Chapter 11

Hearing

Icebreaker: Rain Song Activity

1. All of the students in class will engage in the same auditory activity.
2. Select an audio file of a rain storm that can be easily located online by all students.
3. Each student will listen to the rain storm.
4. Students will record their impressions and discuss sounds, auditory patterns and frequencies that occur during the rain storm.

Chapter Objectives (1 of 2)

11.01 Describe the physical aspects of sound, including sound waves, tones, sound pressure, and sound frequencies.

11.02 Describe the perceptual aspects of sound, including thresholds, loudness, pitch, and timbre.

11.03 Identify the basic structures of the ear and describe how sound acts on these structures to cause electrical signals.

11.04 Describe how different frequencies of sound vibrations are translated into neural activity in the auditory nerve.

Chapter Objectives (2 of 2)

11.05 Understand evidence supporting the idea that perceiving a tone's pitch depends on both *where* vibrations occur in the inner ear and on the *timing* of these vibrations.

11.06 Describe what happens as nerve impulses travel along the pathway that leads from the ear to the cortex, and how pitch is represented in the cortex.

11.07 Describe some of the mechanisms responsible for hearing loss.

11.08 Describe procedures that have been used to measure infants' thresholds for hearing and their ability to recognize their mother's voice.

Physical and Perceptual Aspects of Sound

Two definitions of “sound”

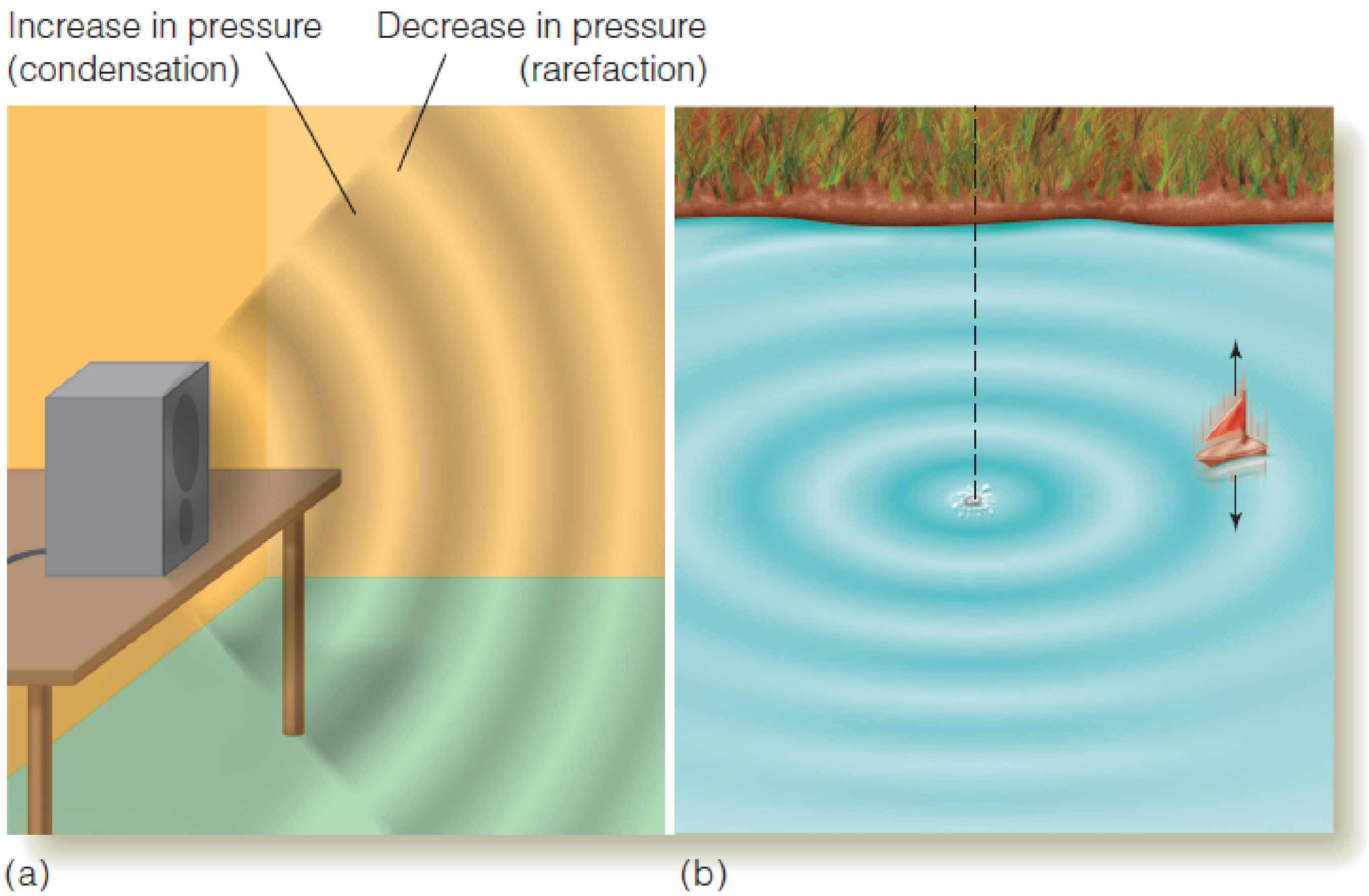
- Physical definition: pressure changes in the air or other medium
- Perceptual definition: the experience we have when we hear

Sound as Pressure Changes (1 of 2)

Loud speakers produce sound through a process.

- The diaphragm of the speaker moves out, pushing air molecules together called condensation.
- The diaphragm also moves in, pulling the air molecules apart called rarefaction.
- The cycle of this process creates alternating high- and low-pressure regions that travel through the air.

Sound as Pressure Changes (2 of 2)



Pure Tones (1 of 4)

