Intro to Audition & Hearing

Lecture 16
Chapter 9, part II

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Sensation & Perception (PSY 345 / NEU 325)
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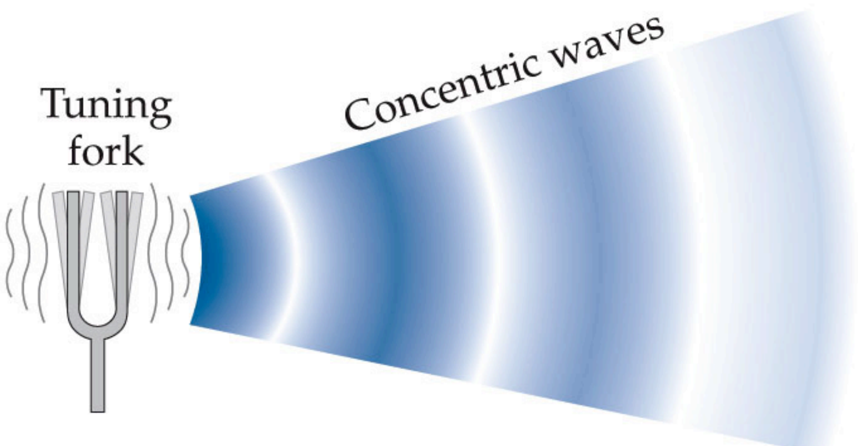
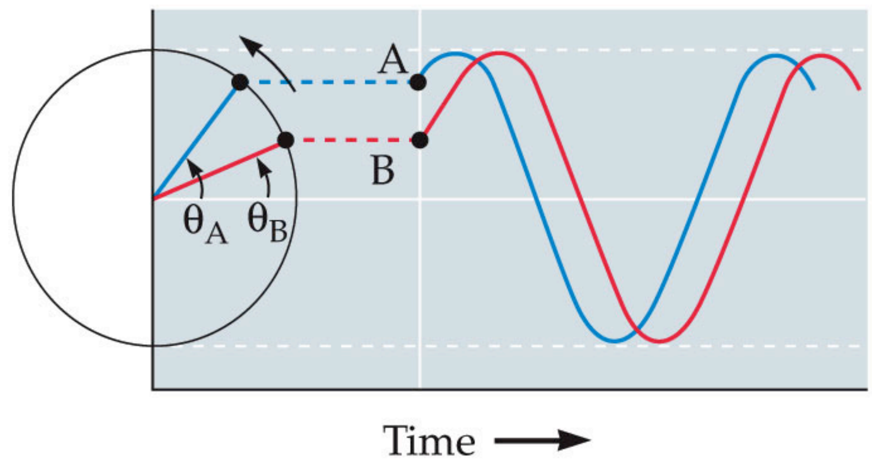
Sine wave: one of the simplest kinds of sounds: sound for which pressure as a function of time is a sine function

- **Period**: The time required for one cycle of a repeating waveform (frequency = 1 / period)
- **Phase**: The relative position of two or more sine waves
    - There are 360 degrees of phase across one period





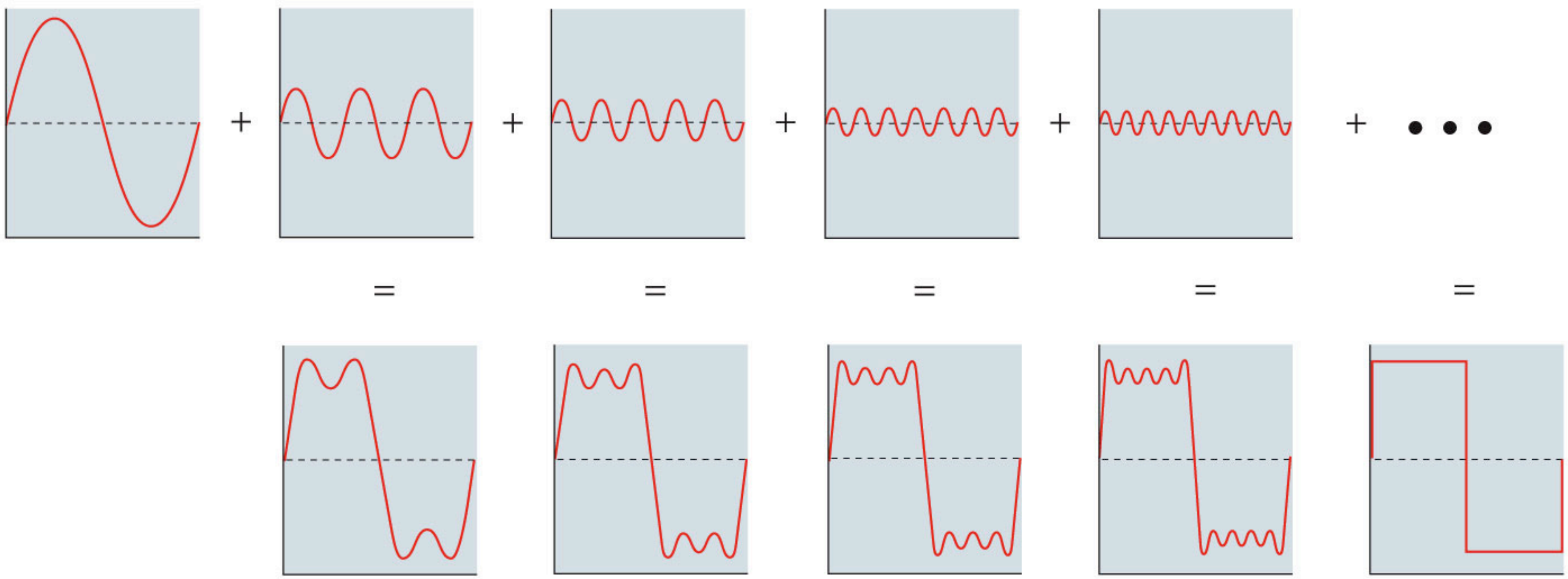
But: sine waves are a very *unnatural* kind of sound

- complex natural sounds can be broken down into a sum of sine waves

Complex sounds can be described by Fourier analysis

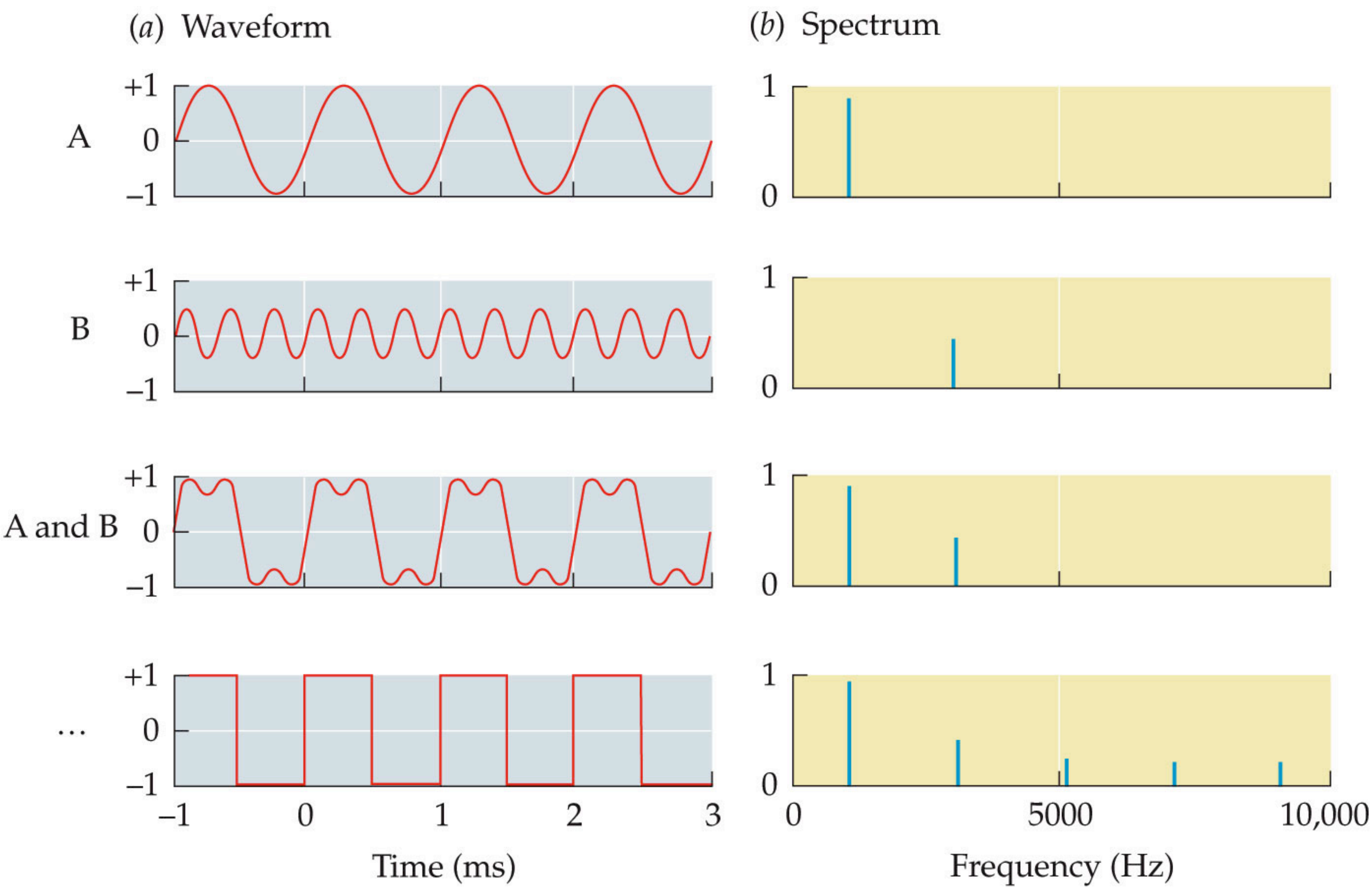
- **Fourier analysis**: mathematical theory by which any sound can be divided into a sum of sine waves

example: generating a square wave from a sum of sine waves



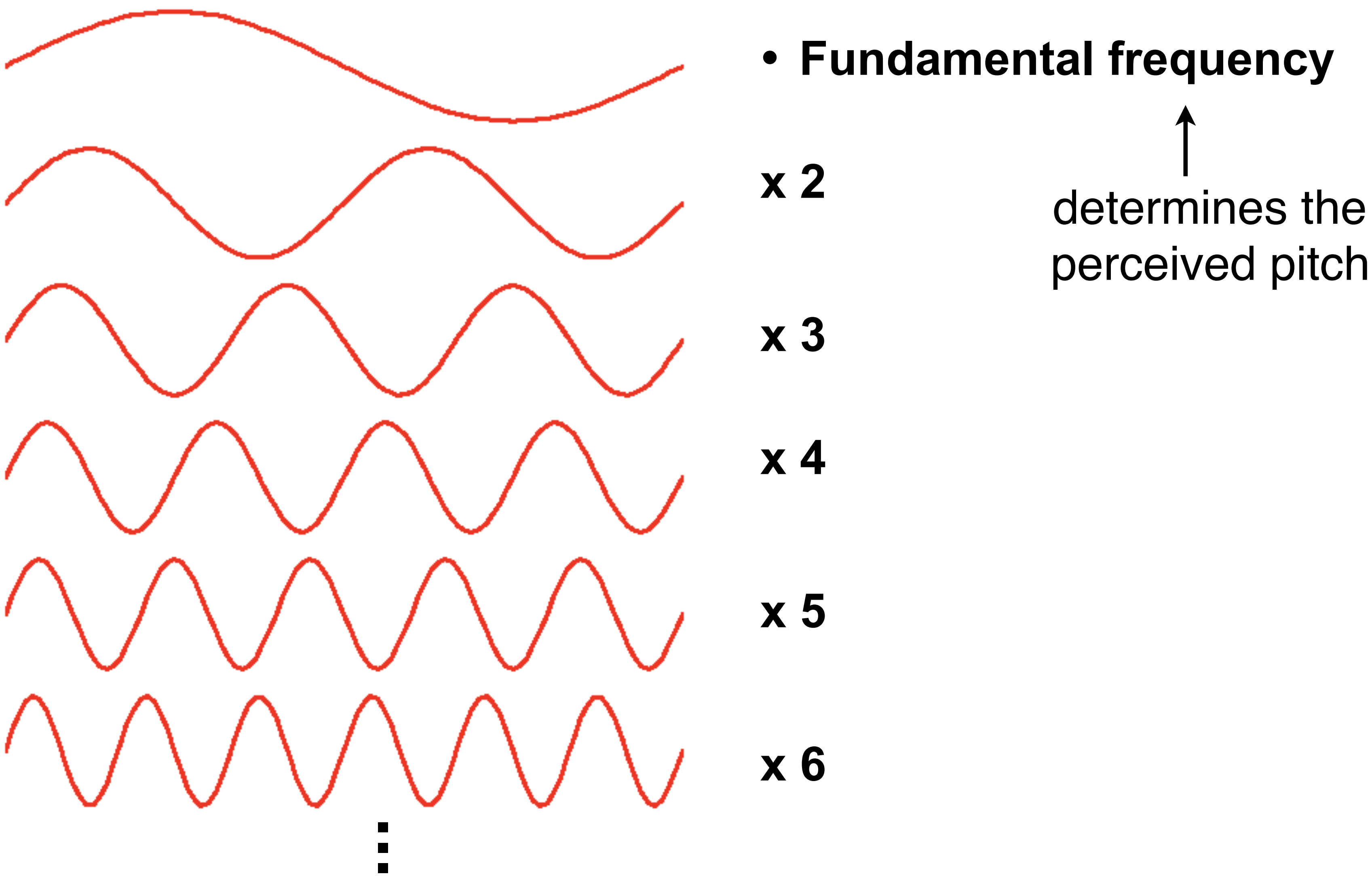
http://sites.sinauer.com/wolfe3e/chap1/fourierF.htm

Fourier spectrum: shows the amplitude for each sine wave frequency present in a complex sound



Harmonic spectrum: Typically caused by a simple vibrating source (e.g., guitar string, saxophone reed)

- Also referred to as a "**harmonic stack**"

