Intro to Audition & Hearing

Lecture 15
Chapter 9, part II

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Sensation & Perception (PSY 345 / NEU 325)
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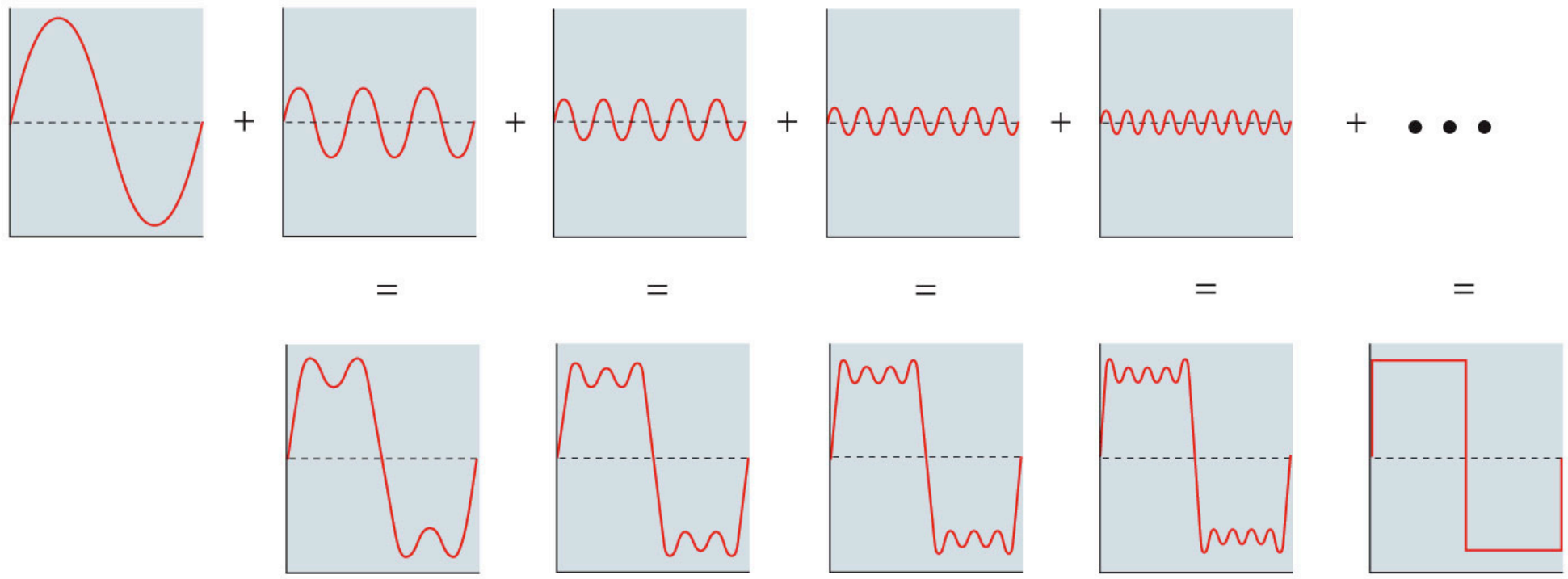
Complex sounds can be described by Fourier analysis

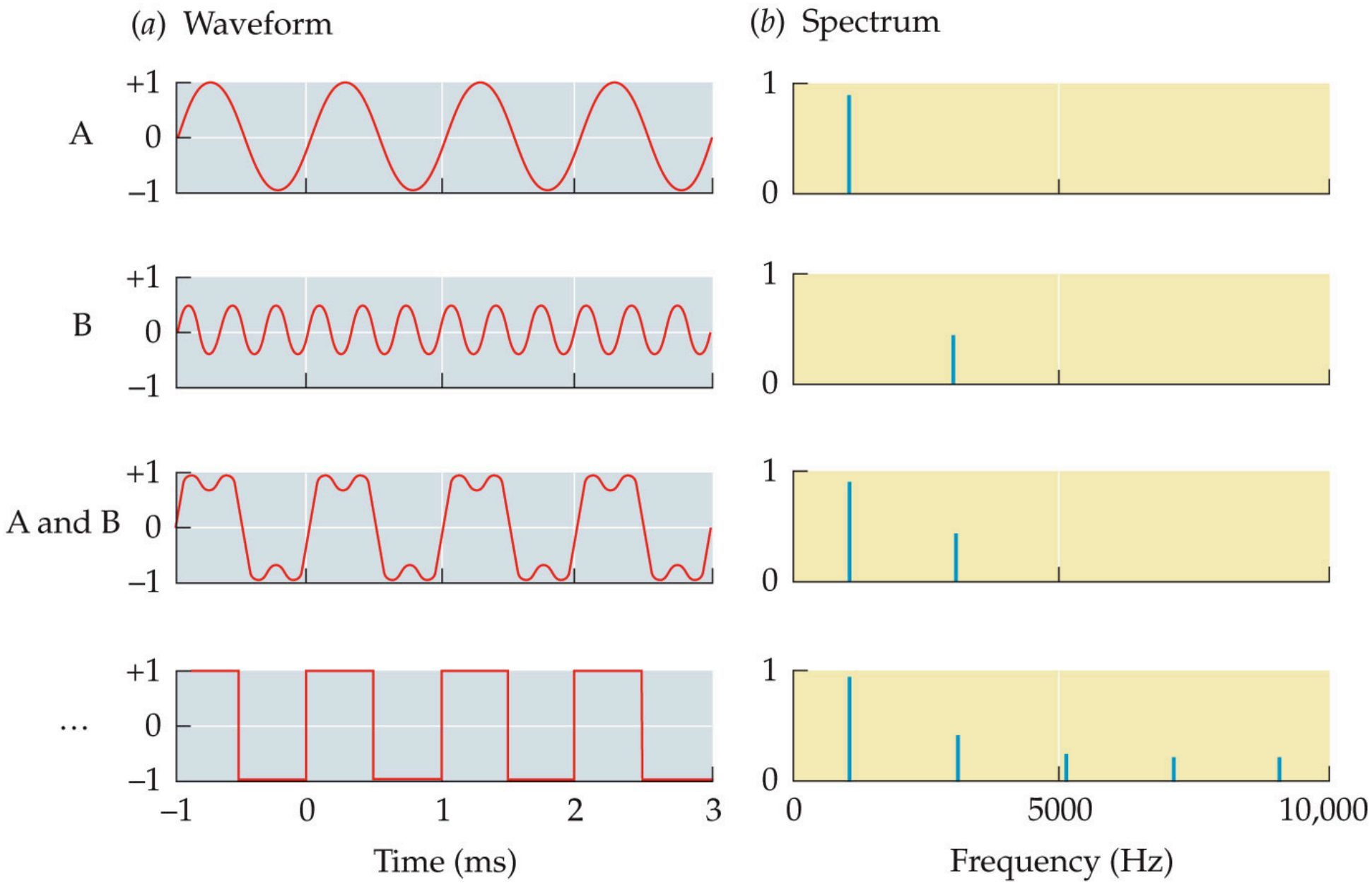
- **Fourier analysis**: mathematical theory by which any sound can be divided into a sum of sine waves

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



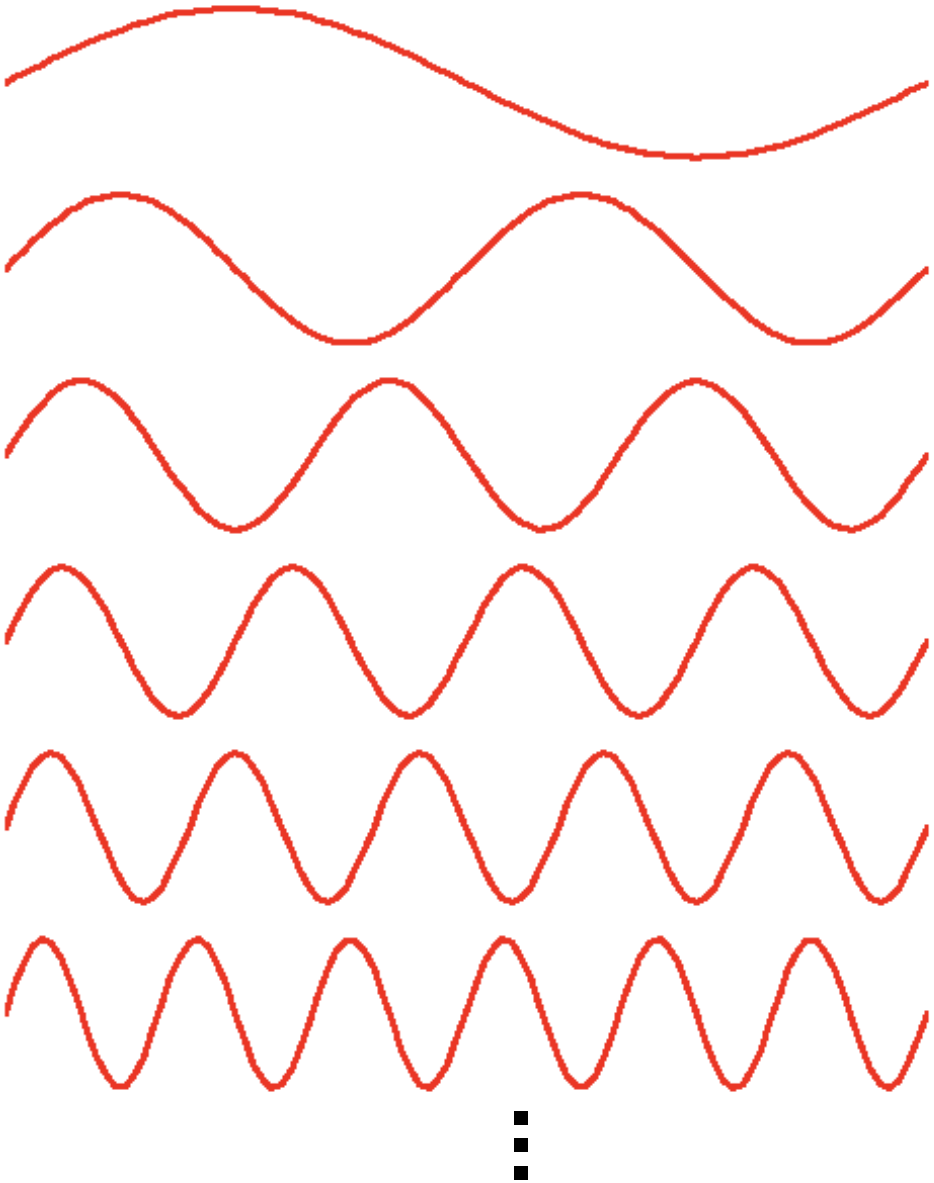
https://oup-arc.com/access/content/sensation-and-perception-5e-student-resources/sensation-and-perception-5e-activity-1-2?previousFilter=tag_chapter-01

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**"