Pure tone: created by a sine wave

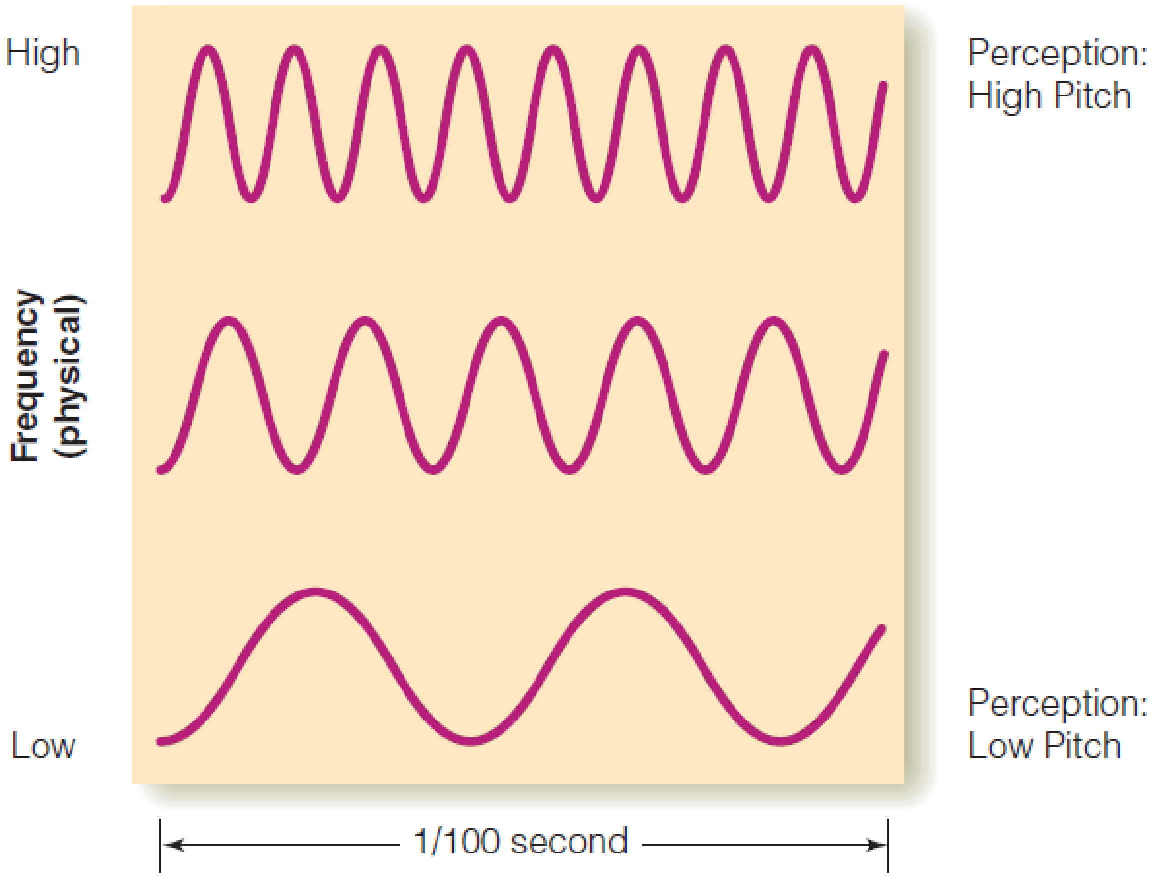
- Amplitude: difference in pressure between high and low peaks of wave
  - Perception of amplitude is known as loudness.
  - Decibel (dB) is used as the measure of loudness.
  - Number of dB = 20 logarithm(p/po).
  - The decibel scale relates the amplitude of the stimulus with the psychological experience of loudness.

Pure Tones (2 of 4)

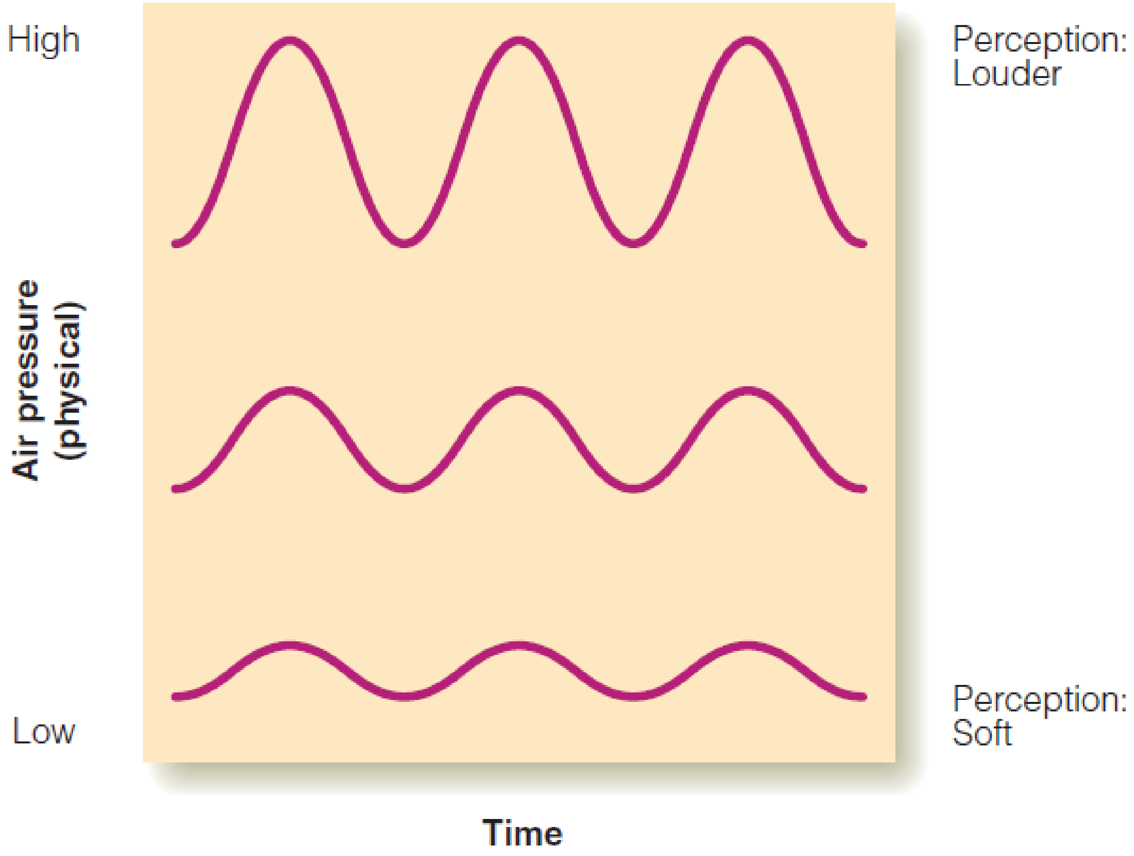
Frequency: number of cycles within a given time period

- Measured in Hertz (Hz): 1 Hz is one cycle per second.
- Perception of pitch is related to frequency.
- Tone height is the increase in pitch that happens when frequency is increased.

Pure Tones (3 of 4)



Pure Tones (4 of 4)



Complex Tones and Frequency Spectra (1 of 2)

Both pure and some complex tones are periodic tones.

Fundamental frequency is the repetition rate and is called the first harmonic.

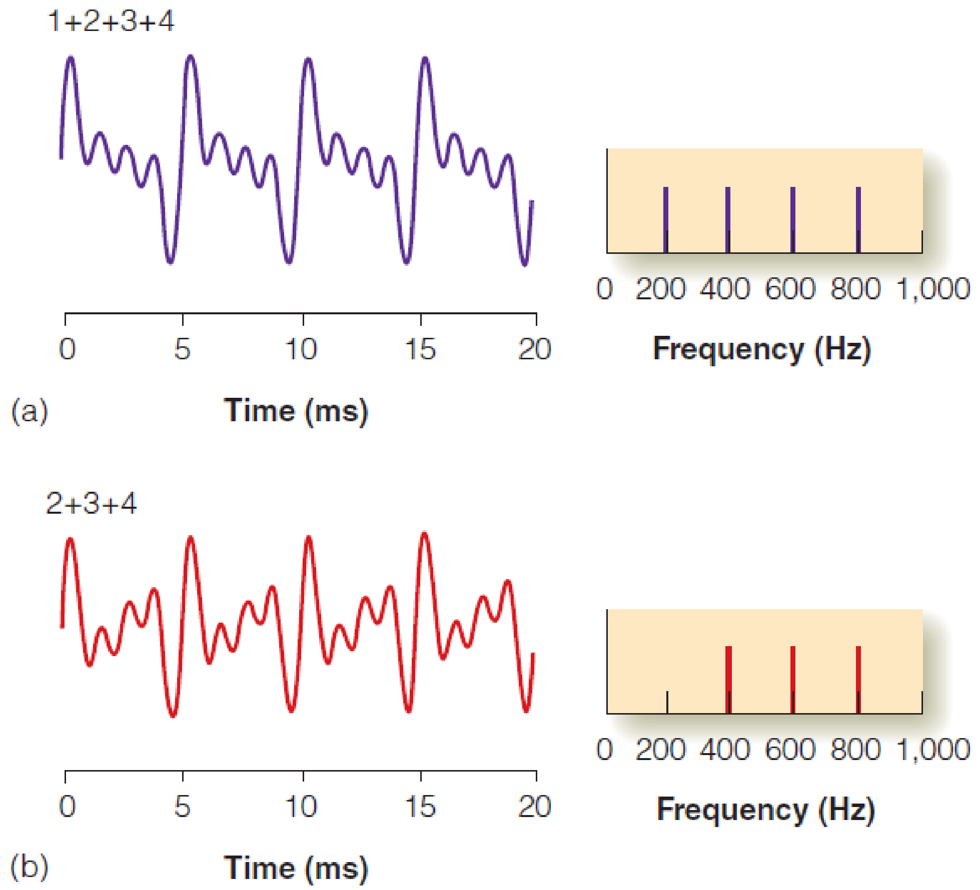
Periodic complex tones consist of several pure tones called harmonics.