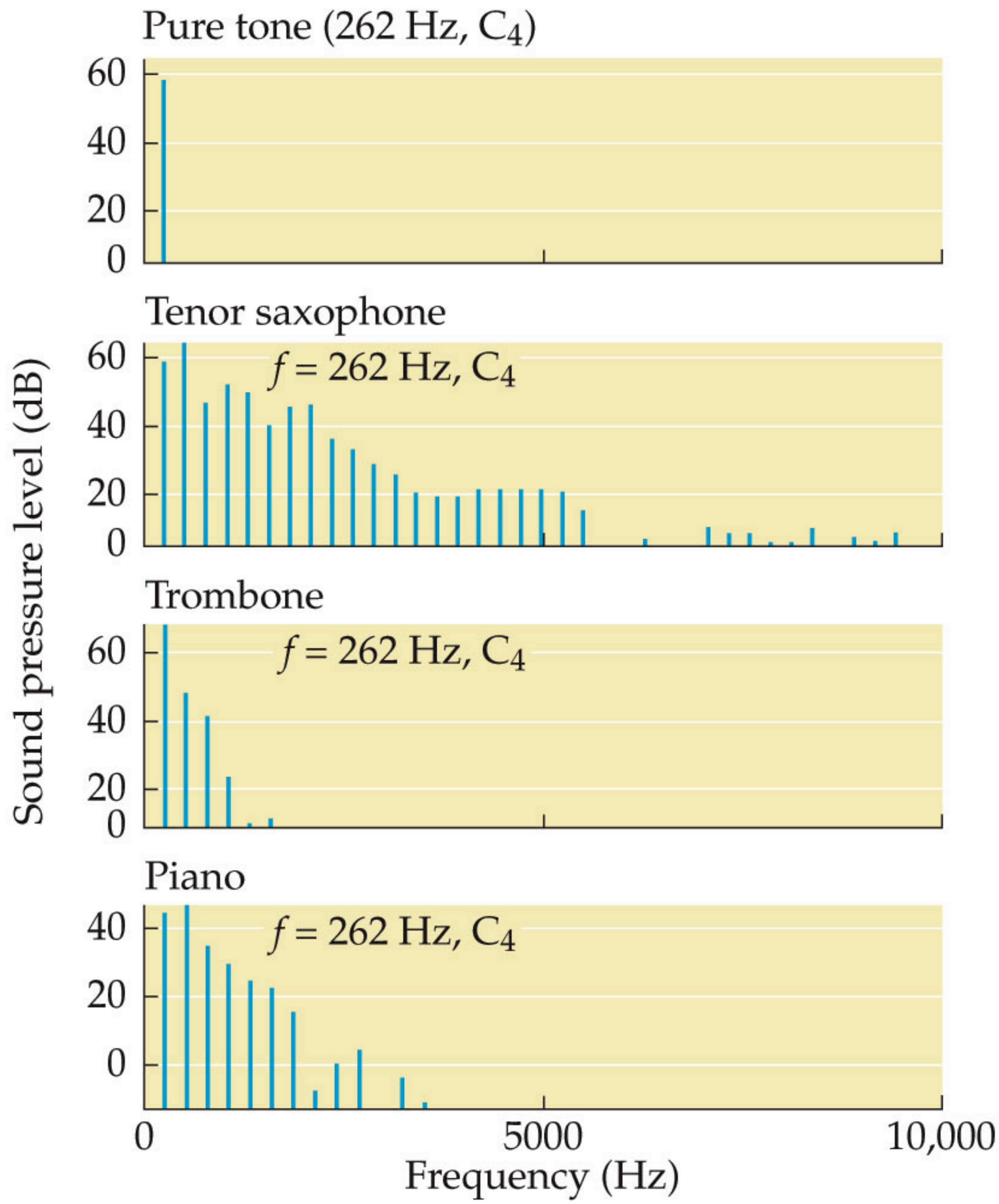


Timbre: psychological sensation by which a listener can judge that two sounds with the same loudness and pitch are dissimilar

- timbre quality is conveyed by harmonics and other high frequencies

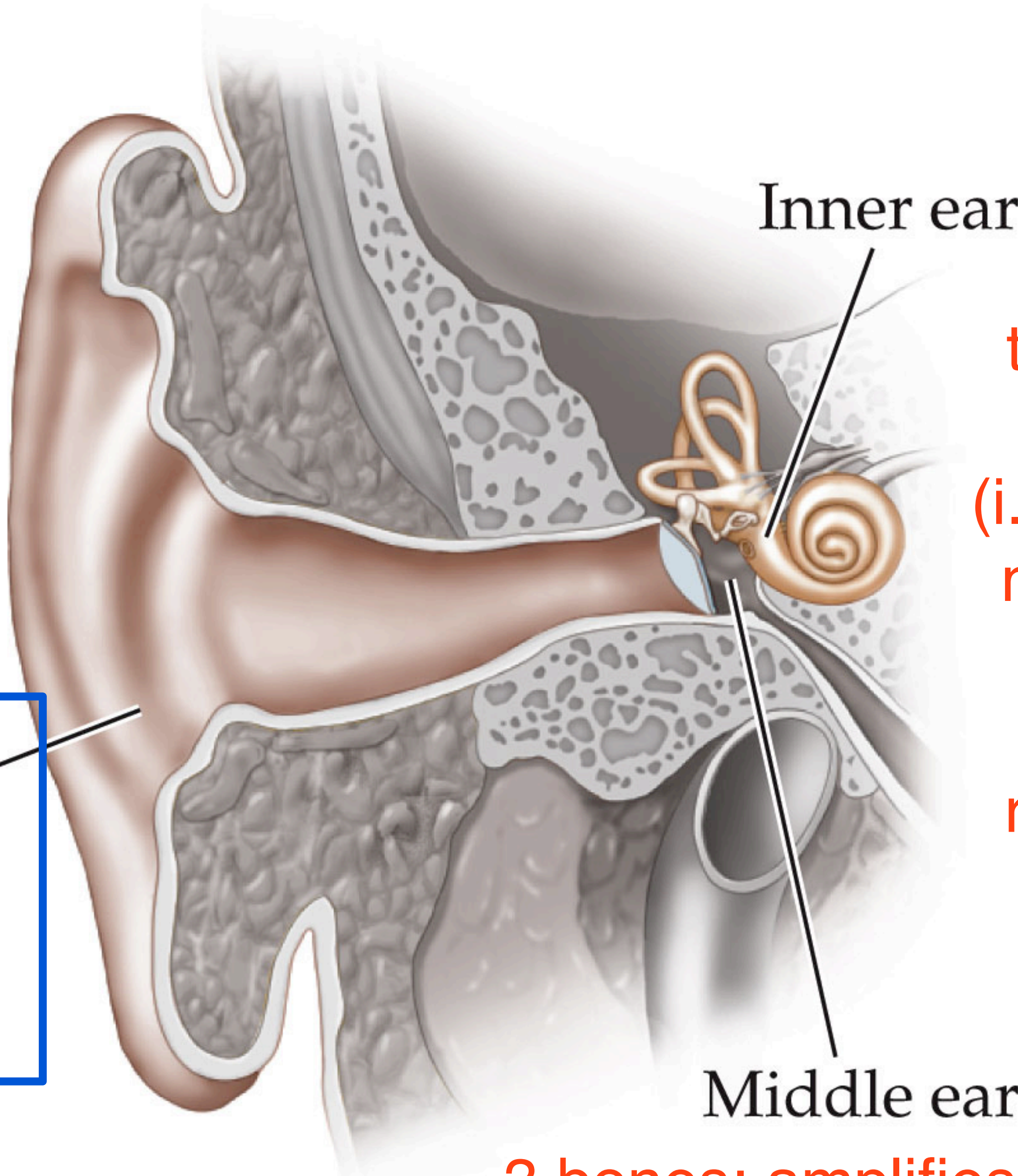
(more on this when we get to "music")

Harmonic sounds with the same fundamental frequency can sound different (i.e., have different timbre) due to differences in high harmonics



Part 2: The Auditory System

Figure 9.10 Structures of the human ear (Part 3)



Outer ear: collects and transforms sound

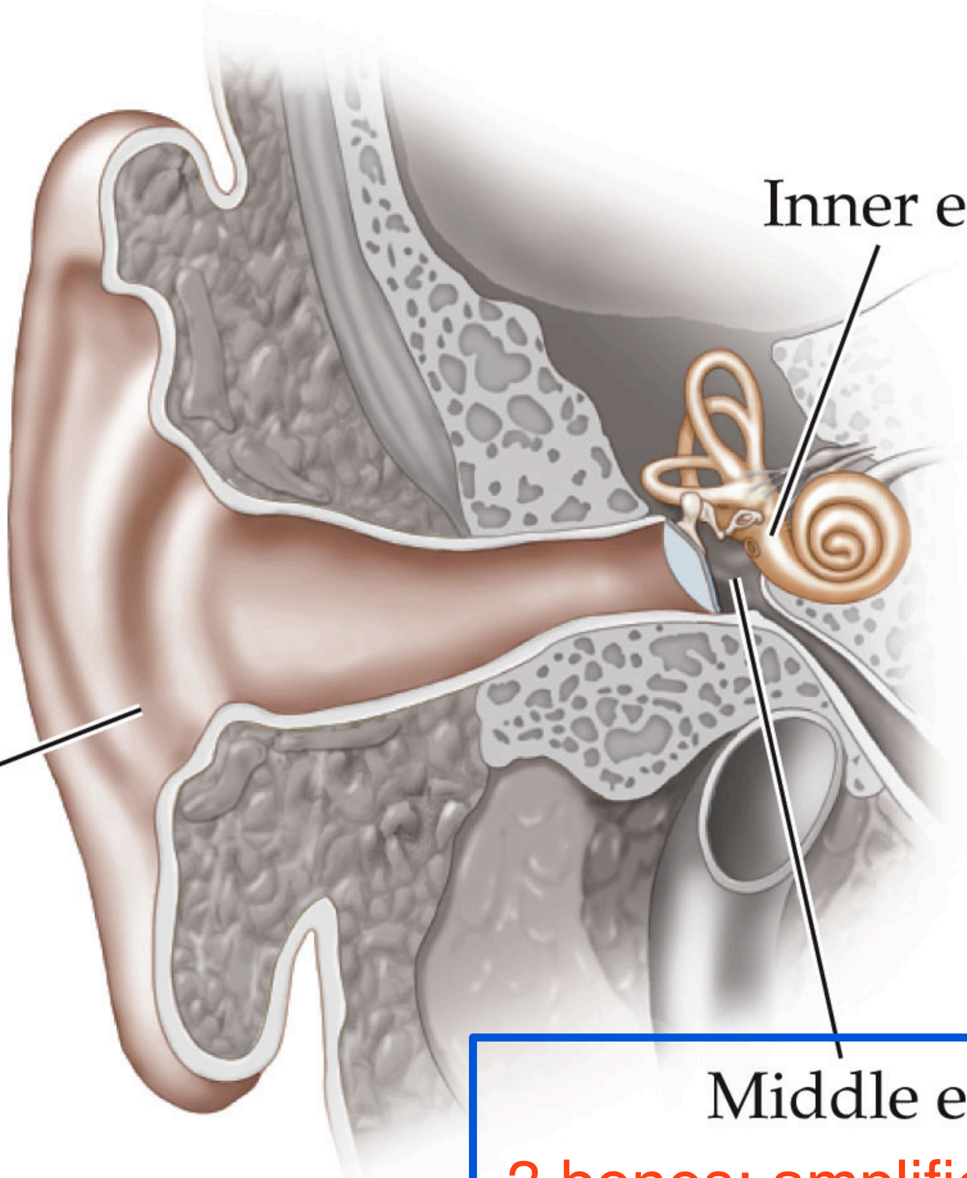
Inner ear: transduces sound (i.e., converts mechanical energy to neural responses)

Middle ear: 3 bones: amplifies sound

Outer ear

- Sound first collected from environment by the **pinnae**
- Sound waves funneled by the pinnae into the **ear canal**
- length and shape of ear canal enhances certain frequencies

Pinna size and shape vary greatly



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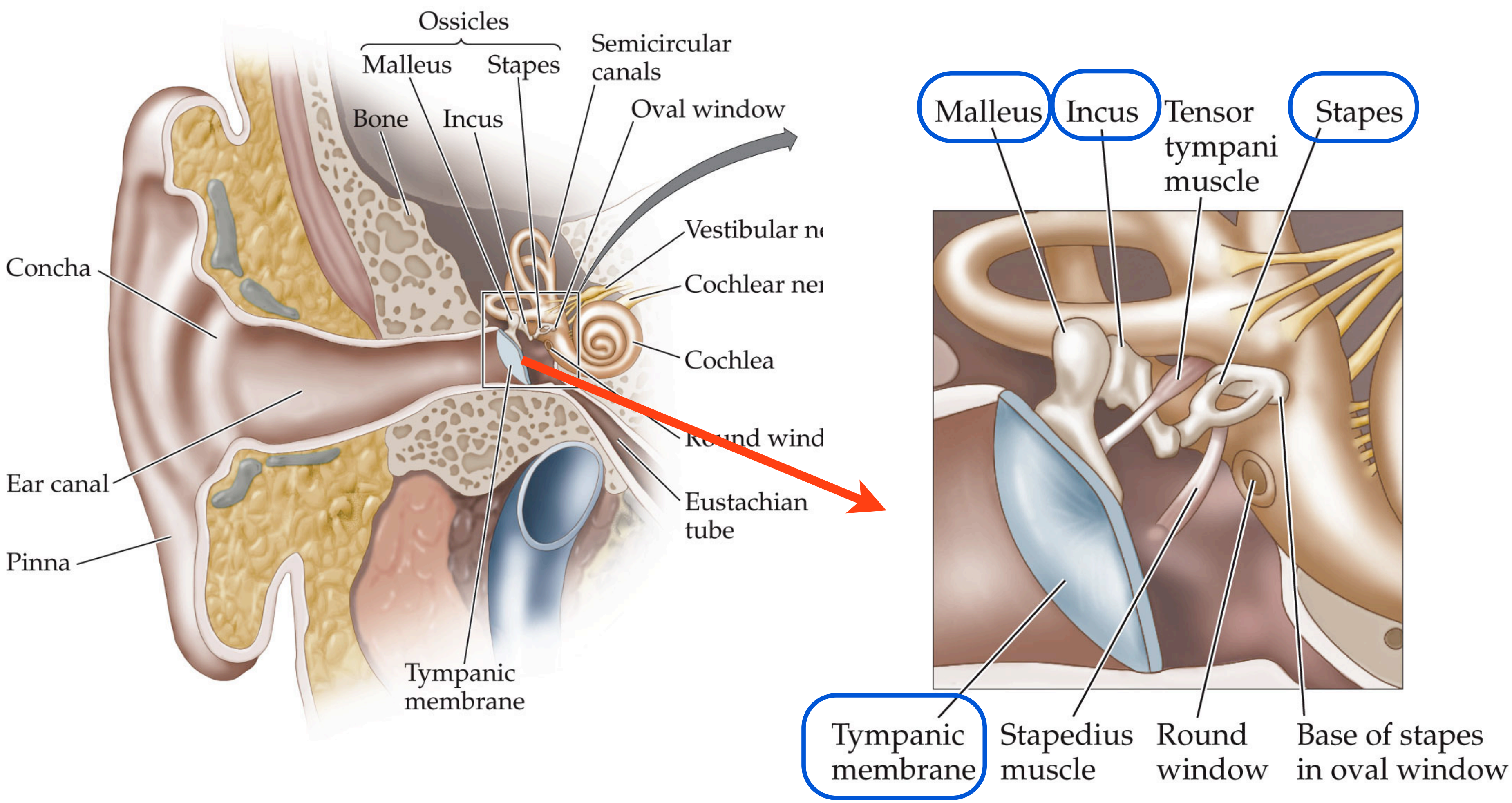
Middle ear: 3 bones: amplifies sound

