Hearing in the Environment

(Chapter 10)

Lecture 17

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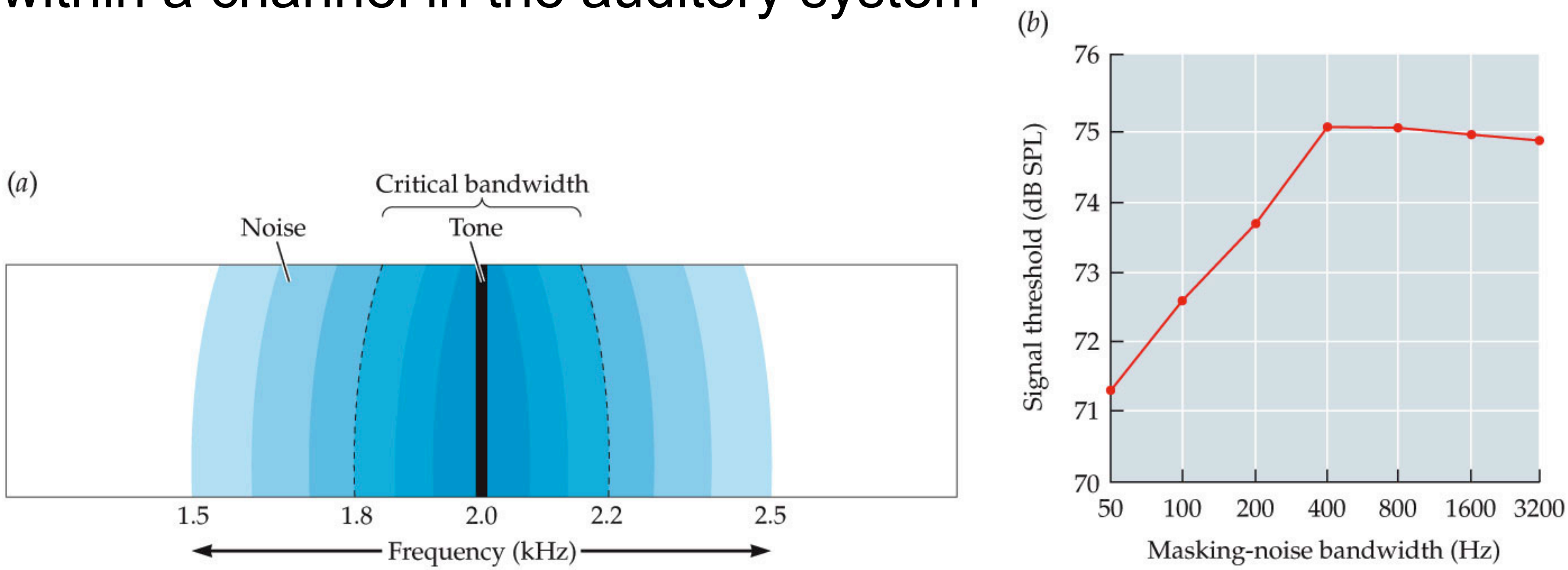
Sensation & Perception (PSY 345 / NEU 325)

Spring 2022

Chapter 9 leftovers

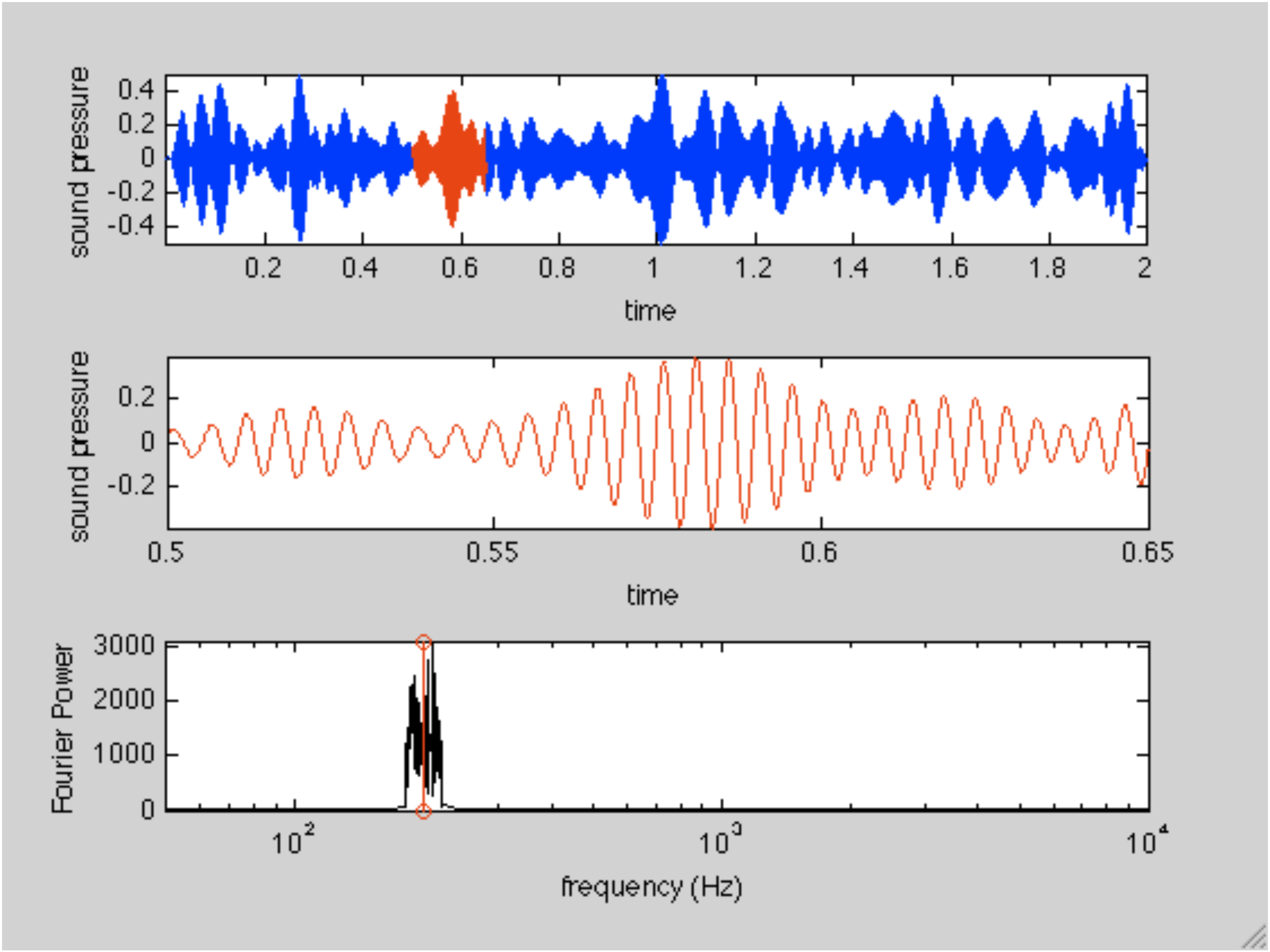
• **Critical bandwidth**: range of frequencies conveyed within a channel in the auditory system



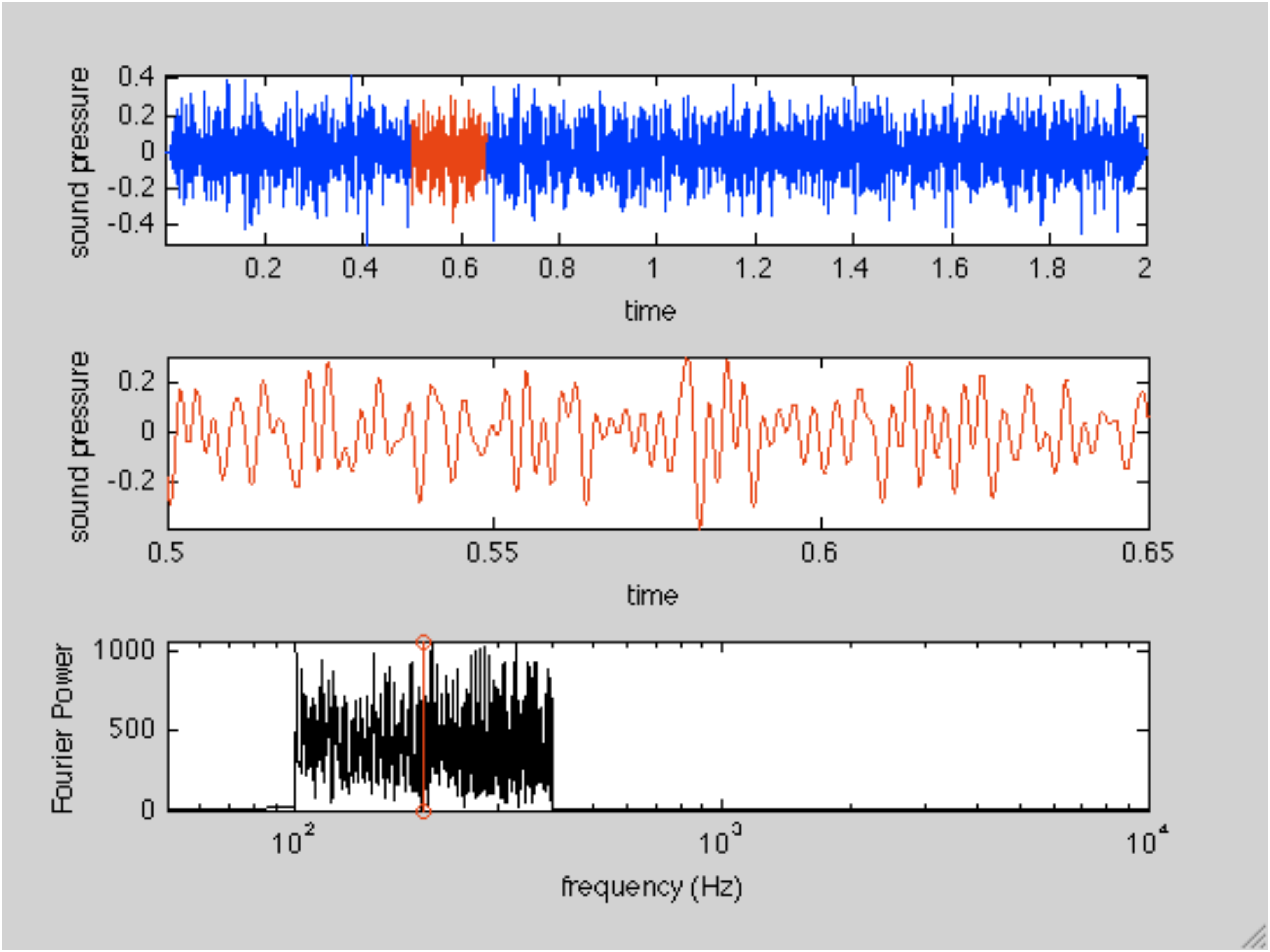
Technique for measuring bandwidth of frequency channels:

• present a tone on top of a noise background
• start with very narrow band of noise
• increase the noise bandwidth, measure threshold for tone detection
• keep increasing noise bandwidth until doing so doesn’t cause a decrease in sensitivity (increase in threshold)

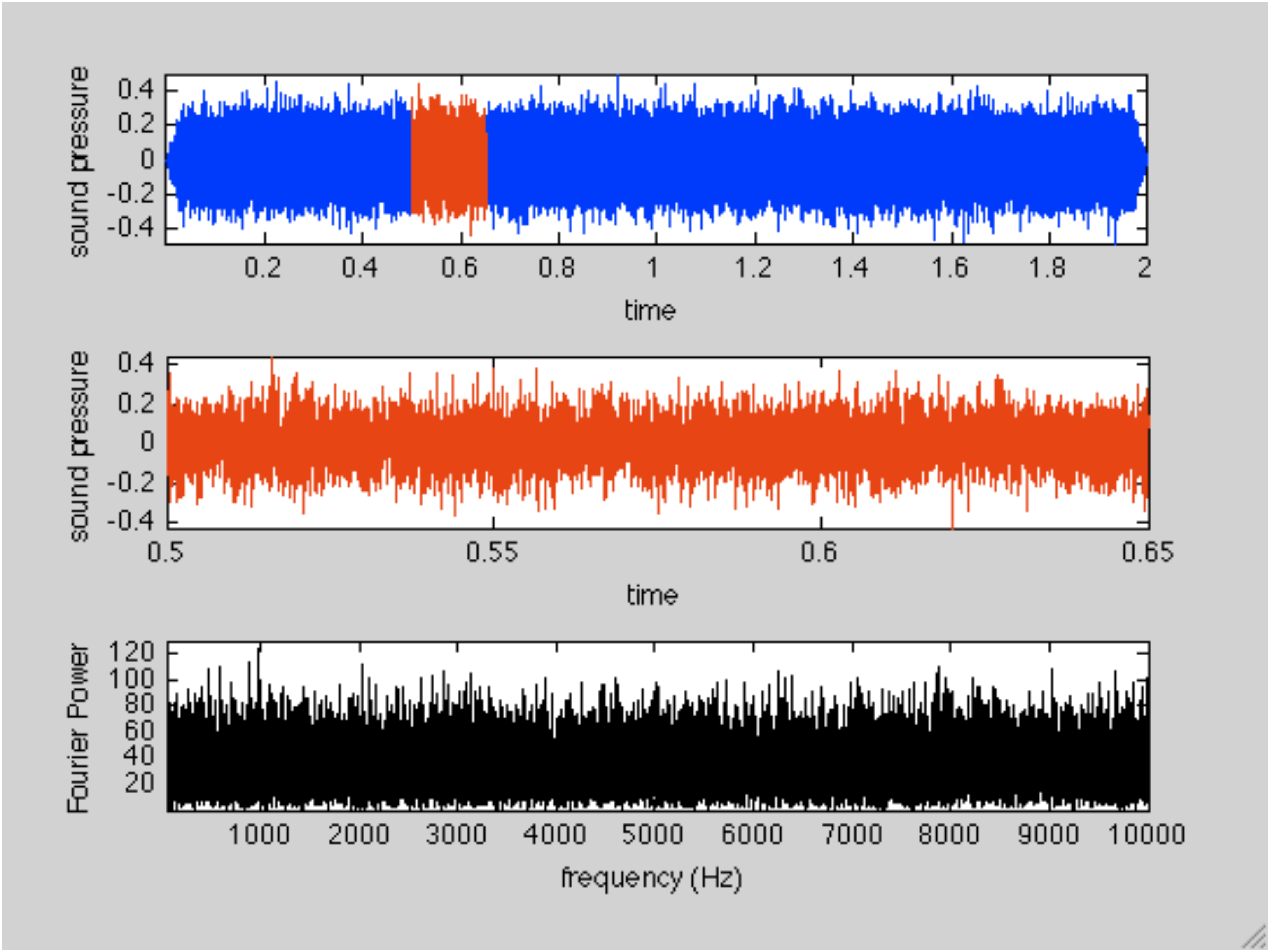
Narrow-Band Noise



Broad-Band Noise



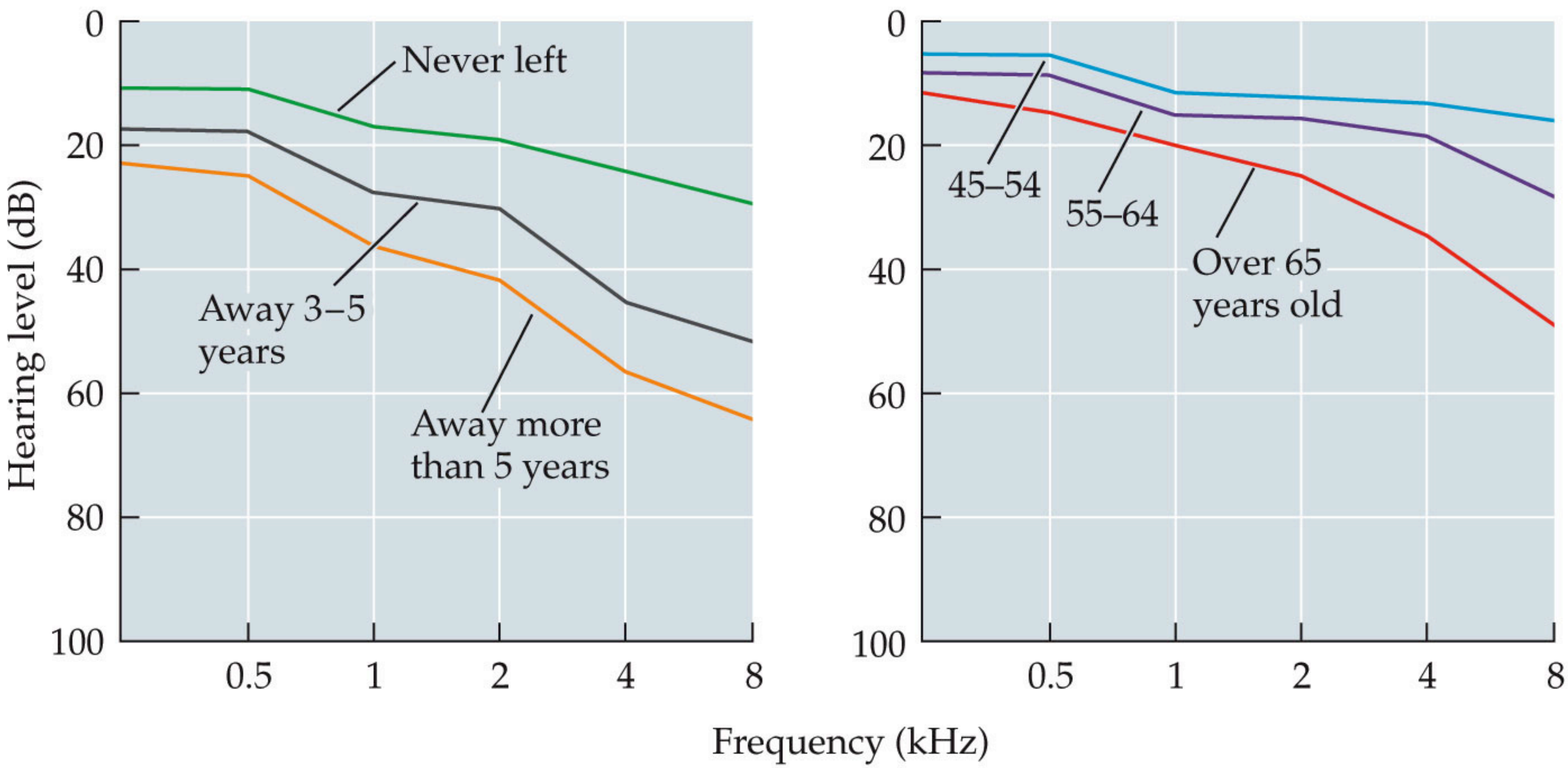
White Noise
(equal power at all frequencies)



Hearing Loss: effects of noise exposure

Easter Islanders

Age-related hearing loss
(most pronounced at high freqs)



Hearing Loss

Hearing loss: Natural consequence of aging

- Young people: frequency range of 20–20,000 Hz
- By college age: 20–15,000 Hz

hearing test!
(next time in class)

consequences of age-related reductions in high-frequency sensitivity

- “dispersion devices” for loitering youths

- introduced in UK despite some debate over ethics / legality.