- Additional harmonics are multiples of the fundamental frequency.

Additive synthesis: process of adding harmonics to create complex sounds

Frequency spectrum: display of harmonics of a complex sound

Complex Tones and Frequency Spectra (2 of 2)



Perceptual Aspects of Sound (1 of 6)

Loudness is the perceptual quality most closely related to the level or amplitude of an auditory stimulus.

- Decibels

Audibility curve

Auditory response area

Perceptual Aspects of Sound (2 of 6)

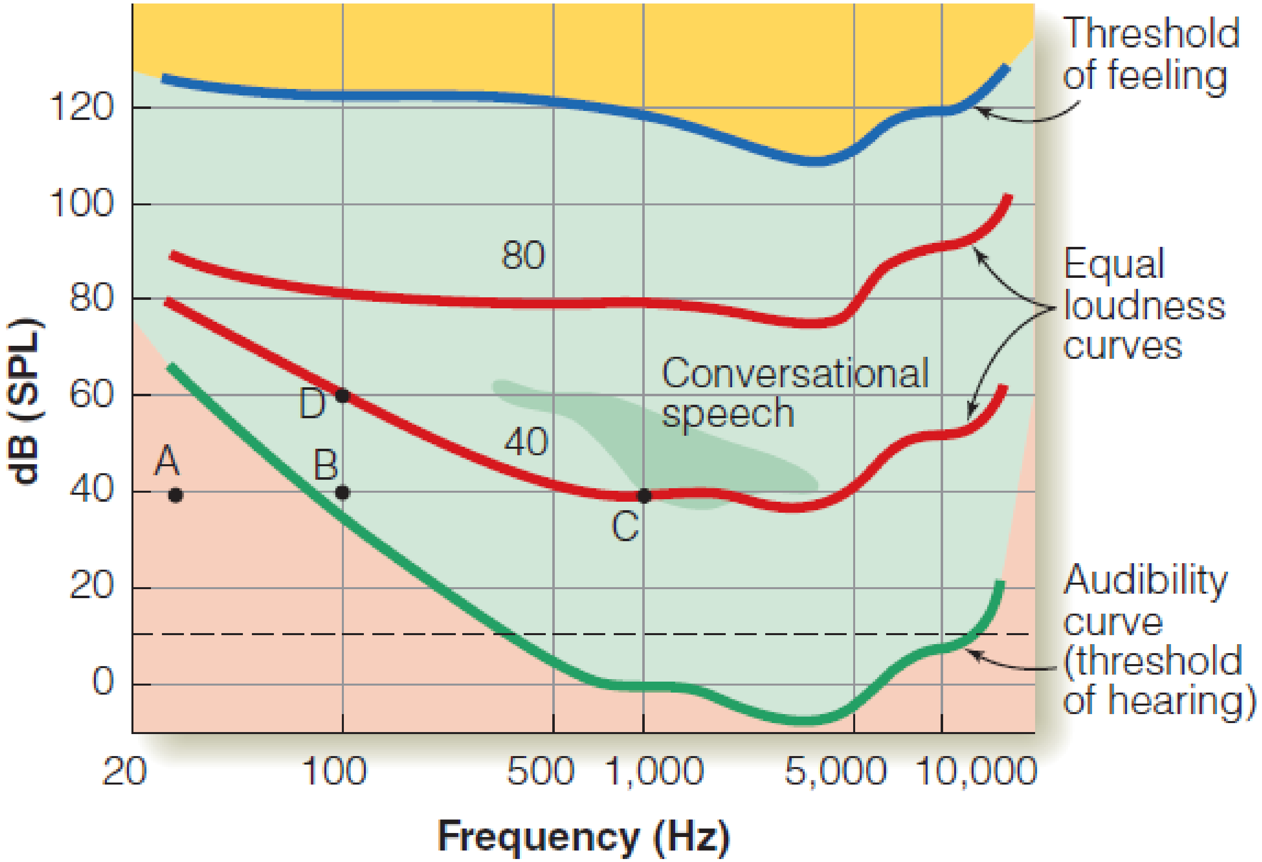
- Human hearing range: 20 to 20,000 Hz
- Audibility curve: shows the threshold of hearing in relation to frequency
  - Changes on this curve show that humans are most sensitive to 2,000 to 4,000 Hz.
- Auditory response area: falls between the audibility curve and the threshold for feeling.
  - It shows the range of response for human audition.

Perceptual Aspects of Sound (3 of 6)

Equal loudness curves: determined by using a standard 1,000 Hz tone

- Two dB levels are used: 40 and 80
- Participants match the perceived loudness of all other tones to the 1,000 Hz standard.
- Resulting curves show that tones sound:
  - At almost equal loudness at 80 dB.
  - Softer at 40 dB for high and low frequencies than the rest of the tones in the range.

Perceptual Aspects of Sound (4 of 6)



Perceptual Aspects of Sound (5 of 6)

Pitch – the perceptual quality we describe as high and low

Timbre: all other perceptual aspects of a sound besides loudness, pitch, and duration

- It is closely related to the harmonics, attack, and decay of a tone.

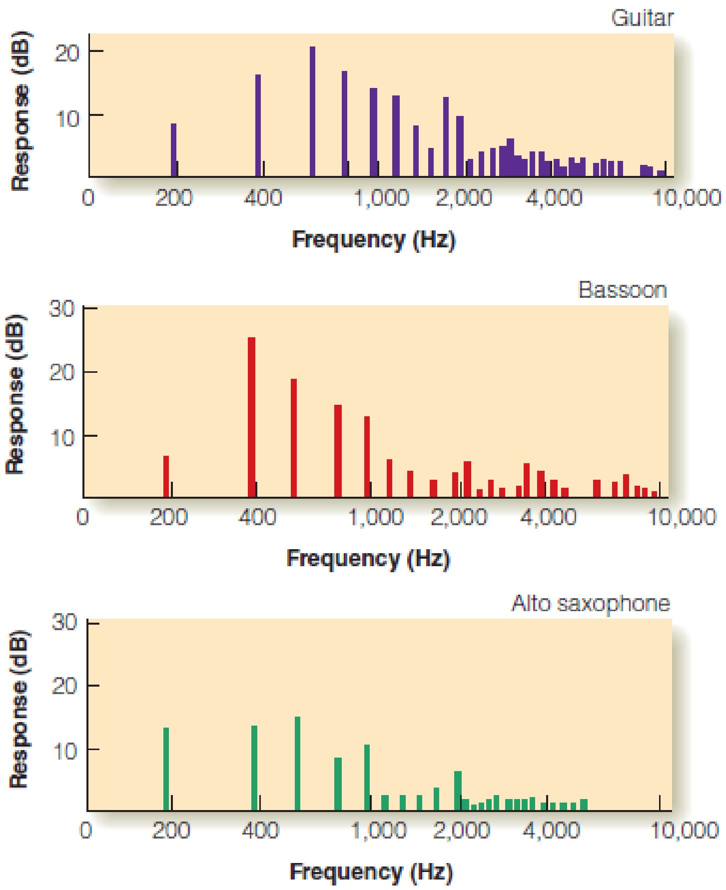
Effect of missing fundamental frequency

- Removal of the first harmonic results in a sound with the same perceived pitch, but with a different timbre.
    - This is called periodicity pitch.