Middle ear



Ossicles
Malleus
Stapes
Bone
Incus
Semicircular canals
Oval window
Vestibular n
Cochlear ne
Cochlea
Round wind
Eustachian tube
Concha
Ear canal
Pinna
Tympanic membrane
Malleus
Incus
Tensor tympani muscle
Stapes
Tympanic membrane
Stapedius muscle
Round window
Base of stapes in oval window

Middle ear

- **Tympanic membrane** (eardrum): border between outer and middle ear
- middle ear consists of three tiny bones, ossicles, that amplify and transmit sounds to the inner eardrum

Ossicles: The smallest bones in the body

- **Malleus**: Receives vibrations from the eardrum
- **Incus**: The middle ossicle
- **Stapes**: Connected to the incus on one end and the oval window of the cochlea on the other

- **Oval window** is border between middle and inner ear

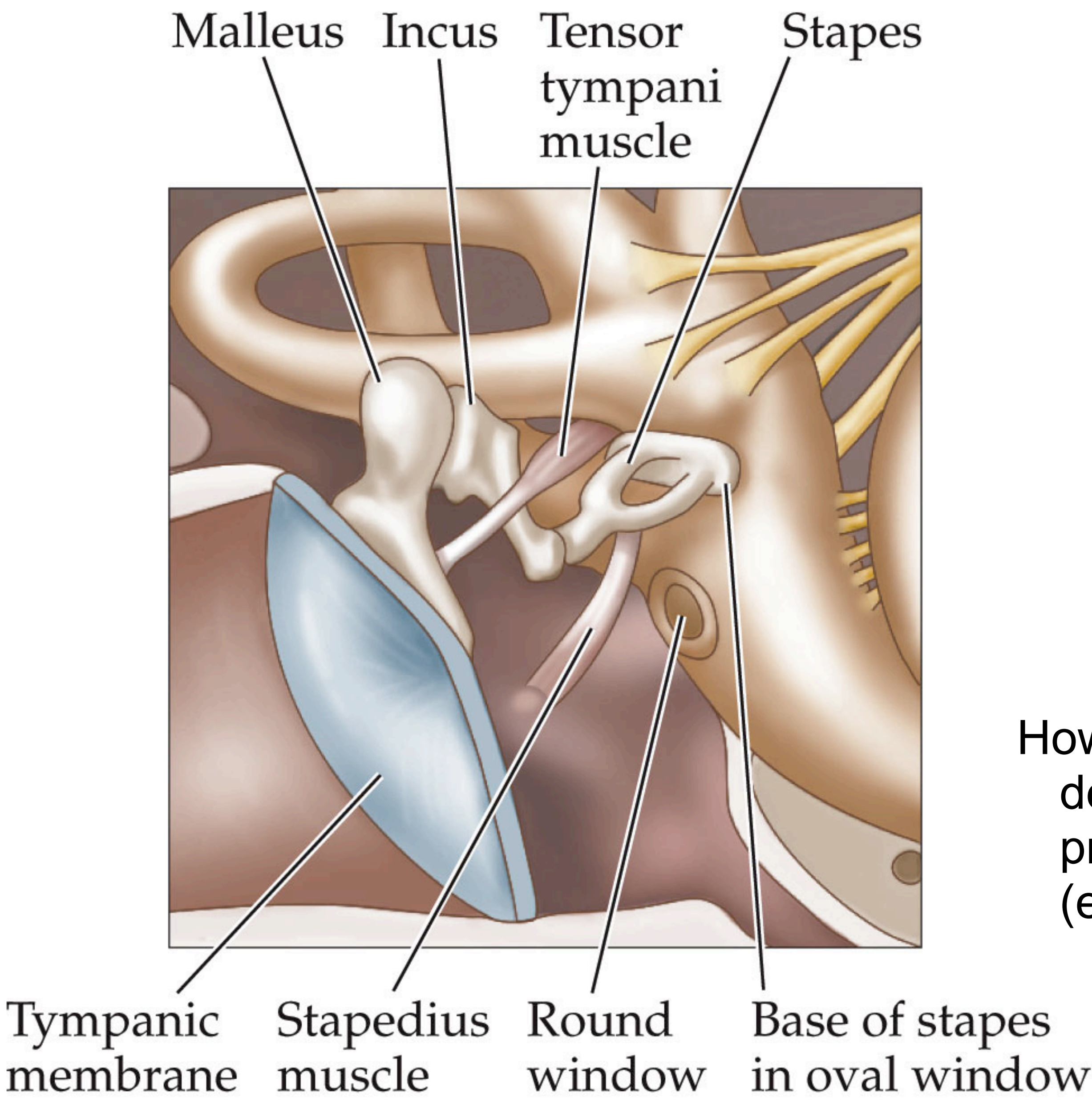
Two ways in which sound is amplified in middle ear:

- **Ossicles** have hinged joints that work like levers to amplify sounds
- **Tympanic membrane** has much larger surface area than base of the stapes (where it pushes on oval window)

(think of a snow-shoe vs. a high-heeled shoe)

- Inner ear consists of fluid-filled chambers
  - Takes more energy to move liquid than air

"impedance matching"
(it's hard for air to move water)

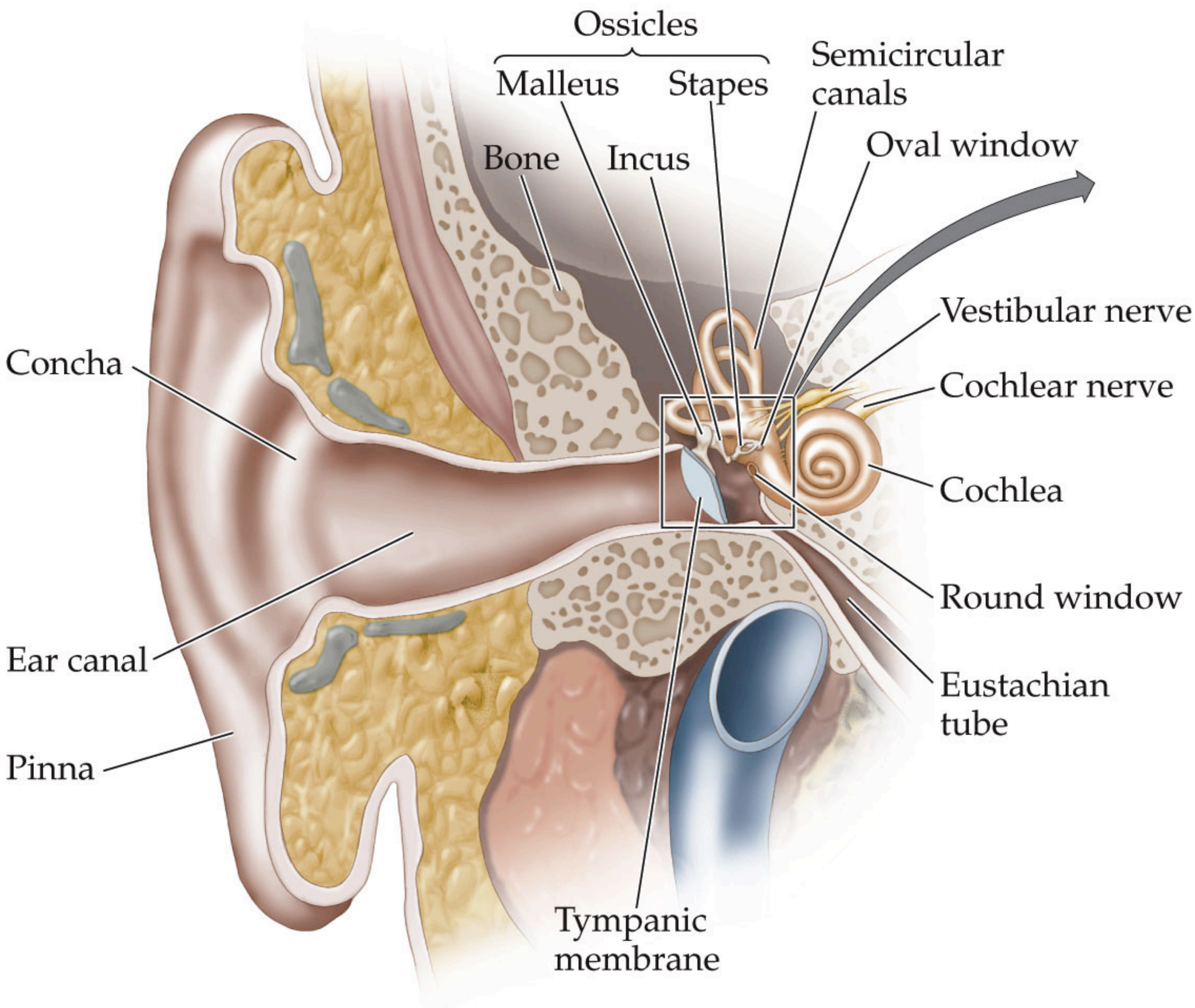


<u>muscles</u>

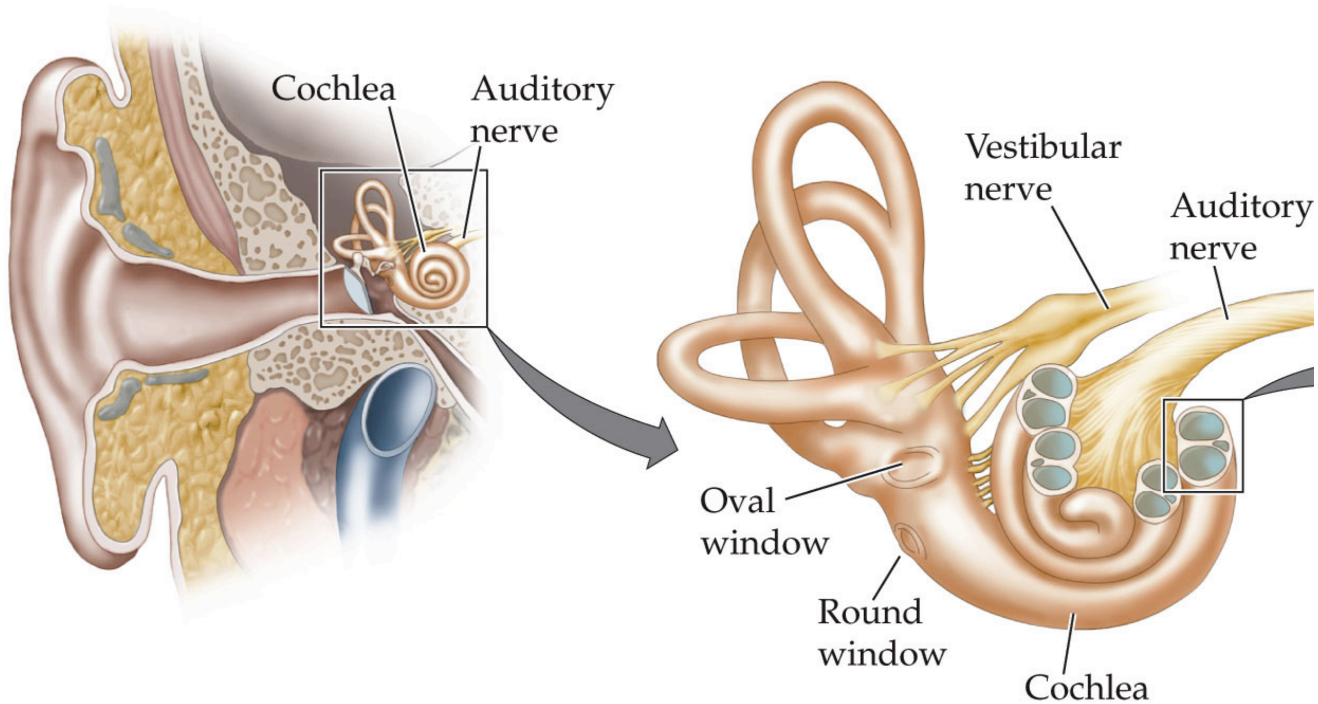
- **tensor tympani**
- **stapedius**

- smallest muscles in human body
- tighten to reduce amplification of loud sounds

However, acoustic reflex has delay of 200 ms, so cannot protect against abrupt sounds (e.g., gun shot)


Ossicles
Malleus
Stapes
Semicircular canals
Bone
Incus
Oval window
Vestibular nerve
Cochlear nerve
Concha
Cochlea
Round window
Ear canal
Eustachian tube
Pinna
Tympanic membrane

