Hearing and Its Loss

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NOVA Lecture Series, Fall 2015

Overview of the Six Lectures

1. Background information and info about sound
2. Basics of Hearing, *Conductive and Sensorineural Hearing Loss*
3. Audibility, Loudness, Masking, Pitch Perception, Sound Localization
4. Congenital and Acquired Hearing Loss
5. Hearing Aids, Assistive Hearing Systems
6. Regeneration, Cochlear Implants, Brainstem Implants, The Future, Summing Up

Corrections from Lecture 1

Lou Ann Walker is NOT blind and deaf, as Helen Keller was. Rather, Ms. Walker was born to deaf parents and has written about that experience. She does agree with Ms. Keller that the primary problem of deafness is that it cuts the deaf person off from communication.

I showed a statistic suggesting that the lifetime cost of hearing loss for people born in 2000 was $2 billion. Obviously, that is not the cost per person but the total cost for all hearing-impaired persons born that year. Other estimates of specific costs were provided on that same slide.

Common Knowledge about the Auditory System

The sound waves in the air vibrate the eardrum . . .
and that makes something happen in the fluids of the inner ear (cochlea)

Neural activity begins in the cochlea and somehow travels to the brain

And (somehow) we HEAR!!

Cochlear Demonstration (~7 minutes total)

From: Breedlove, et al., *Biological Psychology,* Fifth Edition, 2007, published by Sinauer Associates and Sumanas, Inc.

Provides overview: external ear, middle ear, inner ear, basilar membrane and traveling waves (better seen at home), innervation of hair cells, shearing, ion exchange, neurotransmitter release

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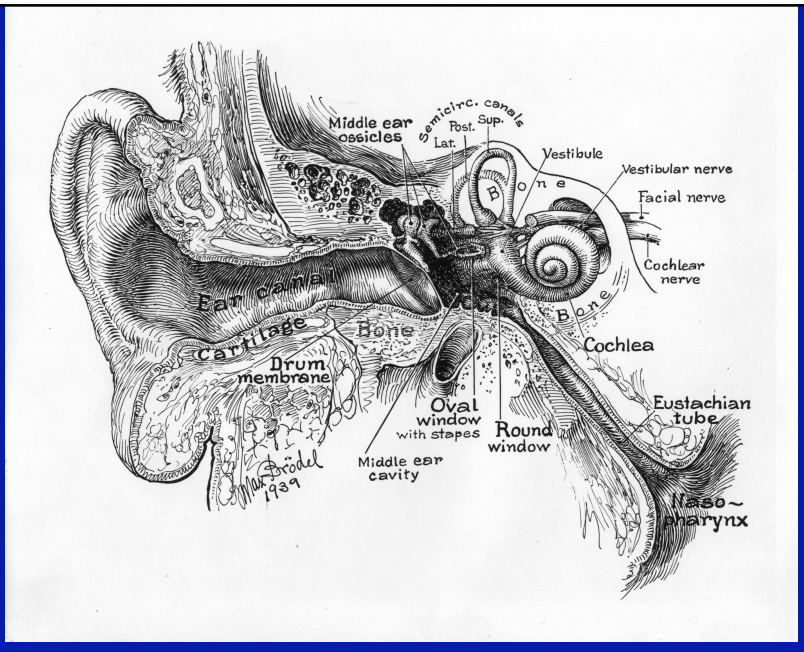
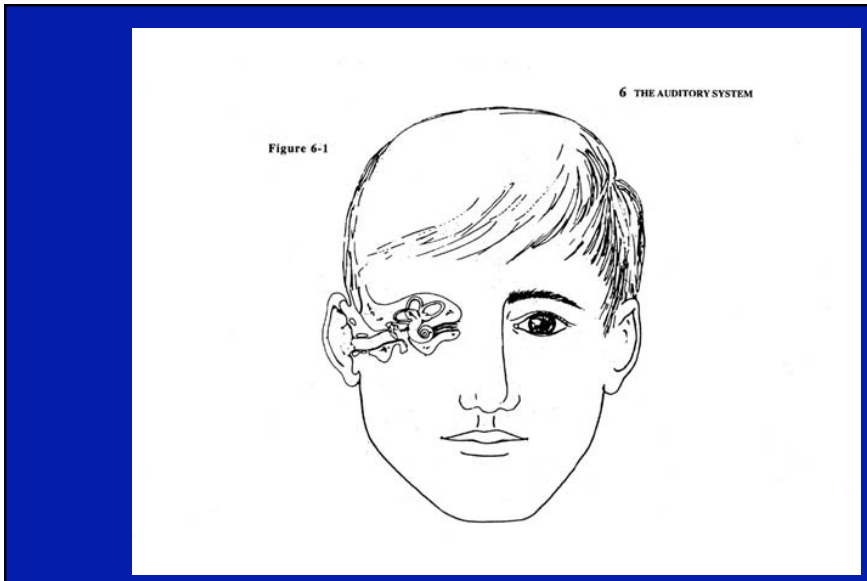
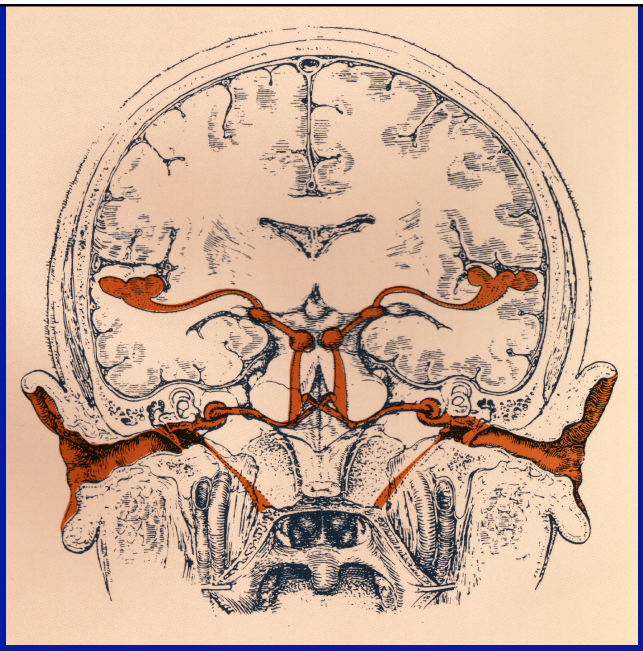
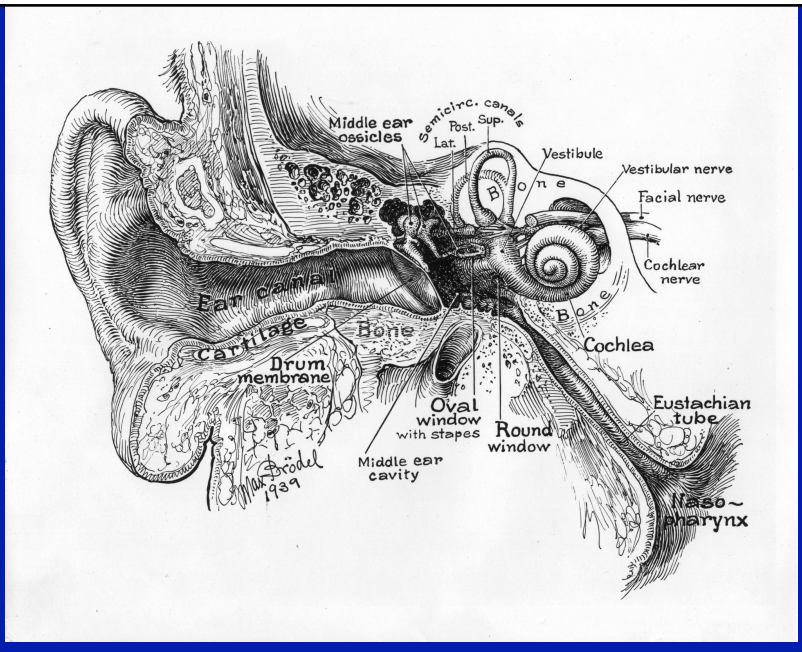


