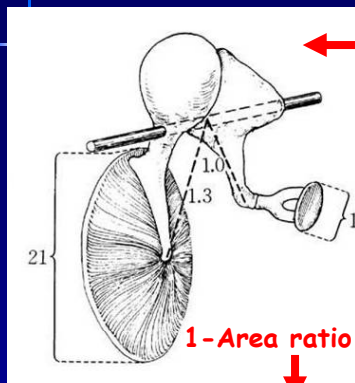
Middle ear functions:

ME matches the relatively low impedance of airborne sounds to the higher impedance of inner ear fluids:



- **Focusing the force** at the large diameter TM onto the much smaller diameter OW
- Mechanical advantage gained by the **ossicular lever action**

Middle ear mechanics:



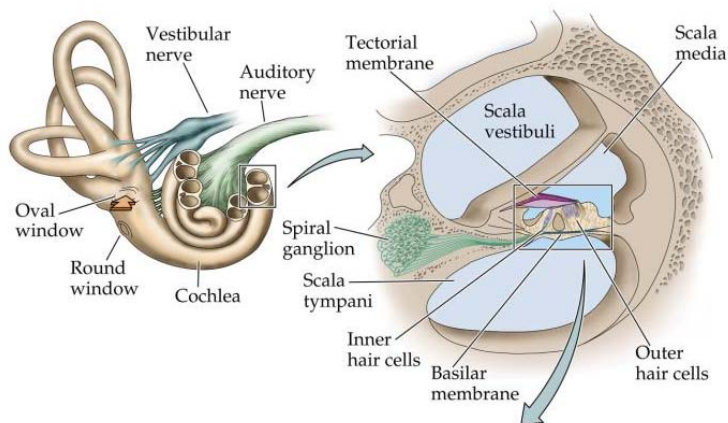
Malleus and Incus behave as 1st degree lever

$$\frac{\text{Diameter of TM}}{\text{Diameter of OW}} = \text{Area ratio } 21:1$$

Normal hearing - Sensory transduction

Sound processing in inner ear:

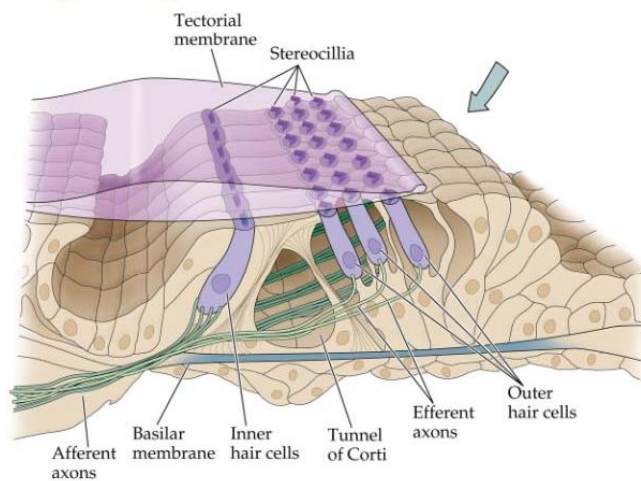
Structure of the inner ear



Normal hearing - Sensory transduction

Sound processing in inner ear:

Organ of Corti (Sense organ of hearing)



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Normal hearing - Sensory transduction

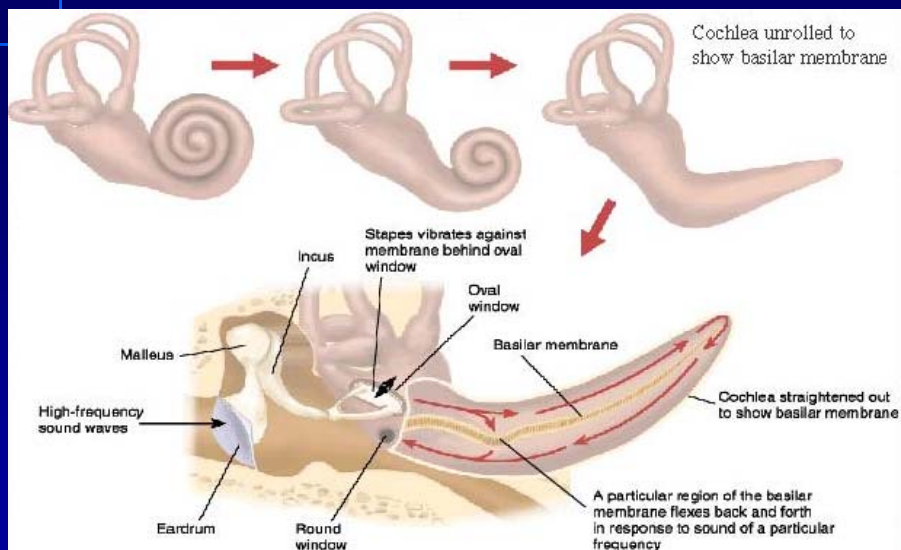
Sound processing in inner ear:

The inner ear has 2 main functions:

- **Mechanical frequency analysis:**
Decomposing complex acoustical waveforms into **simpler** elements
- **Sensory transduction:**
Acoustically generated pressure waves are transformed into **neural** impulses

Normal hearing - Sensory transduction

Frequency analysis in inner ear:

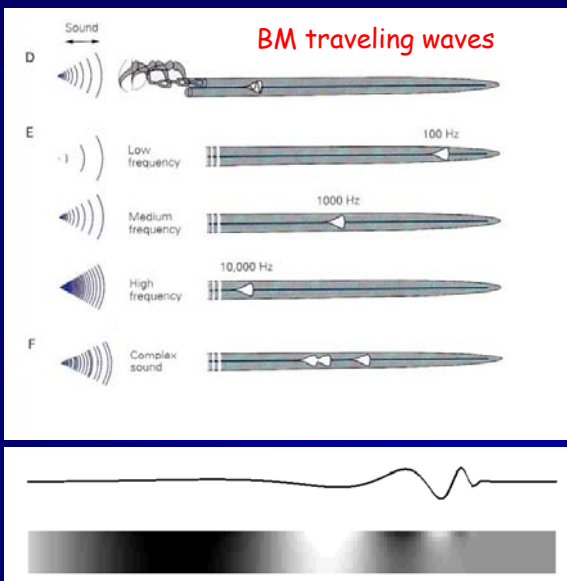


Normal hearing - Sensory transduction

Frequency analysis in inner ear:

The BM vibrations create the **traveling waves** which peak on characteristic place on the basilar membrane according to the frequency of the stimulating sound

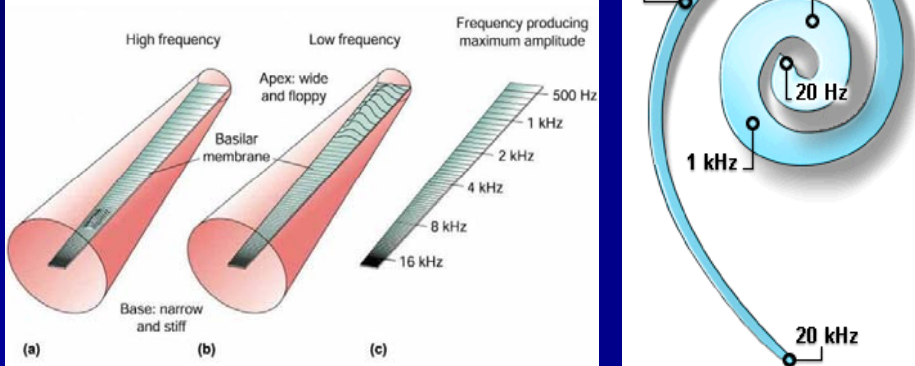
This is called **PLACE THEORY** of hearing



Normal hearing - Sensory transduction

Frequency analysis in inner ear:

Basilar membrane is tonotopically organized



Normal hearing - Sensory transduction

Frequency analysis in inner ear:

Thus, the inner ear acts as a:

- Complex
- Multichannel
- Mechanical

FREQUENCY ANALYZER

Travelling waves
Basilar membrane displacement as a function of frequency

Base Apex

Stéphane Bédard

Normal hearing - Sensory transduction

Sensory transduction in inner ear:

Tectorial membrane

Outer hair cell

Inner hair cell

Basilar membrane

Nerve fibers

HAIR CELL

stereocilia

kinocilium

nucleus

primary afferent nerve

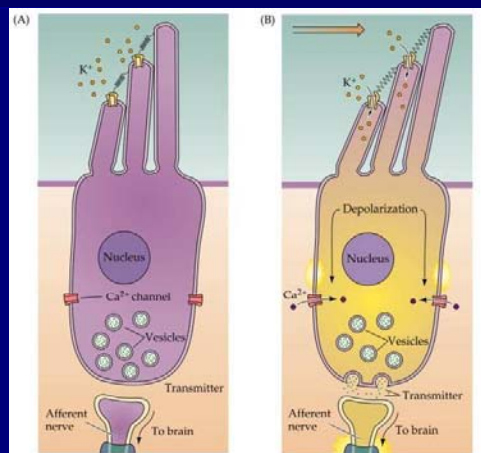
transmitter vesicles

The **tectorial membrane** picks up the sound pressure waves in the inner ear fluids, and pushes down on the hairs (cilia) of the **sensory Cells** (mainly outer hair cells)