The Mosquito MK4 Anti-loitering device

The original Mosquito Device, highly effective at dispersing youths, preventing loitering and reducing anti-social behaviour

http://www.compoundsecurity.co.uk/security-equipment/mosquito-mk4-anti-loitering-device

The Mosquito or **Mosquito alarm** (marketed as the **Beethoven** in France, the **Swiss-Mosquito** in Switzerland and **SonicScreen** in the US and Canada) is an electronic device, used to deter loitering by young people, which emits a sound with a very high frequency. The newest version of the device, launched late in 2008, has two frequency settings, one of approximately 17.4 kHz that can generally be heard only by young people, and another at 8 kHz that can be heard by most people. The maximum potential output sound pressure level is stated by the manufacturer to be 108 decibels (dB).The sound can typically only be heard by people below 25 years of age, as the ability to hear high frequencies deteriorates in humans with age.

The Mosquito was invented by Howard Stapleton in 2005, and was originally tested in Barry, South Wales, where it was successful in reducing teenagers loitering near a grocery store. The idea was born after he was irritated by a factory noise when he was a child. The push to create the product was when Mr. Stapleton's 17-year-old daughter went to the store to buy milk and was harassed by a group of 12 to 15-year-olds. Using his children as test subjects, he determined the frequency of "The Mosquito."[8]

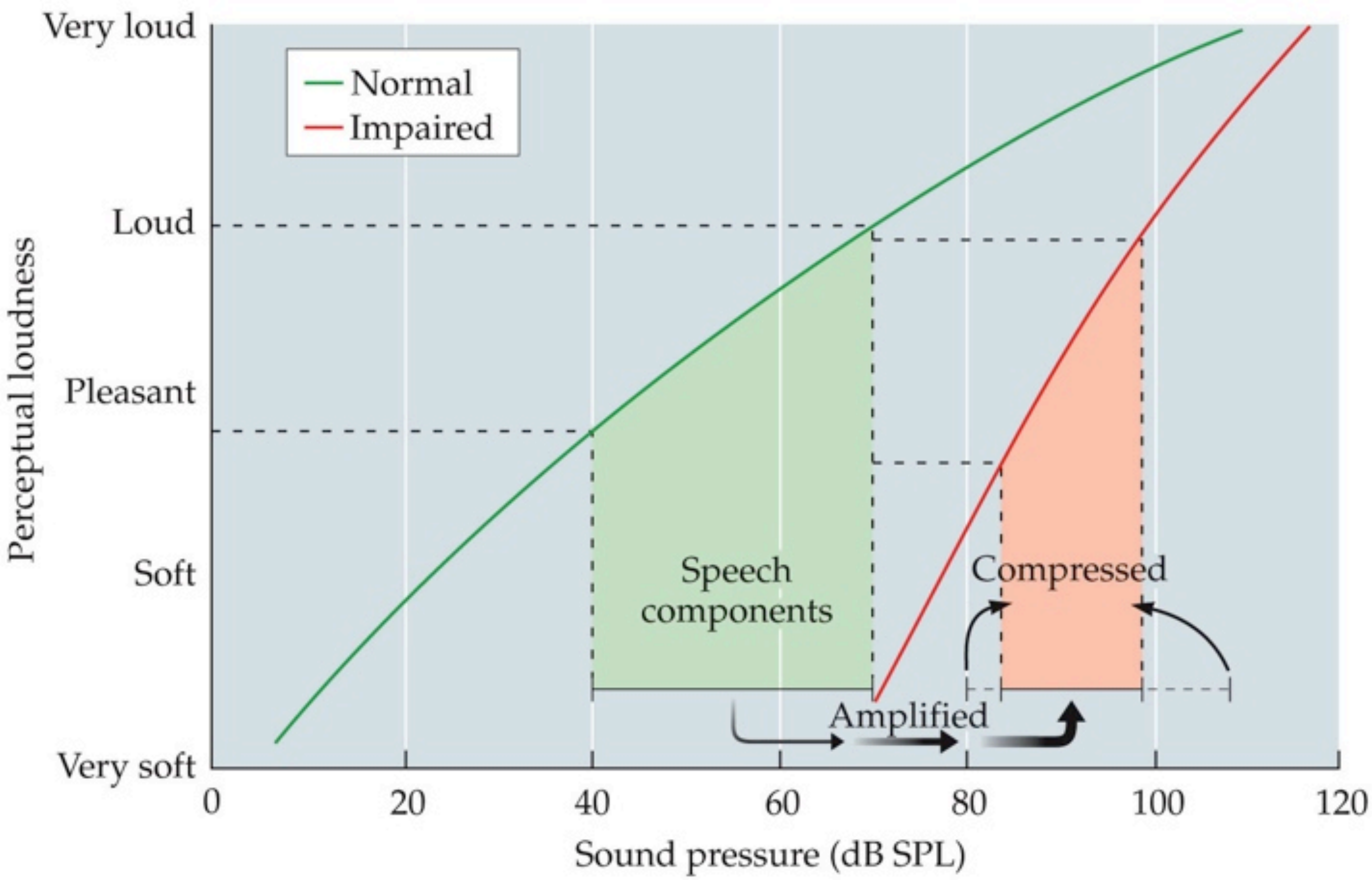
opposition

Opposition categorises it as an indiscriminate weapon which succeeds only in demonising children and young people and may breach their human rights.

A UK campaign called "Buzz off" is calling for The Mosquito to be banned.

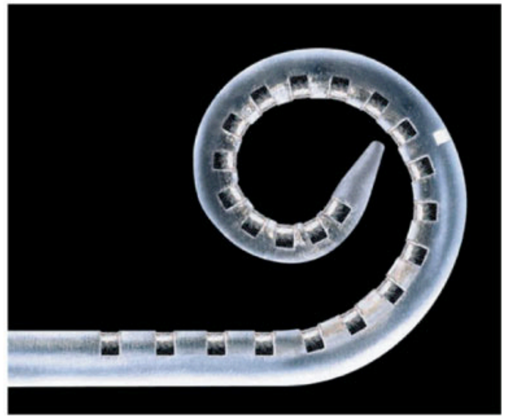
Hearing Aides

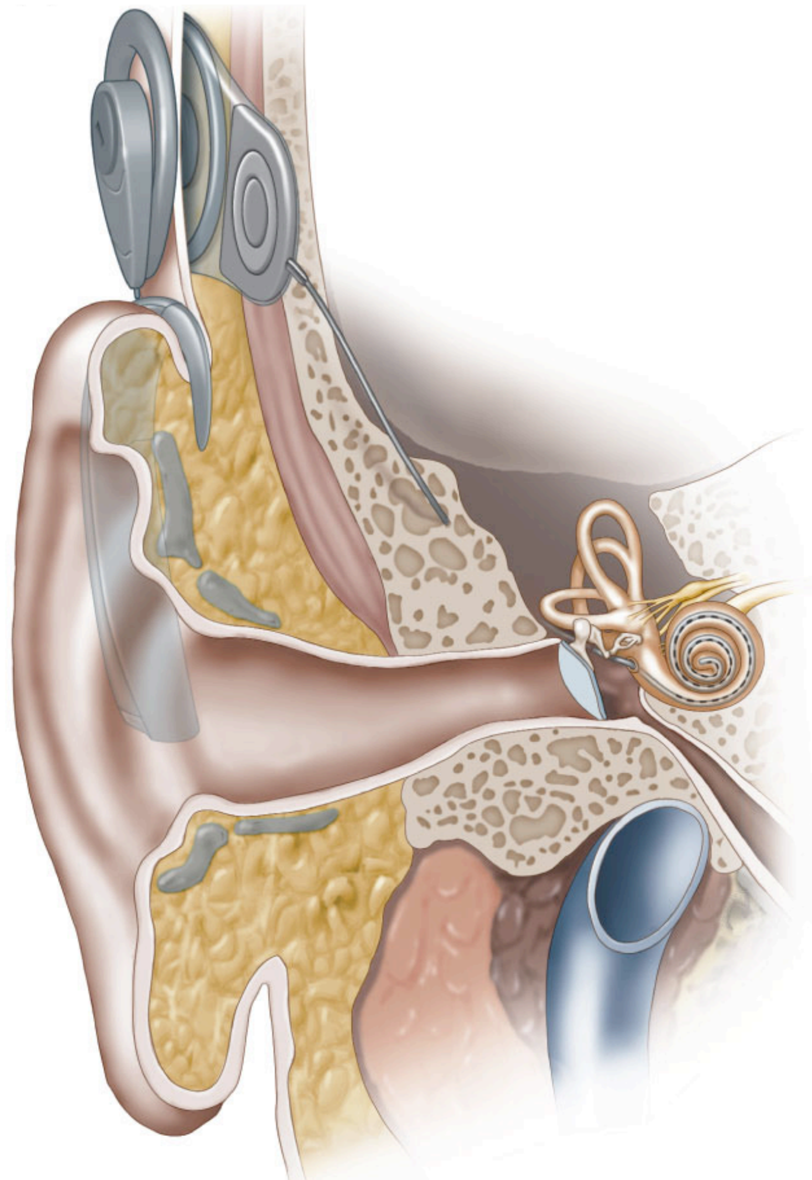
- Earliest devices were horns; today, electronic aids



- Pain still kicks in at same level, so sound levels need to be compressed into detectable range

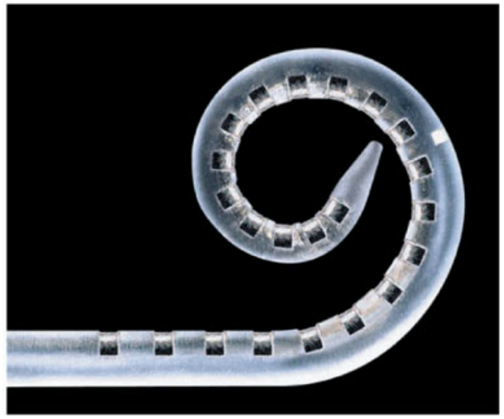
Cochlear implants:

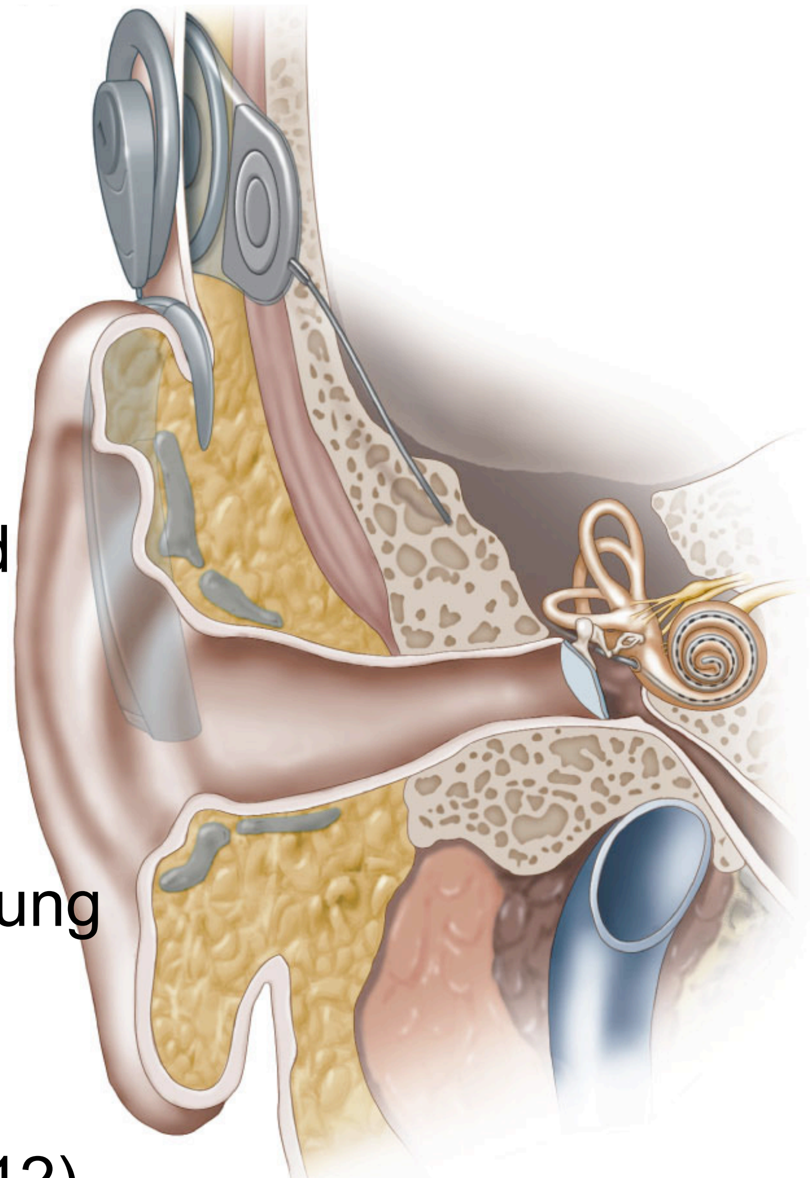




- Tiny flexible coils with miniature electrode contacts
- Surgeons thread implants through round window toward cochlea apex
- Tiny microphone transmits radio signals to a receiver in the scalp

Cochlear implants:



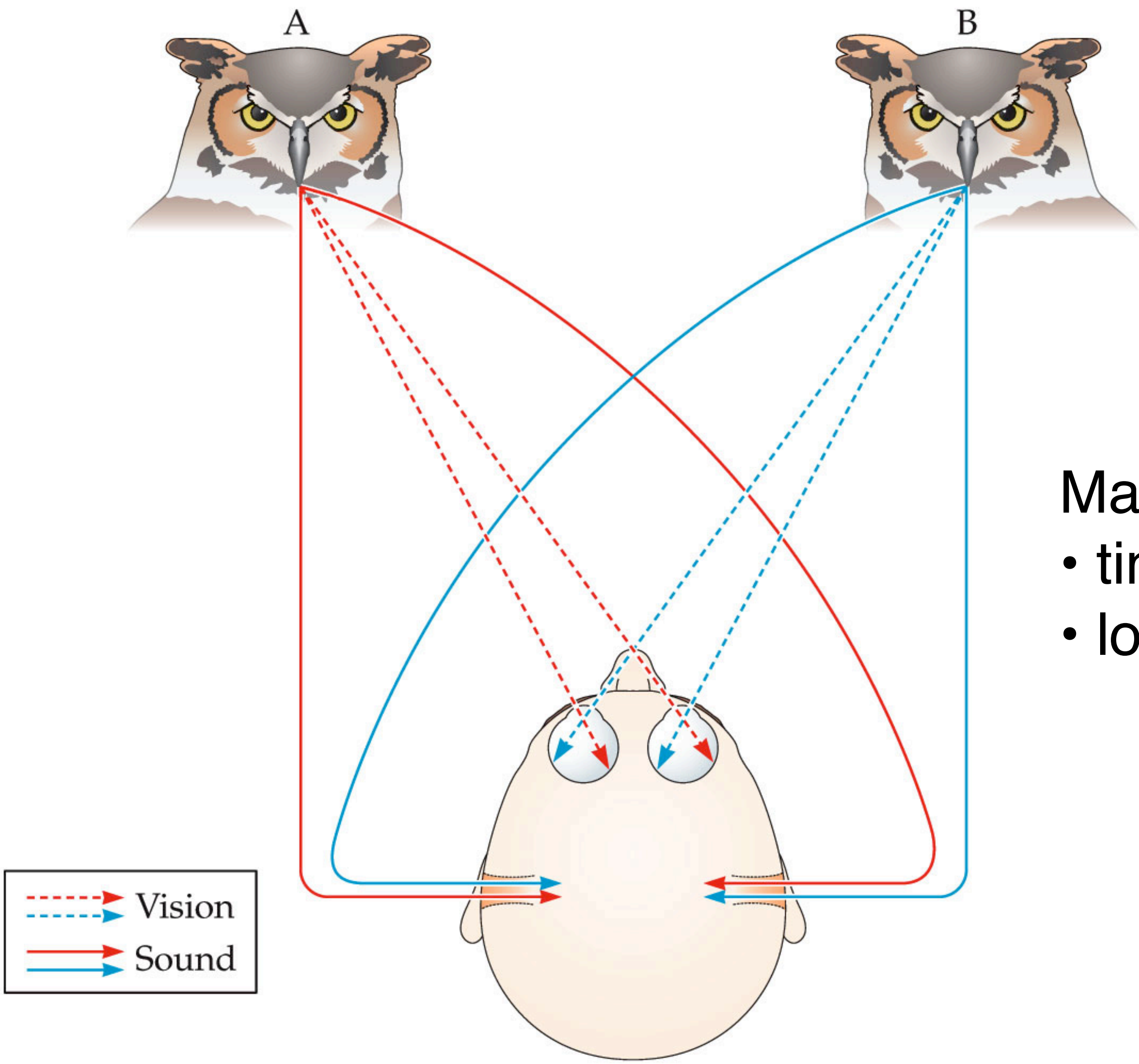


- Chip performs Fourier transform and stimulates appropriate location in cochlea for each frequency
- up to 22 electrodes
- most effective when implanted at young age
- approved by FDA in 1984
- 324,000 total recipients (through 2012)

Hearing in the Environment

(Chapter 10)

Q: How do you detect the location of a sound?