Max Brodel, 1939


6 THE AUDITORY SYSTEM
Figure 6-1

ASPIRIN





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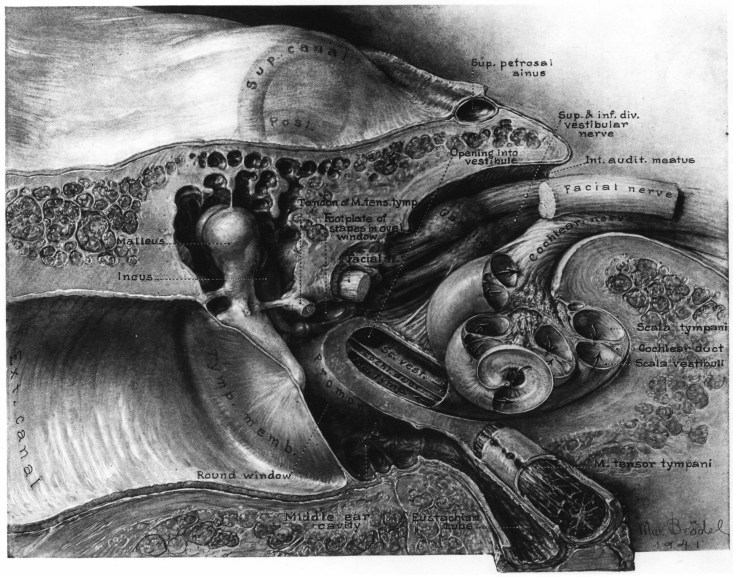

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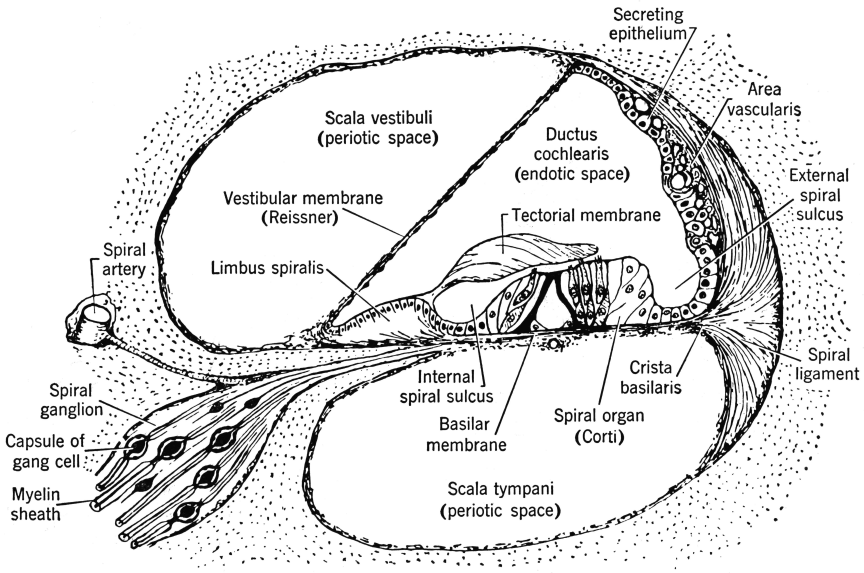
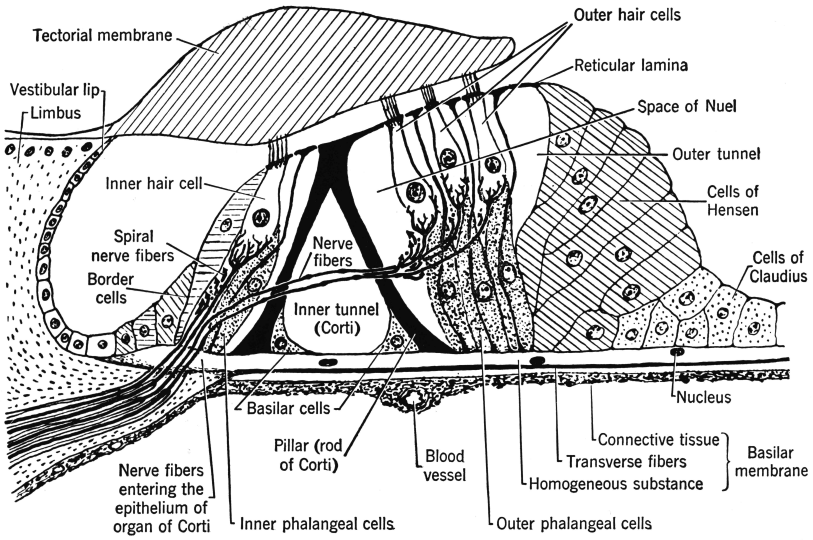


FIG. 1. Diagrammatic cross section of a cochlear canal. The ductus cochlearis (or scala media) contains the organ of Corti with its hair cells, the ultimate end organs of hearing. (From Rasmussen, 1943.)



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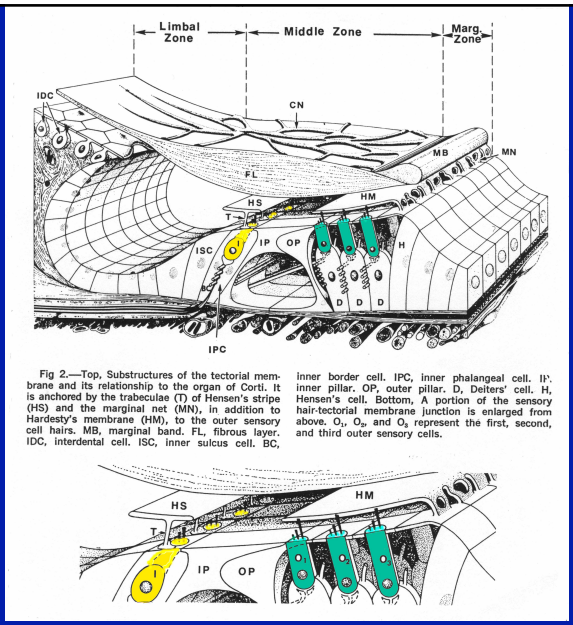

Fig 2.—Top, Substructures of the tectorial membrane and its relationship to the organ of Corti. It is anchored by the trabeculae (T) of Hensen's stripe (HS) and the marginal net (MN), in addition to Hardesty's membrane (HM), to the outer sensory cell hairs. MB, marginal band. FL, fibrous layer. IDC, interdental cell. ISC, inner sulcus cell. BC, inner border cell. IPC, inner phalangeal cell. IP, inner pillar. OP, outer pillar. D, Deiters' cell. H, Hensen's cell. Bottom, A portion of the sensory hair-tectorial membrane junction is enlarged from above. O_1, O_2, and O_3 represent the first, second, and third outer sensory cells.