Attack of tones: buildup of sound at the beginning of a tone

Decay of tones: decrease in sound at end of tone

Perceptual Aspects of Sound (6 of 6)



From Pressure Changes to Electricity (1 of 7)

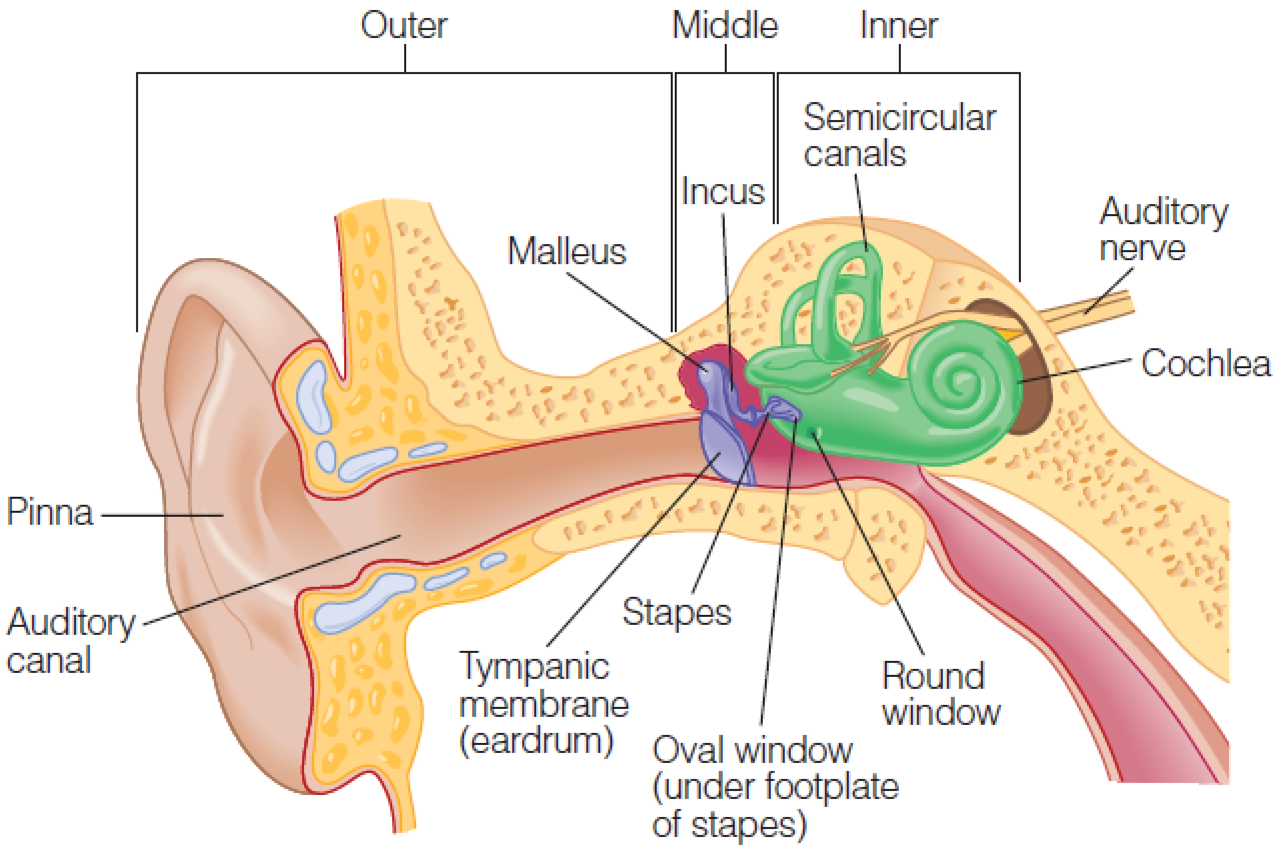
Outer ear: pinna and auditory canal

- Pinna helps with sound location.
- Auditory canal: tube-like 3 cm long structure
  - Protects the tympanic membrane at the end of the canal.
  - The resonant frequency of the canal amplifies frequencies between 1,000 and 5,000 Hz.

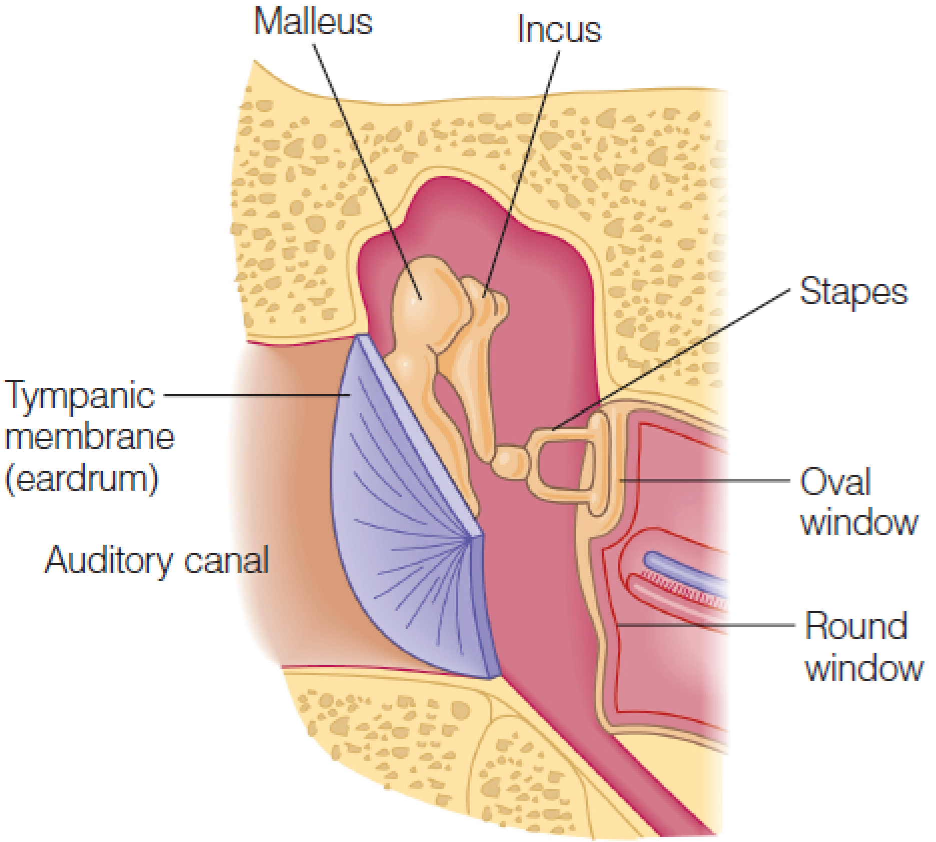
Middle ear

- Two cubic centimeter cavity separating inner from outer ear
- Contains the three ossicles
  - Malleus: moves due to the vibration of the tympanic membrane
  - Incus: transmits vibrations of malleus
  - Stapes: transmits vibrations of incus to the inner ear via the oval window of the cochlea