- **Fundamental frequency**

x 2

x 3

x 4

x 5

x 6

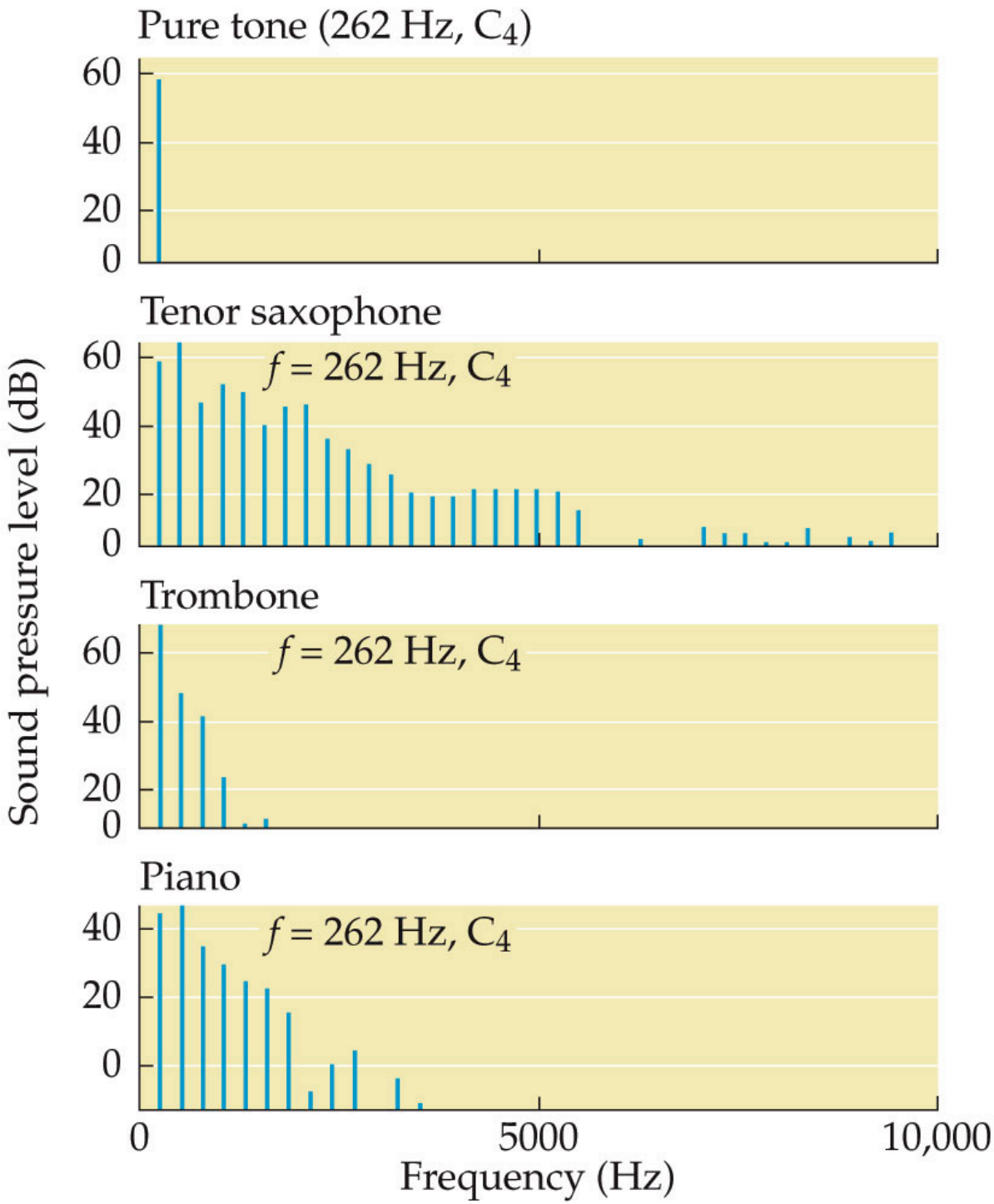
determines the perceived pitch

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

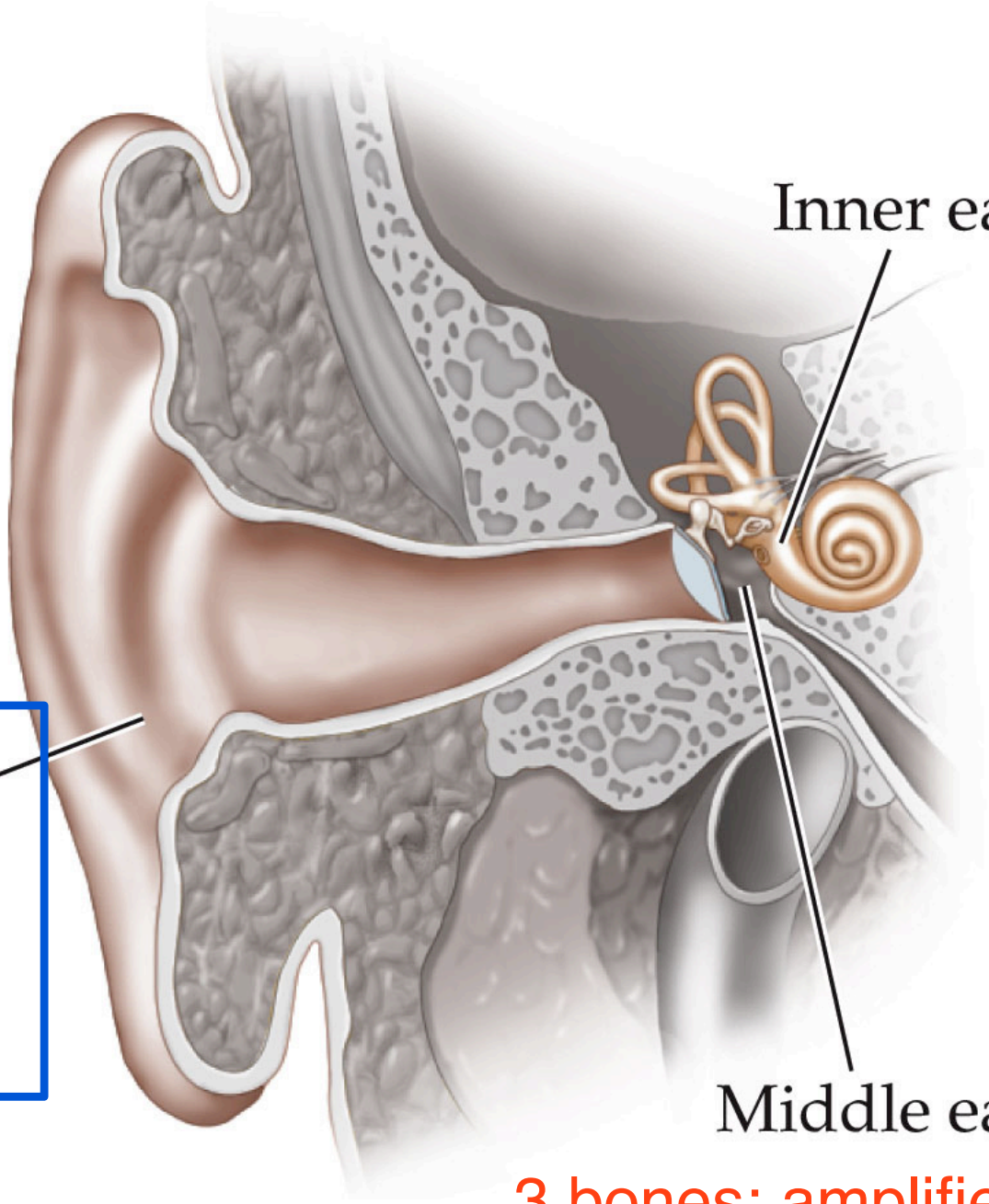
(more on this when we get to "music")

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



Next: The Auditory System

Figure 9.10 Structures of the human ear (Part 3)



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

collects and transforms sound

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

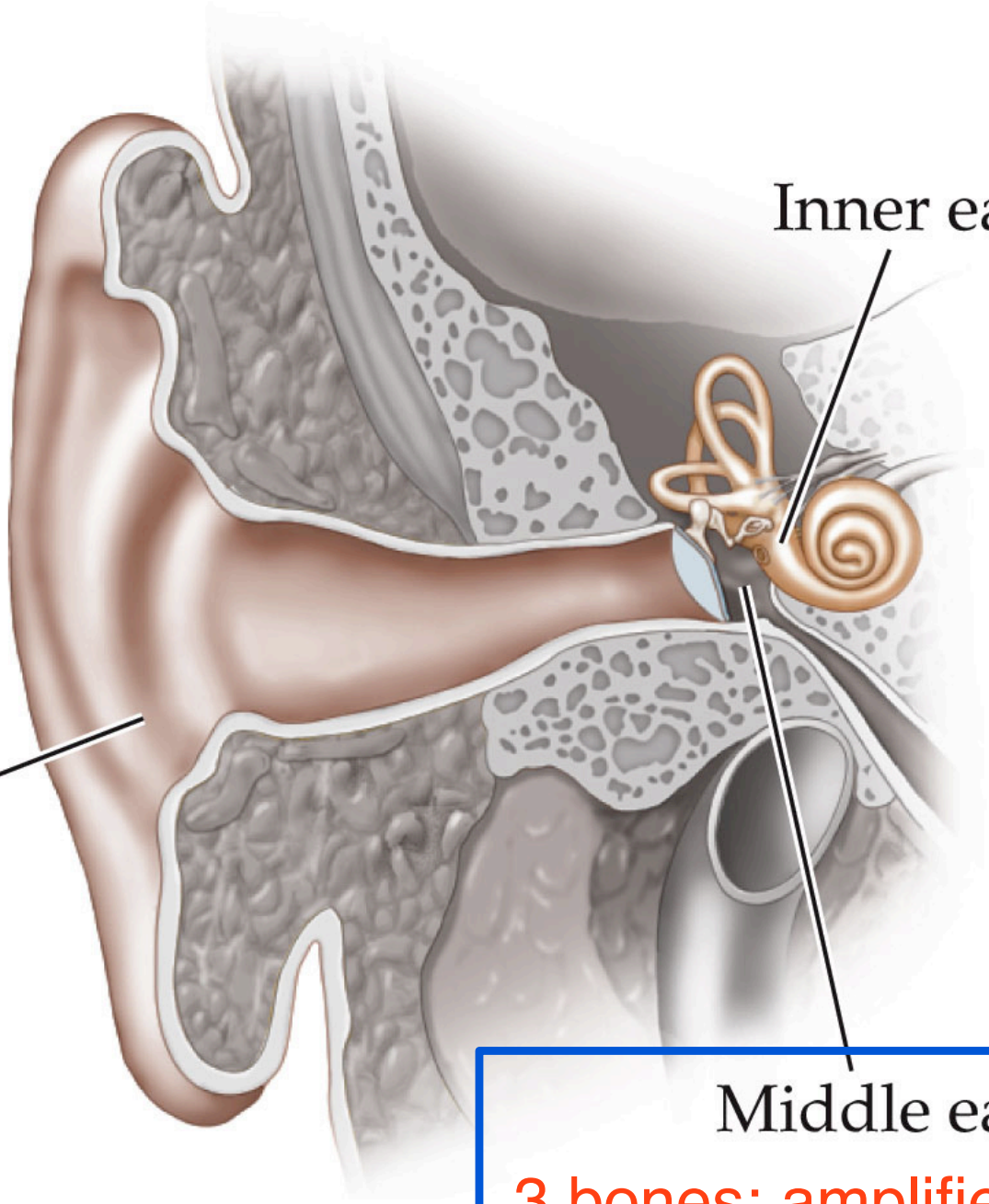
Pinna size and shape vary greatly







Figure 9.10 Structures of the human ear (Part 3)



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

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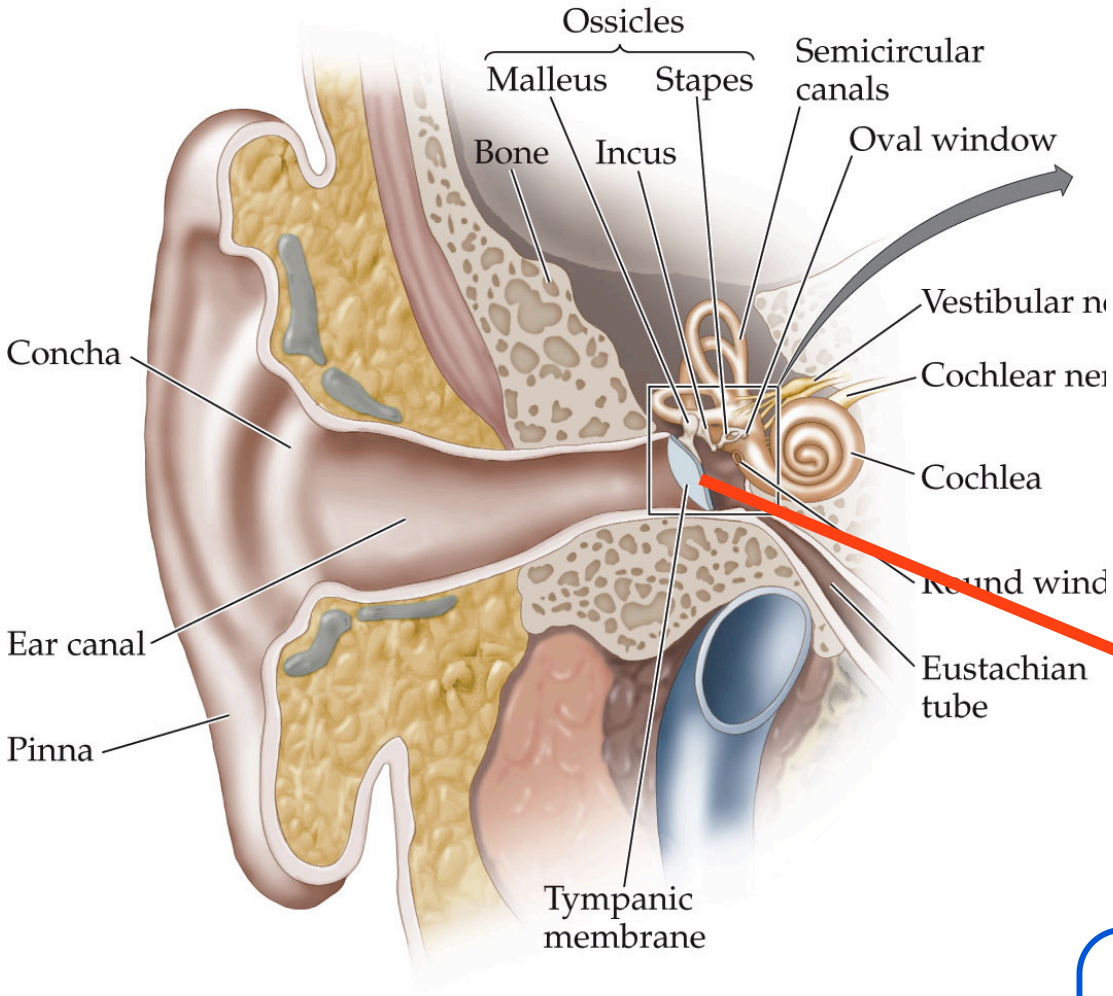
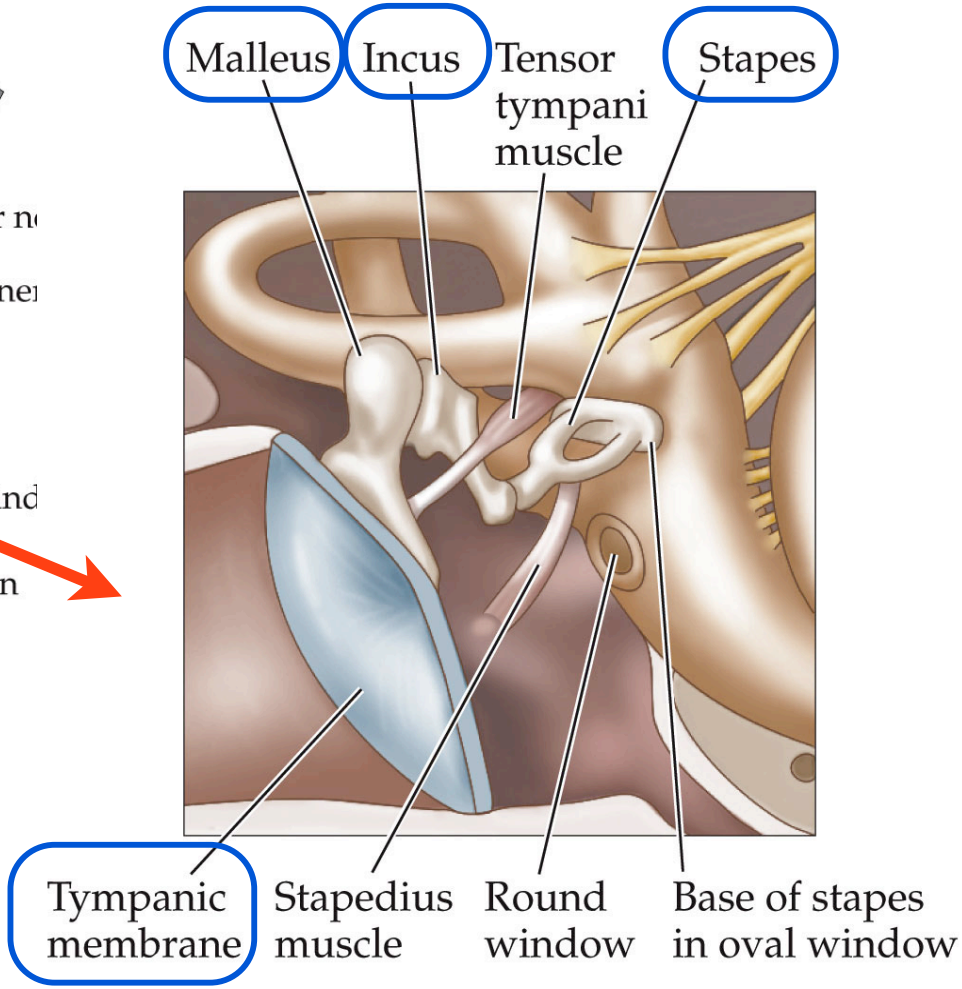
Middle ear