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A more detailed description of the peripheral auditory system

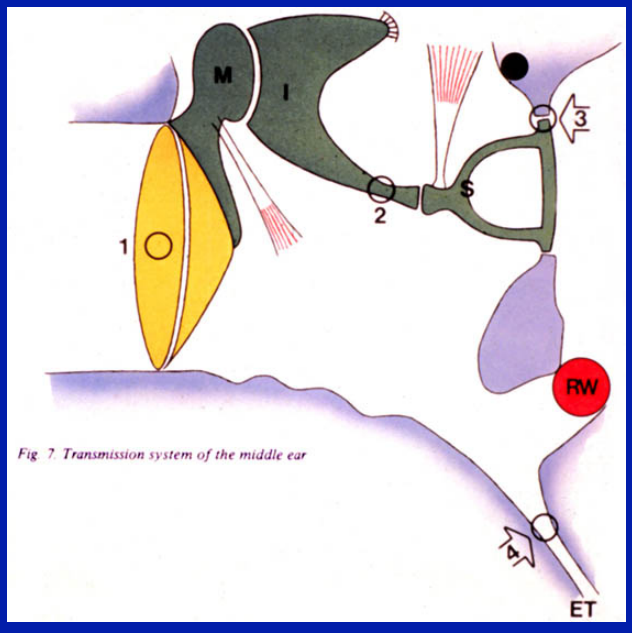


Fig. 7. Transmission system of the middle ear

< < Stapes Footplate in Oval Window

< < Round Window (air on the outside; fluid on the inside)

< < Eustachian Tube

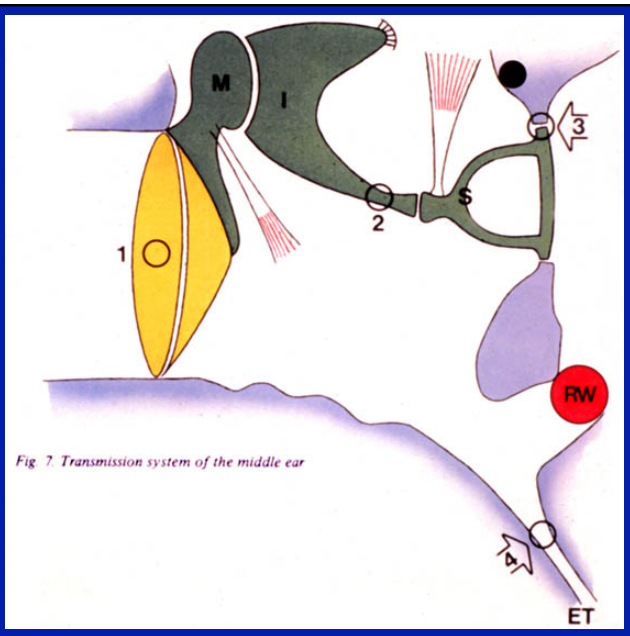


Fig. 7. Transmission system of the middle ear

At threshold of hearing, eardrum moves a few picometers (= 0.000000000001 meter) - less than diameter of a hydrogen atom – an extremely sensitive system

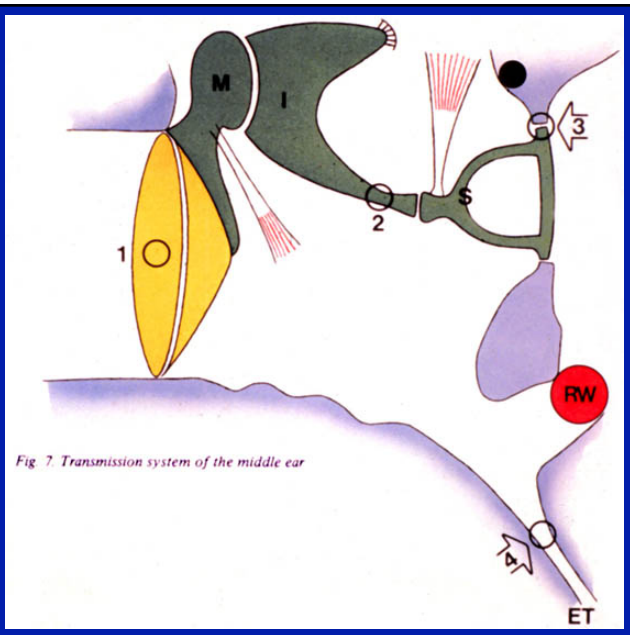


Fig. 7. Transmission system of the middle ear

Physical area of the eardrum is about 67 mm^2 and the physical area of the stapes footplate is about 3.2 mm^2 ==> ~21:1 ratio ==> ~ 26 dB of pressure increase

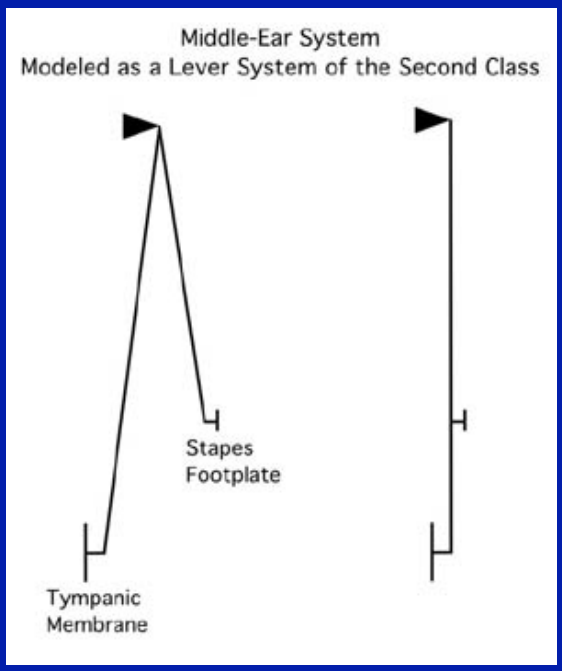
Areas

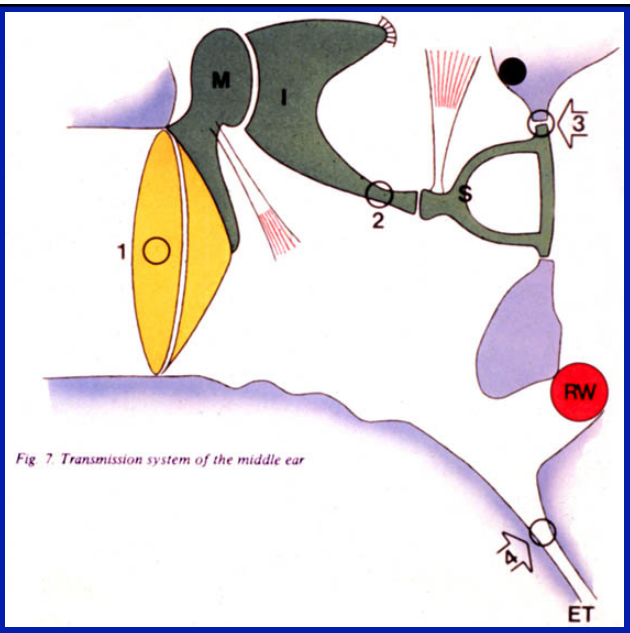
Eardrum ~= 67 mm²

Stapes ~= 3.2 mm²

Area ratio ~= 21:1

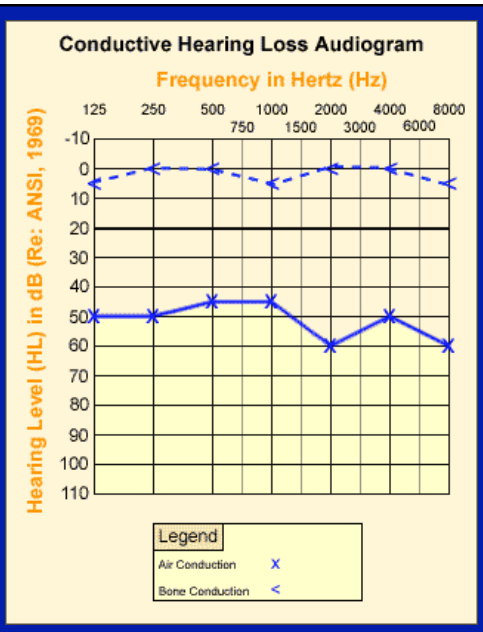
==> ~ 25-30 dB of pressure increase from air to cochlear fluids