From Pressure Changes to Electricity (2 of 7)



From Pressure Changes to Electricity (3 of 7)



From Pressure Changes to Electricity (4 of 7)

Functioning of ossicles

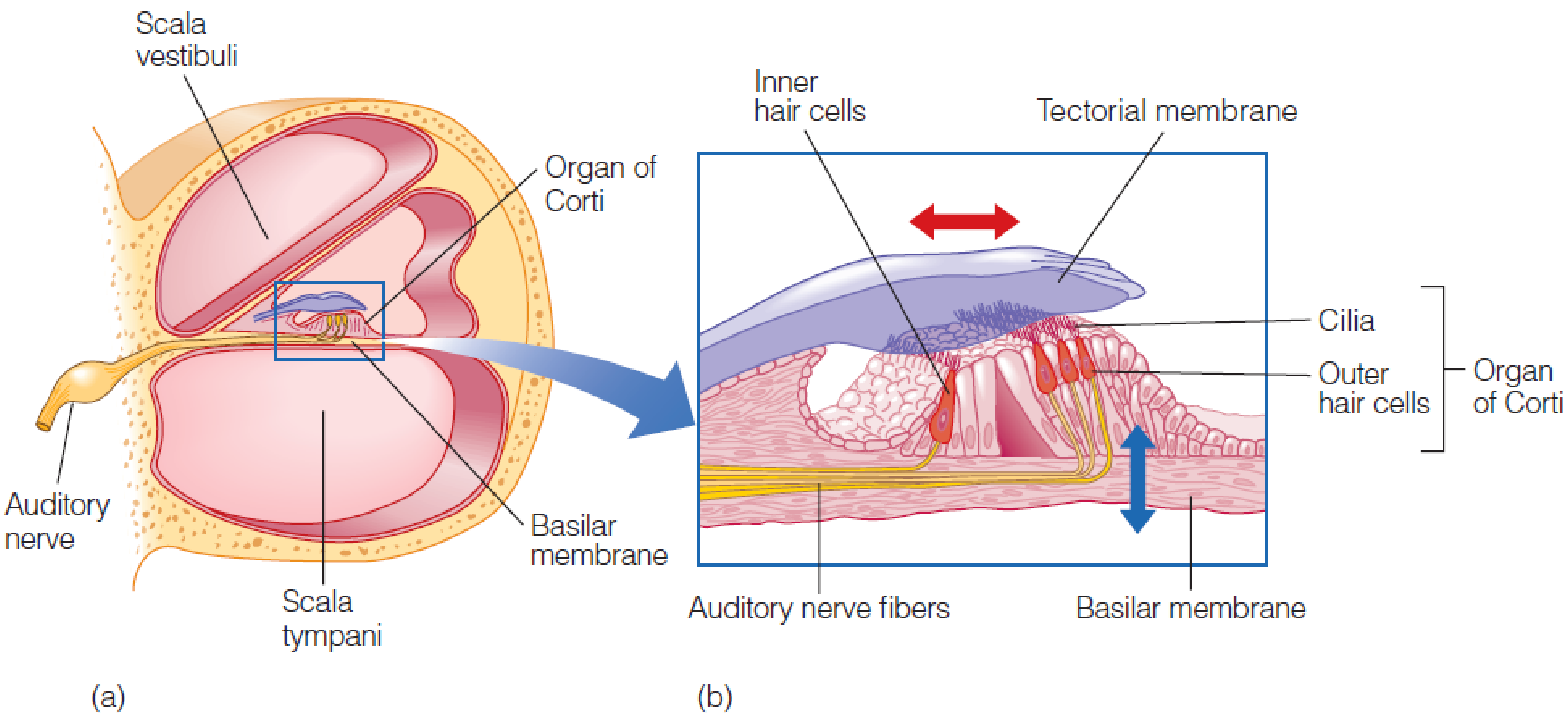
- Outer and inner ear are filled with air.
  - Inner ear is filled with fluid that is much denser than air.
- Pressure changes in air transmit poorly into the denser medium.
- Ossicles act to amplify the vibration for better transmission to the fluid.
- Middle ear muscles dampen the ossicles' vibrations to protect the inner ear from potentially damaging stimuli.

From Pressure Changes to Electricity (5 of 7)

Inner ear

- Main structure is the cochlea.
    - Fluid-filled snail-like structure (35 mm long) set into vibration by the stapes
    - Divided into the scala vestibuli and scala tympani by the cochlear partition
- Cochlear partition extends from the base (stapes end) to the apex (far end).
- Organ of Corti is contained by the cochlear partition.

From Pressure Changes to Electricity (6 of 7)



From Pressure Changes to Electricity (7 of 7)

Key structures

- Basilar membrane vibrates in response to sound and supports the organ of Corti.
- Inner and outer hair cells are the receptors for hearing.
- Tectorial membrane extends over the hair cells.

Transduction takes place through this process:

- Cilia bend in response to movement of the organ of Corti and the tectorial membrane.
- Movement in one direction opens ion channels.
- Movement in the other direction closes the channels.
    - This causes bursts of electrical signals.

Békésy Discovers How the Basilar Membrane Vibrates (1 of 3)

Békésy's Place Theory of Hearing

- Frequency of sound is indicated by the place on the organ of Corti that has the highest firing rate.

Békésy determined this in two ways:

- Direct observation of the basilar membrane in cadavers.
- Building a model of the cochlea using the physical properties of the basilar membrane.

Békésy Discovers How the Basilar Membrane Vibrates (2 of 3)

Physical properties of the basilar membrane

- Base of the membrane (by stapes) is:
  - Three to four times narrower than at the apex.
  - 100 times stiffer than at the apex.

Both the model and direct observation showed that the vibrating motion of the membrane is a traveling wave.

Békésy Discovers How the Basilar Membrane Vibrates (3 of 3)

Envelope of the traveling wave:

- Indicates the point of maximum displacement of the basilar membrane.
- Hair cells at this point are stimulated the most strongly leading to the nerve fibers firing the most strongly at this location.
- Position of the peak is a function of frequency.