Ossicles
Malleus
Stapes
Semicircular canals
Bone
Incus
Oval window
Vestibular n
Cochlear ne
Concha
Cochlea
Ear canal
Eustachian tube
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:

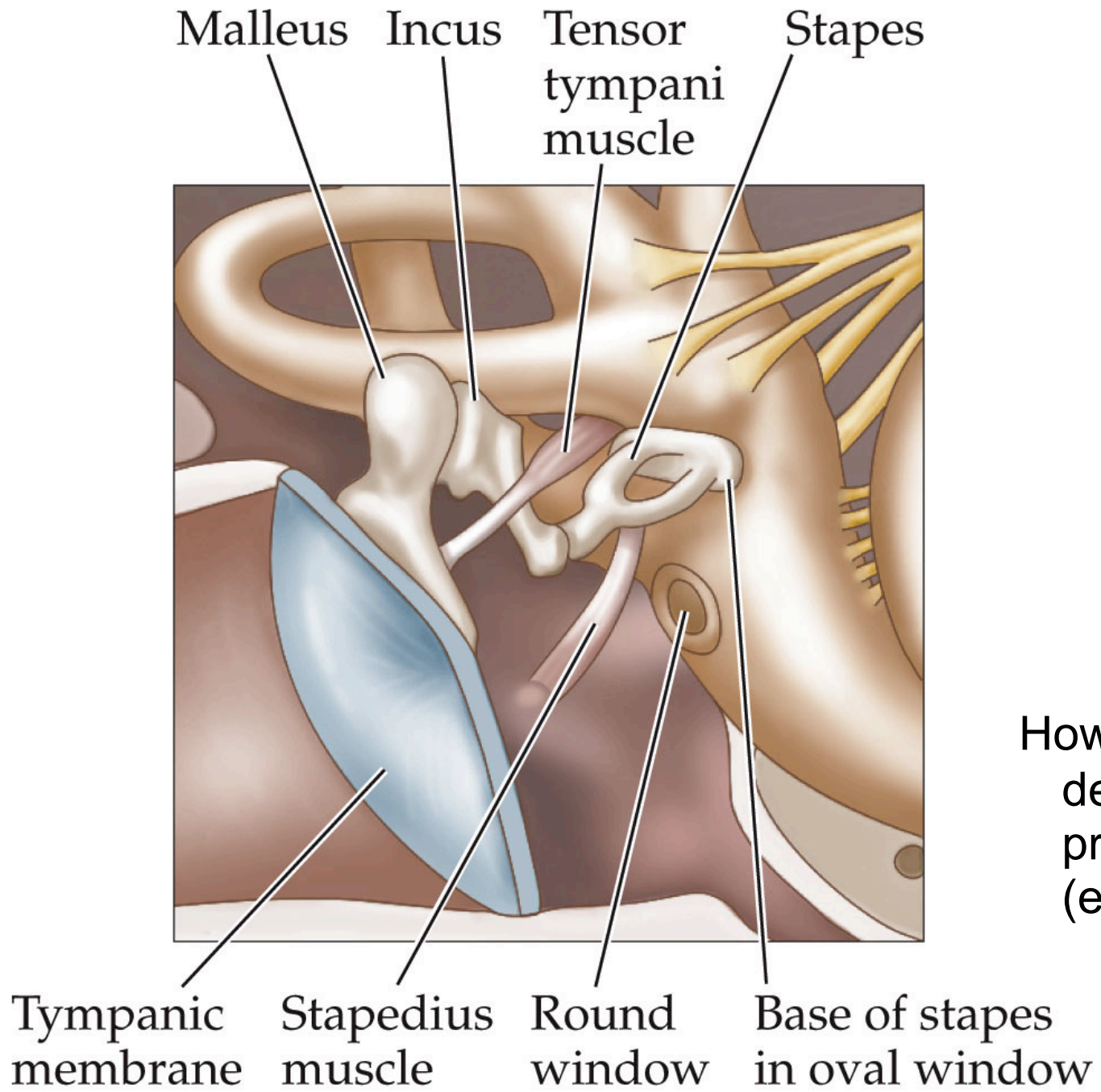
- **Ossicles** have hinged joints that work like levers to amplify sounds
- **Tympanic membrane** has much larger surface area than base of the stapes (where it pushes on oval window)

(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)