<<<<

Our first cause(s) of hearing loss – ear wax or otitis media or otosclerosis and other problems with the middle-ear space

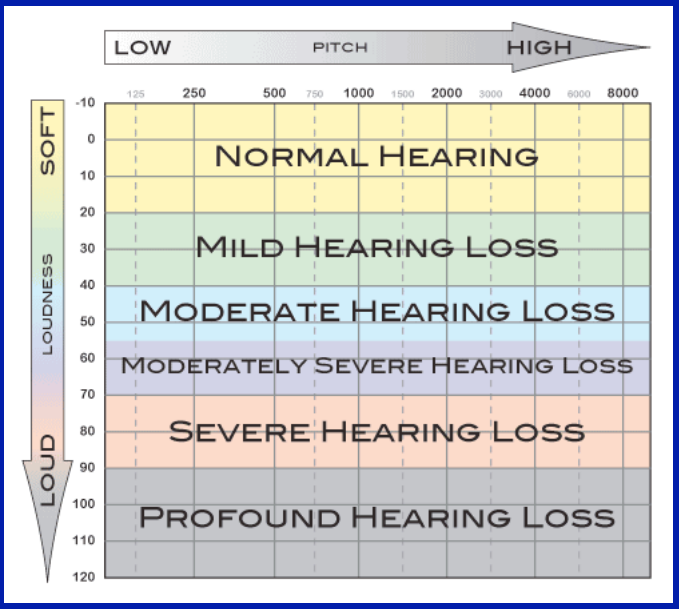


<< Normal-hearing range

<< "Flat" hearing loss of about 50 dB

Bone-conduction values at top (<) reveal cochlea is normal, but middle ear is not

Audiogram Graph Space



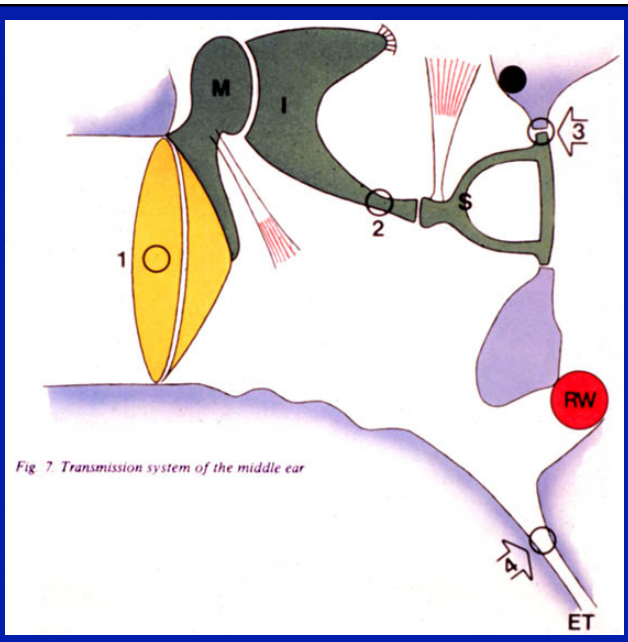


Fig. 7. Transmission system of the middle ear

Pressure-equalizing (PE) tubes can be inserted in eardrum after multiple middle-ear infections

Acoustic Reflex

Two muscles that attach to the middle-ear bones

- Stapedius and Tensor Tympani

Both muscles are activated by (relatively intense) sound

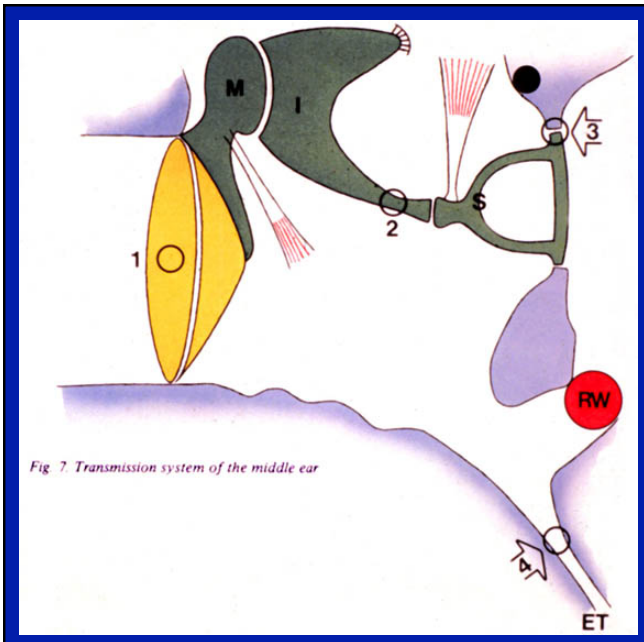
- also by changes in head/body/ position

Contraction of Stapedius muscle alters the mode of vibration of stapes

Result of contraction of middle-ear muscles is attenuation of about 20 dB

Can serve as a protective mechanism

- not the reason it evolved?



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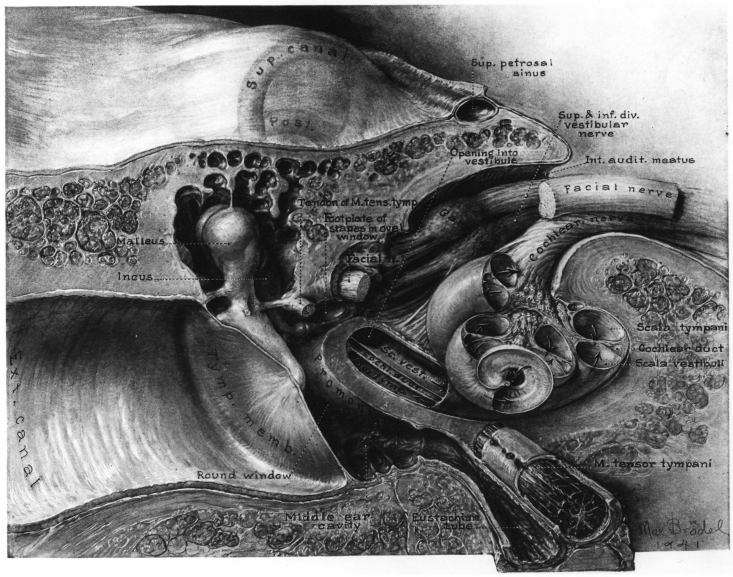
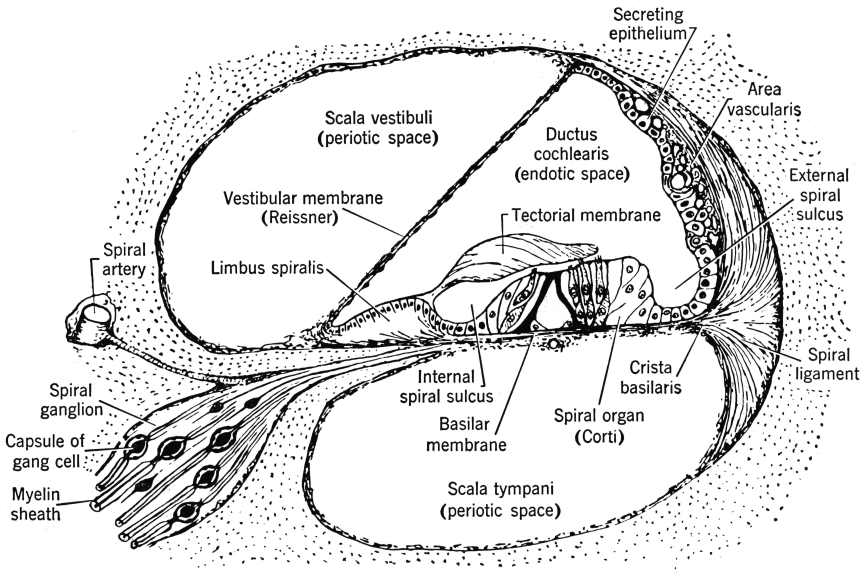
Contraction of the Middle-Ear Muscles reduces efficiency, and produces about 20 dB of protection for Inner Ear (Cochlea)