Inner Ear

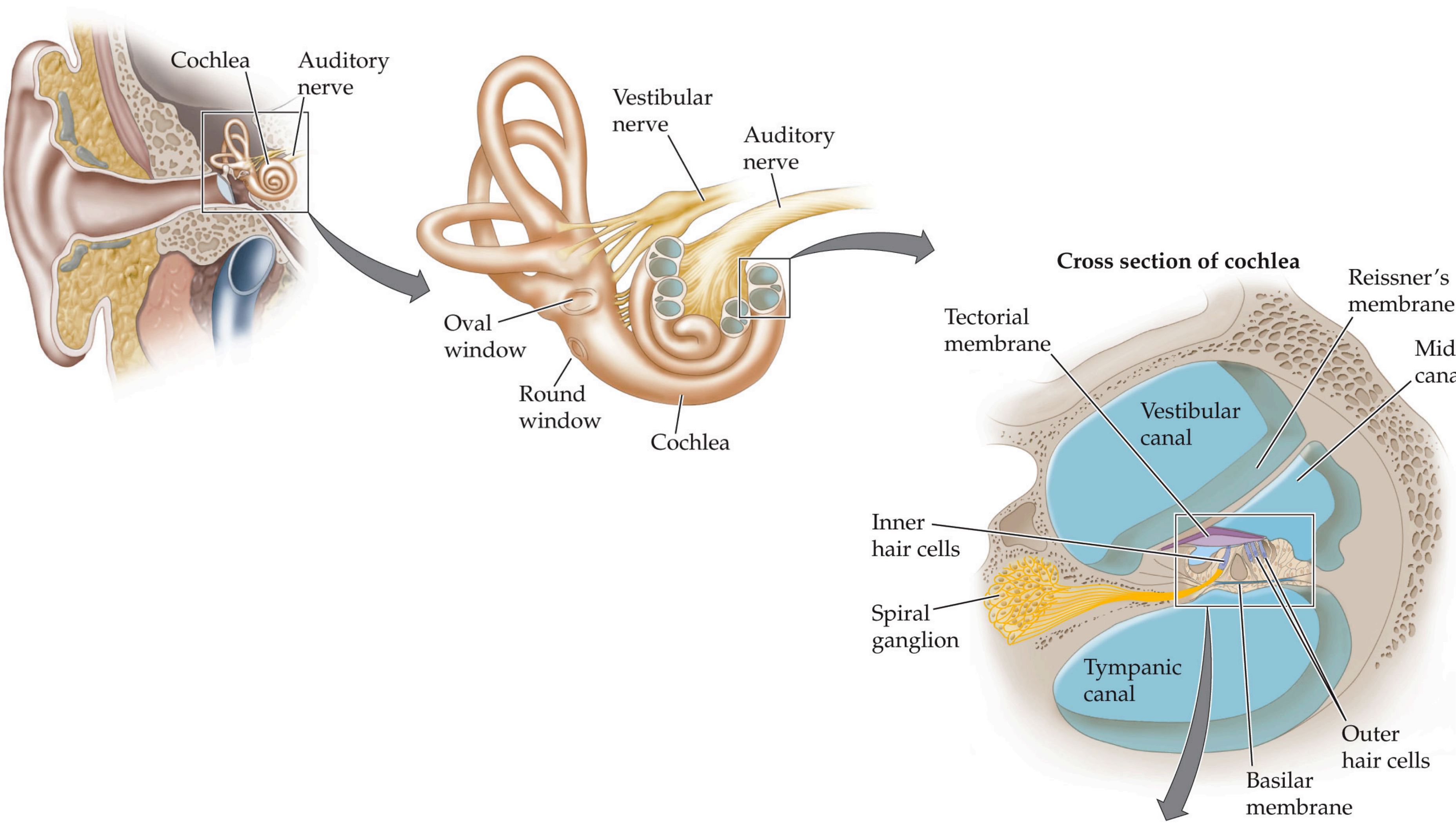


Cochlea - Spiral structure filled with fluids in three parallel canals

- breaks down sound by frequency
- transduction (mechanical -> neural energy)

Cochlear animation: http://www.youtube.com/watch?v=dyenMluFaUw

Figure 9.11 The cochlea

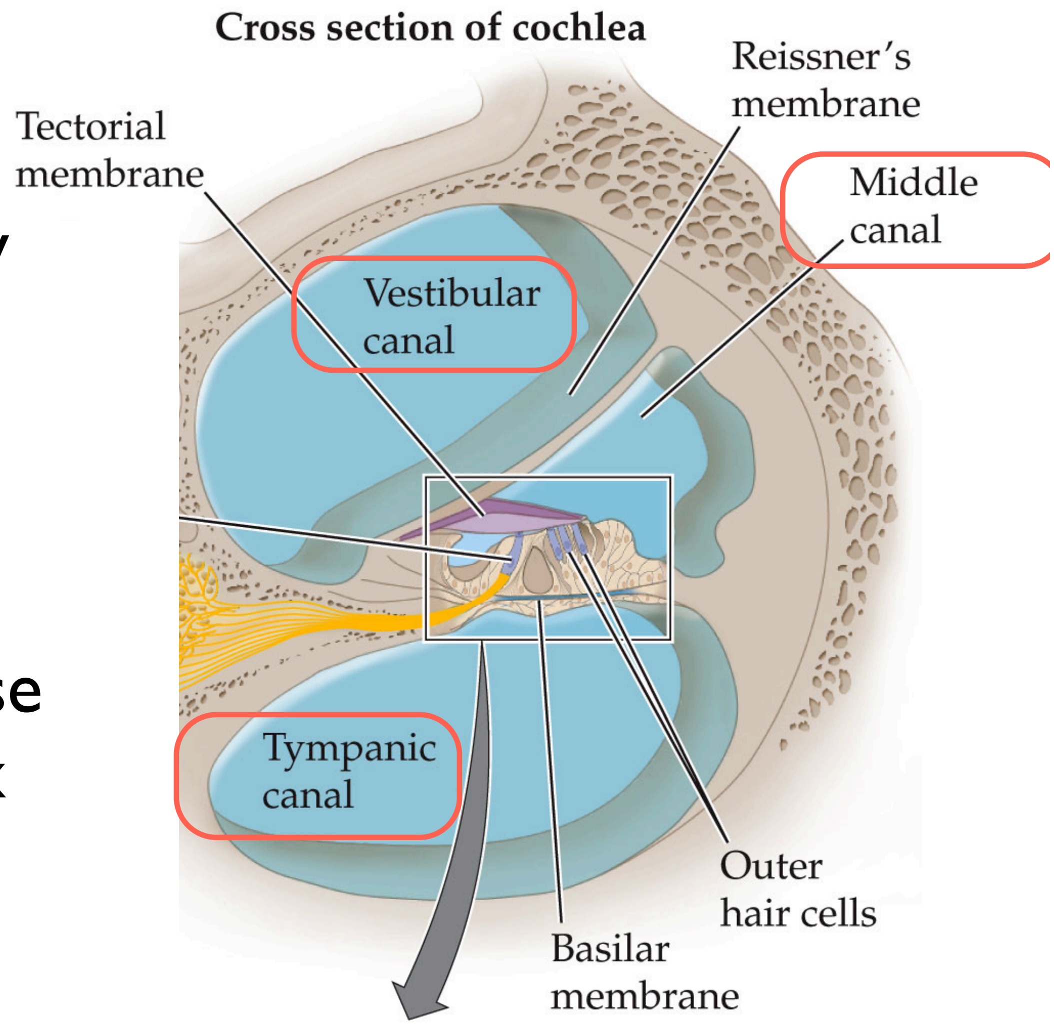


The three canals of the cochlea:

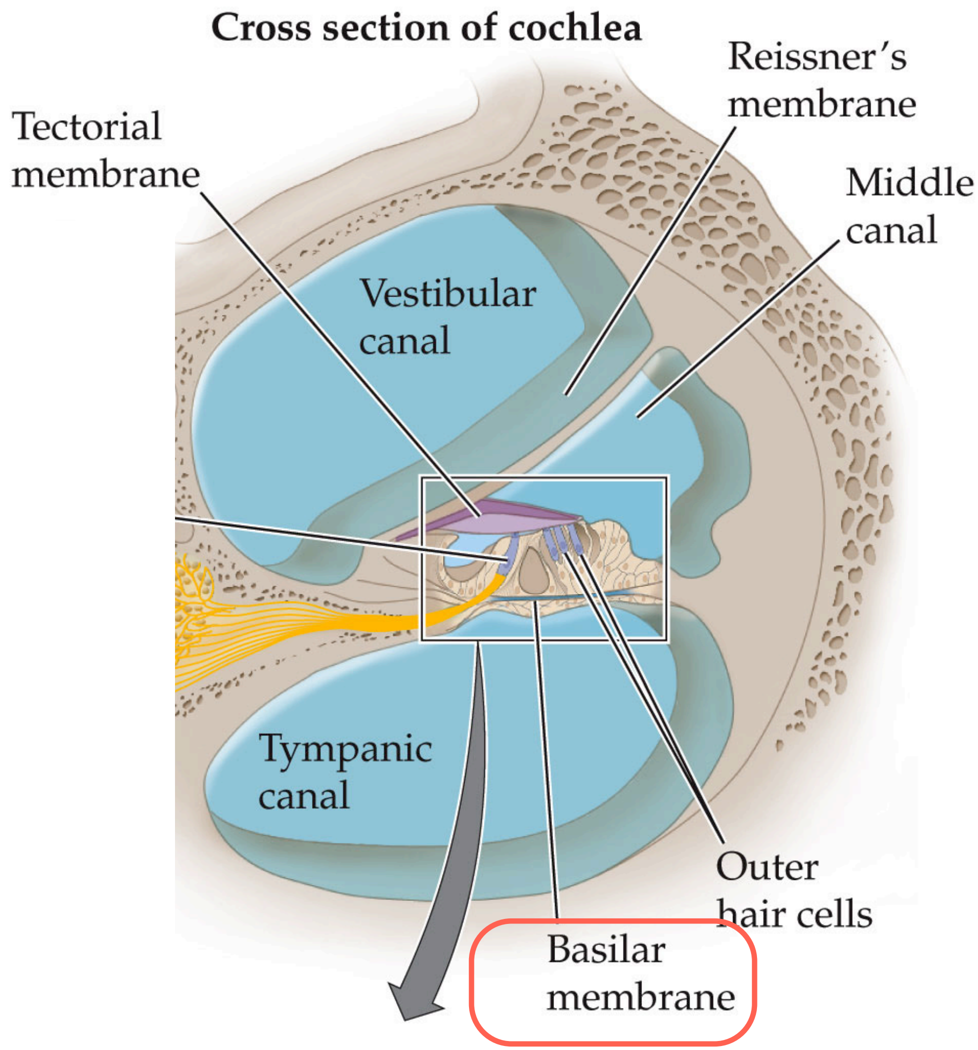
- **Vestibular canal**: extends from oval window at base of cochlea to *helicotrema* at the apex

- **Tympanic canal**: from round window at base to helicotrema at the apex

- **Middle canal**: between the tympanic and vestibular canals



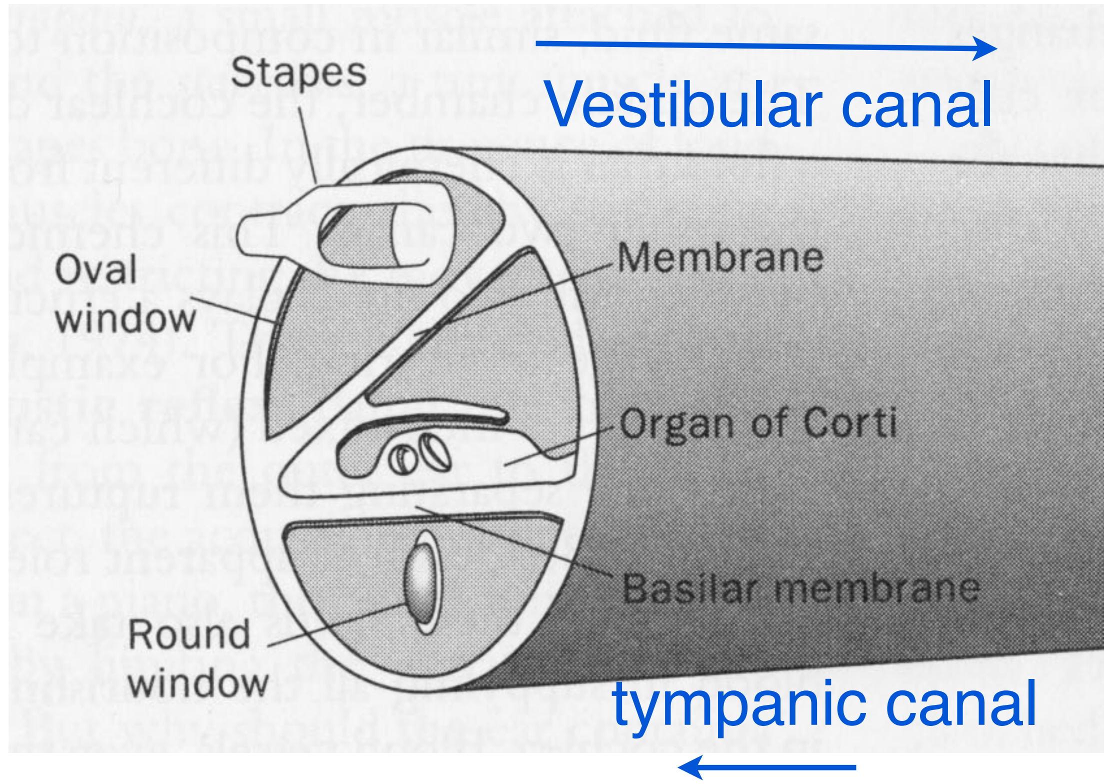
Membranes separating these chambers



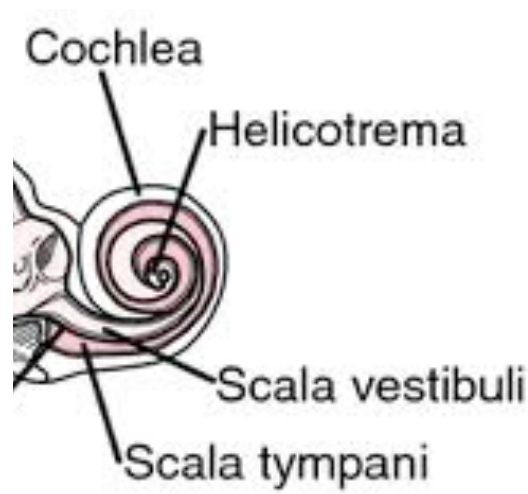
- **Basilar membrane:**
  separates middle and tympanic canals