Normal hearing - Sensory transduction

Sensory transduction in inner ear:

The **cilia** of sensory Cells move according to the incoming sound waves making some intracellular **chemical changes** causing a release of **neurotransmitters** at the synaptic junctions that generate **nerve impulses** in the auditory nerve fibers

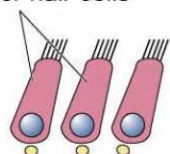


Normal hearing - Neural transmission

Neural transmission in auditory nerve:

Innervation of IHCs and OHCs

Outer hair cells



Inner hair cell

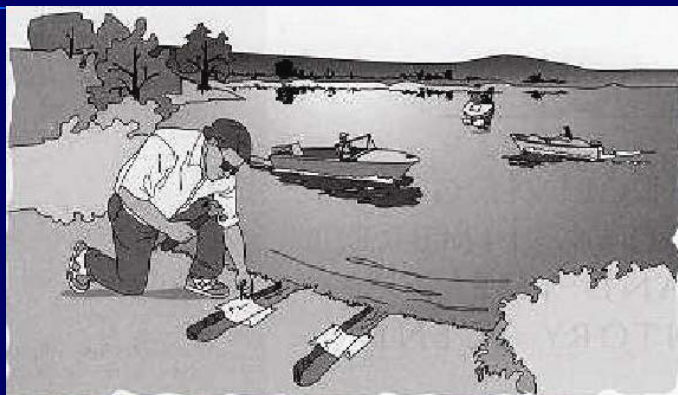


Spiral ganglion cells

Auditory nerve

So, what is the role of the ear?

Again ... the ripples in a lake analogy

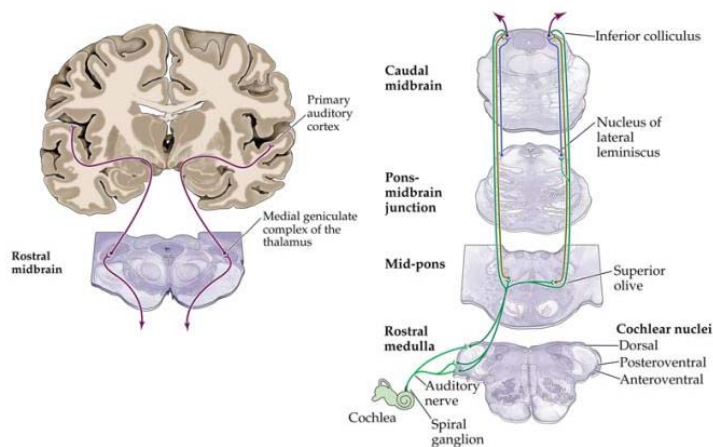


You (or the ear) can only describe the ripples (TM vibrations) in a way your boss (the brain) wants and understands

Normal hearing - Central processing

Central auditory processing:

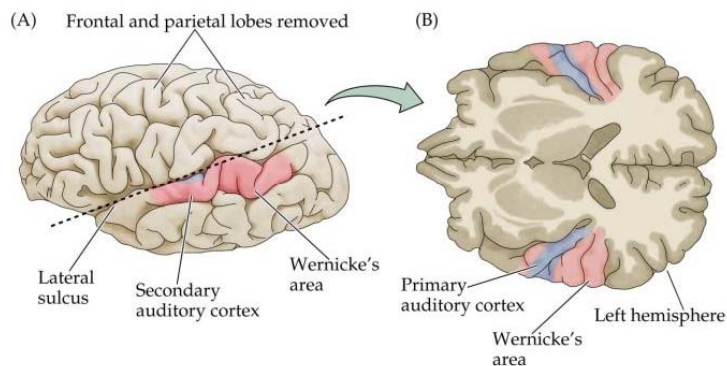
Ascending auditory pathways



Normal hearing - Central processing

Central auditory processing:

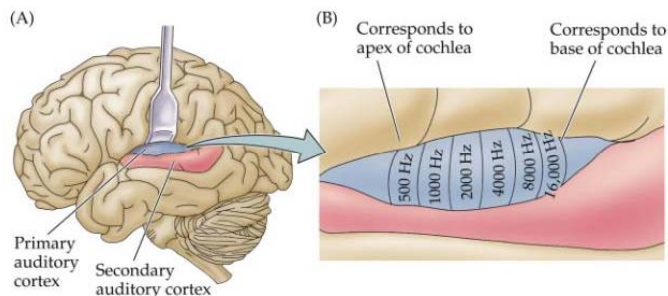
Auditory cortical areas



Normal hearing - Central processing

Central auditory processing:

Tonotopic organization in AI, areas 41 and 42



THANK YOU