Resuming the story – beyond the Middle Ear



Max Brodel, 1941



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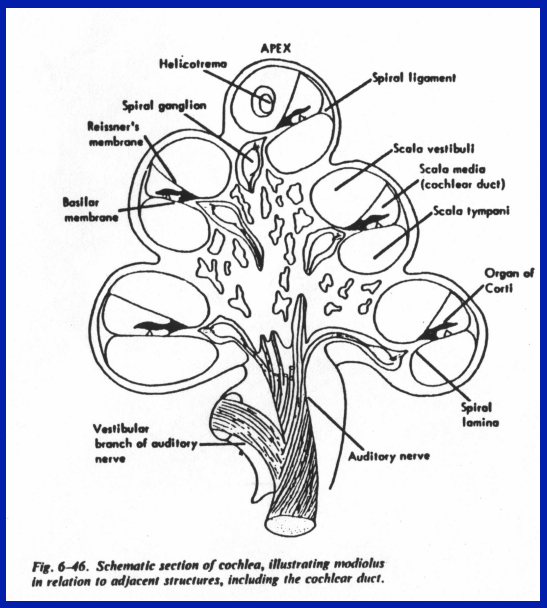
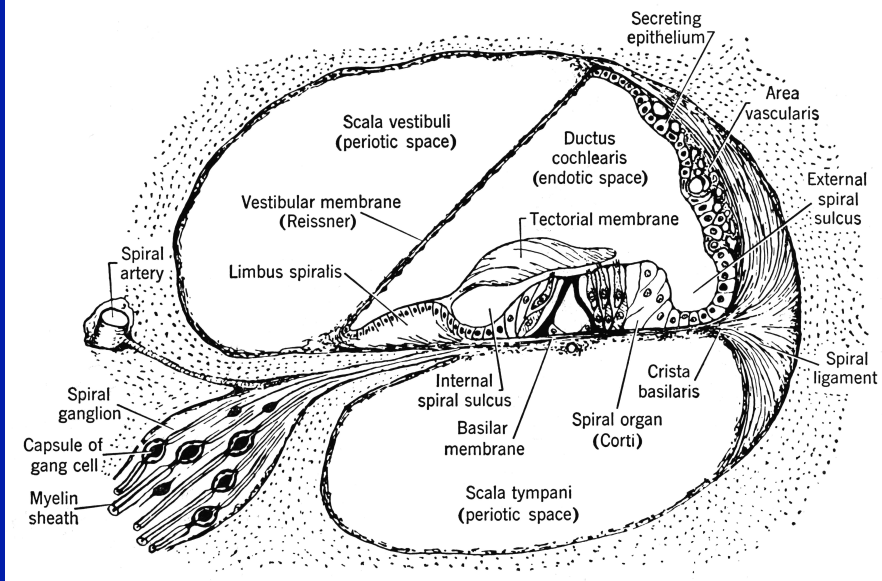


Fig. 6-46. Schematic section of cochlea, illustrating modiolus in relation to adjacent structures, including the cochlear duct.

Zemlin, W.R. *Speech and Hearing Science: Anatomy and Physiology,* Prentice-Hall, Inc., New Jersey, 1968, p. 403.



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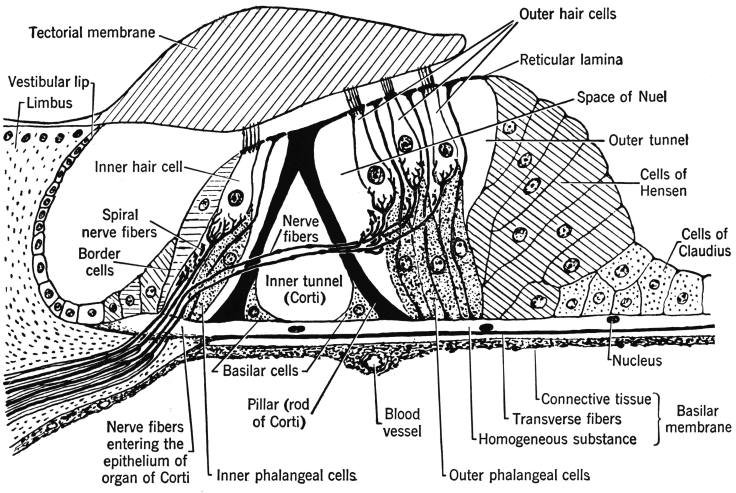

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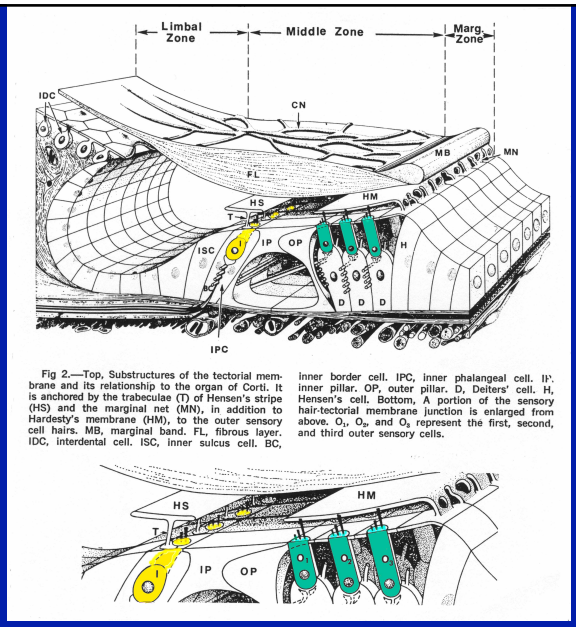
Basilar Membrane, Tectorial Membrane, Supporting cells, and Neural cells (Inner and Outer Hair Cells plus Neurons



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Middle Left: ONE row of Inner Hair Cells (IHCs)

Middle: THREE rows of Outer Hair Cells (OHCs)