Getting the basilar membrane to shake (without breaking the cochlea)

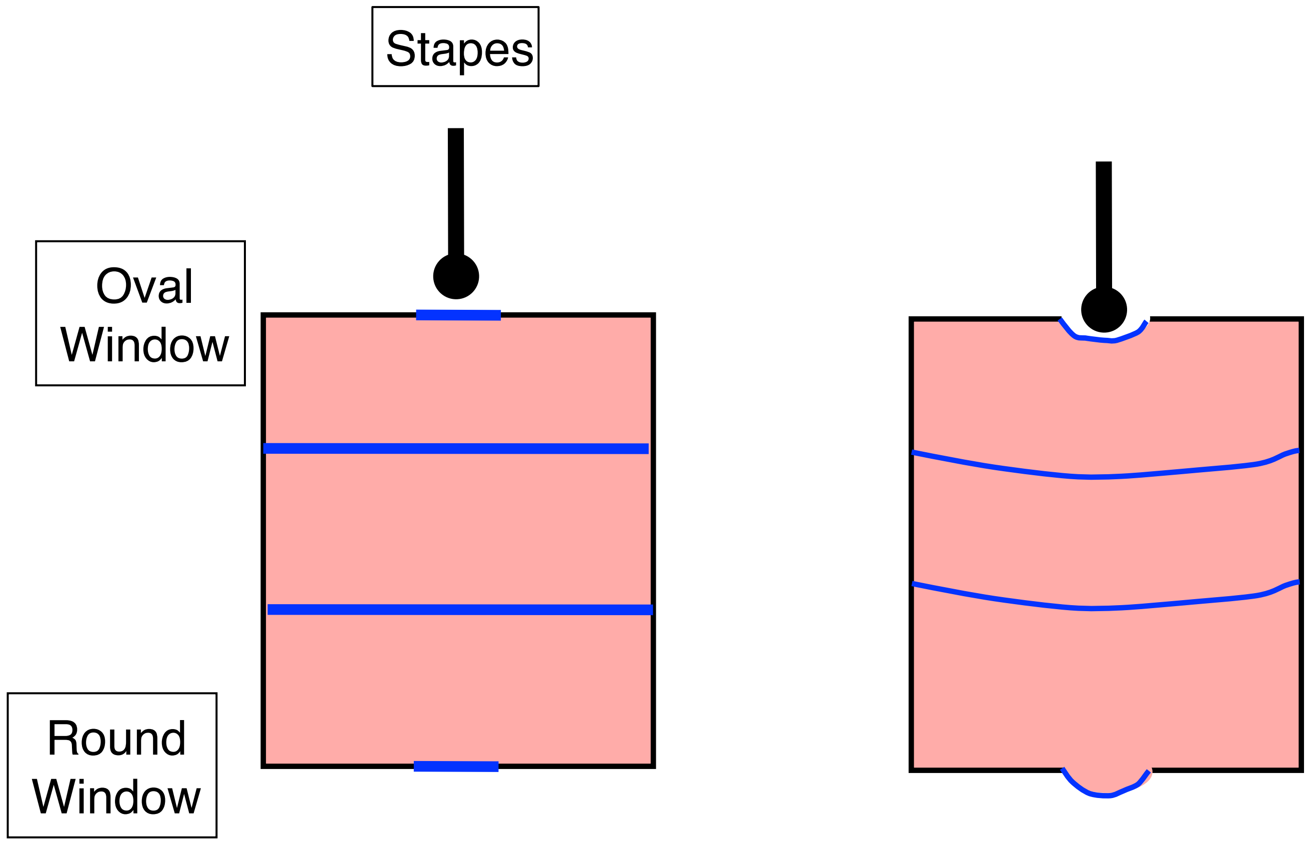
Vibrations cause stapes to push and pull flexible **oval window** in and out of vestibular canal at base of cochlea



Remaining pressure: transmitted through **helicotrema** and back to cochlear base through tympanic canal, where it is absorbed by the **round window**

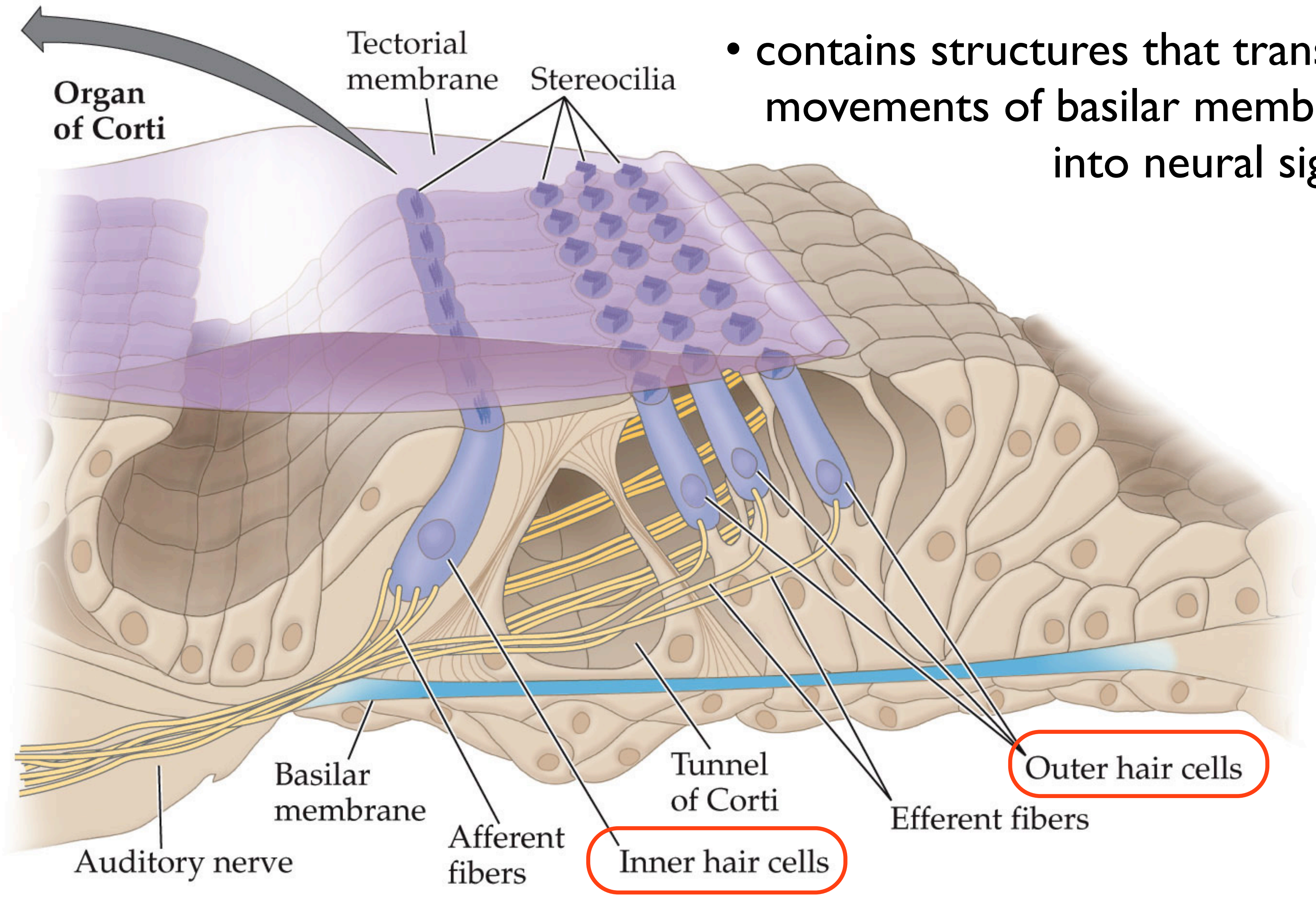


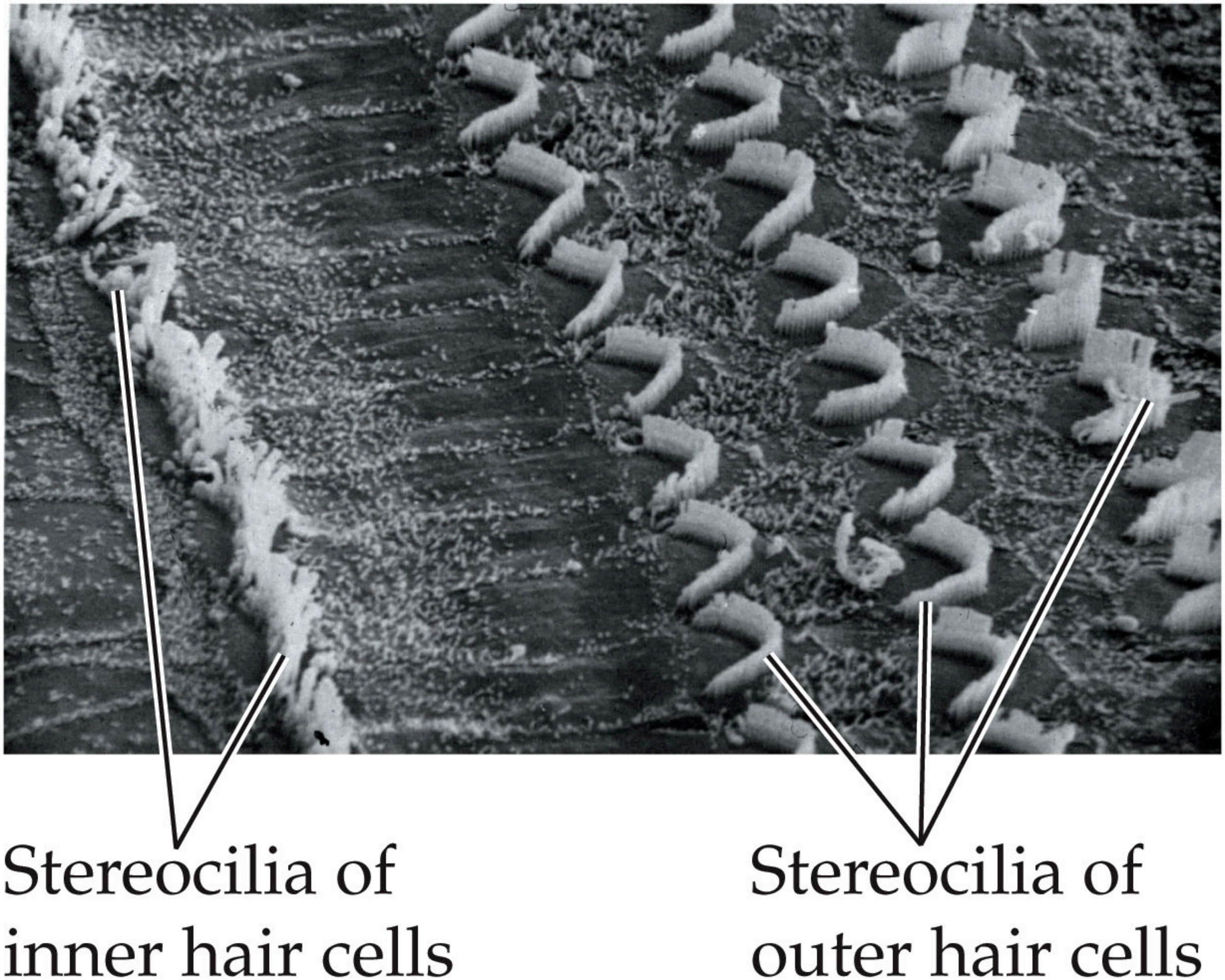
A simplified Cochlea
showing the effects of pressure



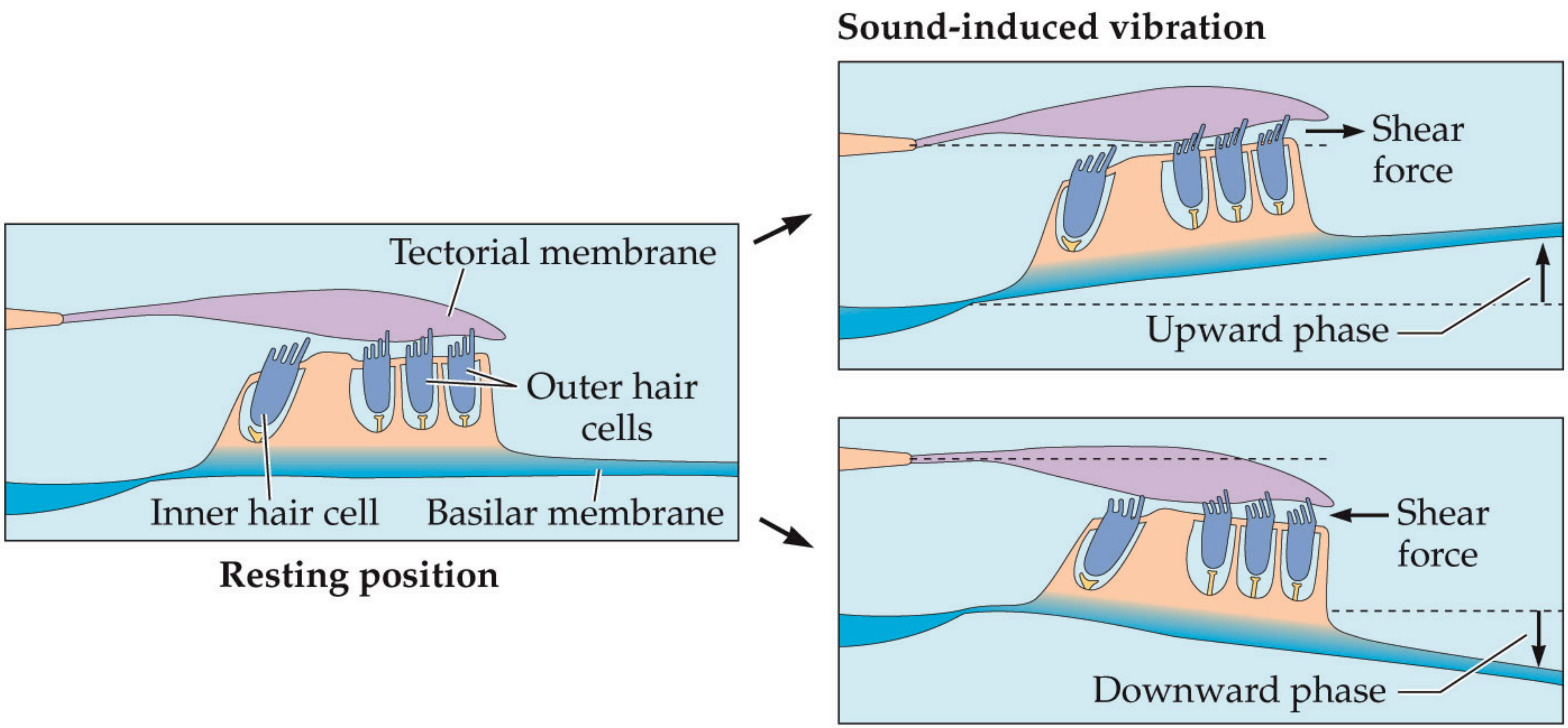
Organ of Corti: A structure on the basilar membrane of the cochlea composed of hair cells and dendrites of auditory nerve fibers