The Cochlea Functions as a Filter (1 of 2)

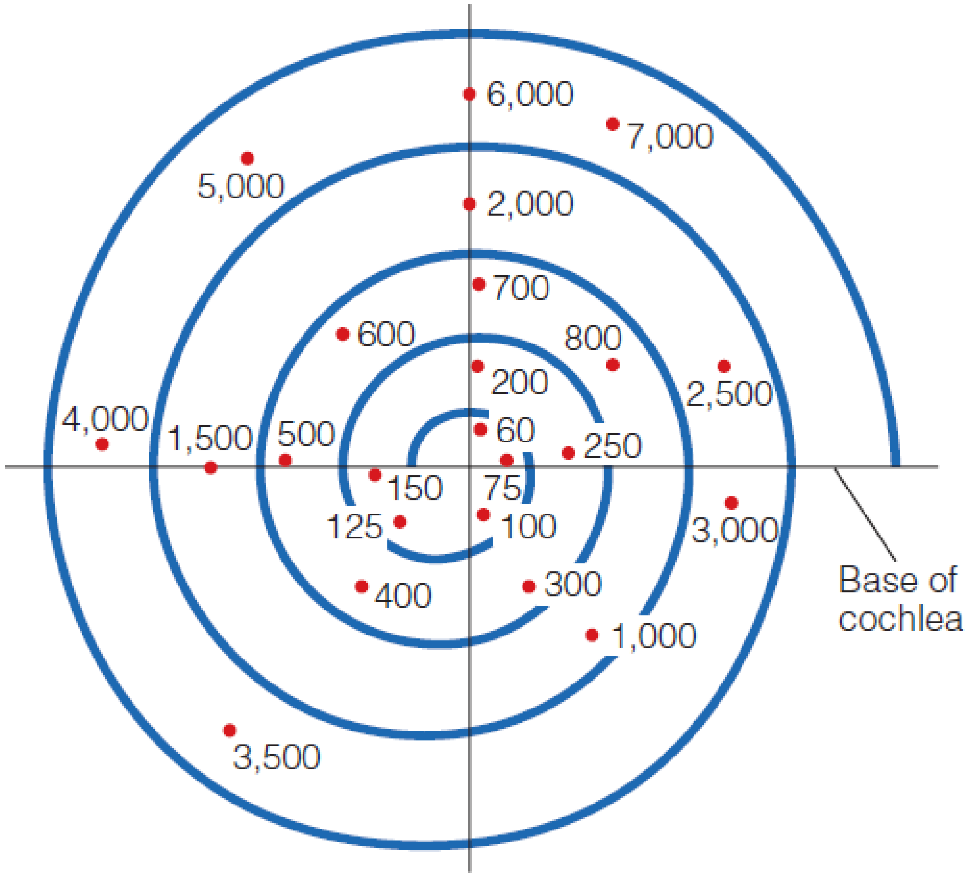
Tonotopic map

- Cochlea shows an orderly map of frequencies along its length.
  - Apex responds best to low frequencies.
  - Base responds best to high frequencies.

Neural frequency tuning curves

- Pure tones are used to determine the threshold for specific frequencies measured at single neurons.
- Plotting thresholds for frequencies results in tuning curves.
- Frequency to which the neuron is most sensitive is the characteristic frequency.

The Cochlea Functions as a Filter (2 of 2)



Returning to the Outer Hair Cells: The Cochlear Amplifier

Békésy used basilar membranes isolated from cadavers, and his results showed no difference in response for close frequencies that people can distinguish.

New research with live membranes shows that the entire outer hair cells respond to sound by slight tilting and a change in length.

- For this reason, these cells are called the cochlear amplifier.

The Physiology of Pitch Perception (1 of 2)

Place theory: based on the relation between a sound’s frequency and the place along the basilar membrane that is activated.

Phase locking

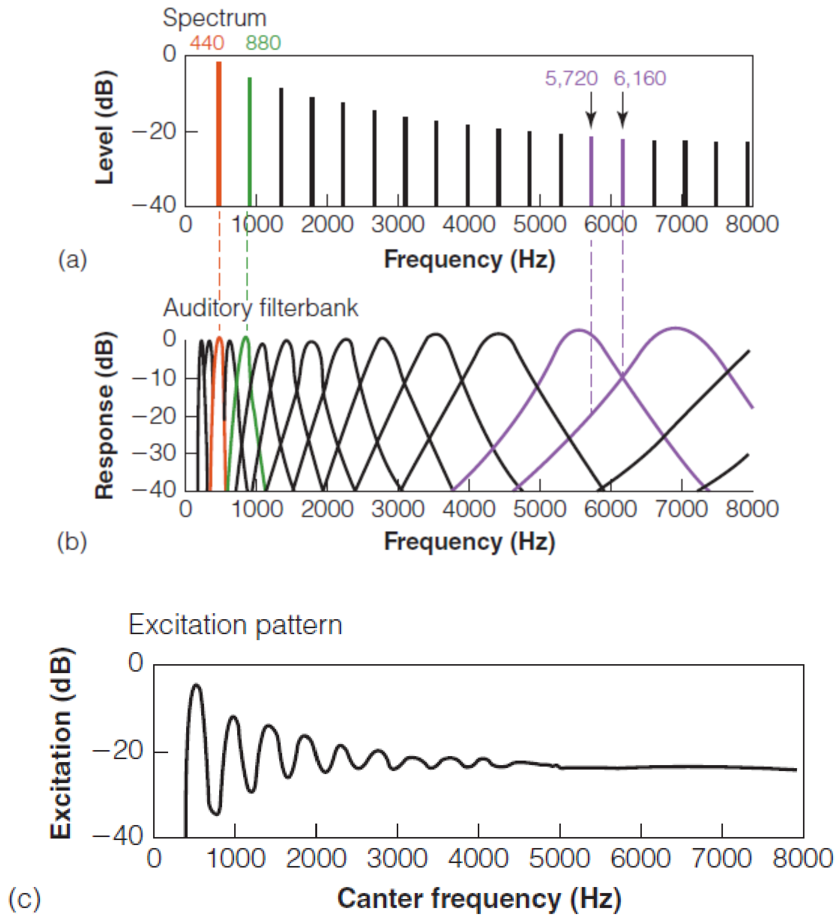
- Nerve fibers fire in bursts.
- Firing bursts happen at or near the peak of the sine-wave stimulus.
- Thus, they are “locked in phase” with the wave.
- Groups of fibers fire with periods of silent intervals creating a pattern of firing.

Temporal coding-major mechanism of pitch perception

Resolved harmonics

Unresolved harmonics

The Physiology of Pitch Perception (2 of 2)



The Pathway to the Brain (1 of 2)