Main answer:

- timing differences
- loudness differences

Position detection by the visual and auditory systems

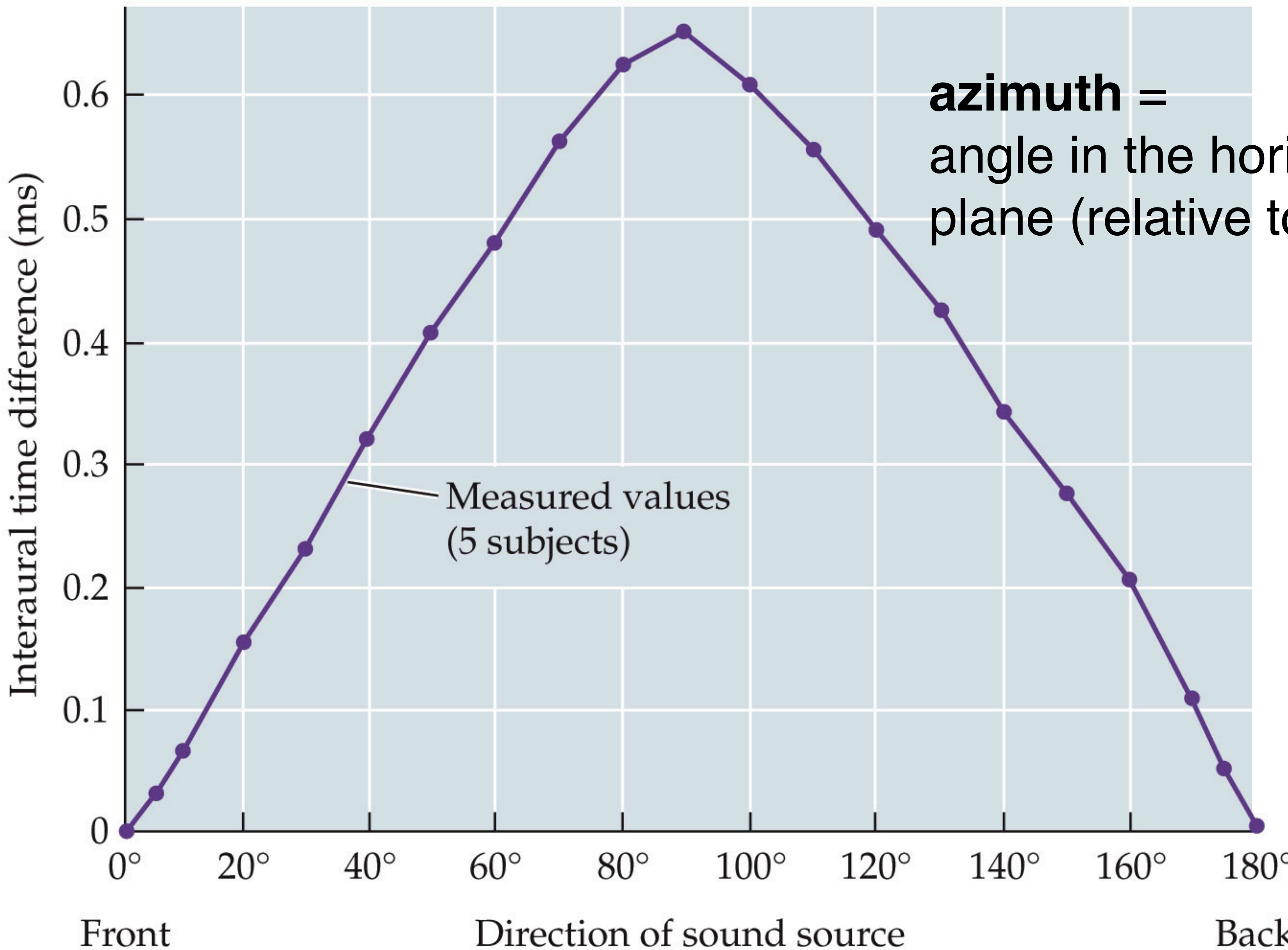
The sound at microphone #1 will:
-be ***more intense***
-arrive ***sooner***

Sound Localization

First Cue: timing

Interaural time differences (ITD): The difference in time between a sound arriving at one ear versus the other

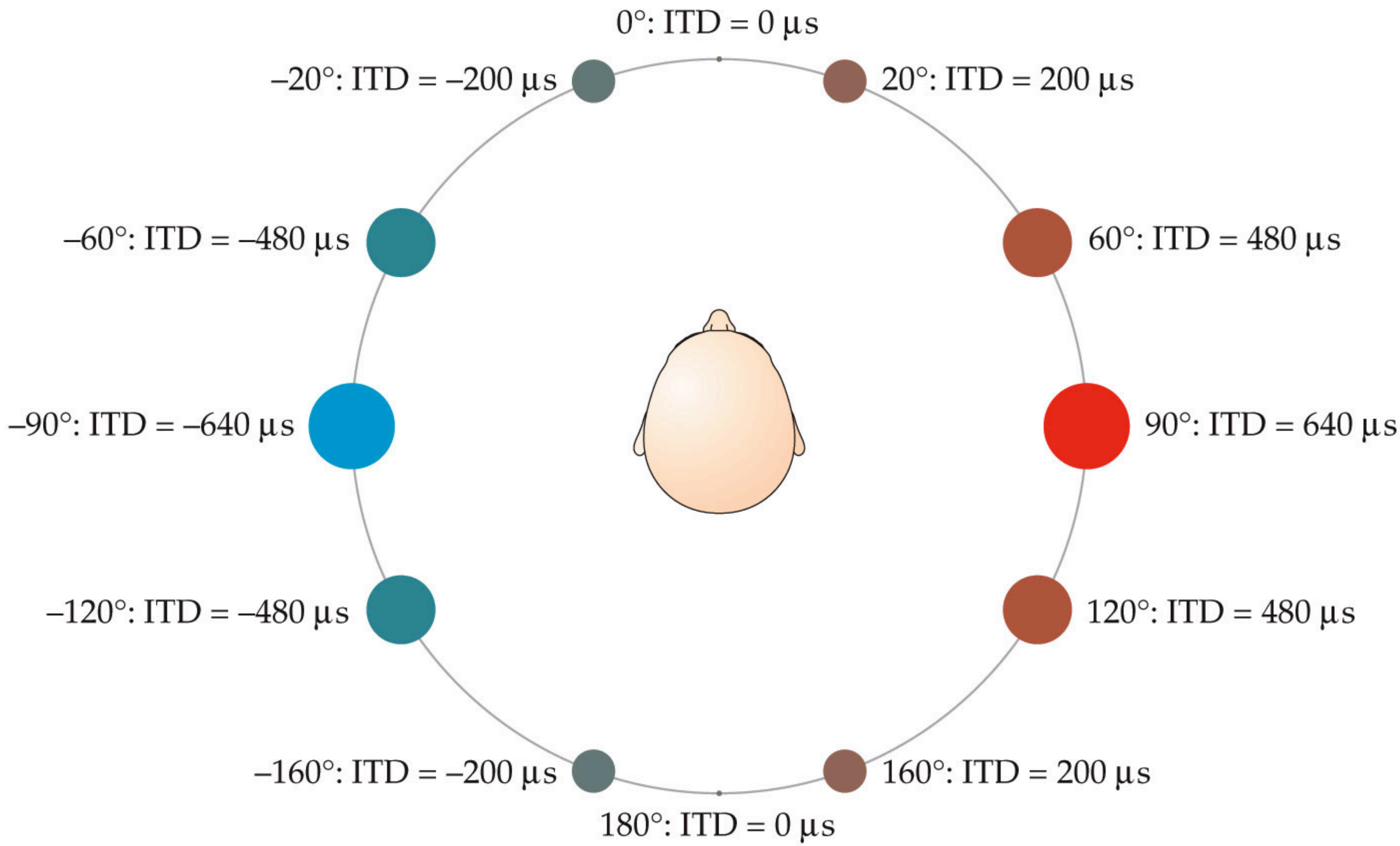
Interaural time differences for sound sources varying in azimuth



azimuth =
angle in the horizontal plane (relative to head)

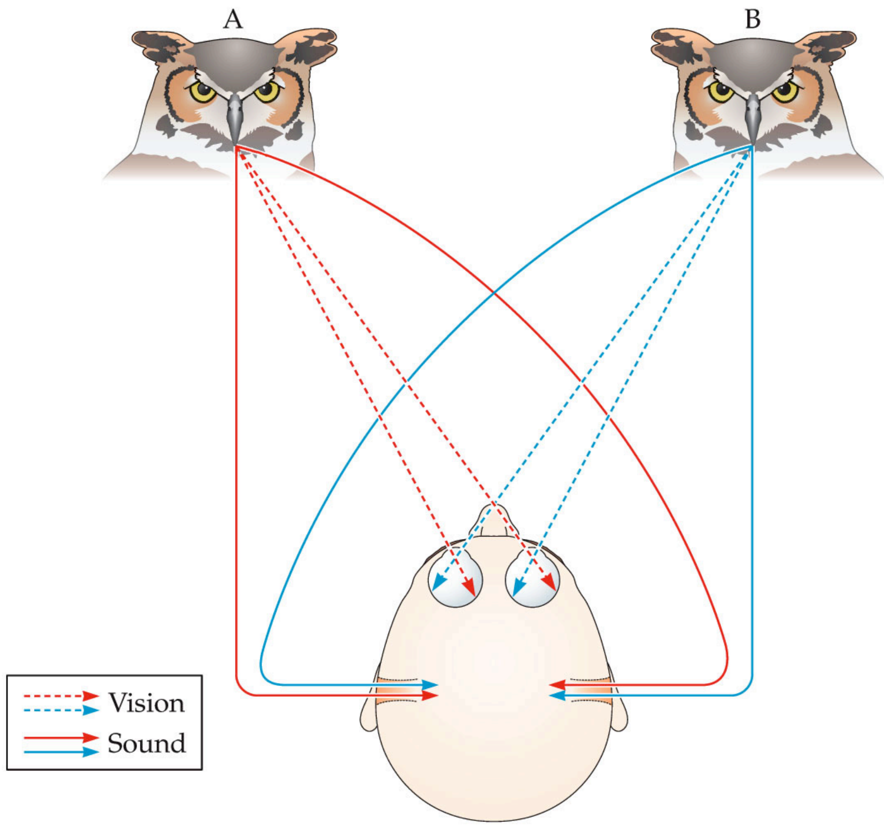
azimuthal angle

Interaural time differences for different positions around the head



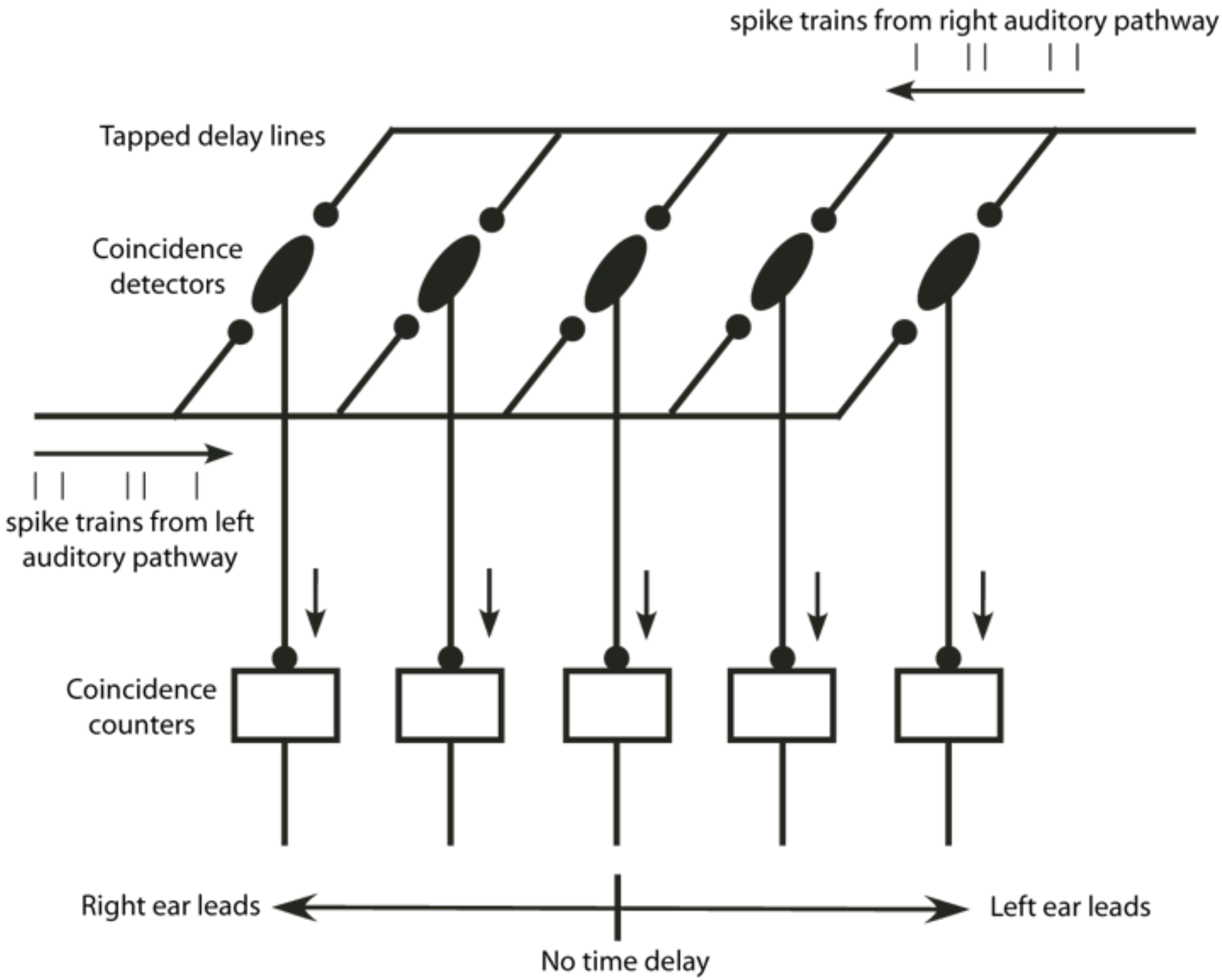
Q: how would you design a system to detect inter-aural time differences?

(Think back to Reichardt detector)



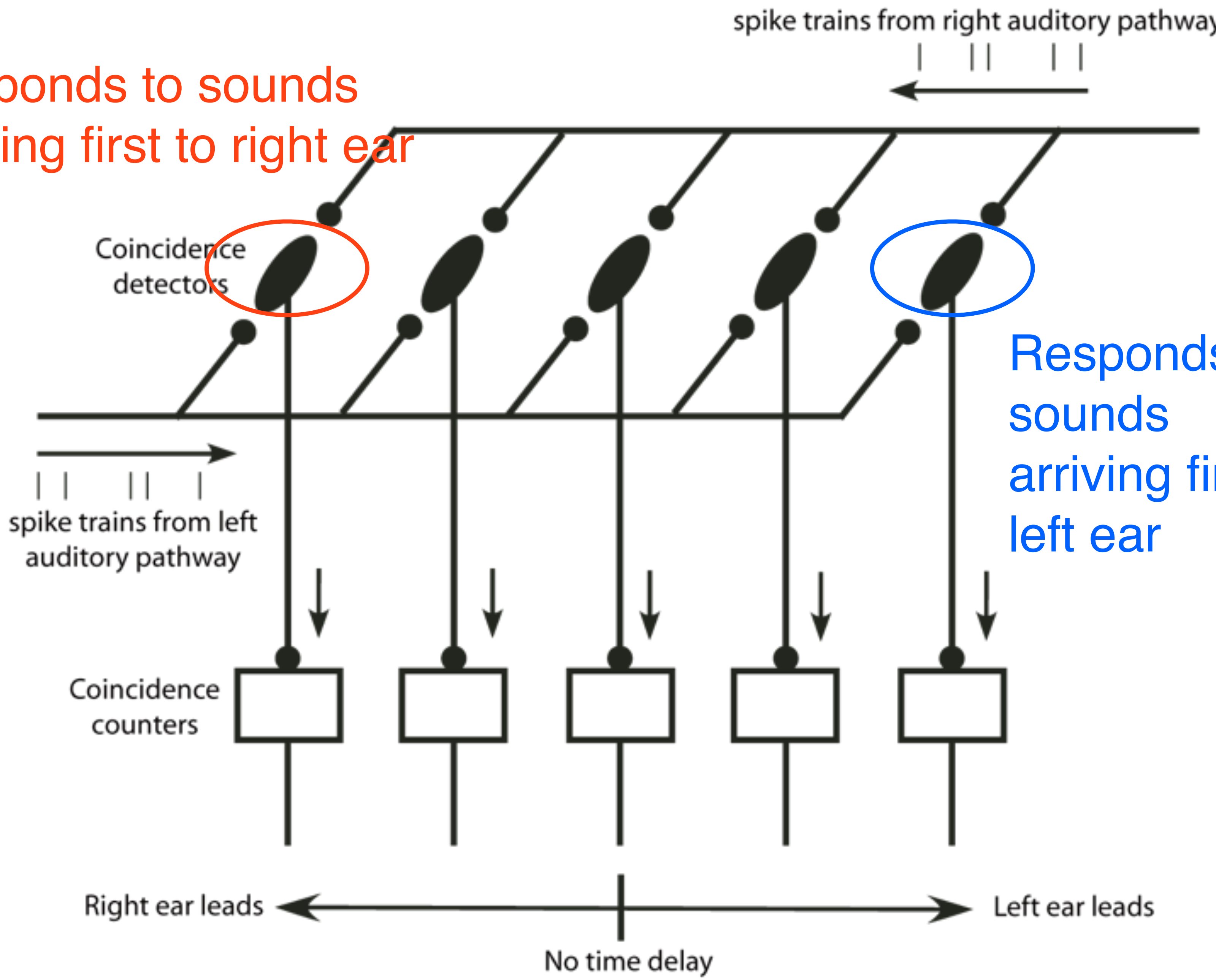
Hint: “delay lines”

Jeffress Model



Jeffress Model

Responds to sounds arriving first to right ear



Responds to sounds arriving first to left ear

Physioloy of ITD processing

- **Medial superior olive (MSO)**:
- ITDs processed (first place where binaural information combined)
- form connections during the first few months of life
- interpretation of ITD changes with age (as head grows, ears get further apart!)