- contains structures that translate movements of basilar membrane into neural signals




Stereocilia of inner hair cells
Stereocilia of outer hair cells

- **Tectorial membrane**: extends into the middle canal, floating above inner hair cells and touching outer hair cells

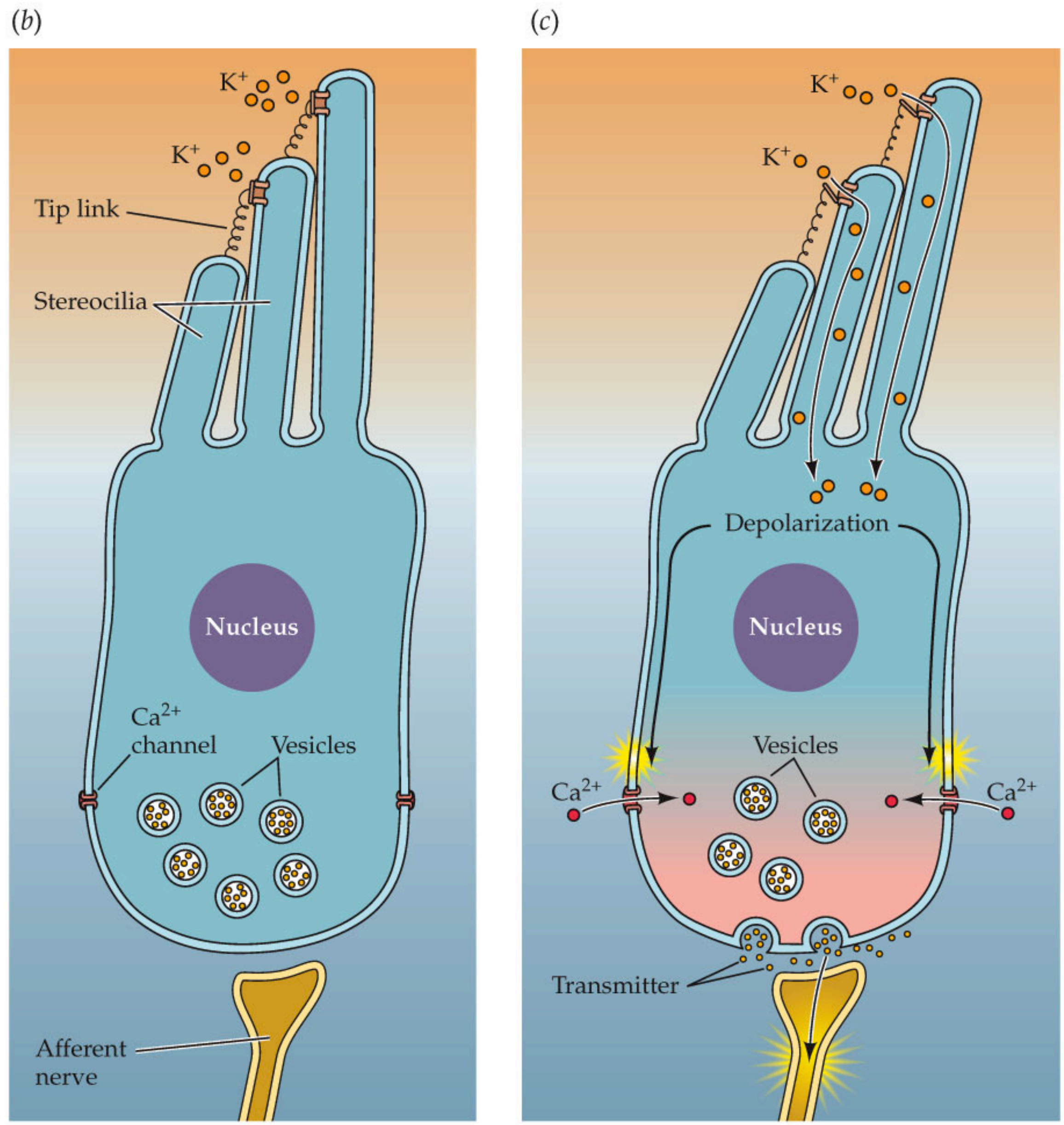


- Vibrations cause displacement of the tectorial membrane, which bends stereocilia attached to hair cells and causes the release of neurotransmitters

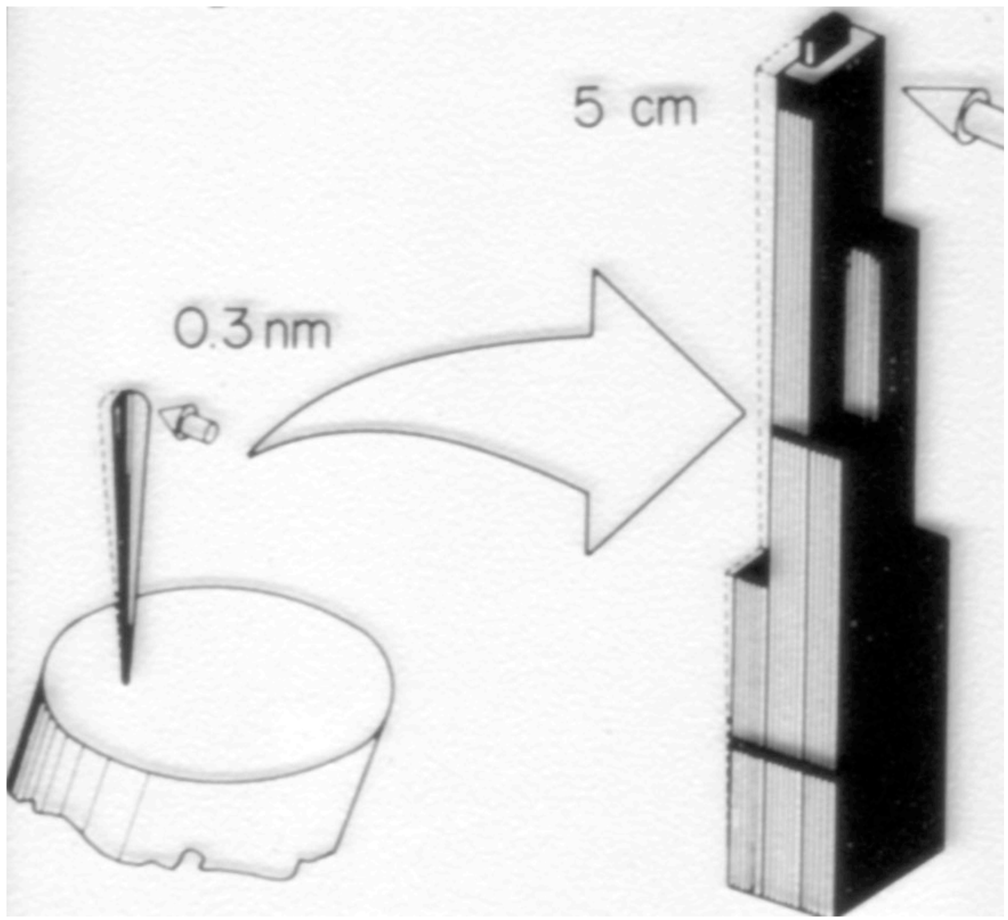
- **hair cells** - arranged in four rows

- **stereocilia**: Hairlike extensions on the tips of hair cells that initiate the release of neurotransmitters when they are flexed

- each tip connected to its neighbor by a tiny filament called a **tip link**



The *displacement threshold*
of a hair cell is small.
Very small.
Really, really, really small.



- **Inner hair cells**: Convey almost all information about sound waves to the brain (using afferent fibers)

- **Outer hair cells**: Convey information from the brain (using efferent fibers).
  - involved in an elaborate feedback system
  - amplify sounds by increasing mechanical deflections of the basilar membrane

Mechanical energy flow in the ear:

pinna → **ear canal** → **tympanic membrane** outer ear

→ **malleus** → **incus** → **stapes** middle ear

→ **oval window** → **vestibular canal** → **helicotrema** inner ear
→ **tympanic canal** → **round** window

Auditory Transduction cascade:

Standing wave in **basilar membrane**
→ movement of **organ of corti** & **tectorial membrane**(amplified by **outer hair cells**)
→ **inner hair cell** displacement → **tip links** → **channel opening**

additional topics this chapter

- auditory nerve
- place code
- temporal code
- characteristic frequency
- coding in the auditory system
- psychoacoustics
- hearing loss & hearing aides
- cochlear implants

The auditory nerve (AN)

- Responses of individual AN fibers to different frequencies are related to their place along the cochlear partition ("place code")
- **Frequency selectivity**: Clearest when sounds are very faint

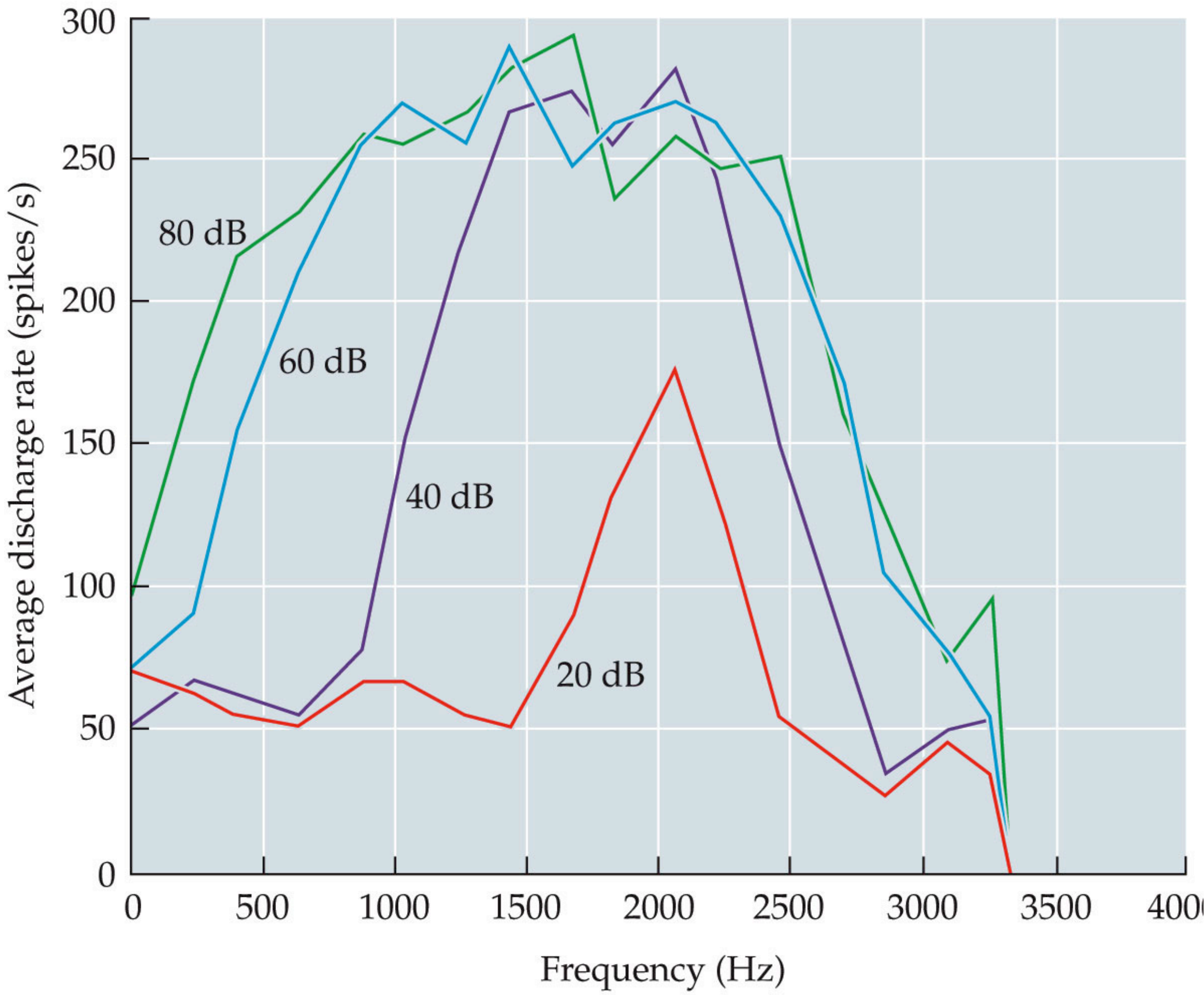
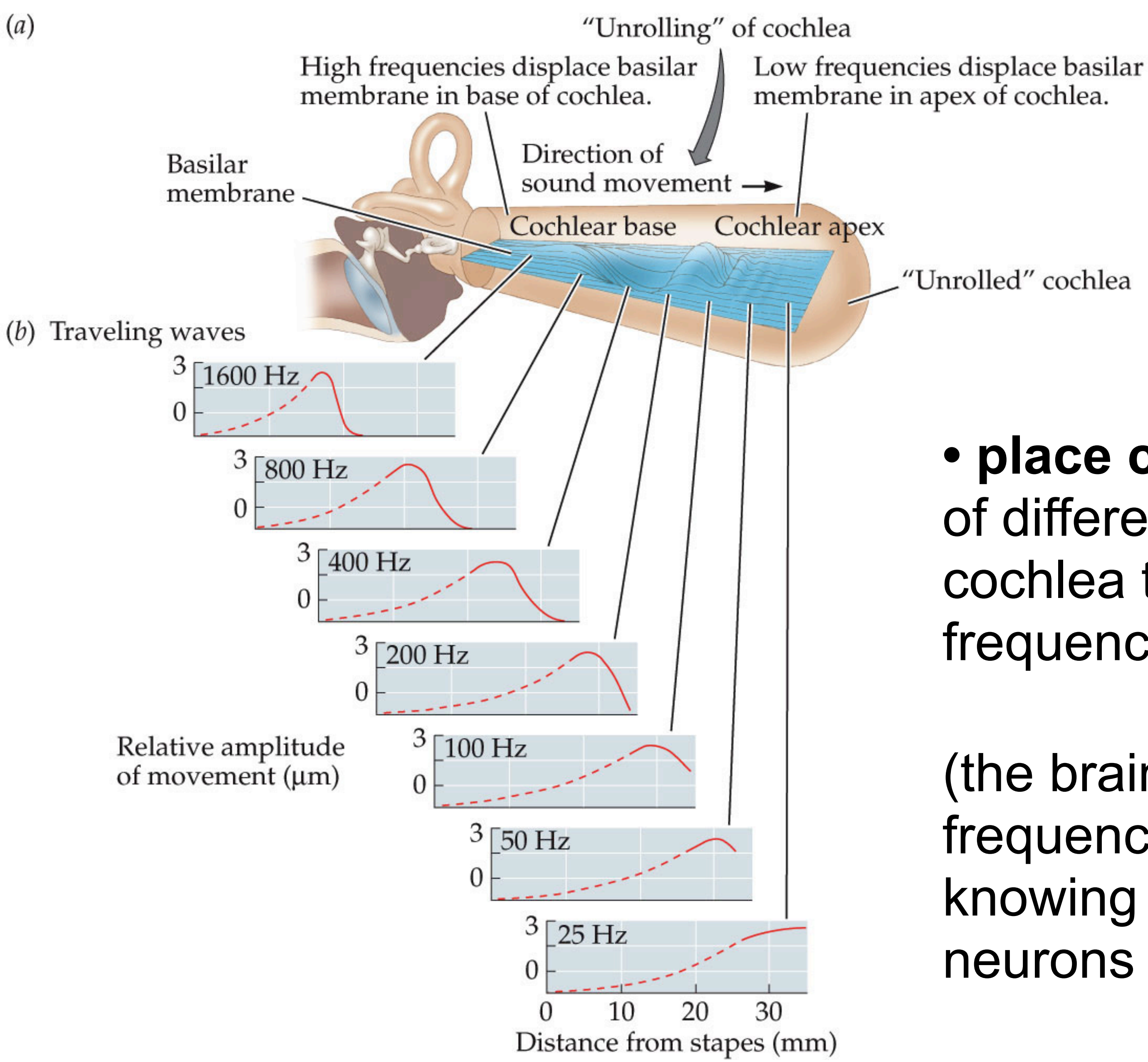