Figure 9.10 Structures of the human ear



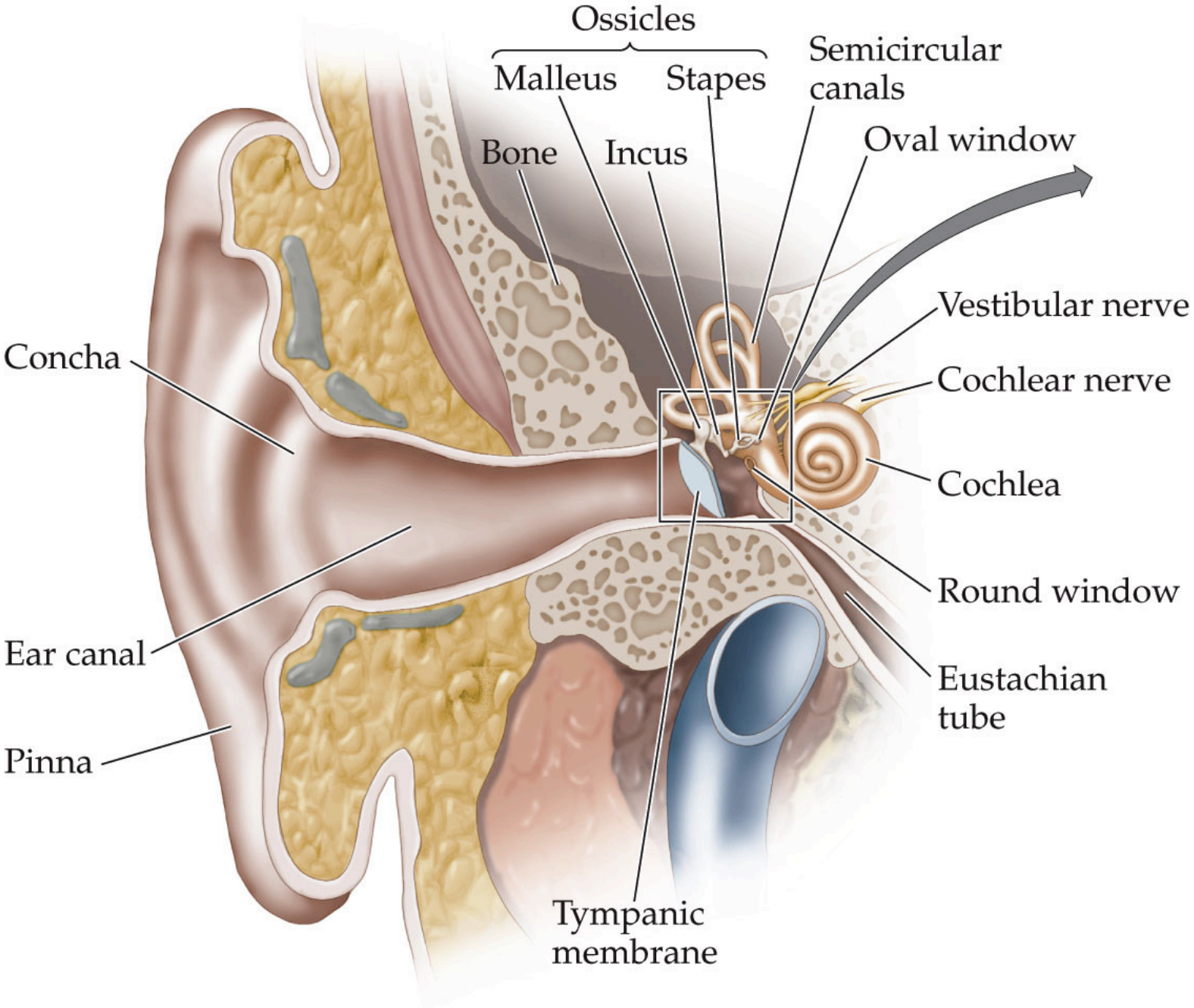
<u>muscles</u>

- tensor tympani
- stapedius

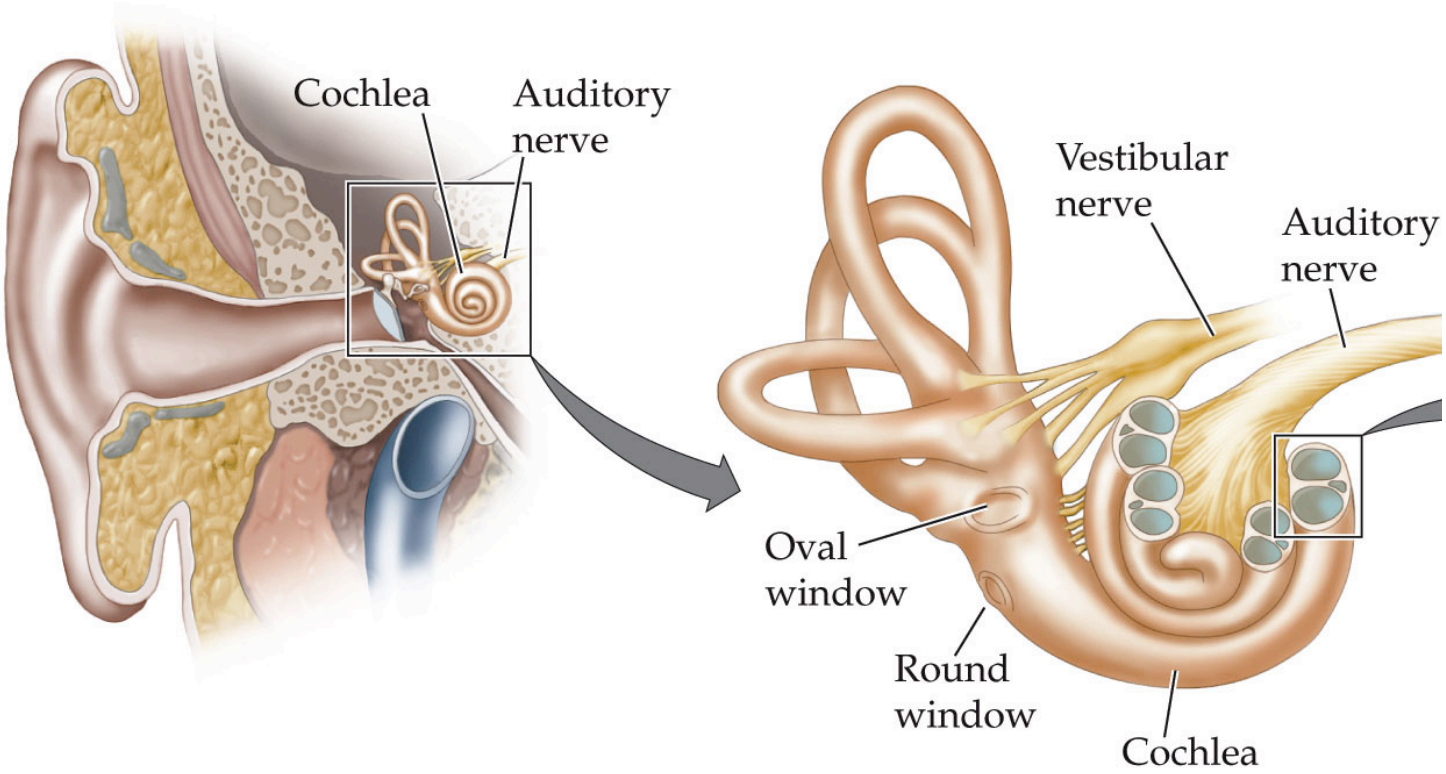
- smallest muscles in human body
- tighten to reduce amplification of loud sounds

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

Figure 9.10 Structures of the human ear



Inner Ear

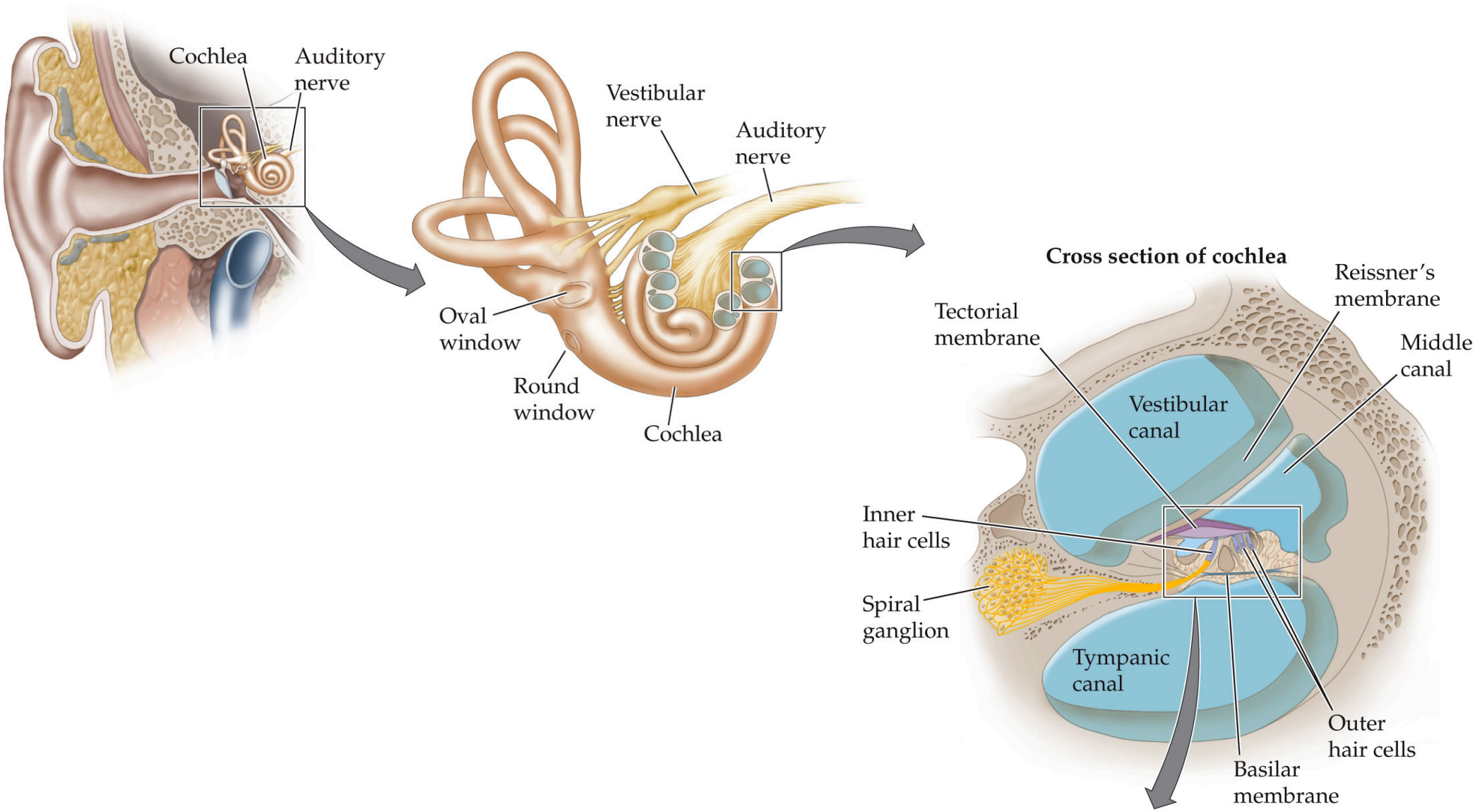


Cochlea - Spiral structure filled with fluids in three parallel canals

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

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

Figure 9.11 The cochlea

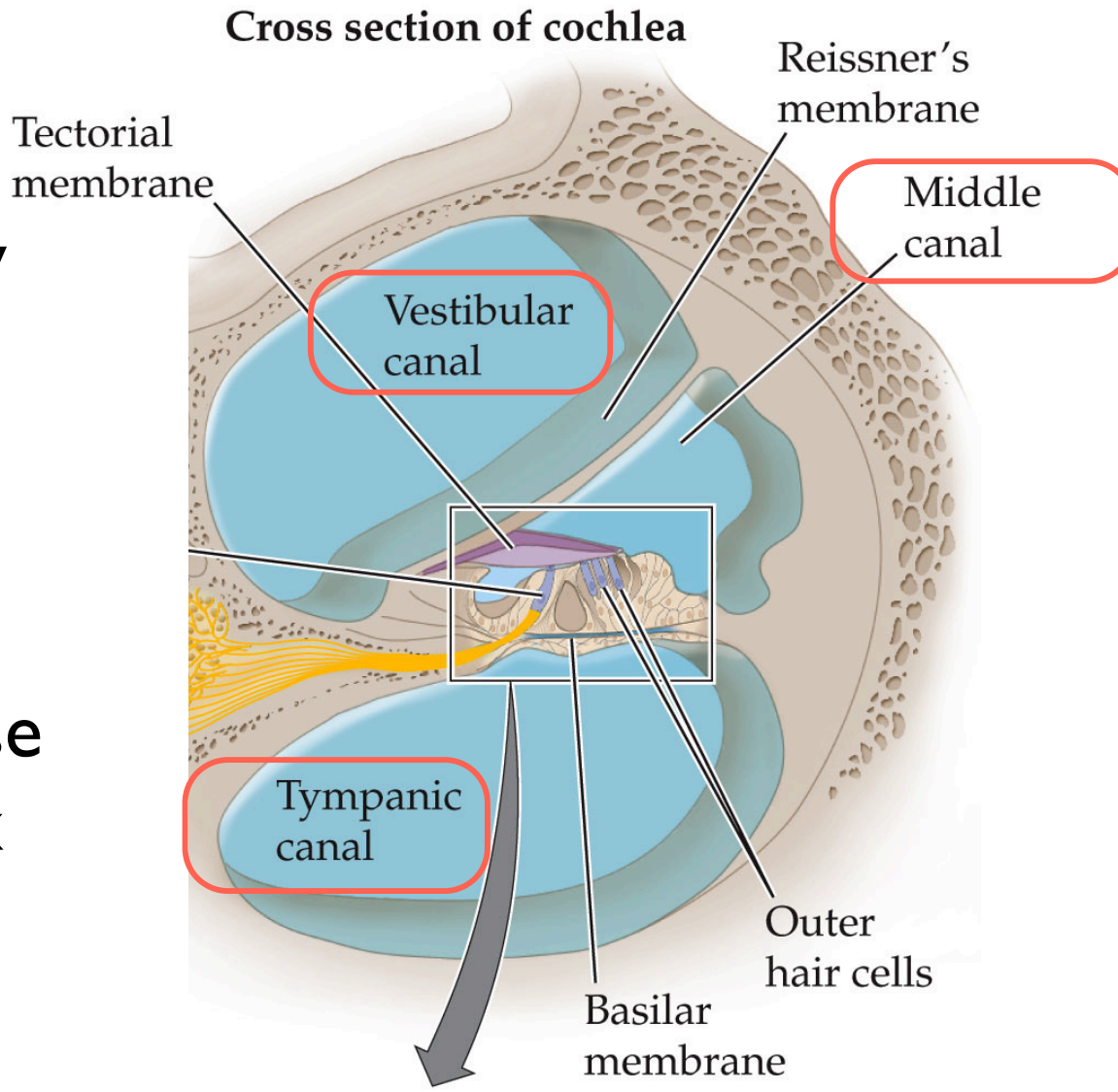


The three canals of the cochlea:

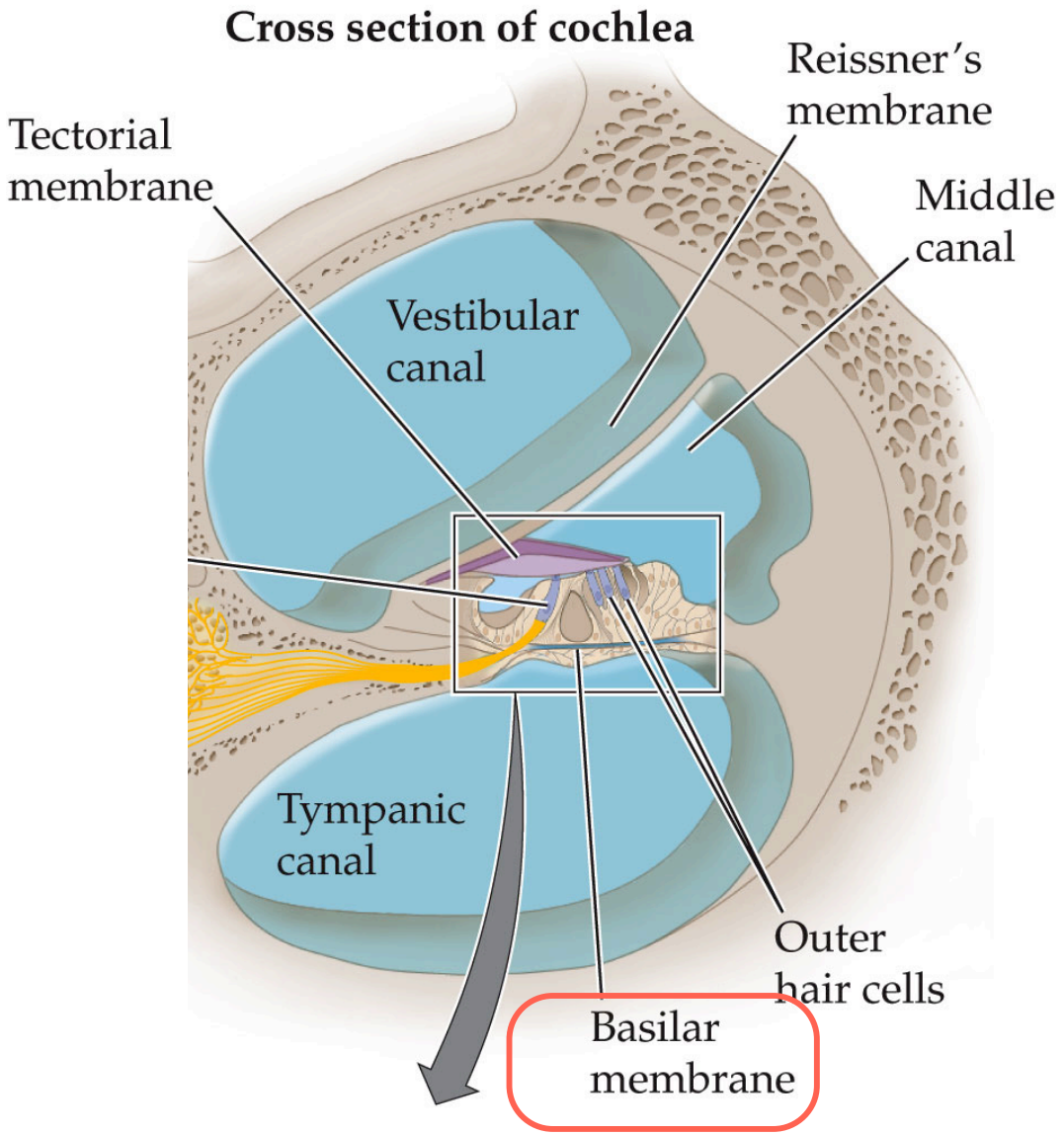
- **Vestibular canal**: extends from oval window at base of cochlea to *helicotrema* at the apex