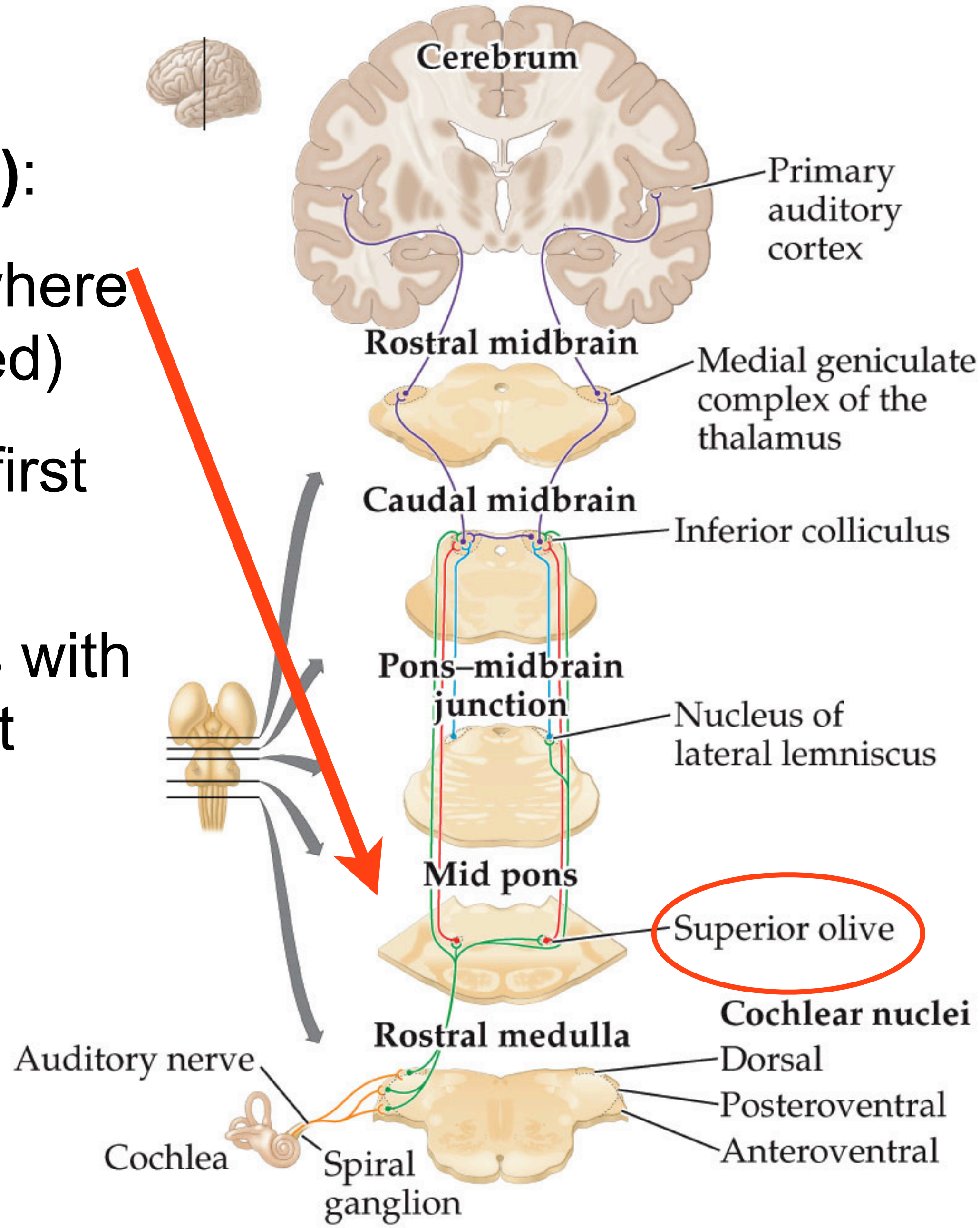
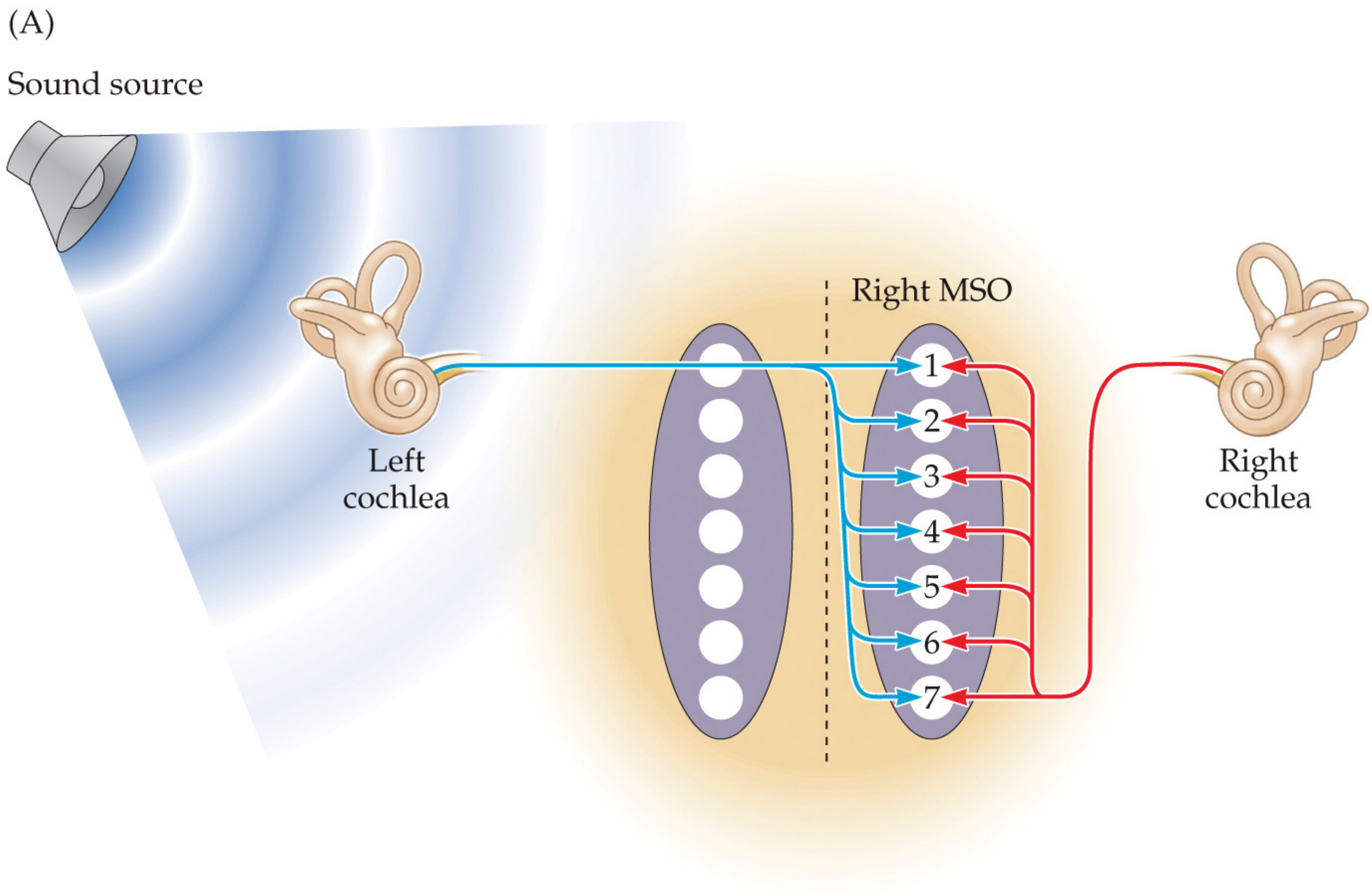


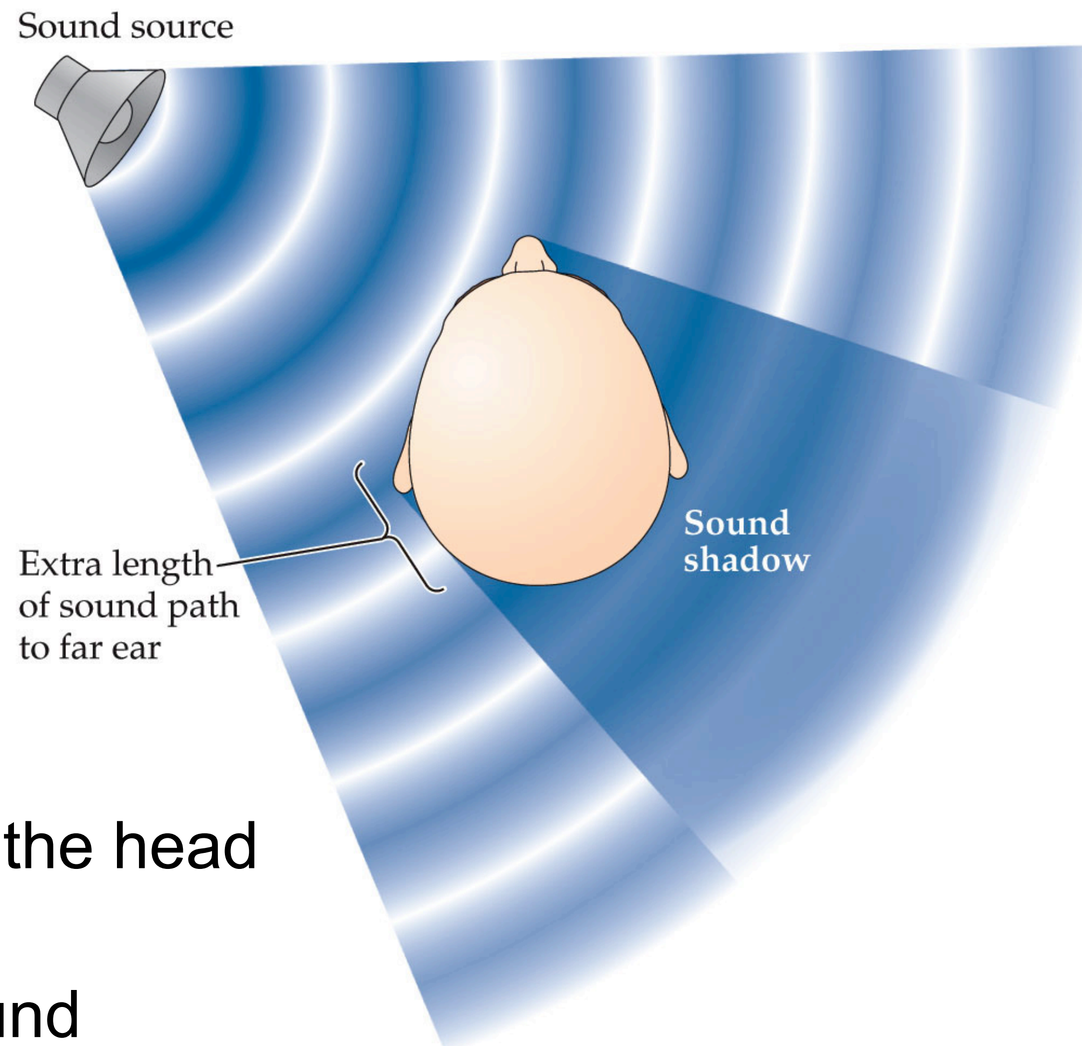
Figure 10.7 Models for the way neurons in the medial superior olive (MSO) can detect time difference between two ears (Part 1)



SENSATION & PERCEPTION 5e, Figure 10.7 (Part 1)

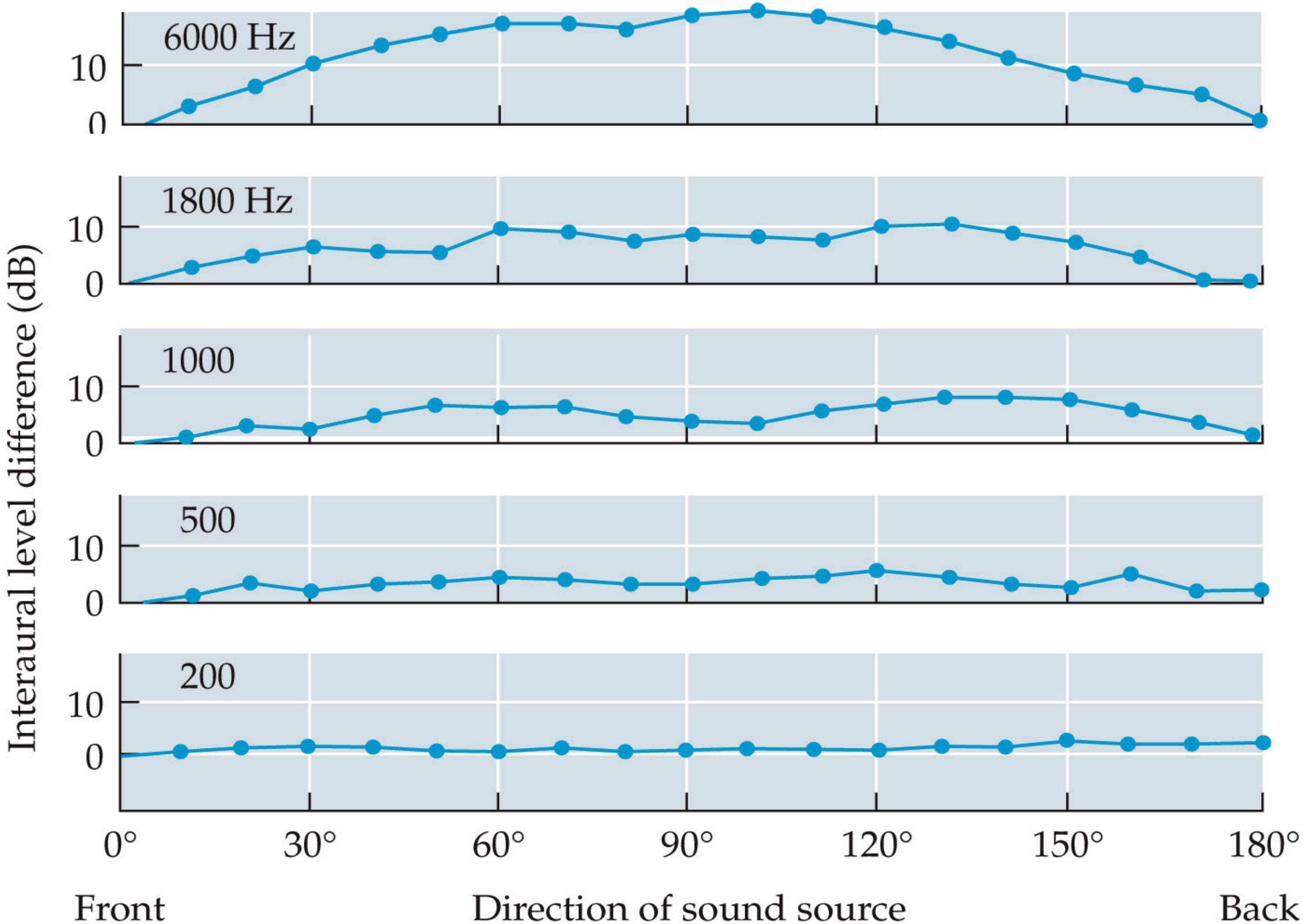
Second cue: Loudness (or “level”) differences (ILDs)

ILD: difference in level (intensity) between a sound arriving at one ear versus the other