Figure 9.14 The cochlea is tuned to different frequencies

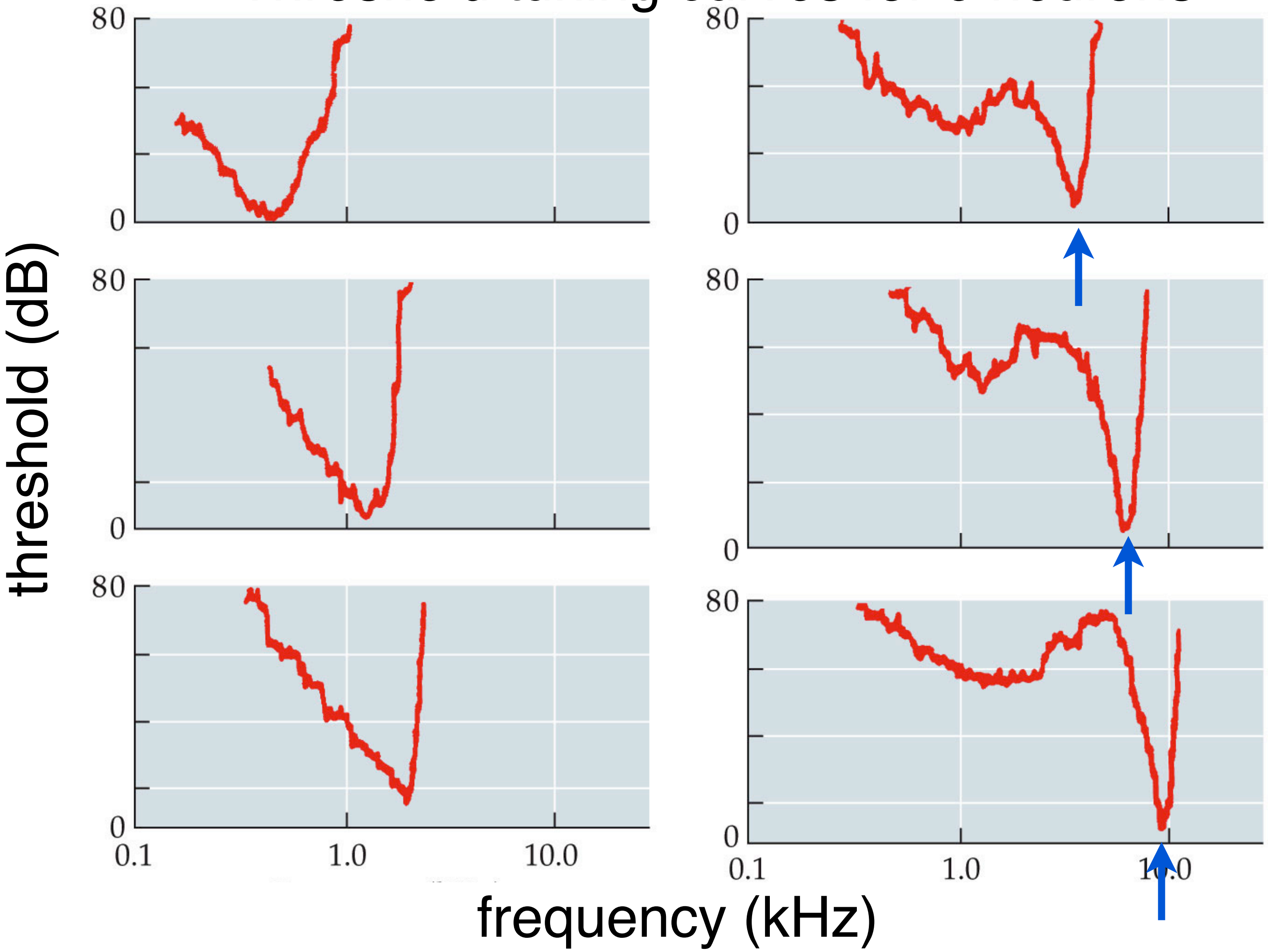


- **place code**: tuning of different parts of the cochlea to different frequencies

(the brain knows what frequency sound by knowing which neurons are firing)

- **Threshold tuning curve**: A map plotting threshold of a neuron as a function of frequency
- (threshold = lowest intensity that will give rise to a response)

Threshold tuning curves for 6 neurons



Characteristic frequency

- frequency to which the neuron is most sensitive

Figure 9.21 Pathways in the auditory system

- **Cochlear nucleus**: first brain stem nucleus at which afferent auditory nerve fibers synapse
- **Superior olive**: brainstem region in the auditory pathway where inputs from both ears converge
- **Inferior colliculus**: midbrain nucleus in the auditory pathway
- **Medial geniculate nucleus (MGN)**: part of the thalamus that relays auditory signals to the cortex

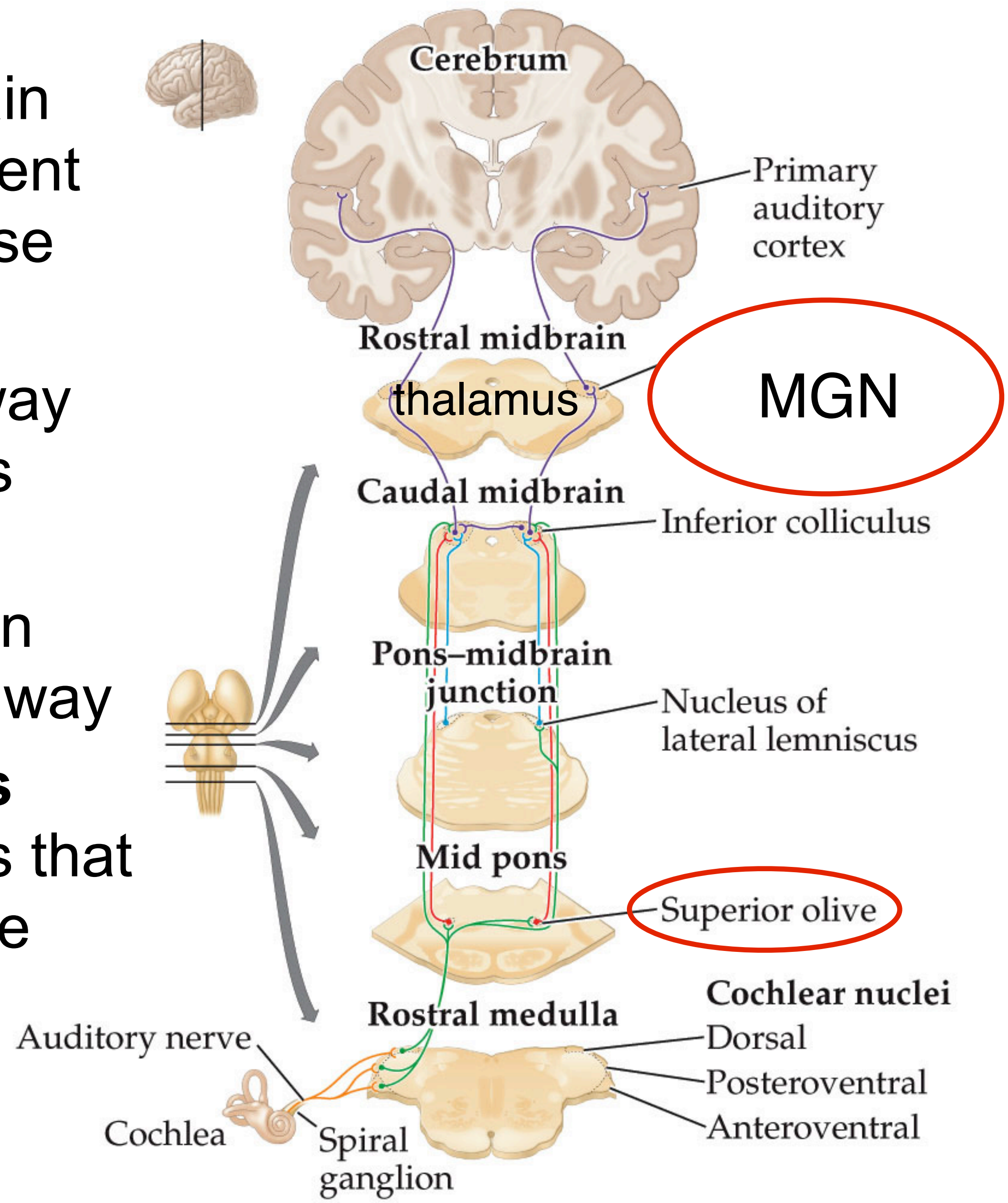
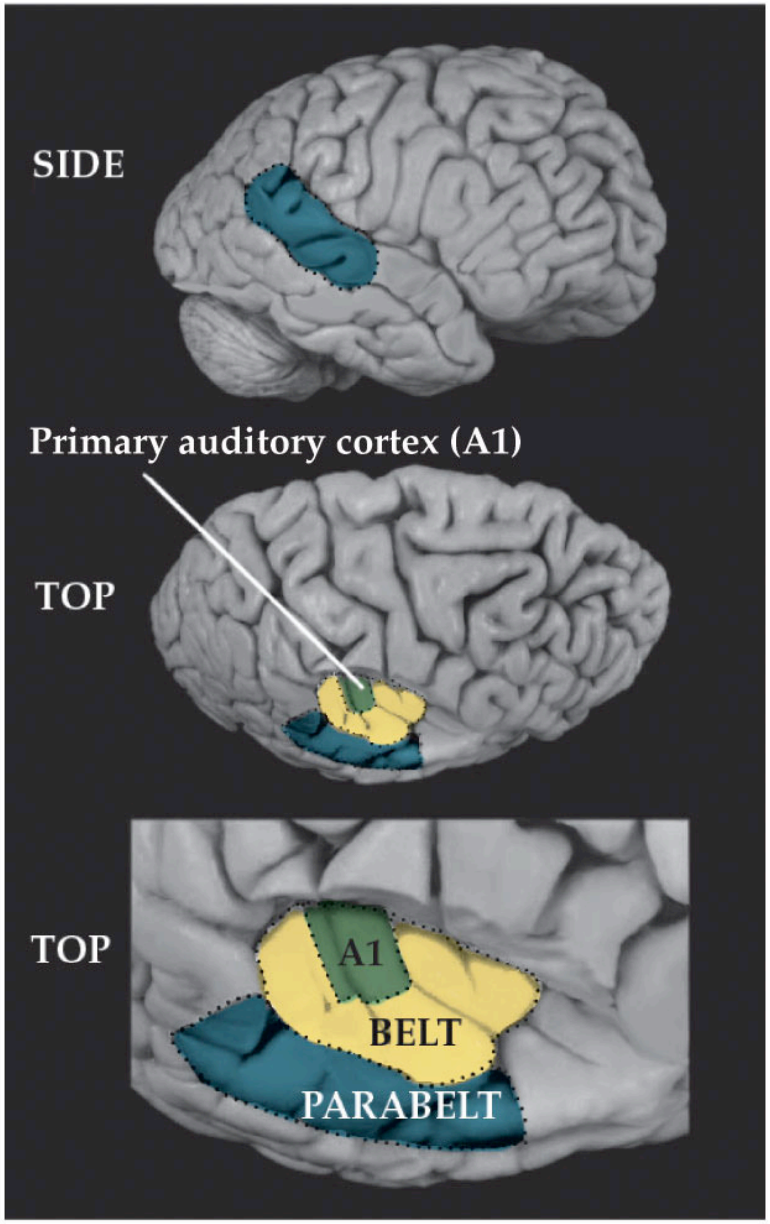


Figure 9.22 The first stages of auditory processing begin in the temporal lobe in areas within the Sylvian fissure

- **Primary auditory cortex (A1)**: First cortical area for processing audition (in temporal lobe)

- **Belt area**: A region of cortex, directly adjacent to A1, with inputs from A1, where neurons respond to more complex characteristics of sounds
- **Parabelt area**: A region of cortex, lateral and adjacent to the belt area, where neurons respond to more complex characteristics of sounds, as well as to input from other senses



Basic Structure of the Mammalian Auditory System

Comparing overall structure of auditory and visual systems:

- **Auditory system**: Large proportion of processing is done *before* A1
- **Visual system**: Large proportion of processing occurs *beyond* V1
- Why? May be due to evolutionary reasons...