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

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



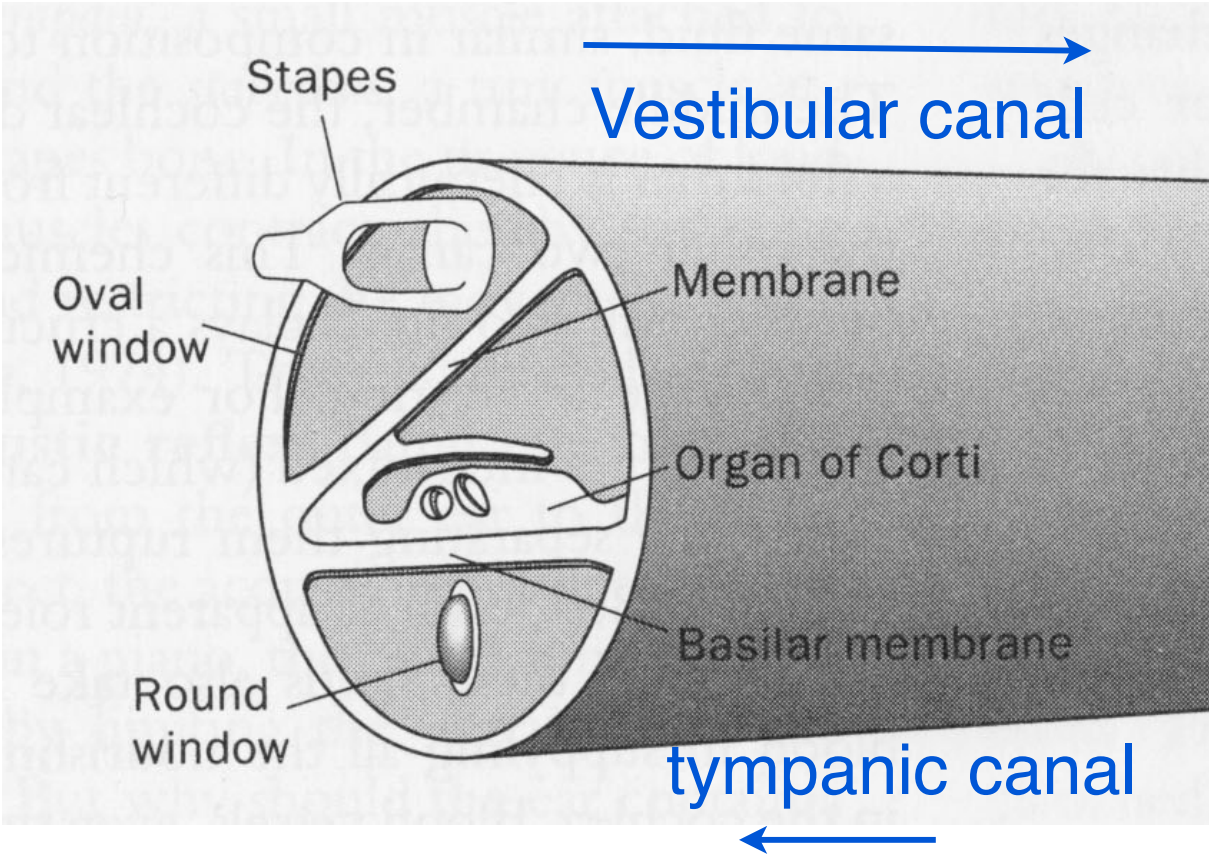
Membranes separating these chambers



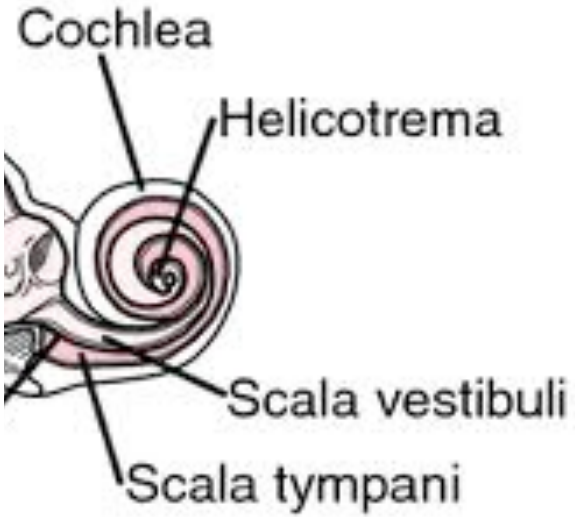
- **Basilar membrane:**
  separates middle and tympanic canals

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

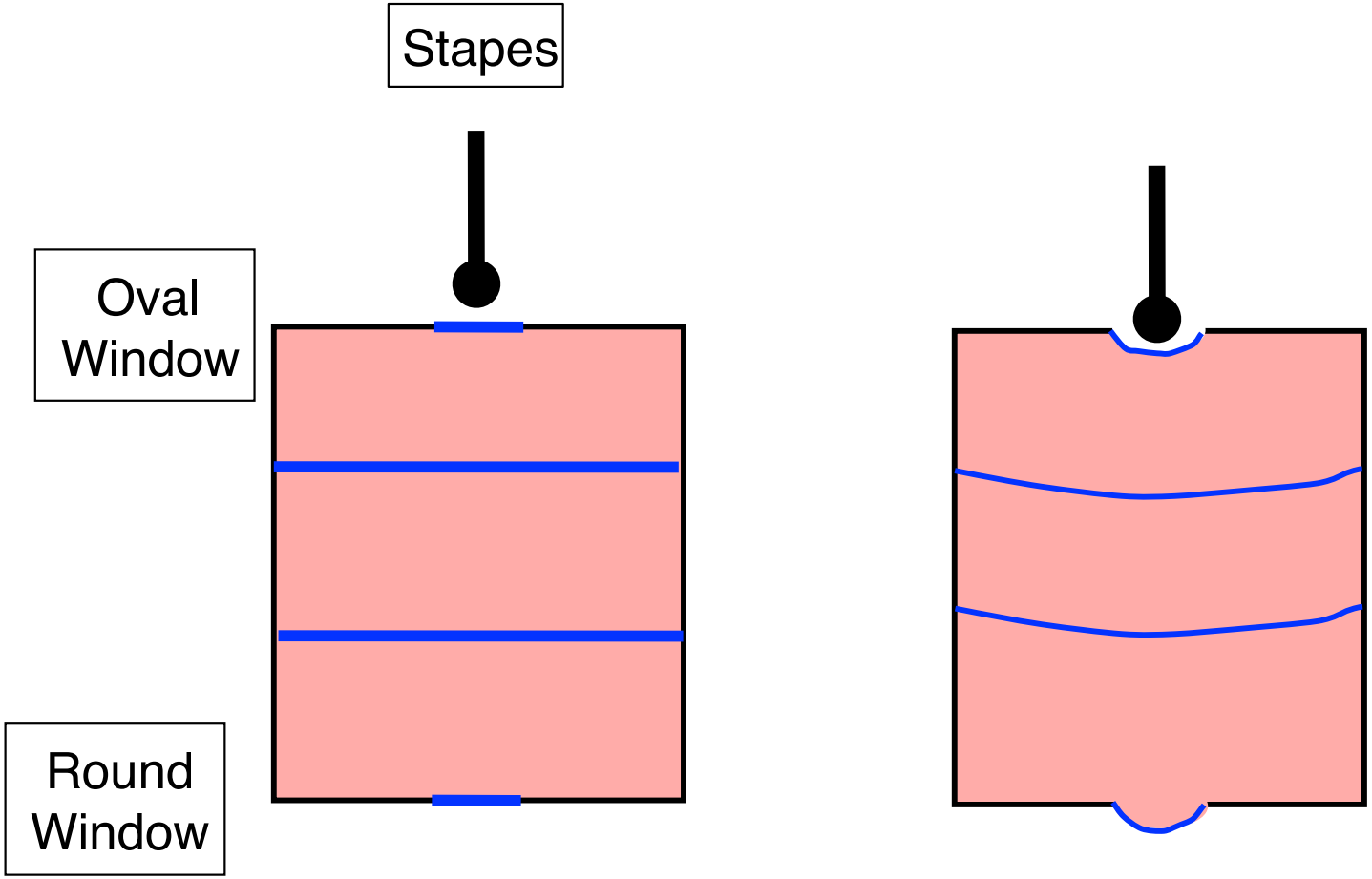
Vibrations cause stapes to push and pull flexible **oval window** in and out of vestibular canal at base of cochlea