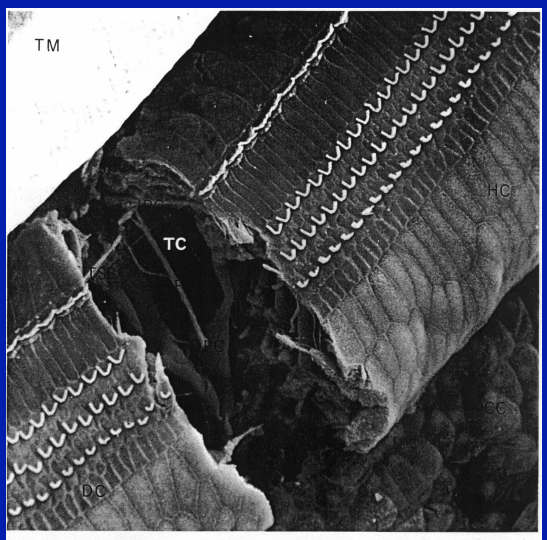
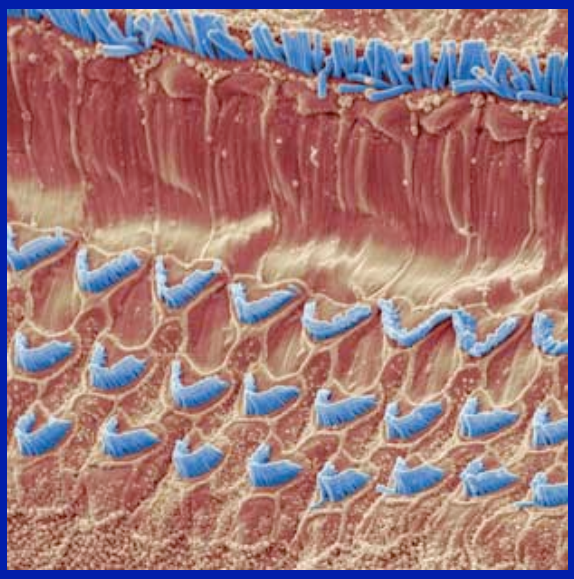


Fig. 2. Shrinkage crack demonstrating internal structure of organ of Corti. *TM*=tectorial membrane, *IHC*=inner hair cell, *TSB*=tunnel spiral bundle, *RF*=tunnel radial fibers, *IPC*=inner pillar cell, *OPC*=outer pillar cell, *DC*=reticular plate of Deiters cells, *HC*=Hensen's cells, *CC*=Claudius cells, *TC*=tunnel of Corti. pw=200 μm.

A view from above the Organ of Corti



< < One row of INNER Hair Cells (IHCs)

A view from above the Organ of Corti

< < Three rows of OUTER Hair Cells (OHCs)

Manley, G.A. Aural History, The Scientist, September 2015

Some Facts about Hair cells

Outer Hair Cells (OHCs)

6-7 rows of stereocilia in a W pattern

at birth, approximately 11,000 - 16,000 OHC

are more susceptible to drugs, acoustic trauma, etc., than IHCs

resting potential about -70 mV

Inner Hair Cells (IHCs)

2-4 rows of stereocilia in a straight line

at birth, approximately 2800 - 4400 IHCs

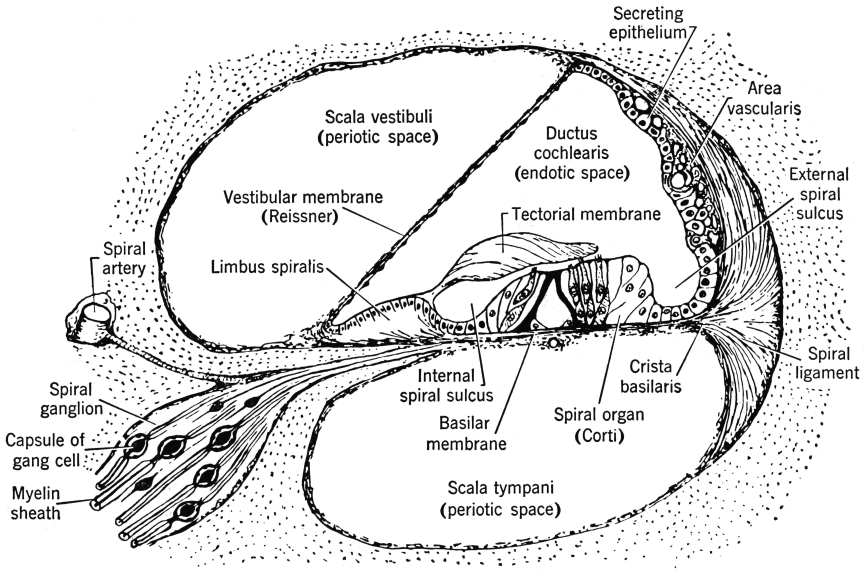
are less susceptible to drugs, acoustic trauma, etc., than OHCs

resting potential about -45 mV

OK, OK, enough about the structures already

How does the cochlea WORK?

Traveling Waves



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Facts about TRAVELING WAVES in the Cochlea

The waves on the mammalian basilar membrane are highly unusual, but we will not get into much detail

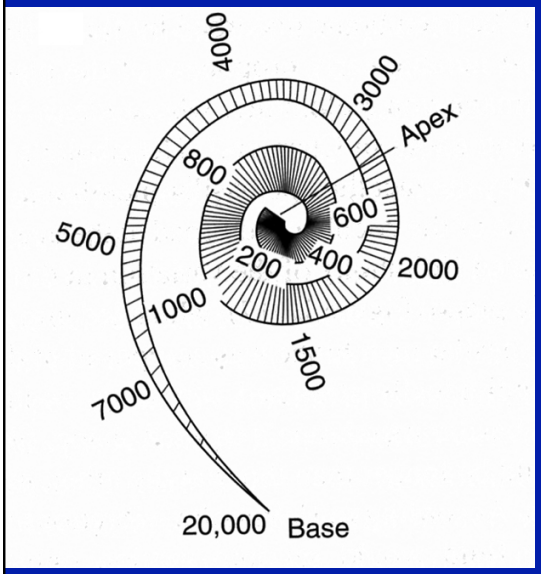
– tis an interesting topic for add'l reading for those who think they know something about waves

Different frequencies produce maximal displacement/vibration/ at different places along the cochlea

– called tonotopic organization

– a "place" encoding system for frequency/pitch/

- a series of narrow filters arranged from high to low center frequencies – FREQUENCY CHANNELS



Place of maximum displacement of basilar membrane (BM) differs for different test frequencies

Thus, a Frequency Map of the Human Cochlea (the frequency channels)

[Looking "up" at a spiral cochlea]

< < Stapes end (middle ear)
Most narrow part of BM; widest is at Apex

Cochlear Demonstration (~7 minutes)

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Some Animations of the Auditory System

Traveling Waves (~1:15 minutes)

From: Auditory Neuroscience: basilar membrane activity in response to Bach's toccata and fugue in D minor– James Hudspeth demonstration

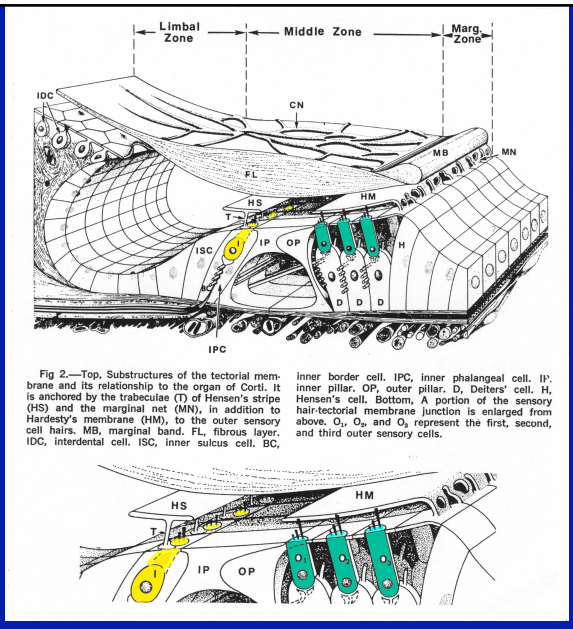
http://auditoryneuroscience.com/topics/basilar-membrane-motion-4-bachs-tocata-fugue

Traveling Waves (~15 seconds)

Basilar membrane activity in response to a tone continuously rising in frequency -- visual and auditory demo

https://auditoryneuroscience.com/topics/basilar-membrane-motion-0-frequency-modulated-tone

Both demos show frequency channels (tonotopic organization) – different parts of the cochlea are displaced (vibrated) by different tonal frequencies