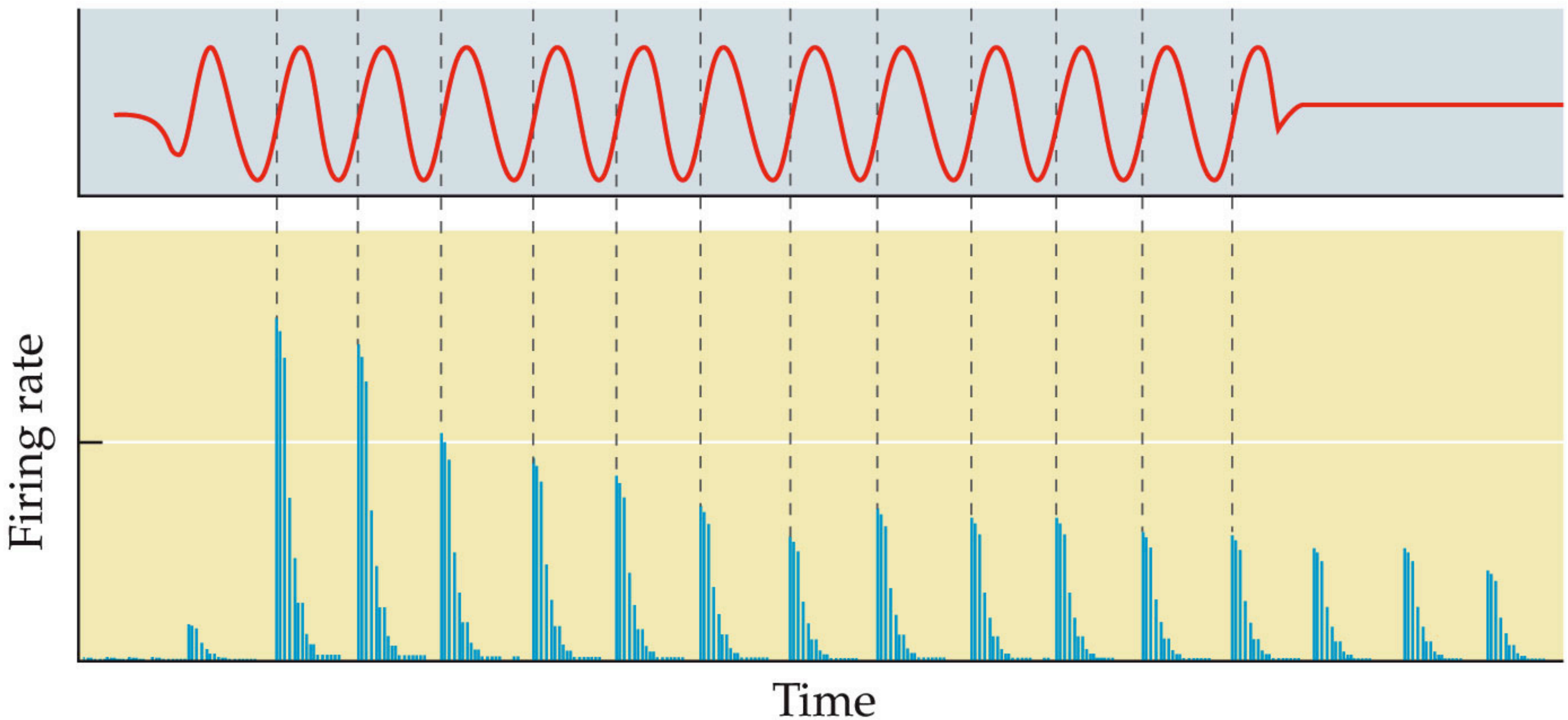
Basic Structure of the Mammalian Auditory System

Tonotopic organization: An arrangement in which neurons that respond to different frequencies are organized anatomically in order of frequency

- Starts in the cochlea
- Maintained all the way through primary auditory cortex (A1)

"place code"

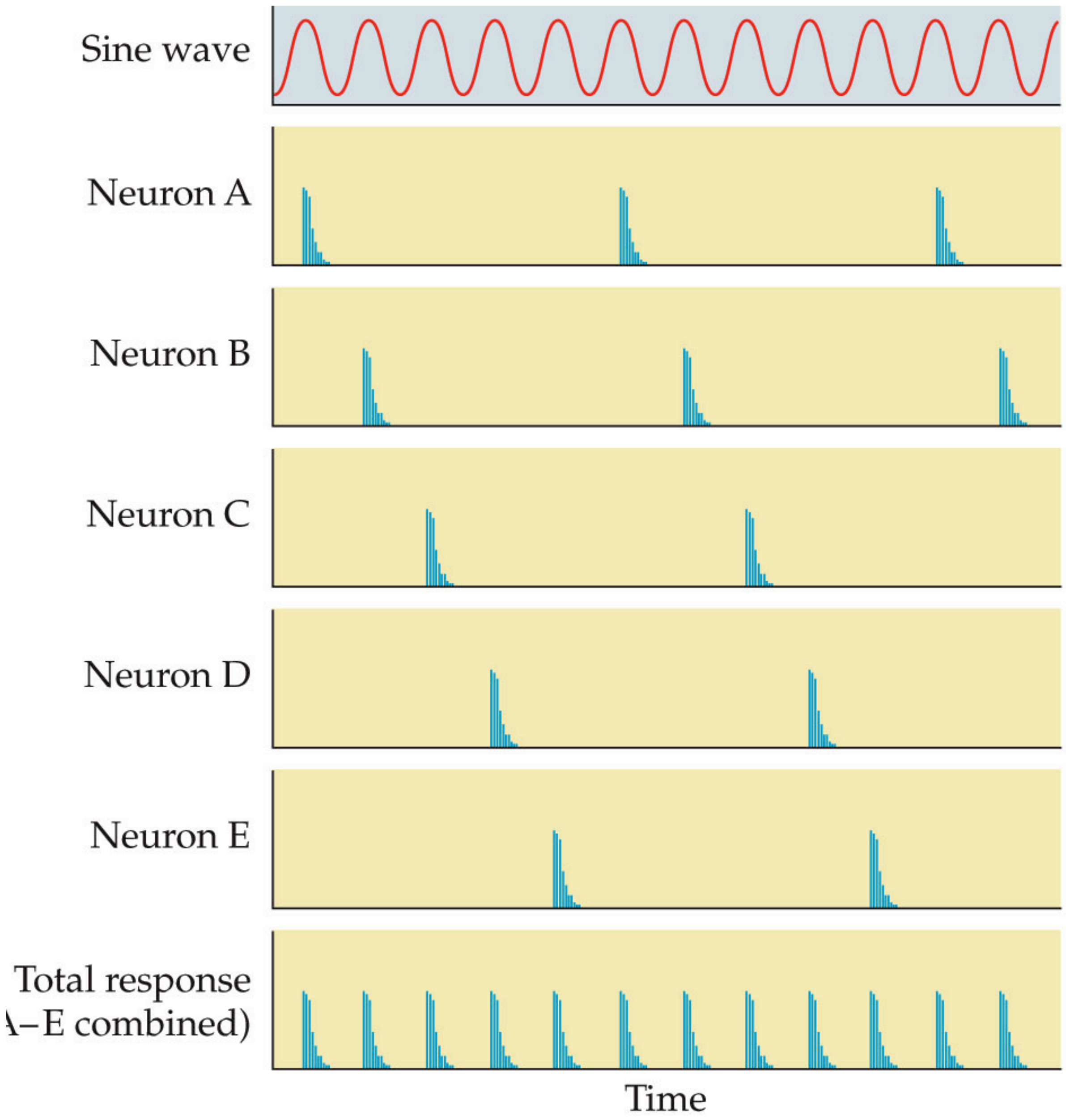
- **Phase locking**: Firing of a single neuron at one distinct point in the period (cycle) of a sound wave at a given frequency
- The existence of phase locking means that the firing pattern of an AN fiber carries a **"temporal code"**



Histogram showing neural spikes for an auditory nerve fiber in response to the same low-frequency sine wave being played many times

The volley principle:

- multiple neurons can provide a temporal code for frequency by working together.



Psychoacoustics

Psychoacoustics: The study of the psychological correlates of the physical dimensions of acoustics

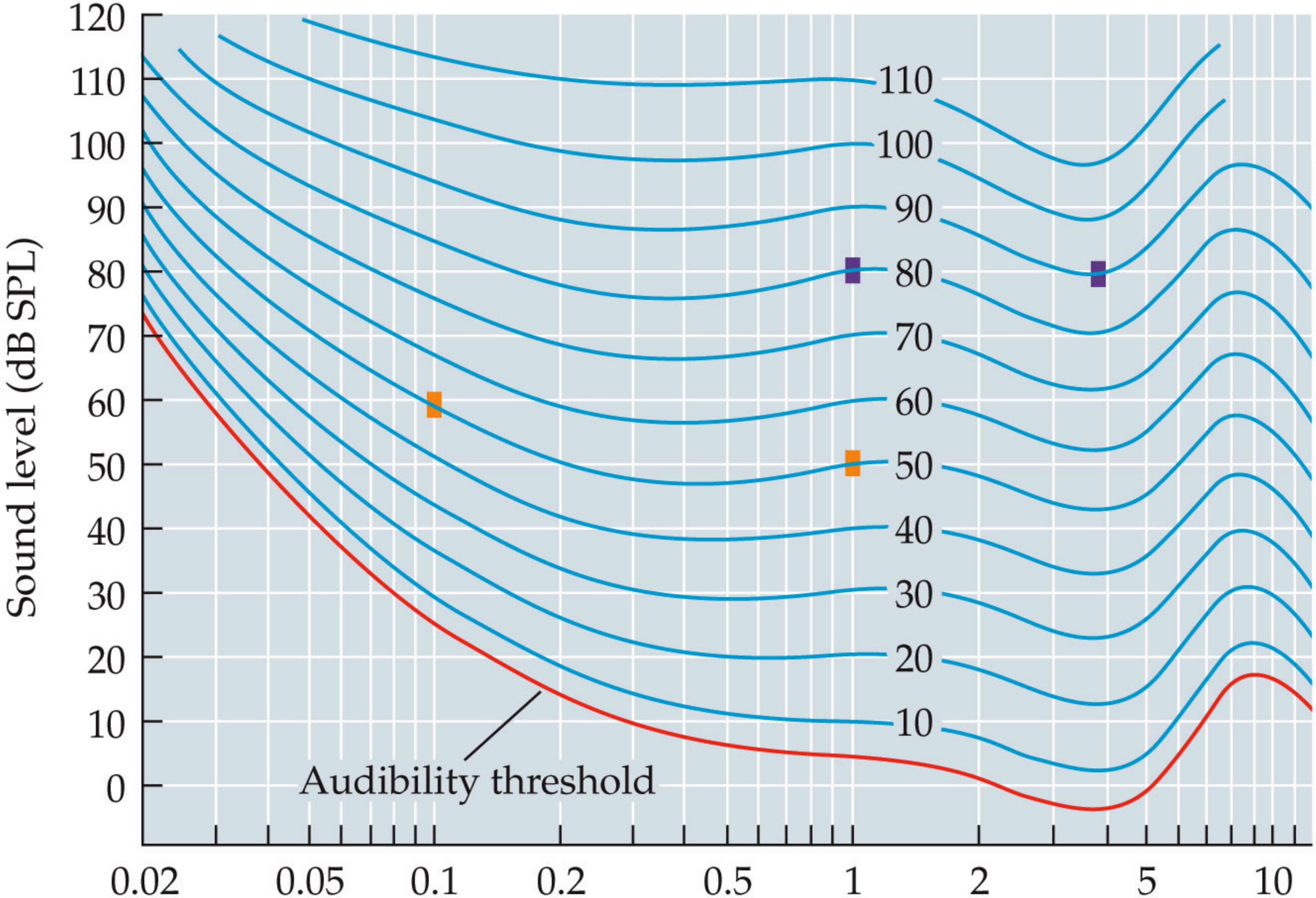
- A branch of psychophysics

Physical Property		Psychological Percept
Frequency	→	Pitch
Amplitude / Intensity	→	Loudness

Q: in what ways are these relationships not exact?

Pitch perception: depends on full set of harmonics (overtones)
Loudness perception: depends on frequency, noise, acoustic environment

Equal-loudness curves



• each line corresponds to tones rated by observers as having the same loudness