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

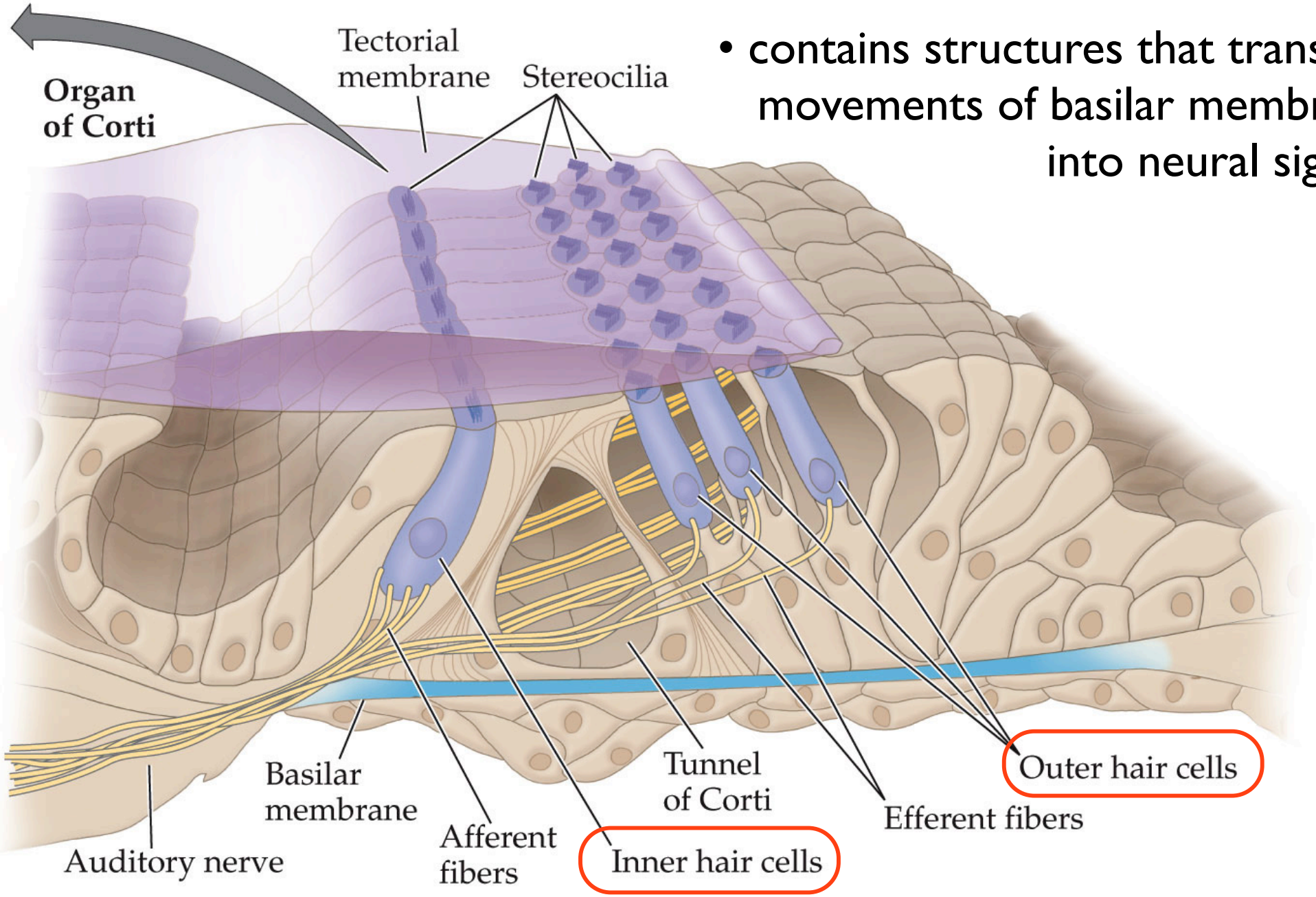
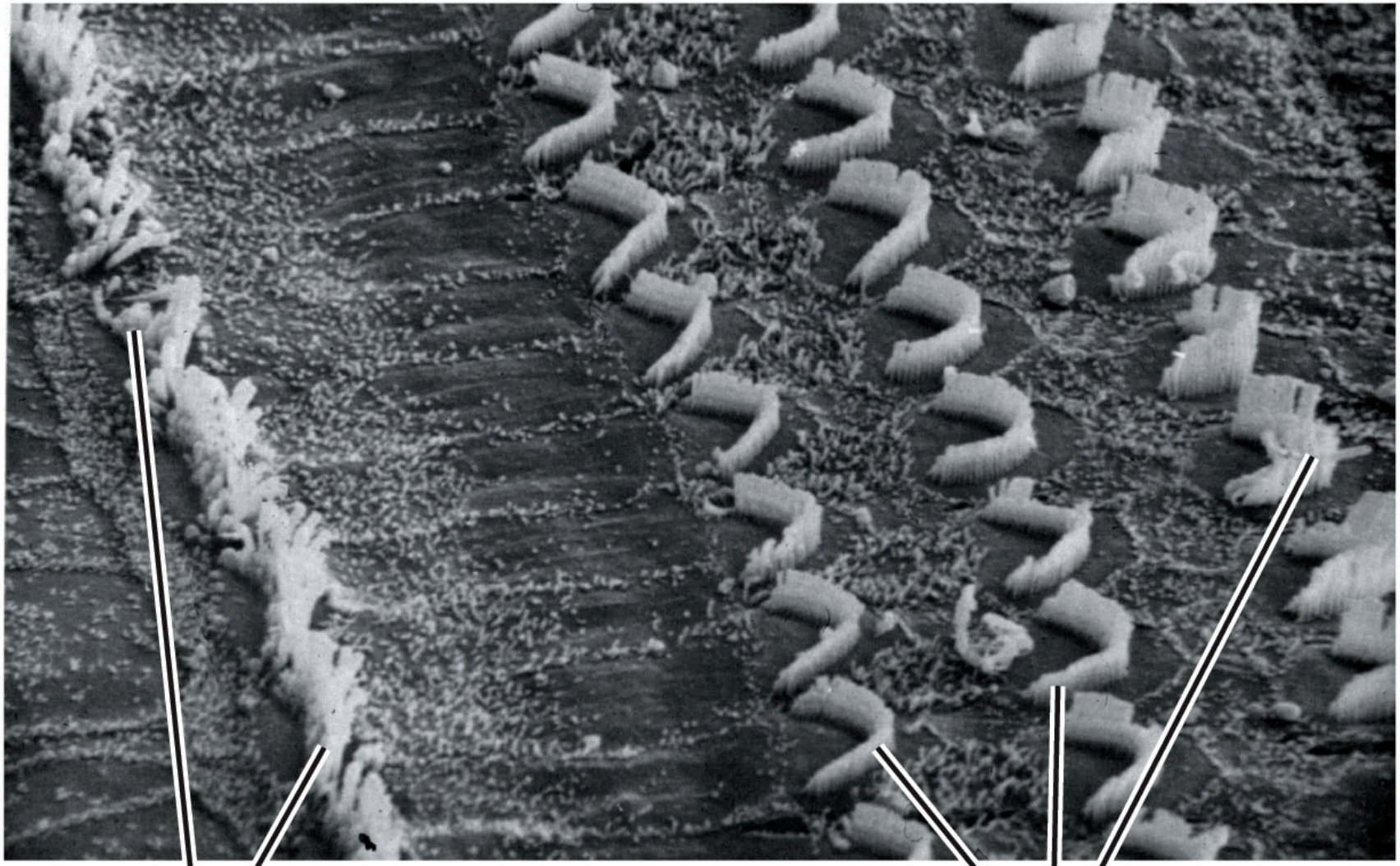
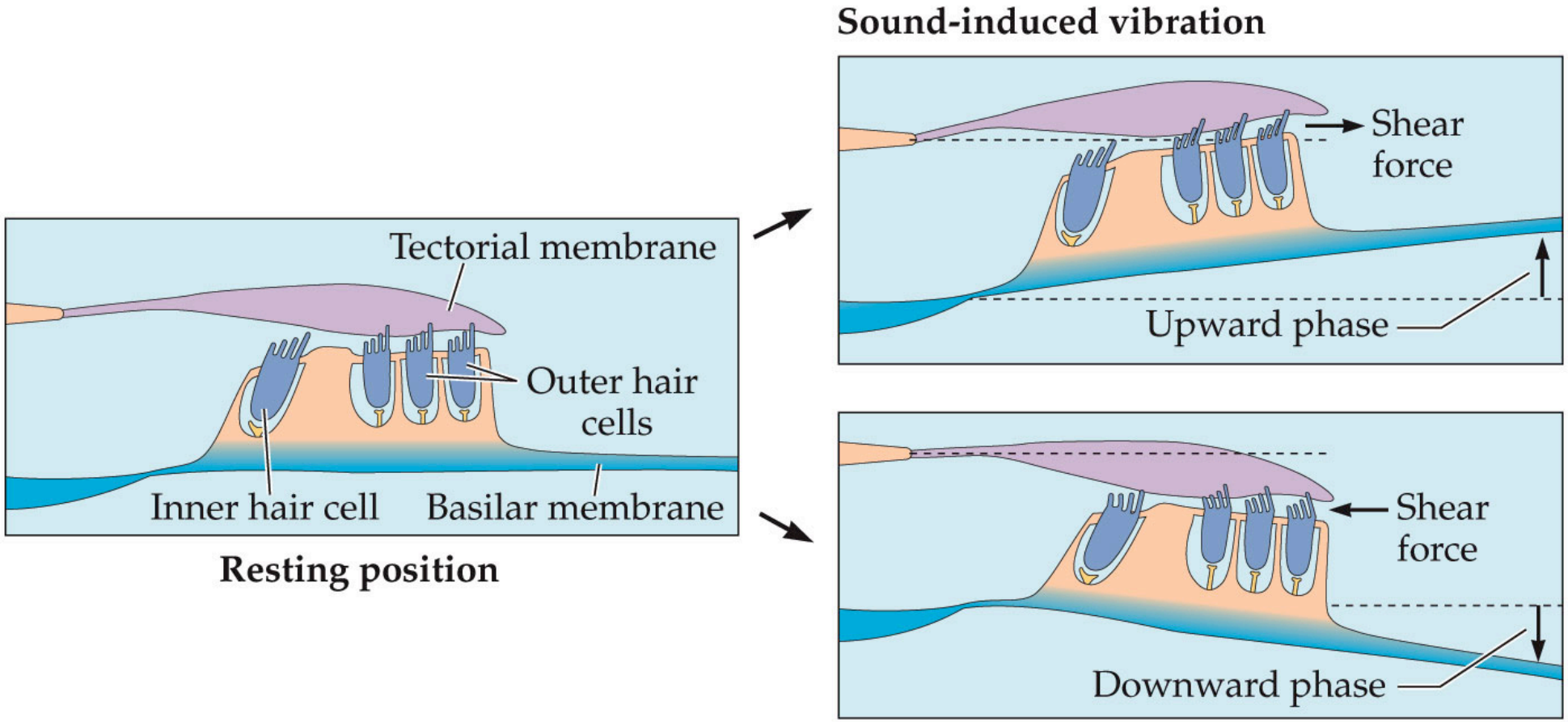


Figure 9.11 The cochlea (cont'd)

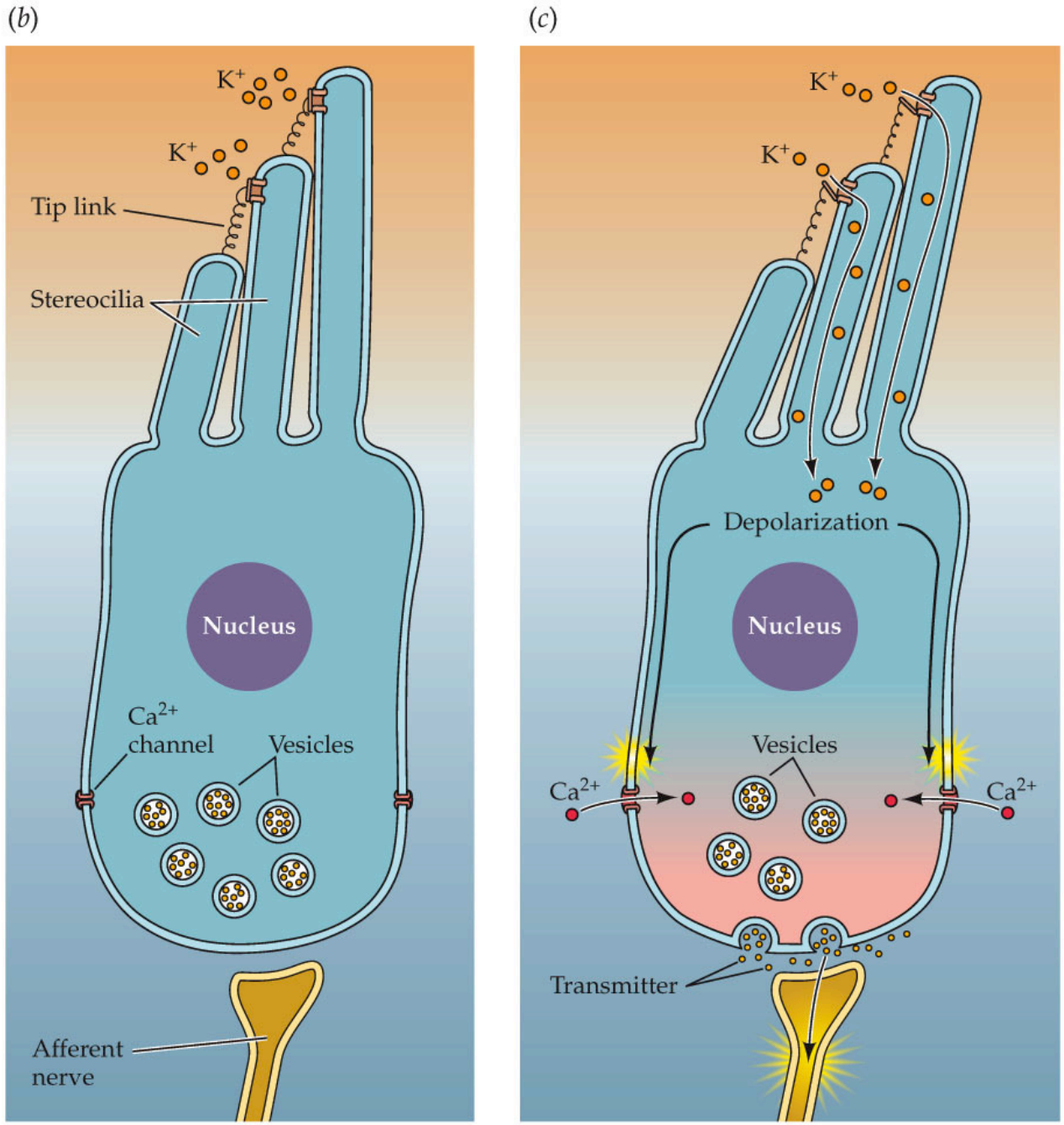


- **Tectorial membrane**: extends into the middle canal, floating above inner hair cells and touching outer hair cells