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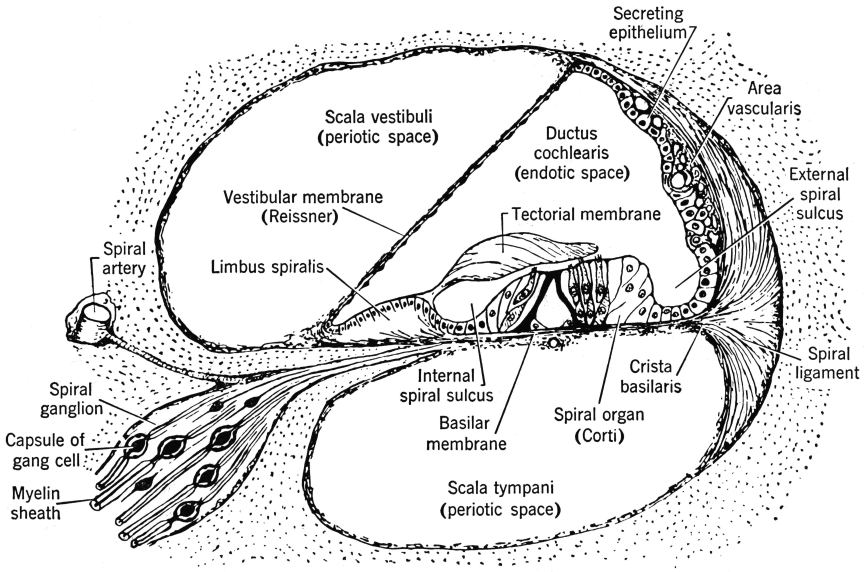

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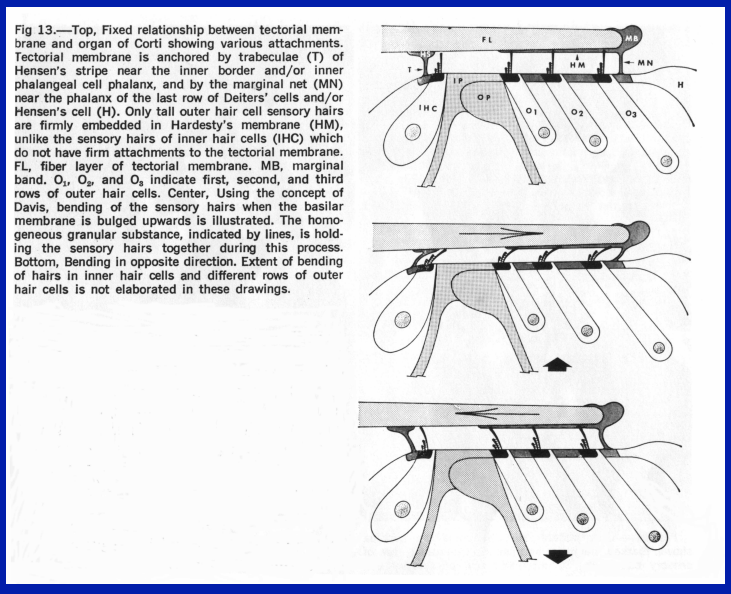

Fig 13.—Top, Fixed relationship between tectorial membrane and organ of Corti showing various attachments. Tectorial membrane is anchored by trabeculae (T) of Hensen's stripe near the inner border and/or inner phalangeal cell phalanx, and by the marginal net (MN) near the phalanx of the last row of Deiters' cells and/or Hensen's cell (H). Only tall outer hair cell sensory hairs are firmly embedded in Hardesty's membrane (HM), unlike the sensory hairs of inner hair cells (IHC) which do not have firm attachments to the tectorial membrane. FL, fiber layer of tectorial membrane. MB, marginal band. O_1, O_2, and O_3 indicate first, second, and third rows of outer hair cells. Center, Using the concept of Davis, bending of the sensory hairs when the basilar membrane is bulged upwards is illustrated. The homogeneous granular substance, indicated by lines, is holding the sensory hairs together during this process. Bottom, Bending in opposite direction. Extent of bending of hairs in inner hair cells and different rows of outer hair cells is not elaborated in these drawings.

David J. Lim, *Fine Morphology of the Tectorial Membrane; Its Relationship to the Organ of Corti*, Archives of Otolaryngology, American Medical Assoc., 1972, 96, p. 214.

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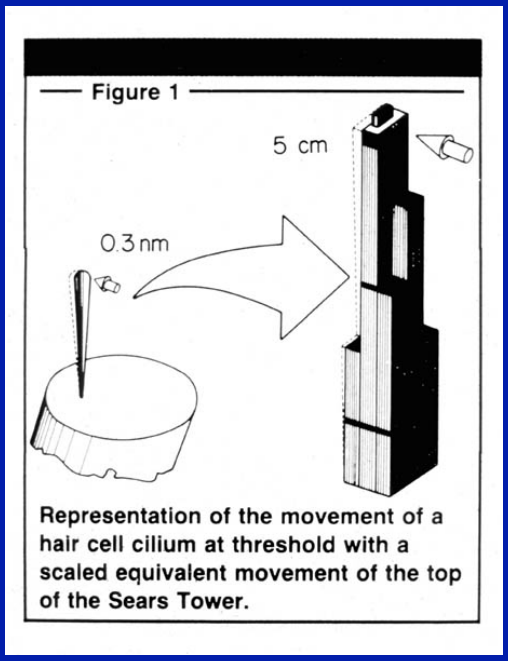
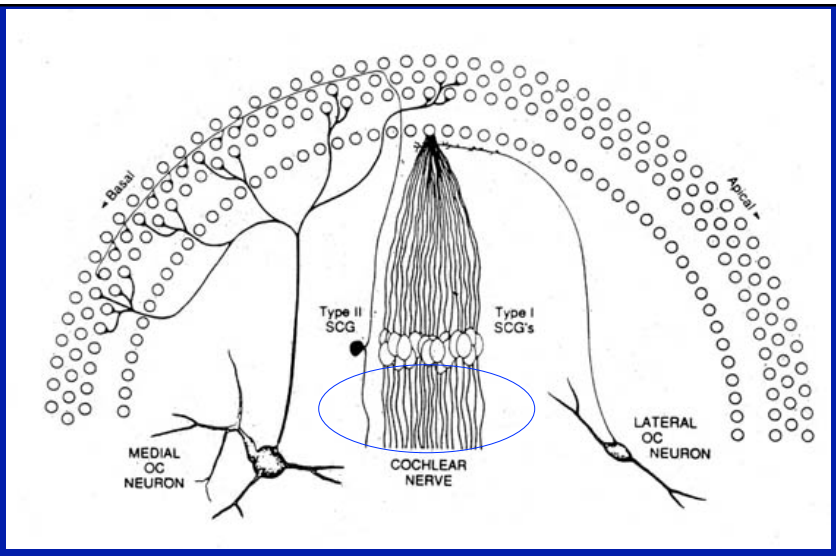
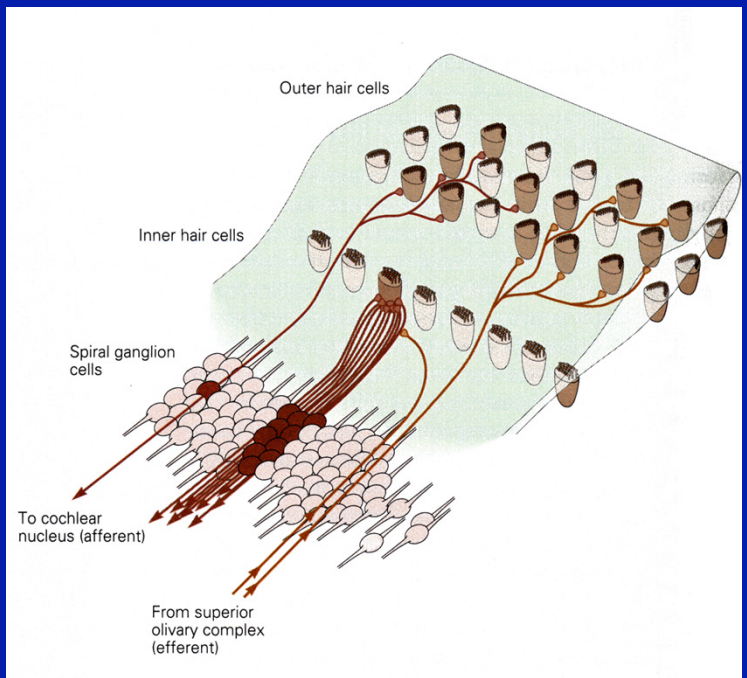
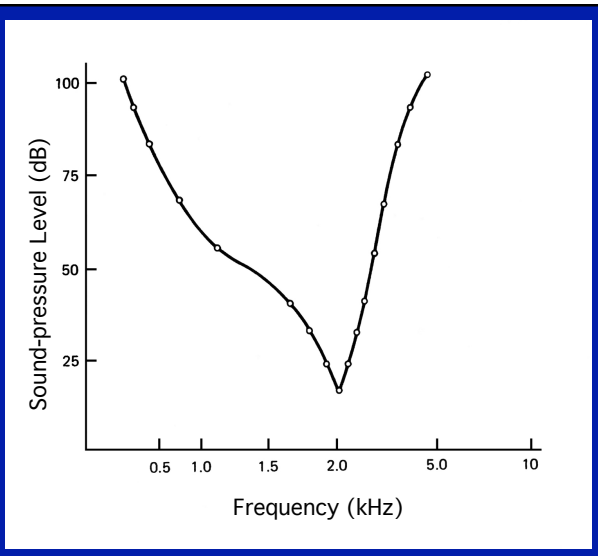