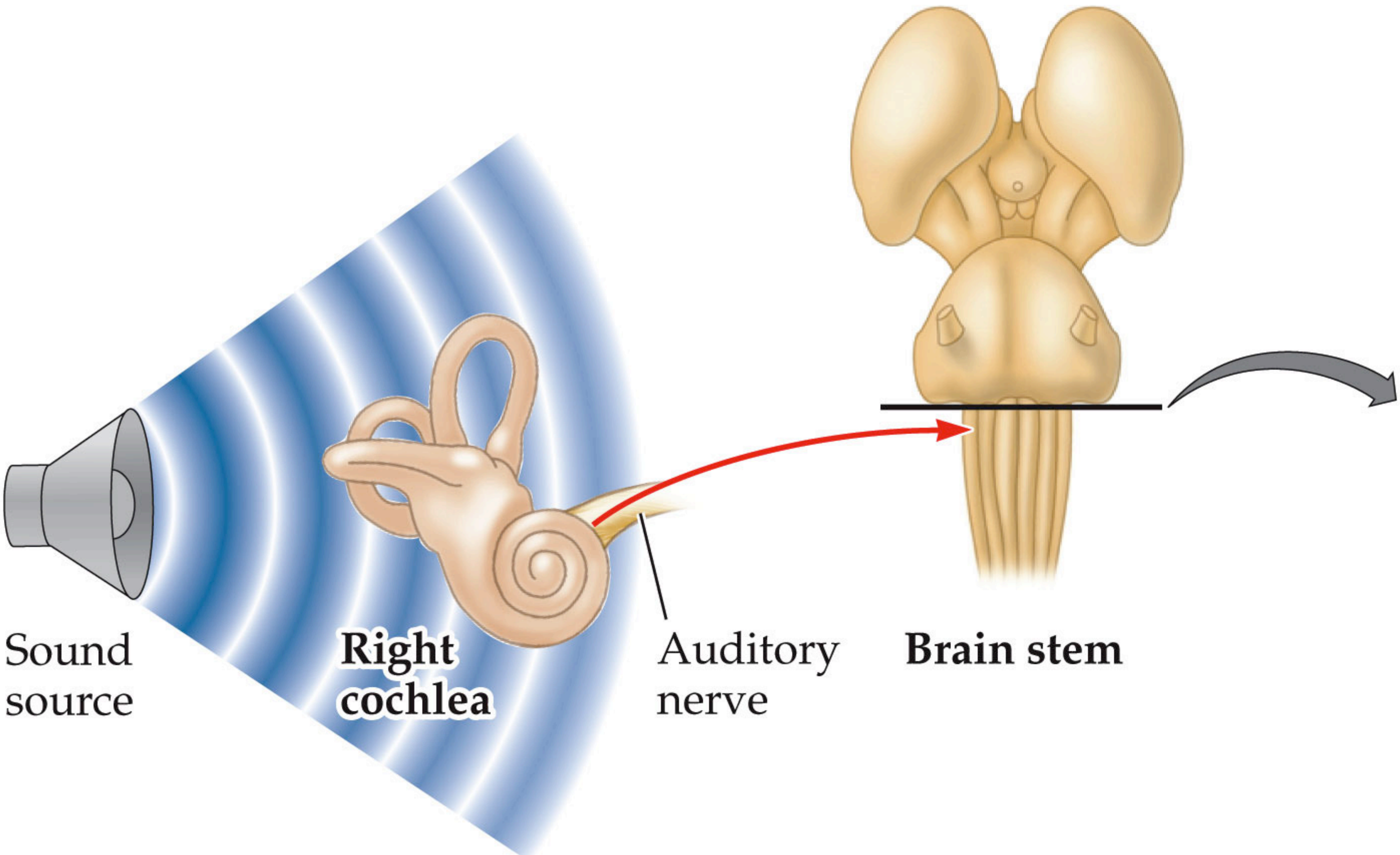


- For frequencies >1000Hz, the head blocks some energy
- correlates with angle of sound source, but not quite as reliable as with ITDs

ILDs for tones of different frequencies



Lateral superior olive (LSO): relay station in the brainstem where inputs from both ears contribute to detection of ILDs



After a single synapse, information travels to medial and lateral superior olive

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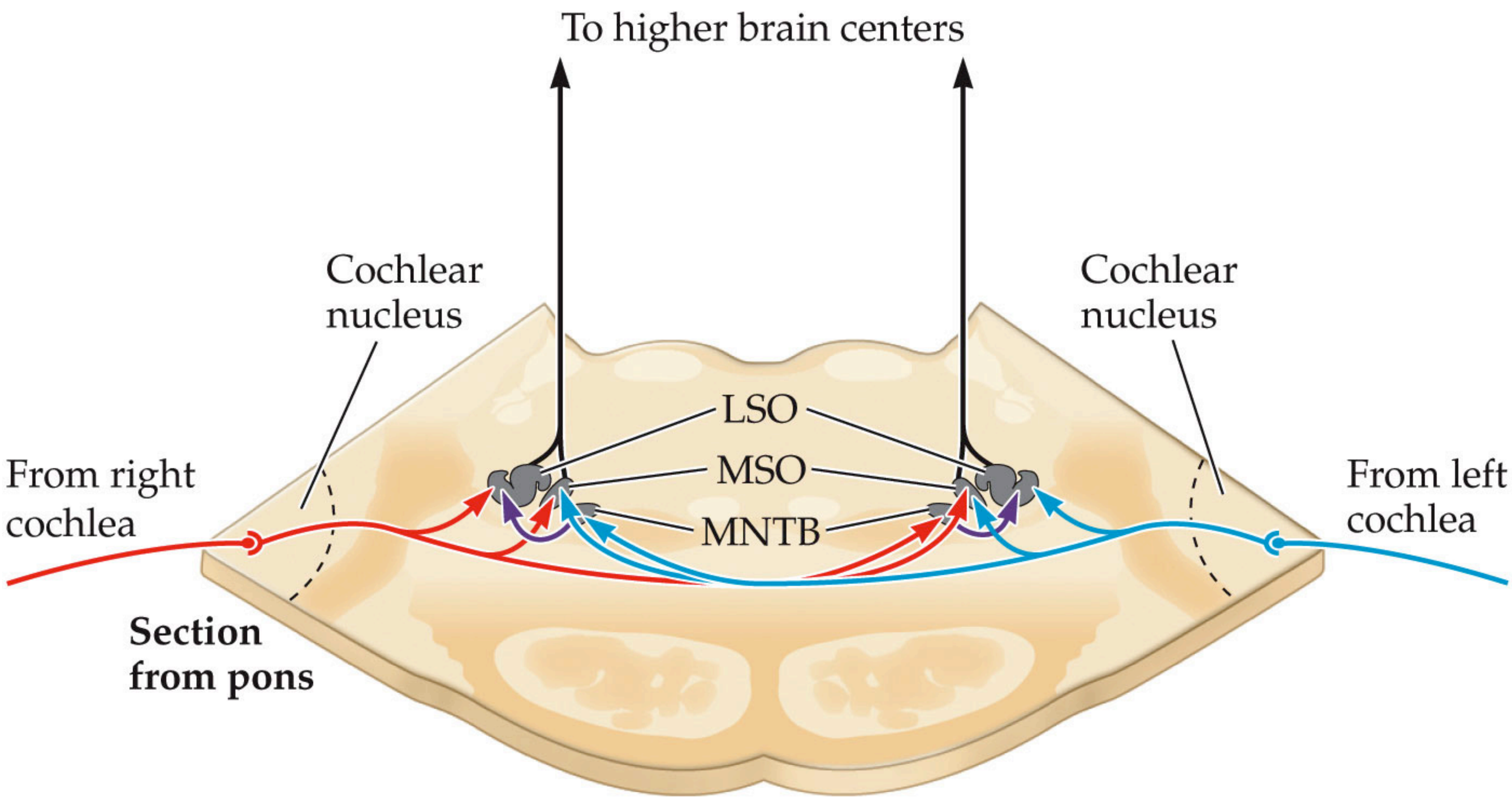
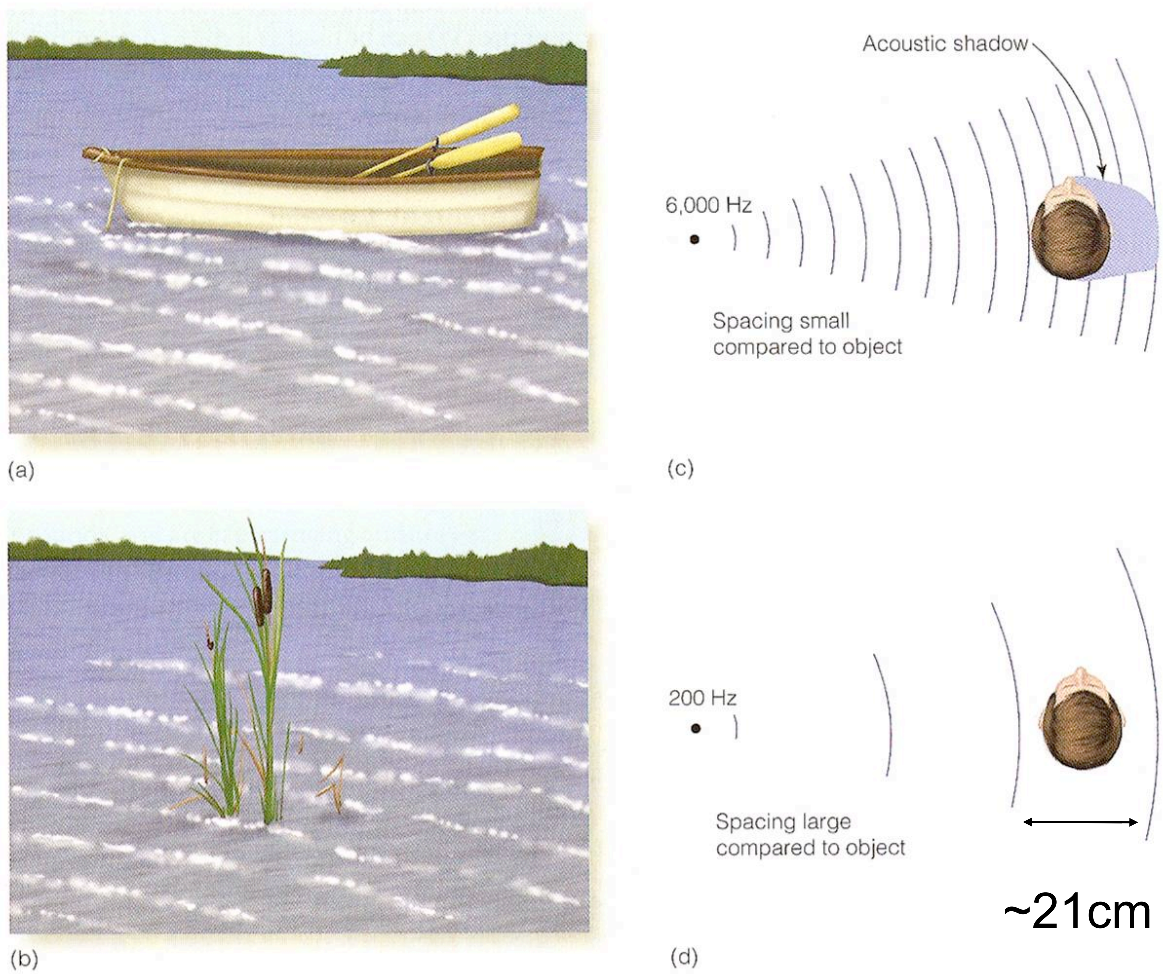


Auditory Localization Demo
(try with headphones)

https://oup-arc.com/access/content/sensation-and-perception-5e-student-resources/sensation-and-perception-5e-activity-10-1?previousFilter=tag_chapter-10

Why 2 cues?



High frequencies

>1600 Hz

Low frequencies

<800 Hz

Both cues contribute for 800-1600 Hz

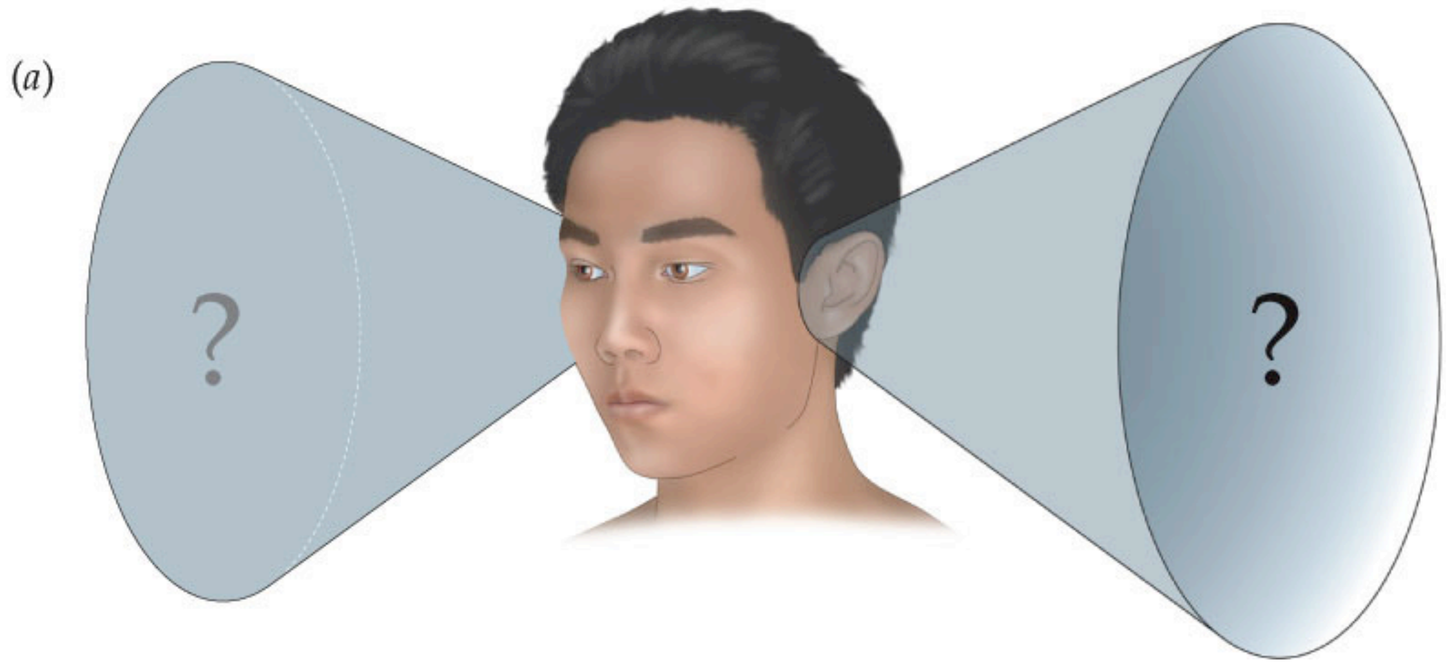
Summary of ITD and ILD

ITD: good for low frequencies (processed in MSO)

ILD: good for high frequencies (processed in LSO)

Problem with using ITDs and ILDs for sound localization:

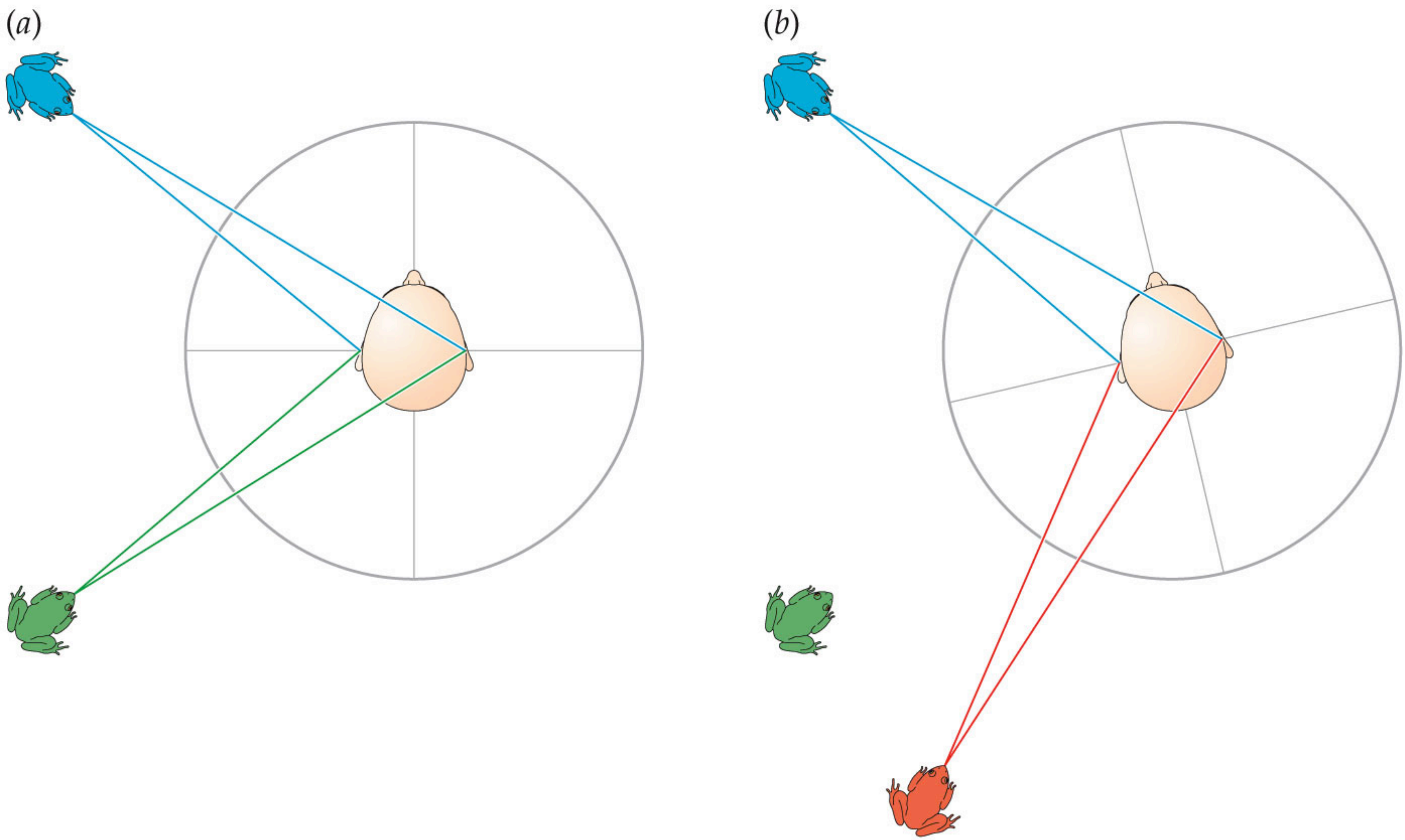
- **Cone of confusion**: A region of positions in space where all sounds produce the same ITDs and ILDs



Q: where is the cone of confusion for a point directly in front of your head?