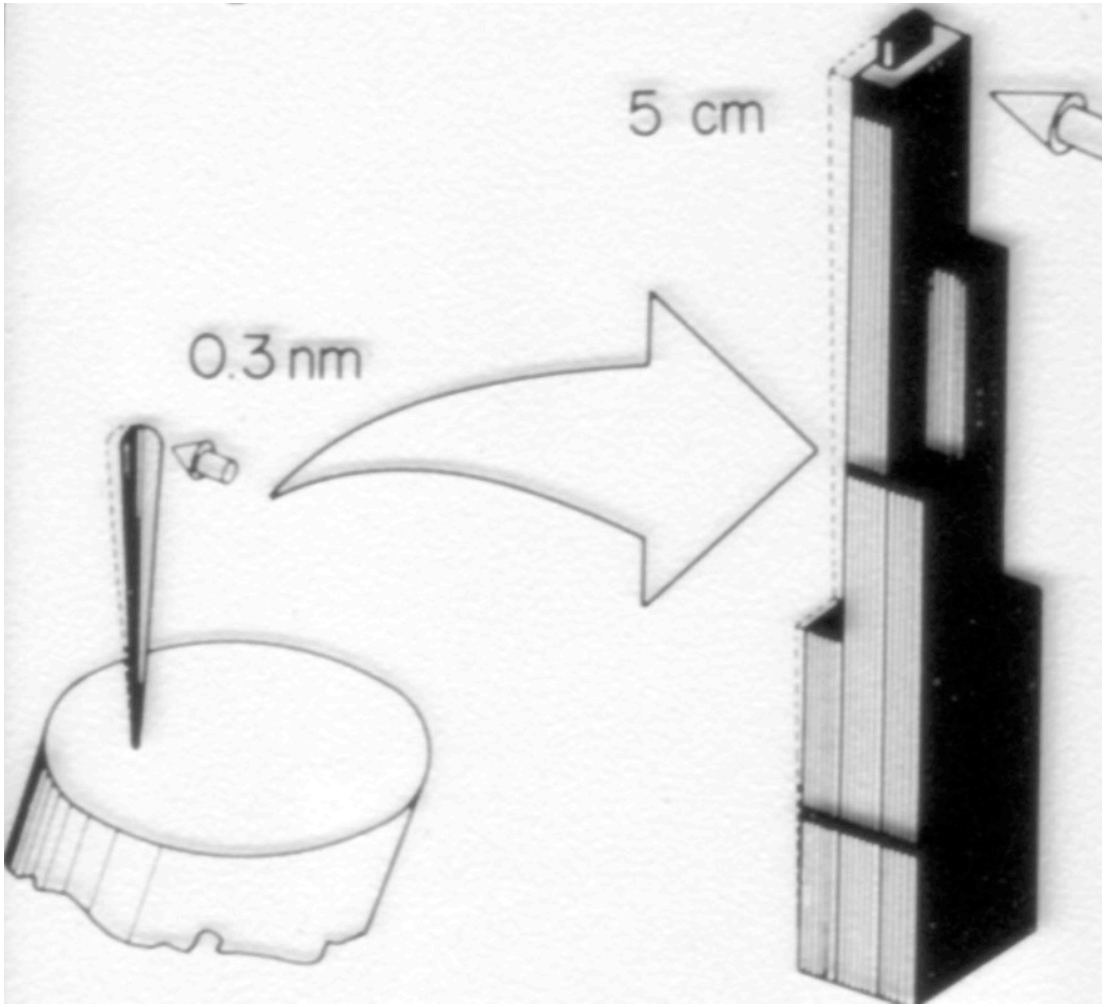


- Vibrations cause displacement of the tectorial membrane, which bends stereocilia attached to hair cells and causes the release of neurotransmitters

- **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

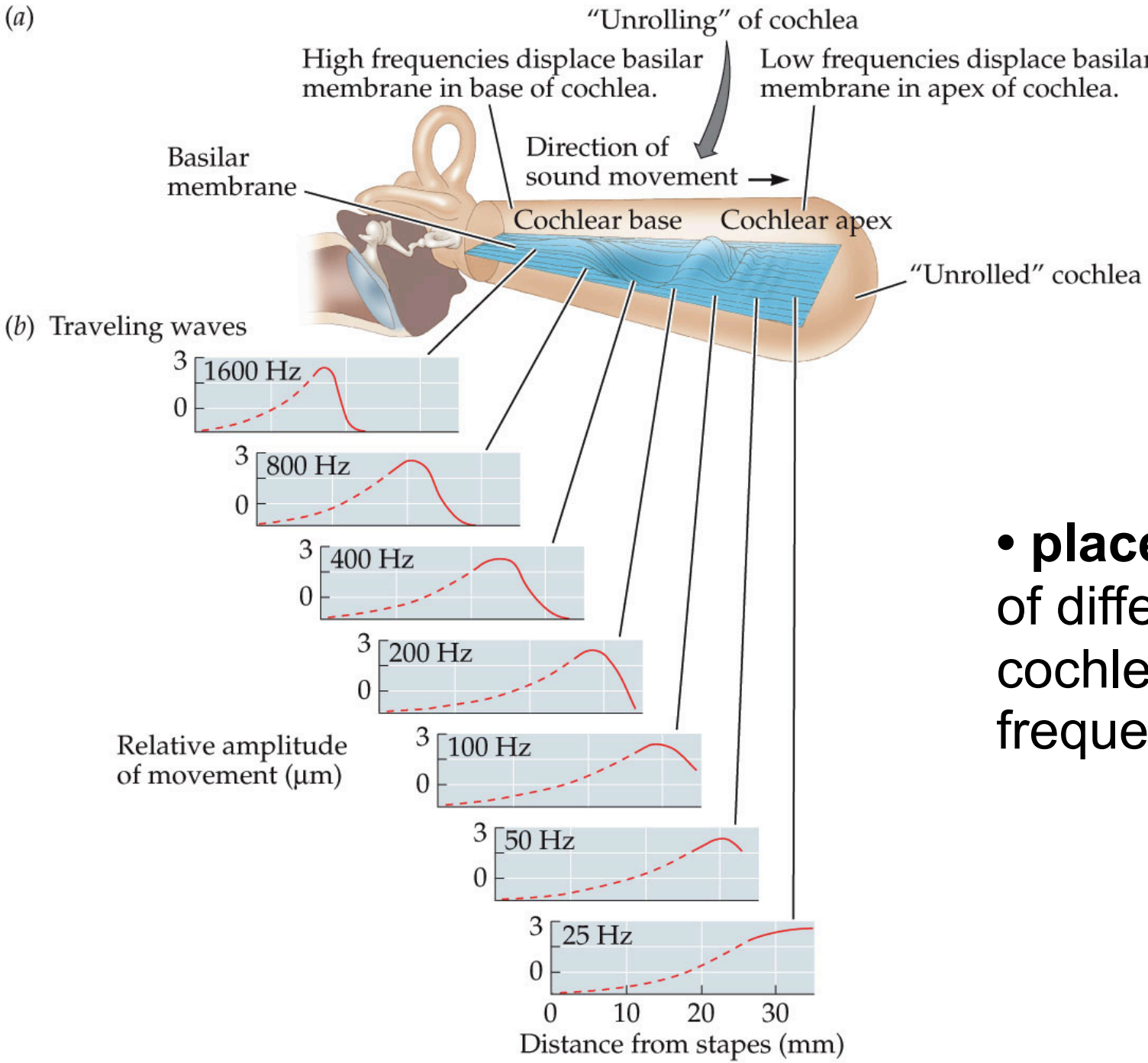
→ malleus → incus → stapes middle ear

→ 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**

Cochlea: physical device tuned to frequency!



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

Basic Structure of the Mammalian Auditory System

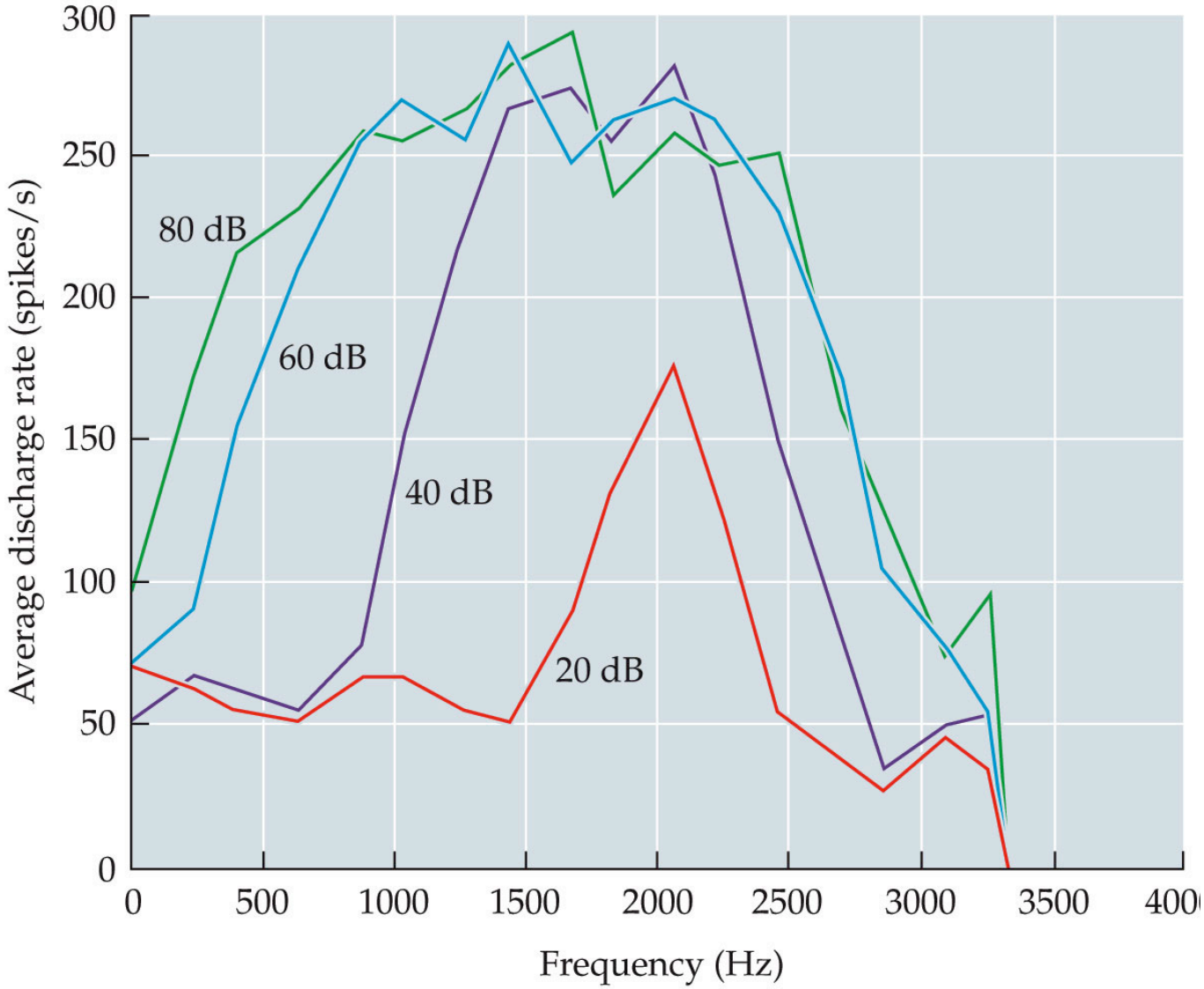
Tonotopic organization: neurons organized spatially in order of preferred frequency

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

"place code"

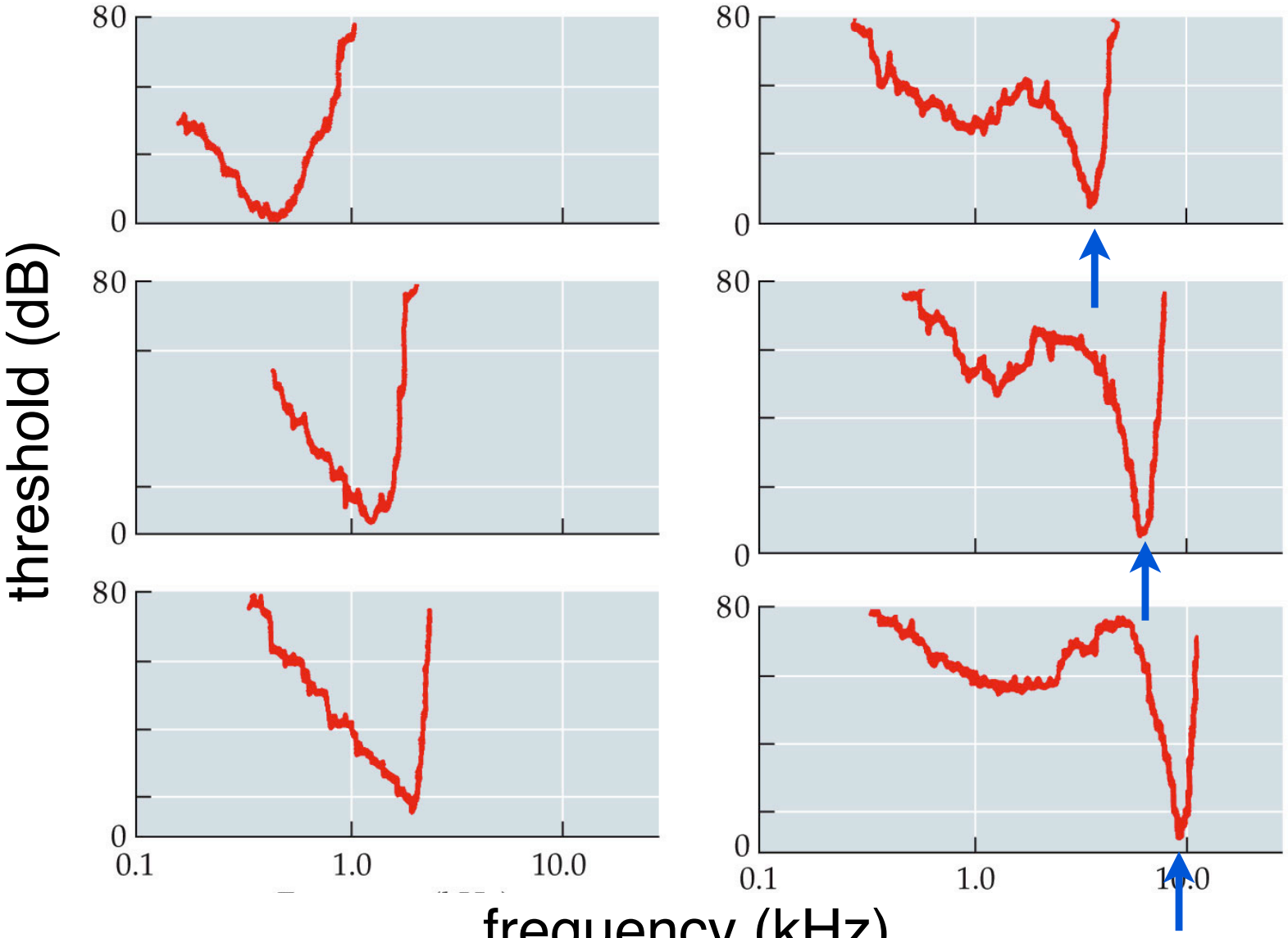
The auditory nerve (AN): fibers stimulated by inner hair cells