The Sears Tower is 1450 feet tall and has 110 stories.



Different "places" along the cochlea are activated by different frequencies.
So, different Inner Hair Cells (IHCs) are activated by different frequencies.
So, different auditory neurons are activated by different frequencies.





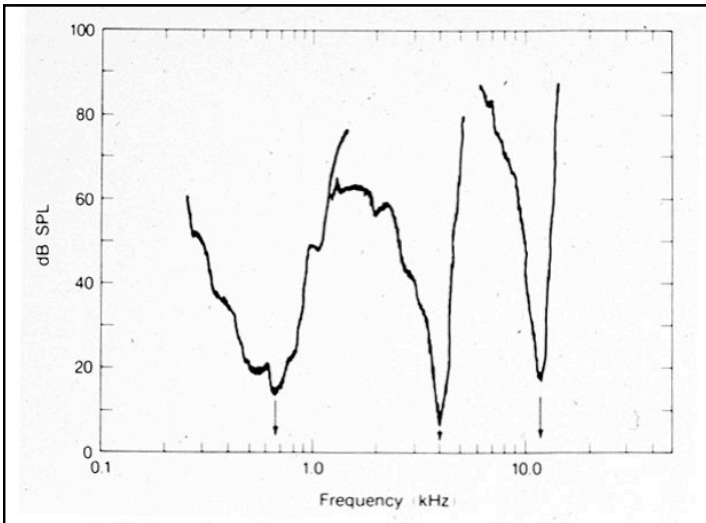
Response Area for single auditory neuron

called a Tuning Curve

From: Kandel, Schwartz, Jessell (1991)
Principles of Neural Science, Elsevier, NY

An asymmetric V-shaped curve
- cell is "deaf" to high-frequency sounds, and is maximally sensitive at one frequency

- a frequency channel



Three different auditory neurons with different Tuning Curves

Each neuron "listens" to a different place along the basilar membrane and thus, "listens" to a different frequency region

Three different Frequency Channels shown

Where We Stand

At the very beginning of processing, sounds are broken down into their constituent frequencies

- accomplished by the mechanical properties of the basilar membrane
- different "places" along the cochlea are activated/vibrated/ by different frequencies
- so different Inner Hair Cells are activated by different frequencies
- so different Auditory Neurons are activated by different freqs
- frequency channels have been established

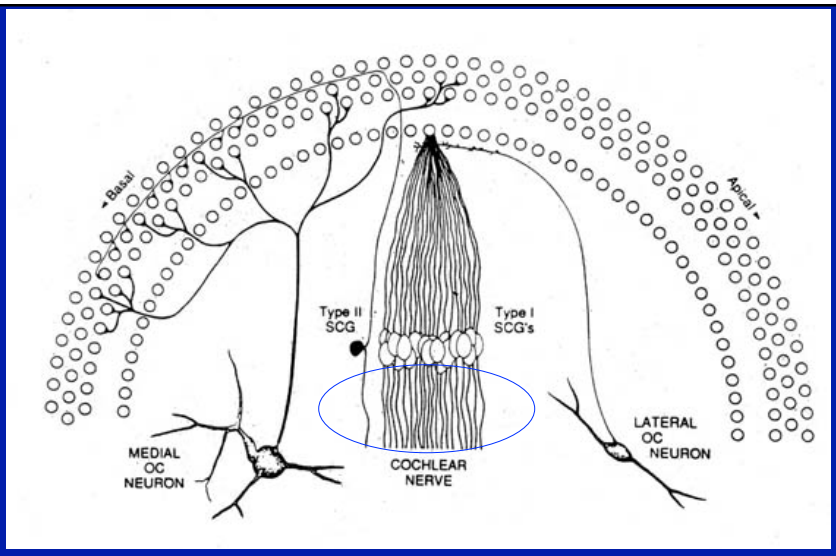
WHAT ARE THE CONSEQUENCES OF THIS ORGANIZATION?

Where We Stand

The auditory system has frequency channels

WHAT ARE THE CONSEQUENCES OF THIS ORGANIZATION?

- each individual Inner Hair Cell is extremely valuable
  - * a lost IHC means that many auditory neurons have lost their source of information about the auditory world
  - * knowledge about a specific frequency region is lost
  - * called Sensorineural Hearing Loss
- the job of the brain is to build neural representations of the complex sounds in the environment using the information contained in the individual frequency channels



Different "places" along the cochlea are activated by different frequencies.
So, different Inner Hair Cells (IHCs) are activated by different frequencies.
So, different auditory neurons are activated by different frequencies.

Some Animations of the Auditory System

Cochlear Demonstration

From: Breedlove, et al., *Biological Psychology,* Fifth Edition, 2007, published by Sinauer Associates and Sumanas, Inc.

http://www.sumanasinc.com/webcontent/animations/content/soundtransduction.html

Also for the vestibular system (not shown in class)

http://www.sumanasinc.com/webcontent/animations/content/vestibular.html

Traveling Waves (and other demos) from: Auditory Neuroscience:
- basilar membrane activity in response to
Bach's toccata and fugue in D minor – James Hudspeth demonstration

http://auditoryneuroscience.com/topics/basilar-membrane-motion-4-bachs-tocata-fugue

- also (a series of tones)

https://auditoryneuroscience.com/topics/basilar-membrane-motion-0-frequency-modulated-tone

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From: University of Wisconsin Neurophysiology Group (not shown in class)

http://www.neurophys.wisc.edu/animations/
http://www.neurophys.wisc.edu/h&b/textbook/textindex.html