Overcoming the cone of confusion

- Turning the head can disambiguate ILD/ITD similarity

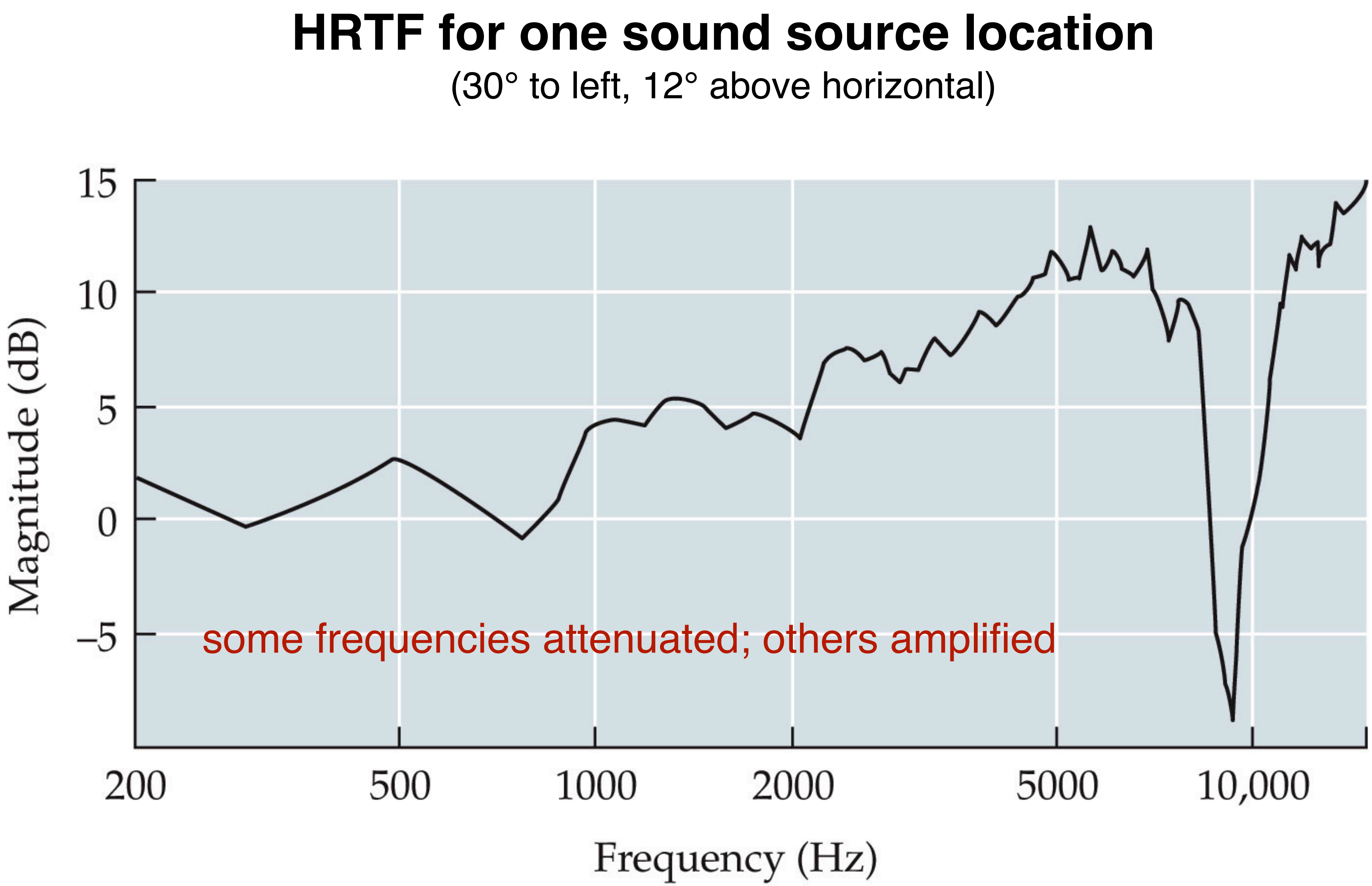


Head-related transfer function (HRTF)

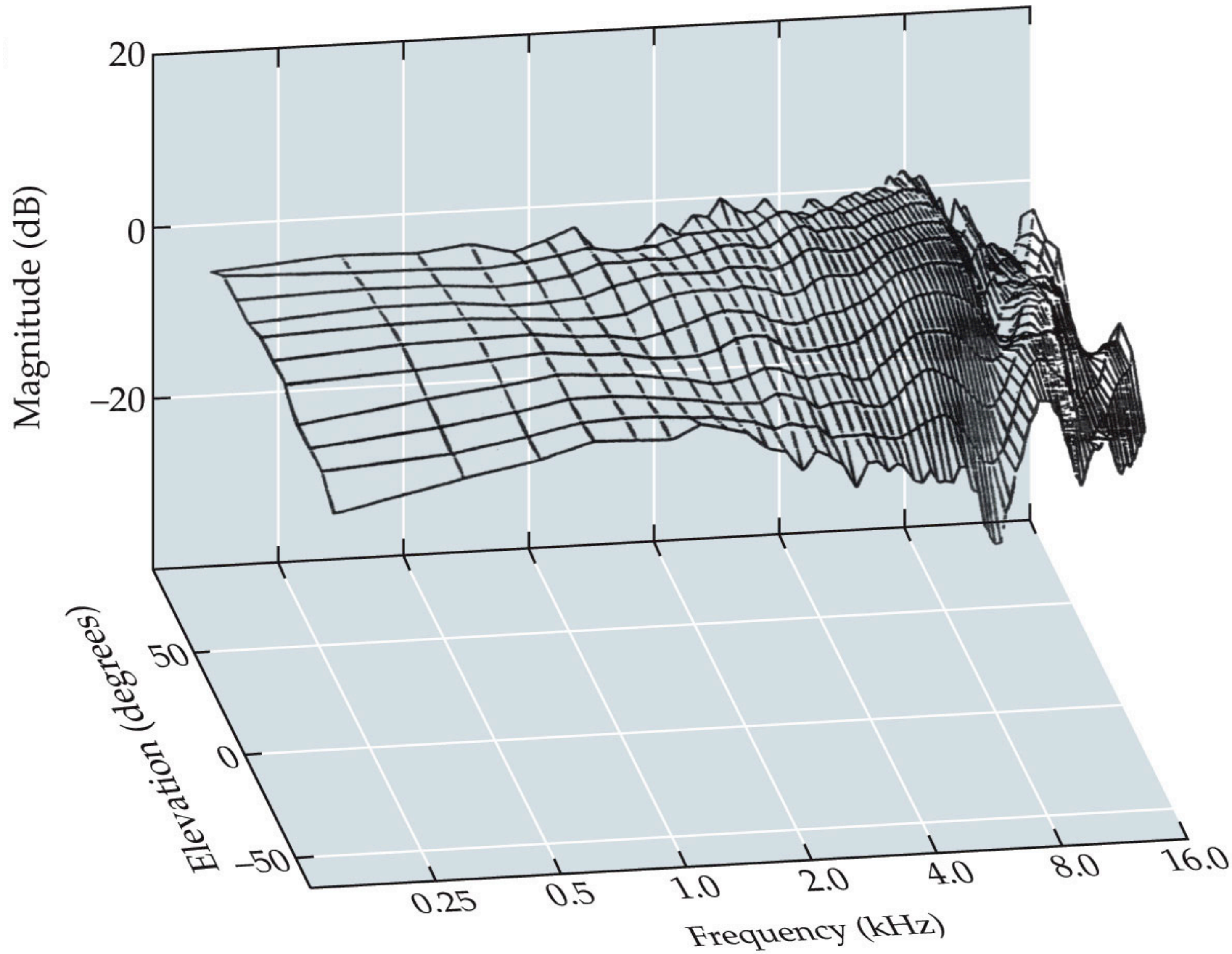
- describes how pinnae, ear canals, head, and torso change the intensity of sounds with different frequencies as the sound location changes

- Each person has his/her own HRTF (based on his/her own body) and uses it to help locate sounds

HRTF: can be measured with microphone in ear canal



HRTF varies with sound source elevation (& azimuth)



- provides information about source location in 3D

Head-related transfer function (HRTF)

- Hofman et al 1998: inserted plastic molds into pinnae, altering subjects' HRTFs
- sound localization performance abruptly degraded

Findings:

- Can learn a new HRTF in about 6 weeks (shown experimentally using inserted artificial pinna)
- Old HRTF is stored (can return to old one instantaneously)

Auditory distance perception

Several Cues:

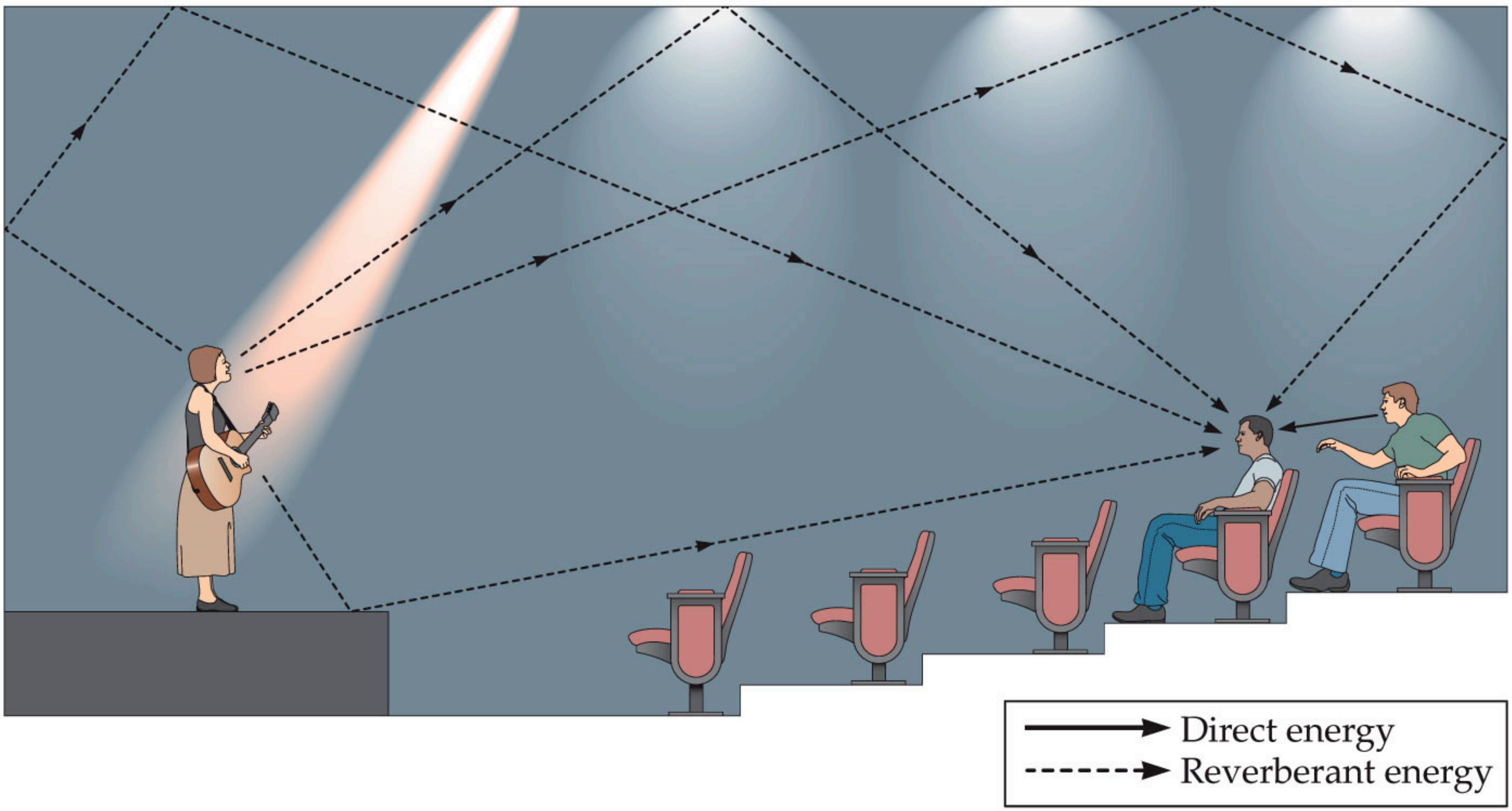
- **Loudness** ("inverse square law") - Intensity decreases as square of the distance: (quieter = farther away) (duh.)

- **Spectral composition** - Higher frequencies decrease in energy more than lower frequencies as sound waves travel

  Example: distant vs. nearby thunder.

  - This cue only works for long distances (d > 1000m)

- **Reverberant energy** - whether most sound is arriving directly (nearby sound source) or from reverberations (far away sound source); conveyed by timing information

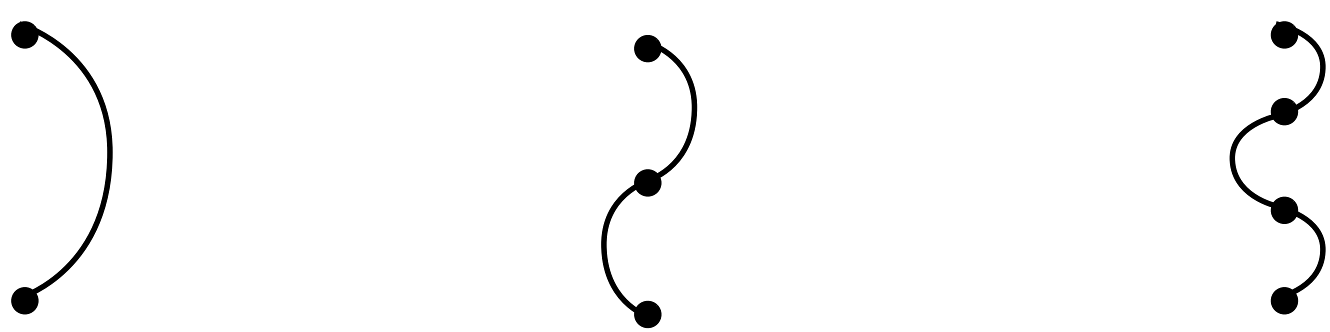


Auditory properties of complex sounds

Harmonics

- Objects tend to vibrate at multiple “resonant frequencies” (integer multiples of some fundamental frequency)
- most vibrations die down, but some persist because their wavelength is reinforced by the object’s physical properties
- Auditory system acutely sensitive to harmonics

Example: guitar string

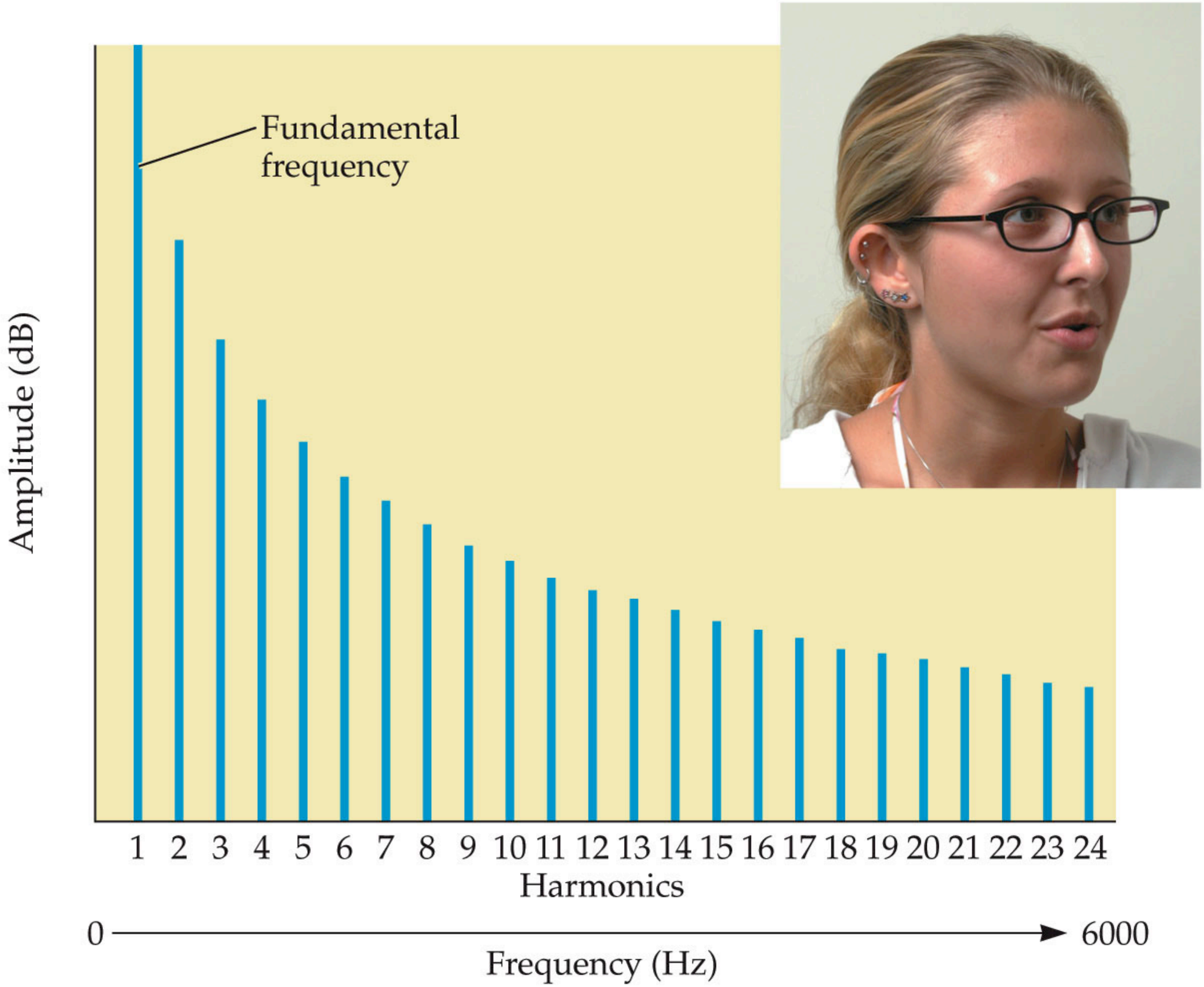


Fundamental F1 (1st harmonic)