SONIC MG

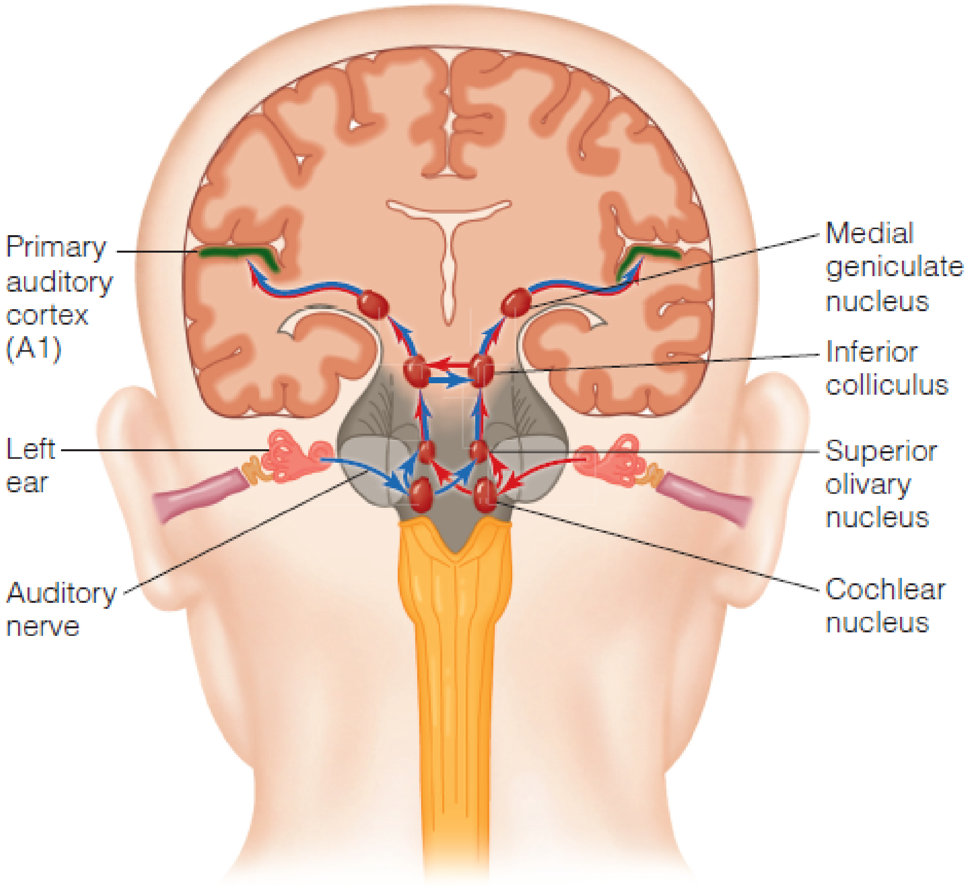
- SON = superior olivary nucleus
- IC = inferior colliculus
- MG = medial geniculate nucleus

Core area

Belt area

Parabelt area

The Pathway to the Brain (2 of 2)



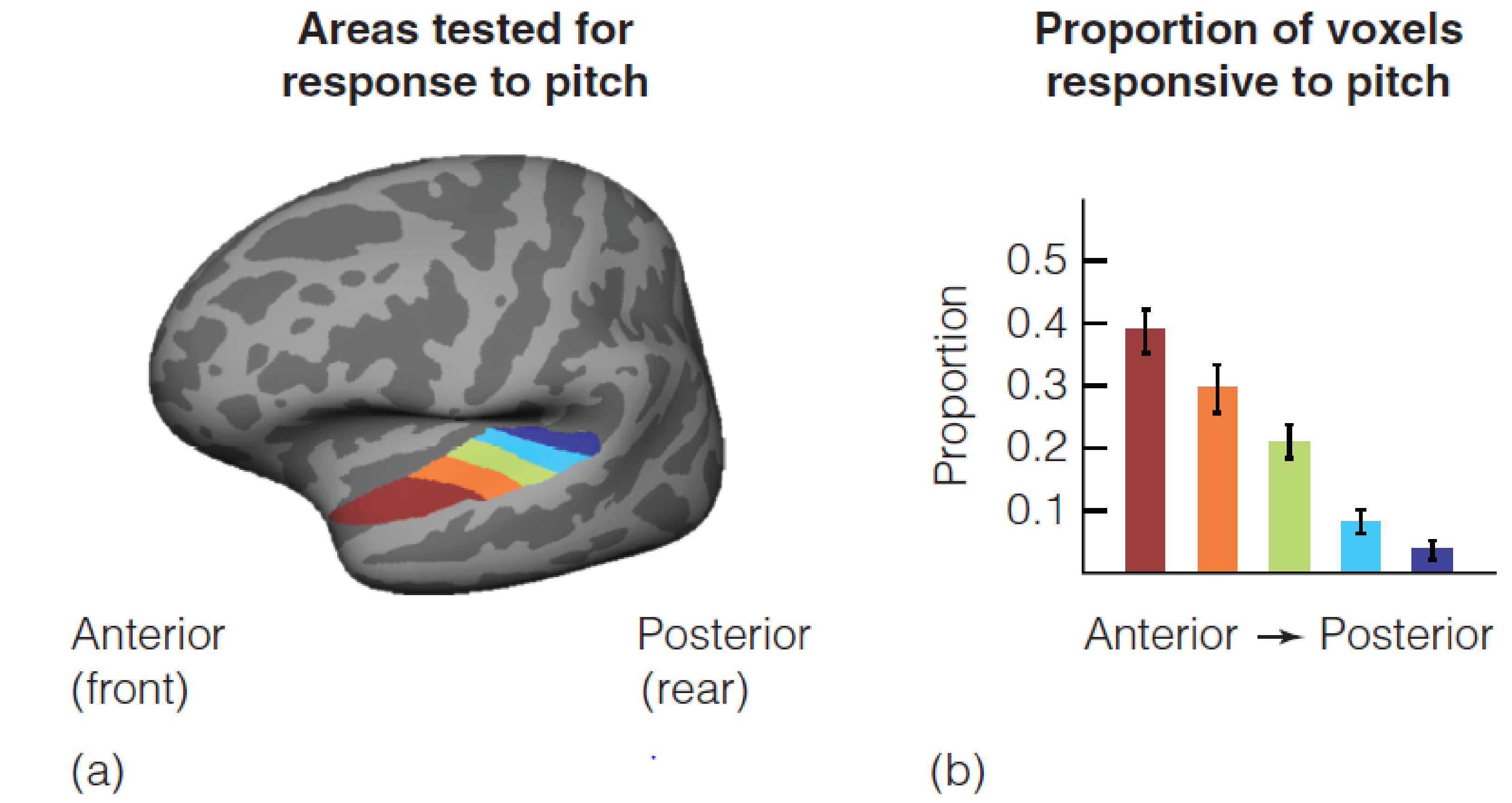
Pitch and the Brain (1 of 2)

There is a shift from earlier emphasis on the cochlea and the auditory nerve to research on the brain.

Place coding is effective for the entire range of hearing.

Temporal coding with phase locking is effective up to 5,000 Hz.

Pitch and the Brain (2 of 2)



Hearing Loss

Presbycusis

- Greatest loss at high frequencies.
- Affects males more severely than females.
- Appears to be caused by exposure to damaging noises or drugs.

Noise-induced hearing loss

- Loud noise can severely damage the organ of Corti.
- OSHA standards for noise levels at work are set to protect workers.
- Leisure noise can also cause hearing loss.