- **Frequency selectivity**: Clearest when sounds are very faint



Threshold tuning curves for 6 neurons

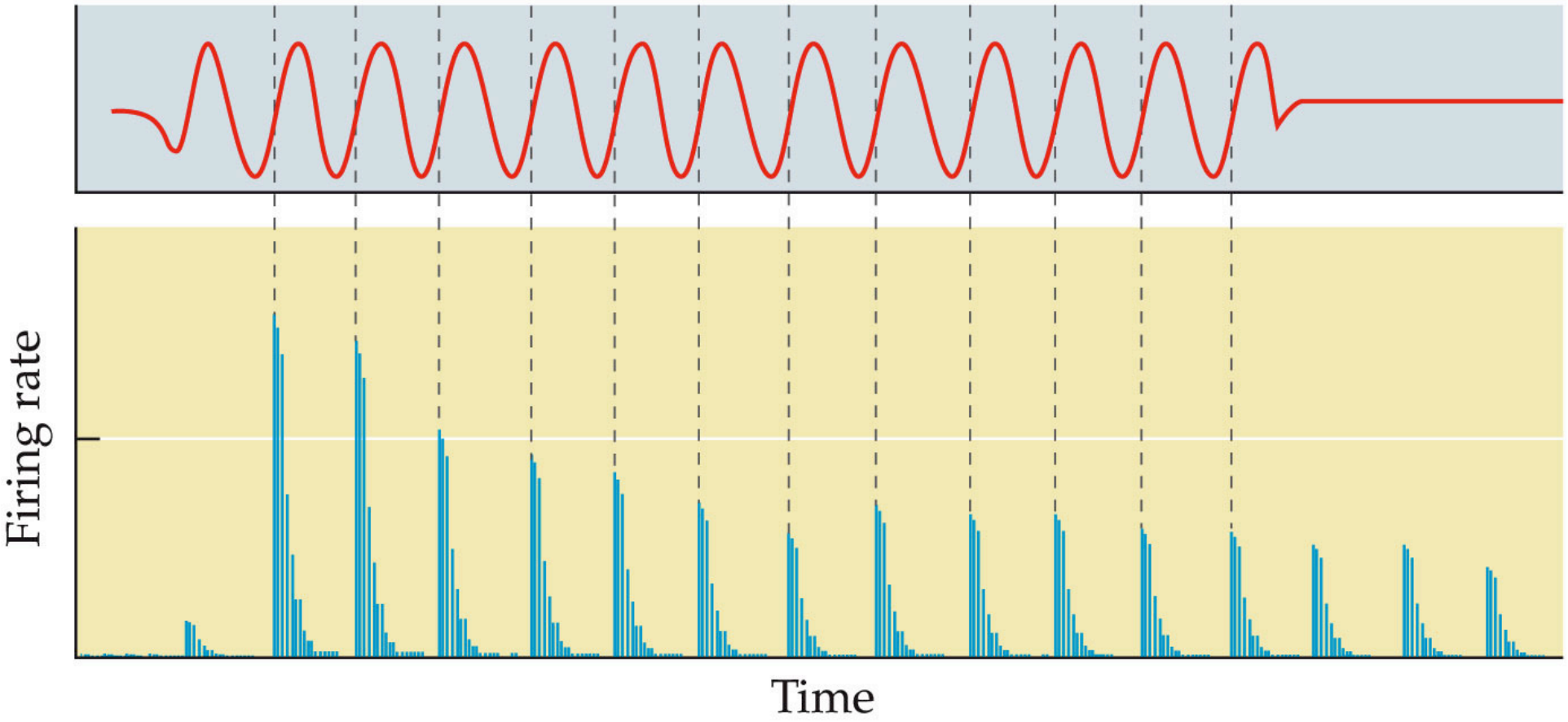
(threshold = lowest intensity that will give rise to a response)



Characteristic frequency

- frequency to which the neuron is most sensitive

- **Phase locking**: Firing locked to period of a sound wave
- example of a **temporal code**



Histogram showing neural spikes for an auditory nerve fiber in response to repetitions of a low-frequency sine wave

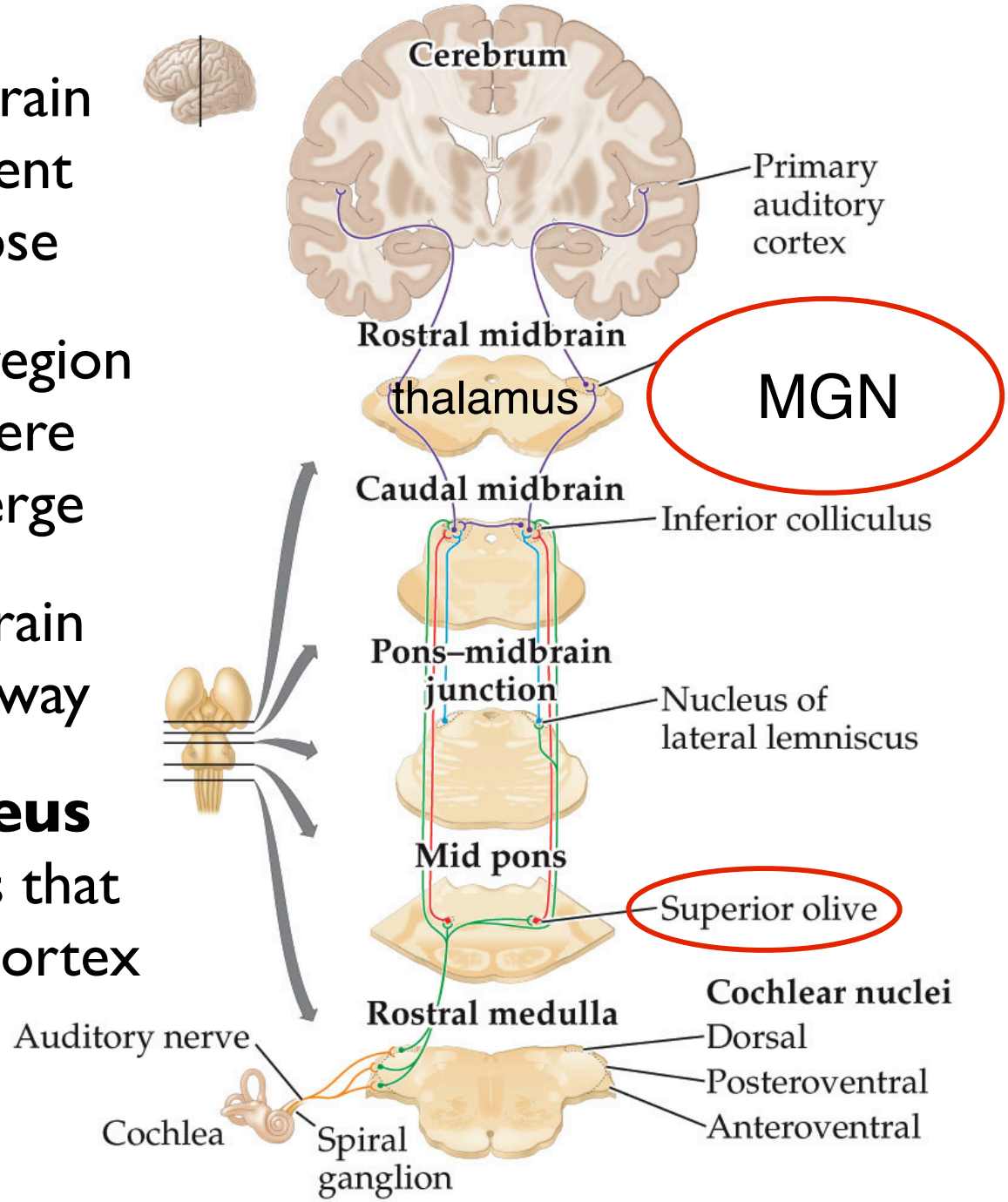
Information flow in the auditory pathway

- **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

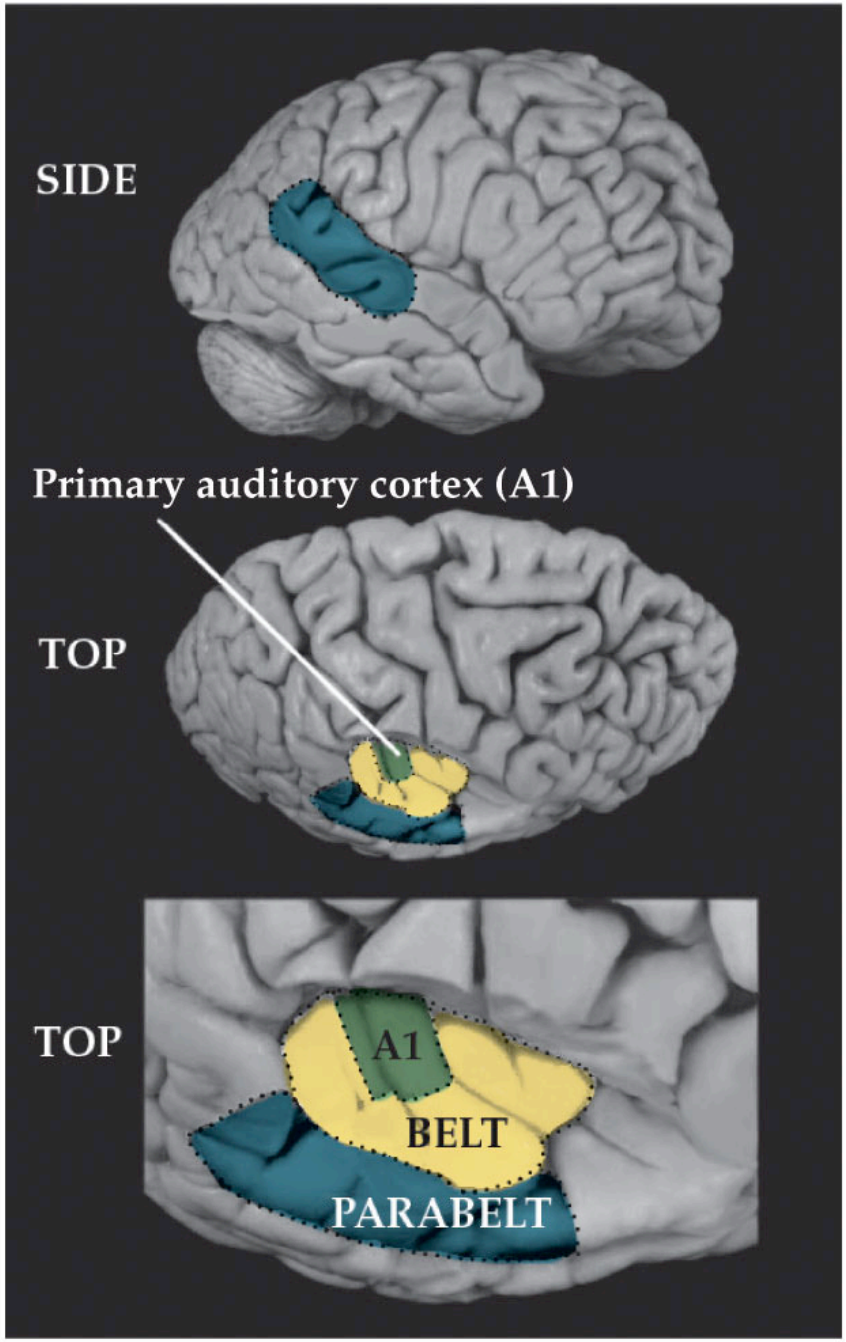
- **Inferior colliculus**: midbrain nucleus in the auditory pathway

- **Medial geniculate nucleus (MGN)**: part of the thalamus that relays auditory signals to the cortex



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

- **Belt & Parabelt areas**: areas beyond A1, where neurons respond to more complex characteristics of sounds



Basic Structure of the Mammalian Auditory System

Comparing overall structure of auditory and visual systems:

- **Auditory system**: Large proportion of processing *before* A1
- **Visual system**: Large proportion of processing *after* V1