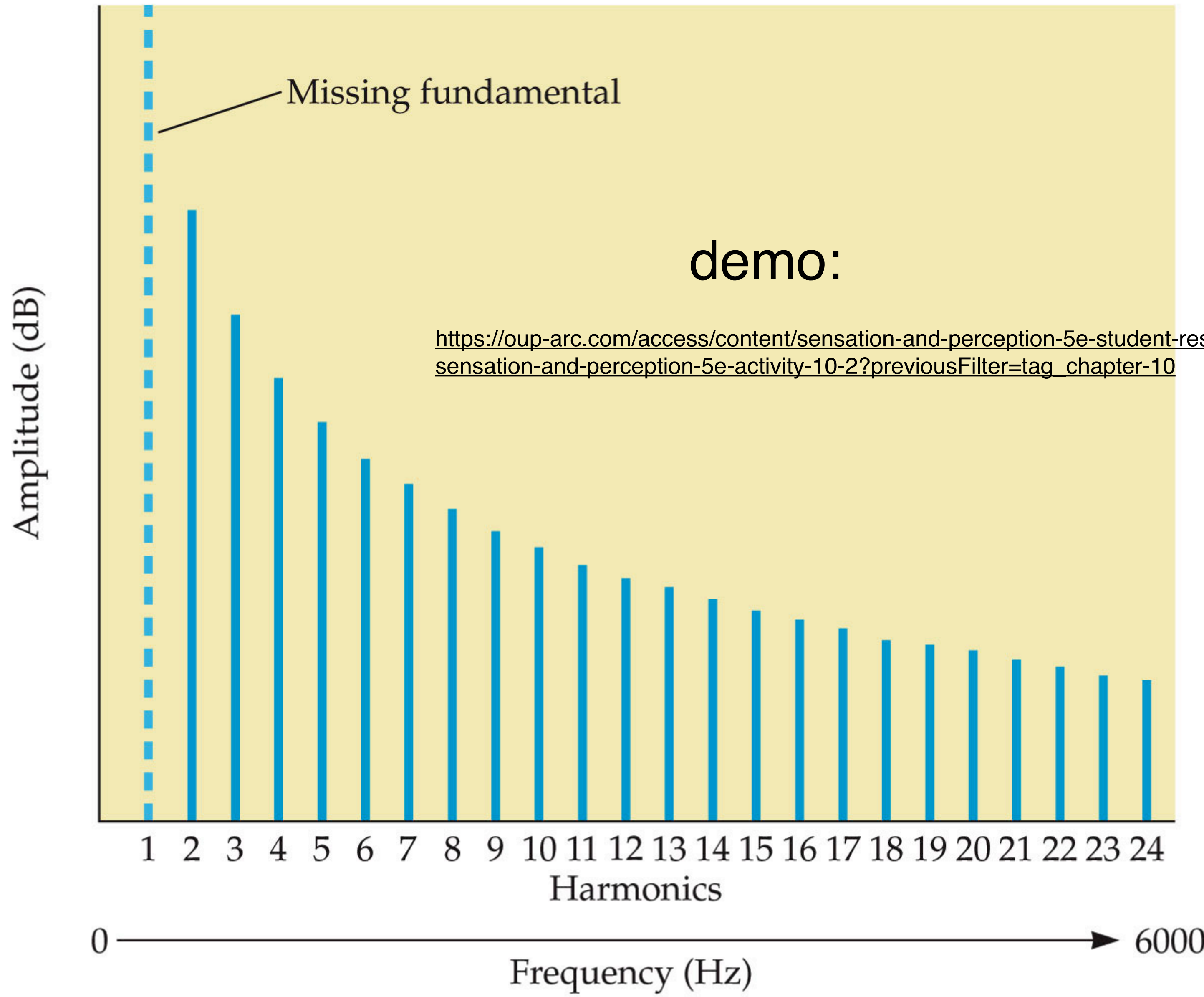
2nd harmonic F2 (2 x F1)

3rd harmonic F3 (3 x F1)

Many sounds, including voices, are harmonic



If the fundamental of a harmonic sound is removed, listeners will still hear its pitch



demo:

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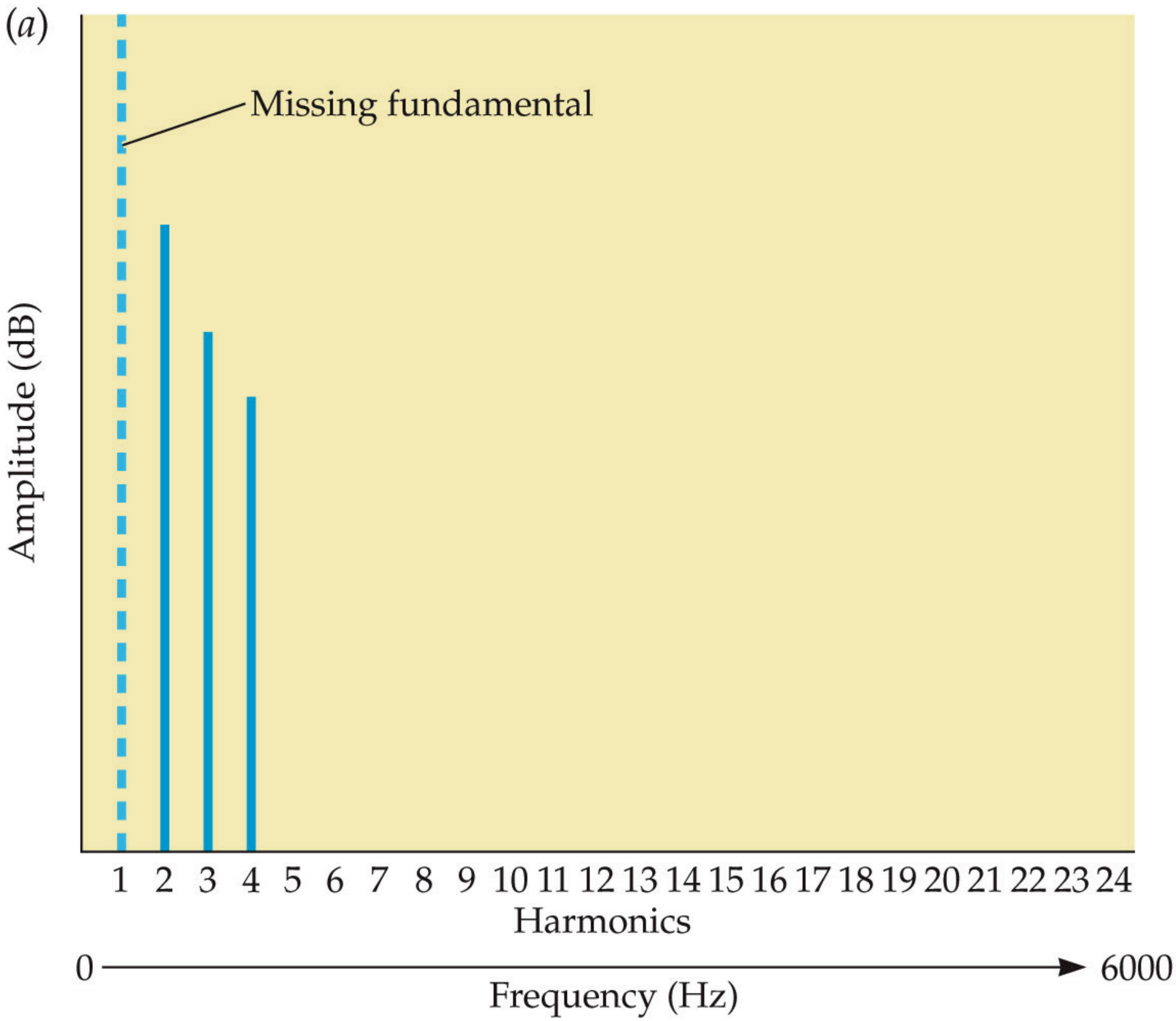
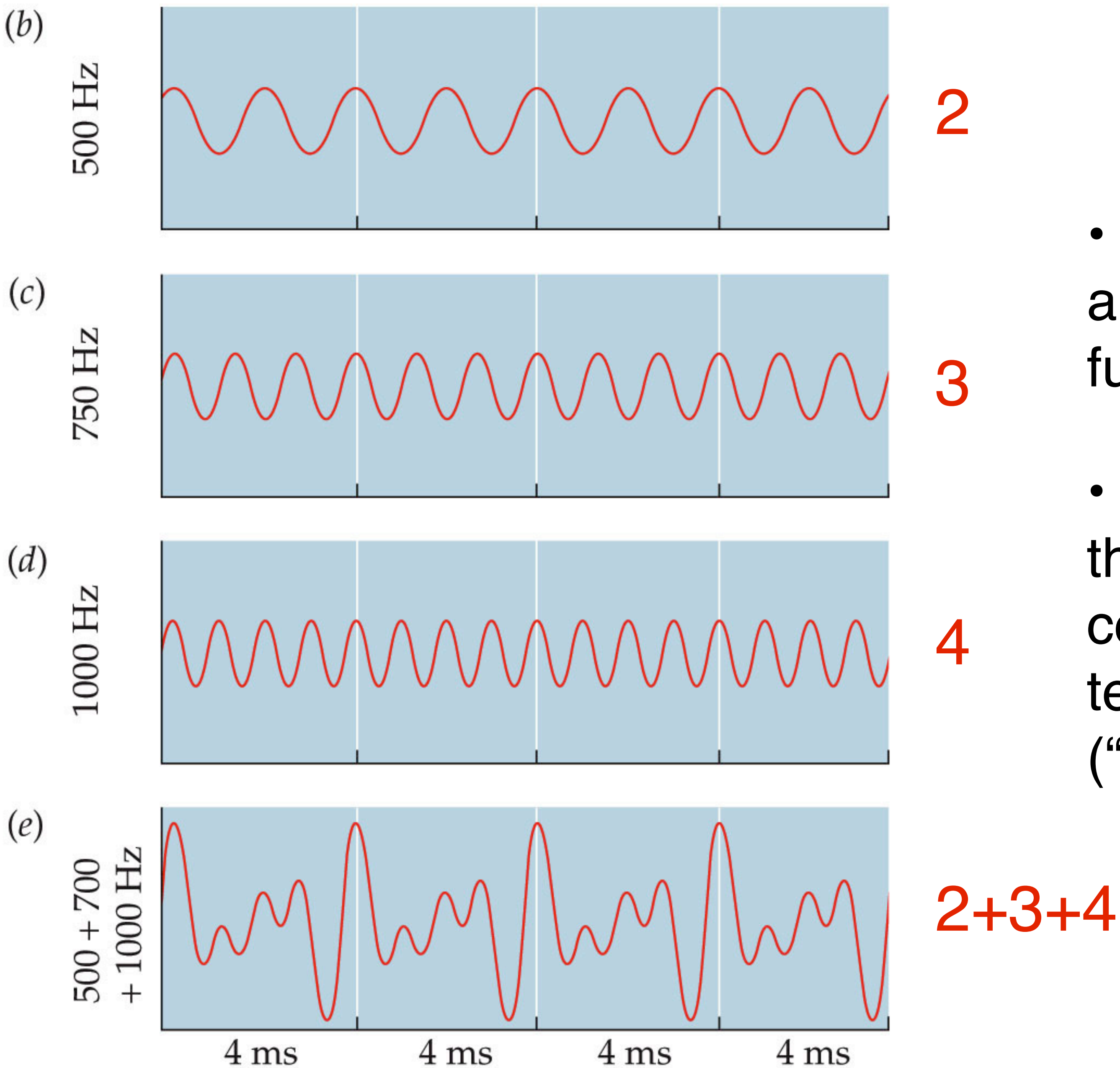
Missing Fundamental



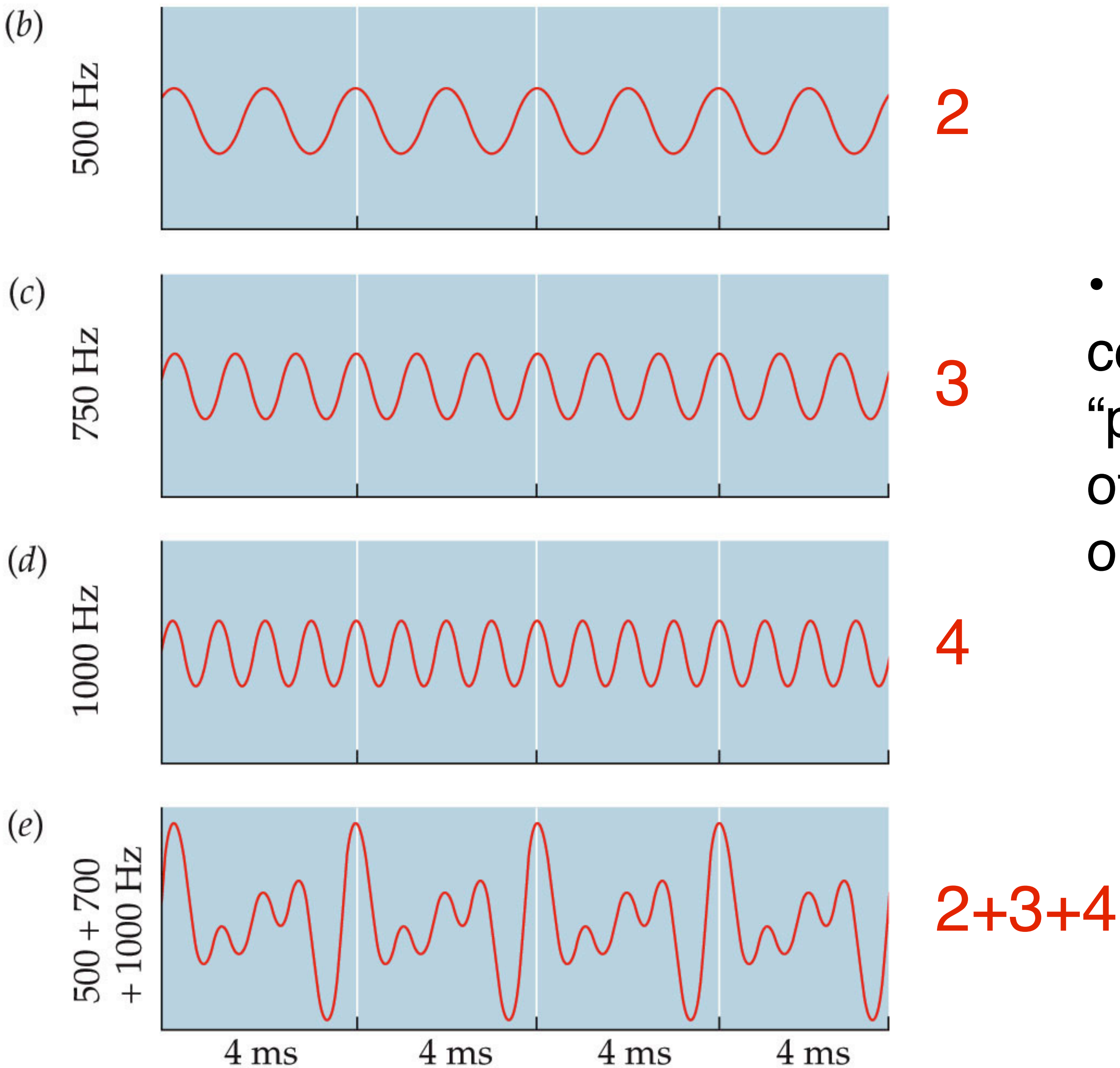
- only 3 harmonics are needed

Only three harmonics are needed to hear a missing fundamental



- all harmonics are aligned at the fundamental freq.
- fundamental could therefore be conveyed by temporal code (“phase locking”)