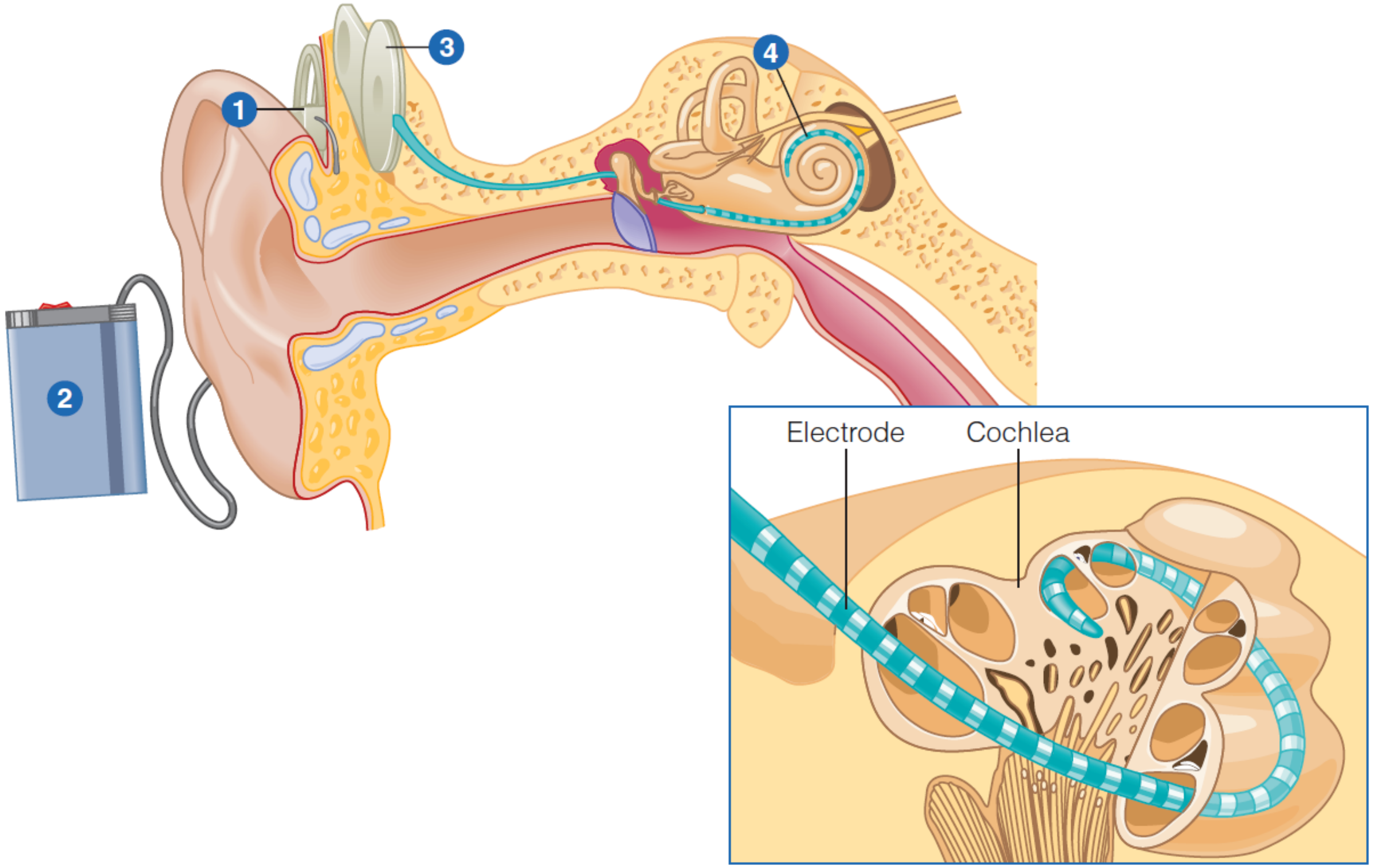
Cochlear Implants (1 of 2)

Electrodes are inserted into the cochlea to electrically stimulate auditory nerve fibers.

The device is made up of:

- A microphone worn behind the ear
- A sound processor
- A transmitter mounted on the mastoid bone
- A receiver surgically mounted on the mastoid bone

Cochlear Implants (2 of 2)



Infant Hearing (1 of 2)

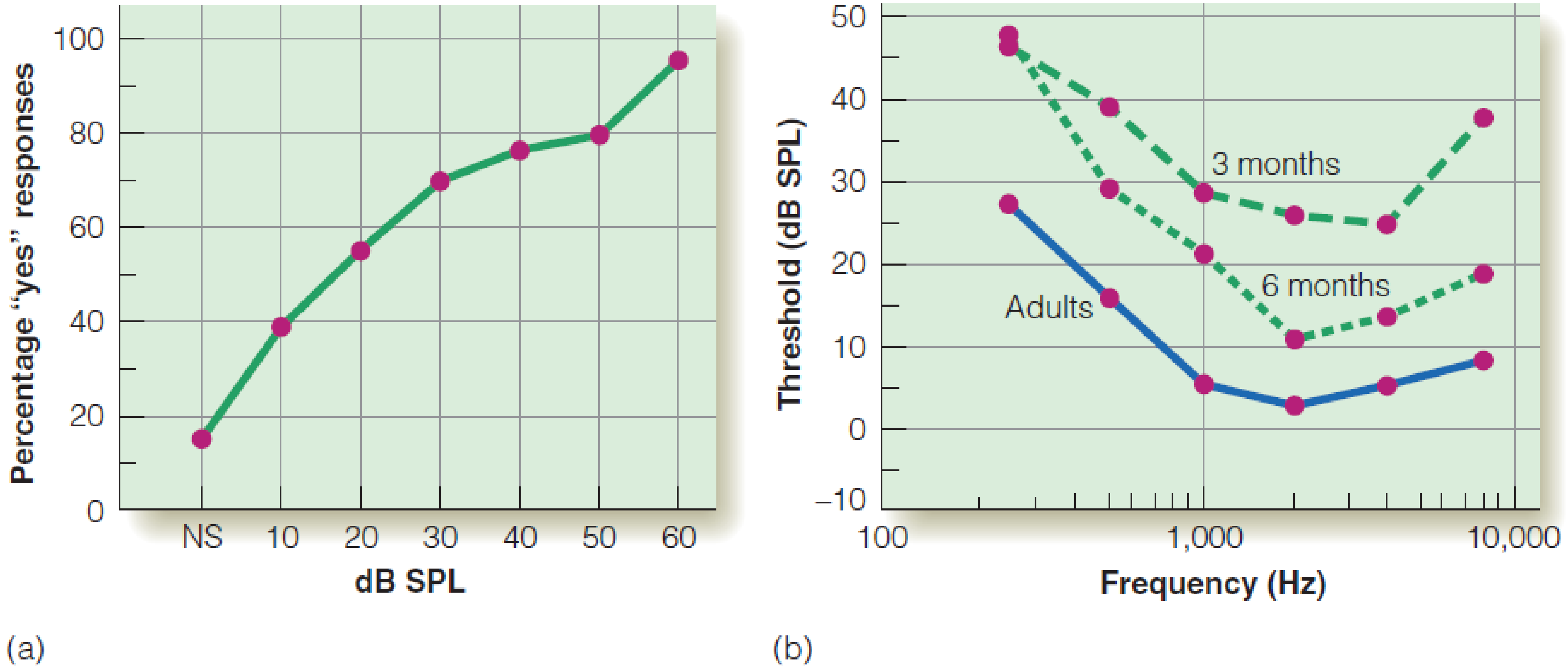
Olsho et al. (1988)

- Audibility curves

DeCasper and Fifer (1980)

- Two-day old infants can recognize their mother’s voice.

Infant Hearing (2 of 2)



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Chapter Summary (1 of 2)

- Describe the physical aspects of sound, including sound waves, tones, sound pressure, and sound frequencies.
- Describe the perceptual aspects of sound, including thresholds, loudness, pitch, and timbre.
- Identify the basic structures of the ear and describe how sound acts on these structures to cause electrical signals.
- Describe how different frequencies of sound vibrations are translated into neural activity in the auditory nerve.

Chapter Summary (2 of 2)

- Understand evidence supporting the idea that perceiving a tone's pitch depends on both *where* vibrations occur in the inner ear and on the *timing* of these vibrations.
- Describe what happens as nerve impulses travel along the pathway that leads from the ear to the cortex, and how pitch is represented in the cortex.
- Describe some of the mechanisms responsible for hearing loss.
- Describe procedures that have been used to measure infants' thresholds for hearing and their ability to recognize their mother's voice.