Only three harmonics are needed to hear a missing fundamental



- Could also be conveyed by "pattern matching" of the place code on the cochlea

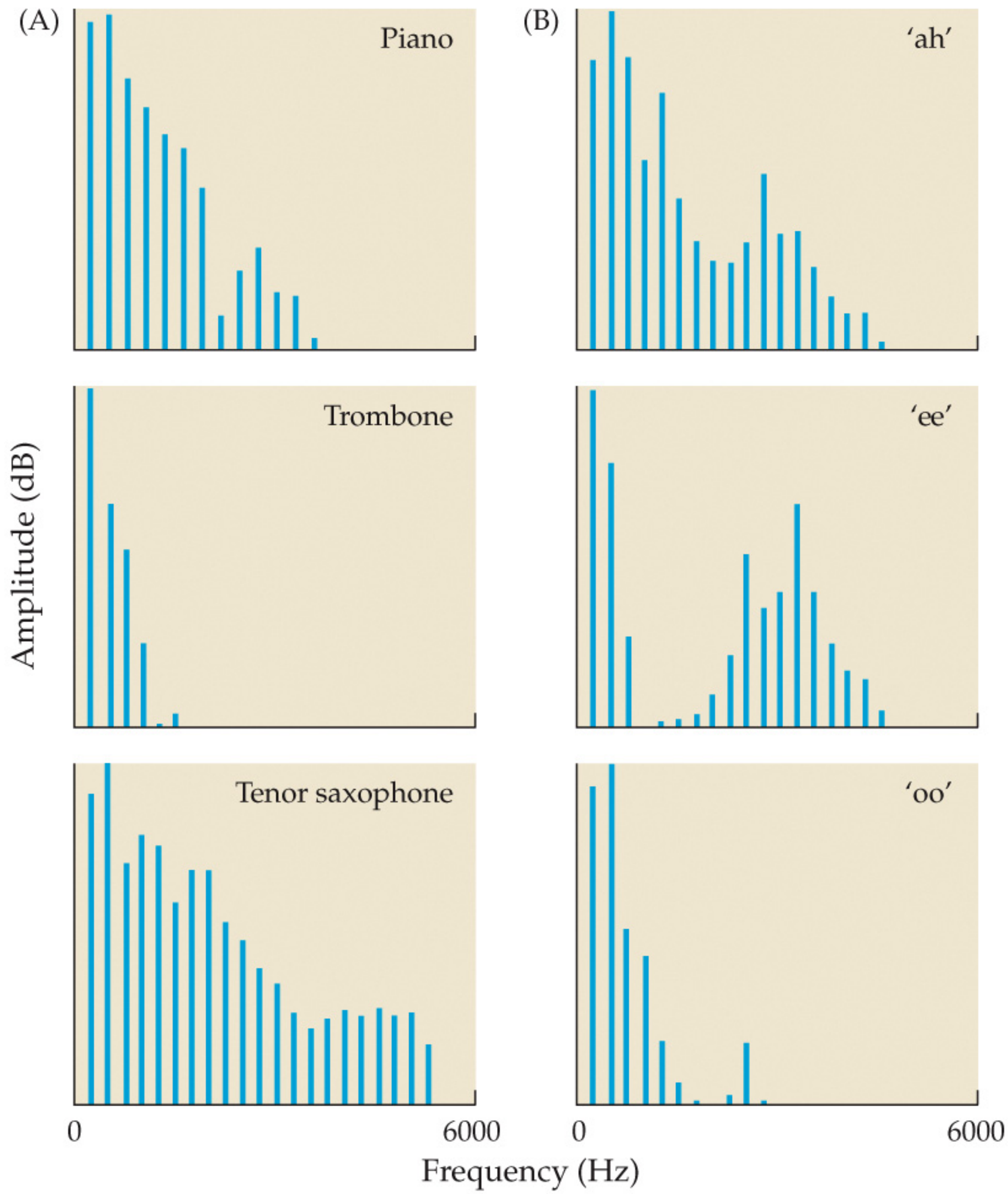
Complex Sounds

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

- conveyed by harmonics and other frequencies
- Perception of timbre depends on context in which sound is heard

Timbre demo: https://oup-arc.com/access/content/sensation-and-perception-5e-student-resources/sensation-and-perception-5e-activity-10-3?previousFilter=tag_chapter-10

Figure 10.20 Timbre



SENSATION & PERCEPTION 5e, Figure 10.20

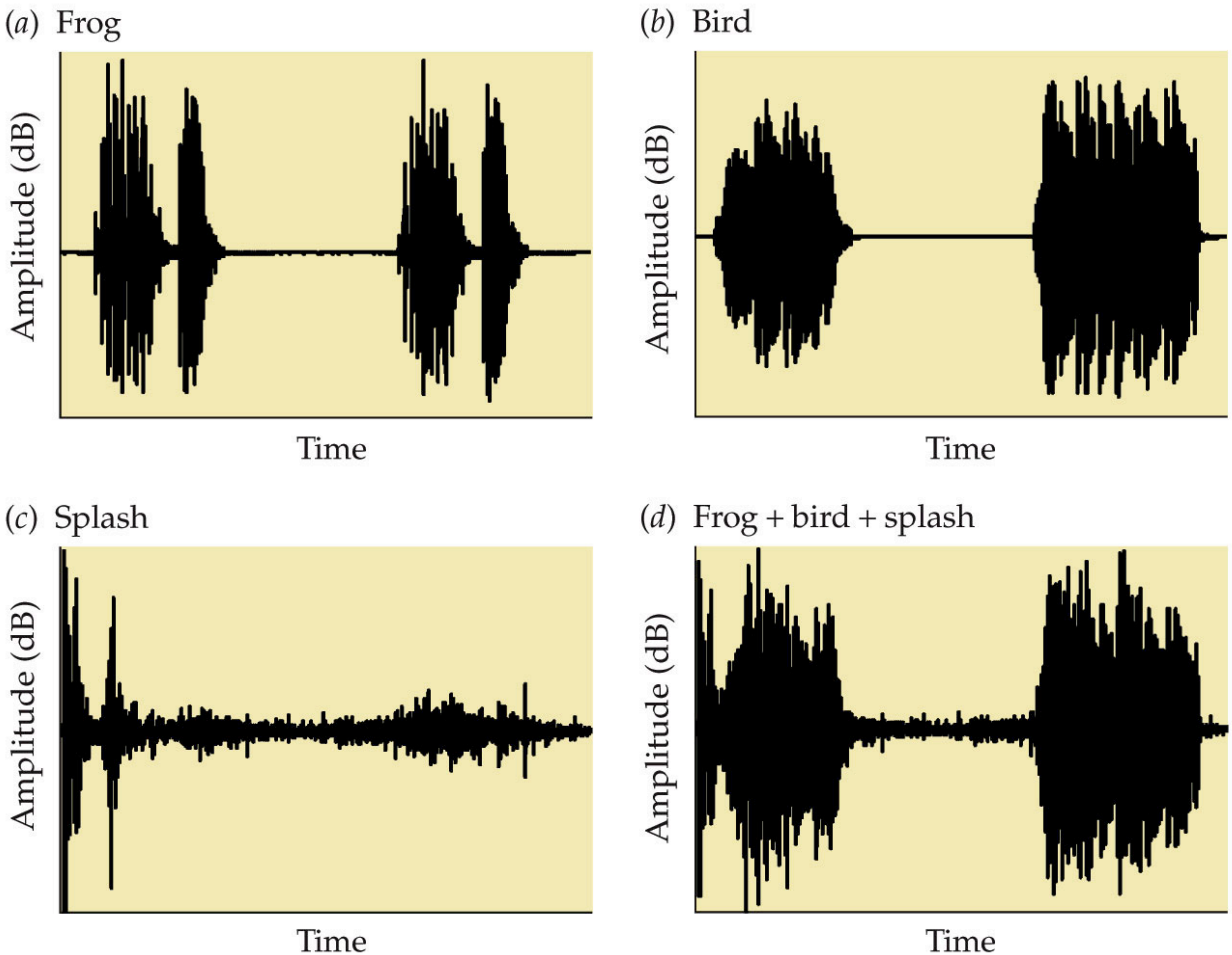
Auditory Scene Analysis

What happens in natural situations?

- Acoustic environment can be a busy place with multiple sound sources
- How does the auditory system sort out these sources?

- **Source segregation** - processing an auditory scene consisting of multiple sound sources into its separate sources

Waveforms from all sounds are summed into a single waveform arriving at the ears



Cocktail party effect

- We can “select out” and attend to one conversation even when many are present simultaneously

- first documented by Colin Cherry, 1953

Cocktail party effect

Cherry's findings:

- Same voice speaking, Presented to Both ears ⇒ *Very Difficult*
- Same voice speaking, Separate ears ⇒ *Easy*

Cocktail party effect

However, subjects:

- couldn’t identify a single phrase from non-attended ear
- couldn’t say for sure if it was English
- didn’t notice a change to German
- didn’t notice speech being played backward

- *Did notice*: change from male to female speaker

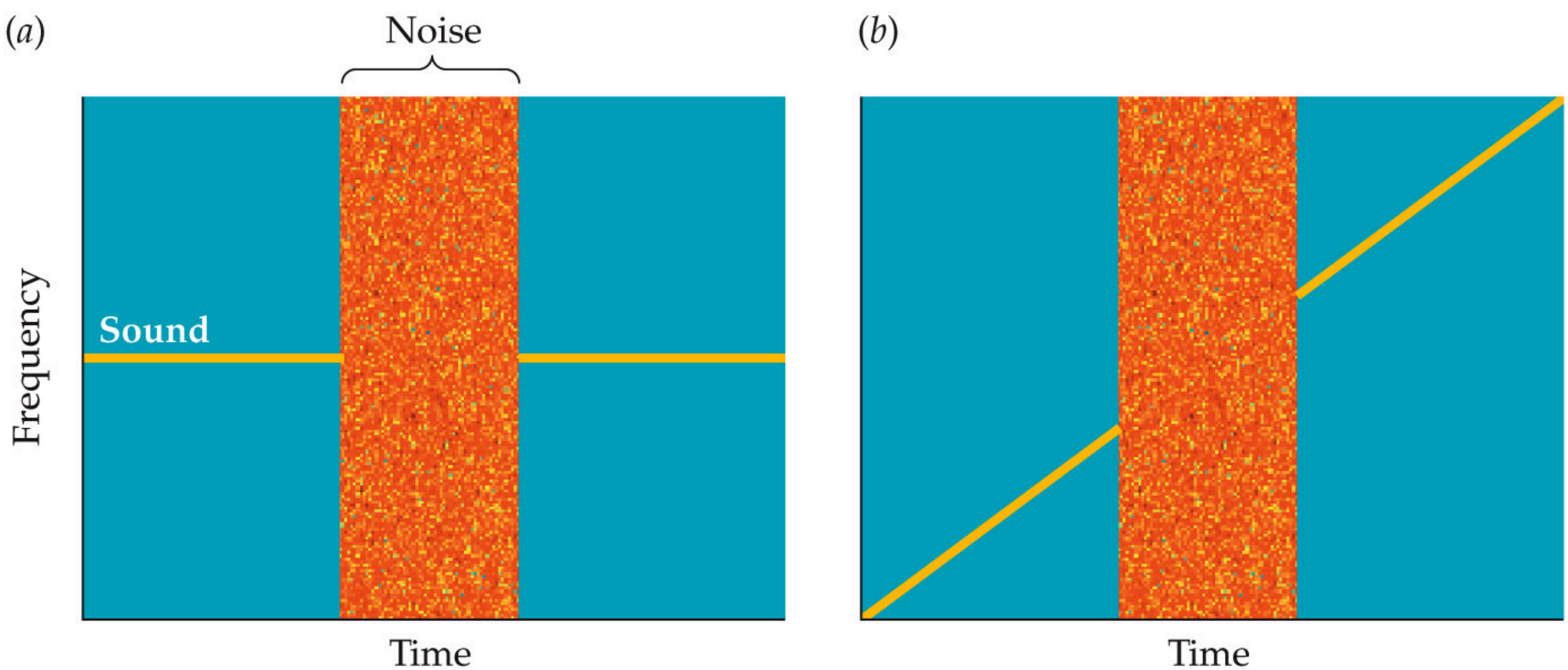
Cocktail party effect

- Suggests we can easily use spatial, timing, and spectral cues to separate sound streams, but cannot attend to multiple sound streams at the same time!

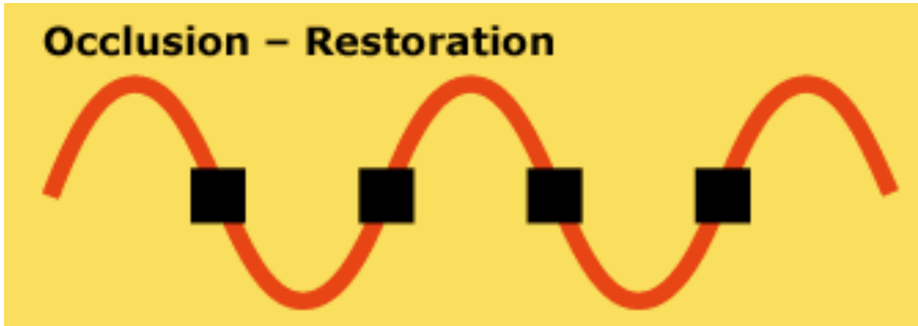
Continuity and Restoration Effects

How do we know that listeners hear sounds as continuous?

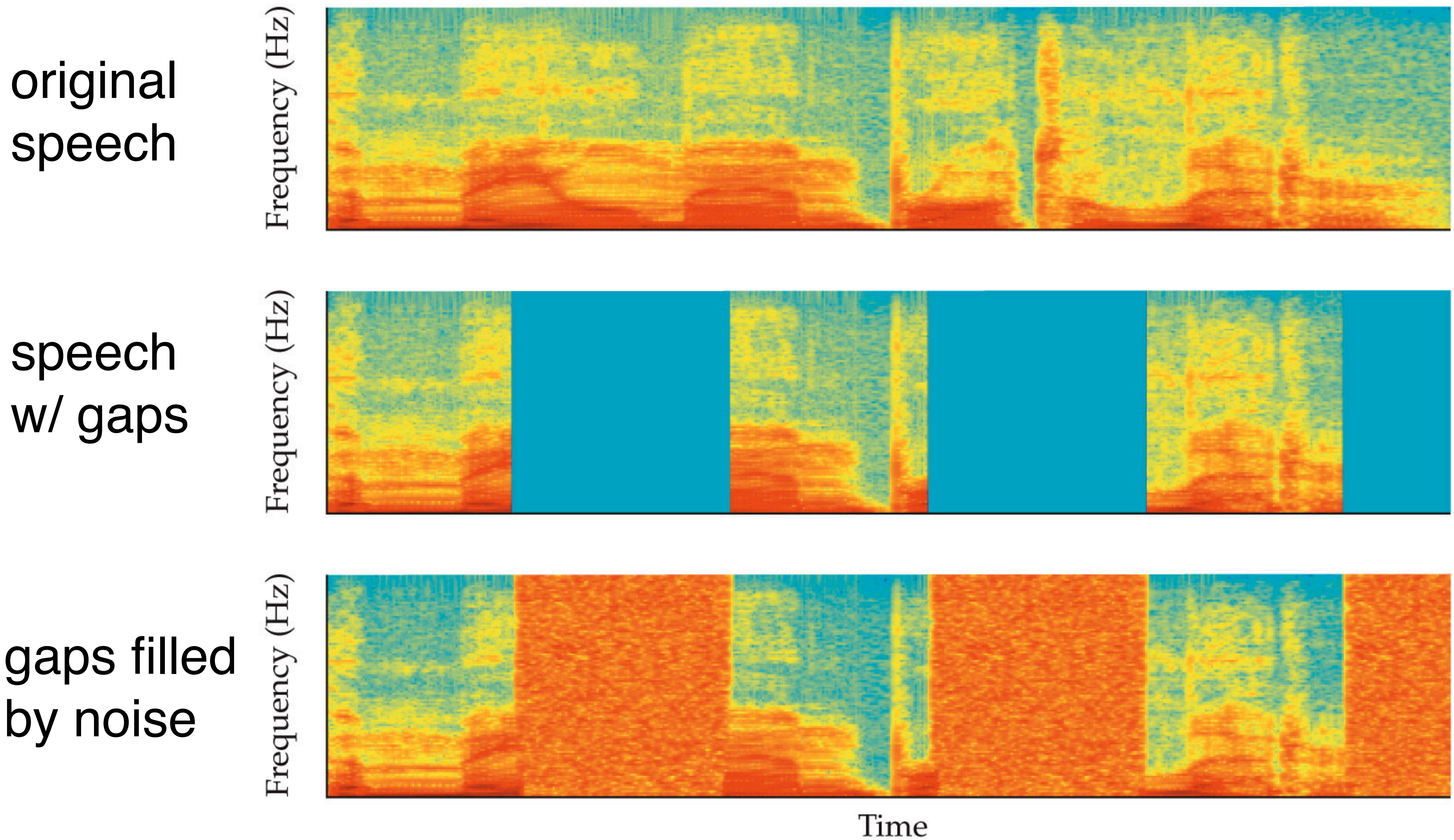
- Principle of *good continuation*: in spite of interruptions, one can still “hear” a sound
- Experiments (e.g., Kluender and Jenison, 1992) suggest that missing sounds are restored and encoded in the brain as if they were actually present!



Continuity Effects



Also true for speech: Adding noise can improve comprehension



Brain automatically fills in sound that is missing due to noise

gap filled by noise (cough)

speech with a gap

Q: Can you tell which phoneme is missing?

Continuity and Restoration Effects in Music

Beat-box tutorial:

http://www.youtube.com/watch?v=8D7hCqGm0X0

Yanny vs. Laurel

https://www.youtube.com/watch?time_continue=11&v=7X_WvGAhMIQ

Summary

- critical bandwidth
- age-related hearing loss
- cochlear implants

- Interaural timing differences (ITD)
- Interaural level differences (ILD)
- MSO, LSO
- cone of confusion
- head-related transfer function (HRTF)
- harmonics
- missing fundamental
- timbre
- auditory scene analysis
- cocktail party effect
- continuity and restoration effects