10

Hearing in the Environment

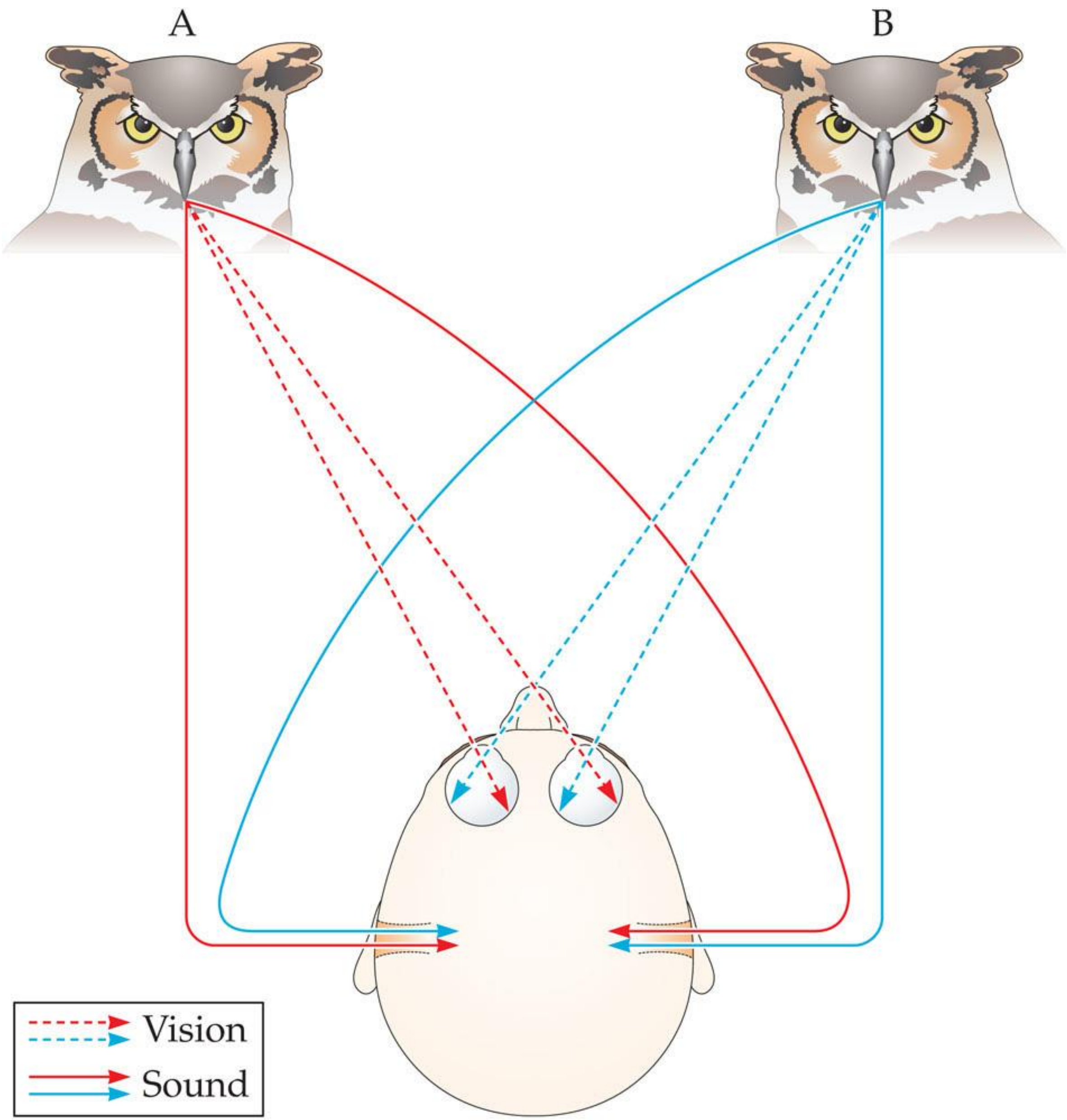
- Sound Localization
- Complex Sounds
- Auditory Scene Analysis
- Continuity and Restoration Effects
- Auditory Attention

Sound Localization

How do you locate a sound?

- If an owl was hooting in the woods at night, how would you know where it was?
- Similar dilemma to determining how far an object is
- Two ears: Critical for determining auditory locations

Figure 10.1 The position of the owl is easily encoded by the visual system because the owl's image falls on different parts of the retina



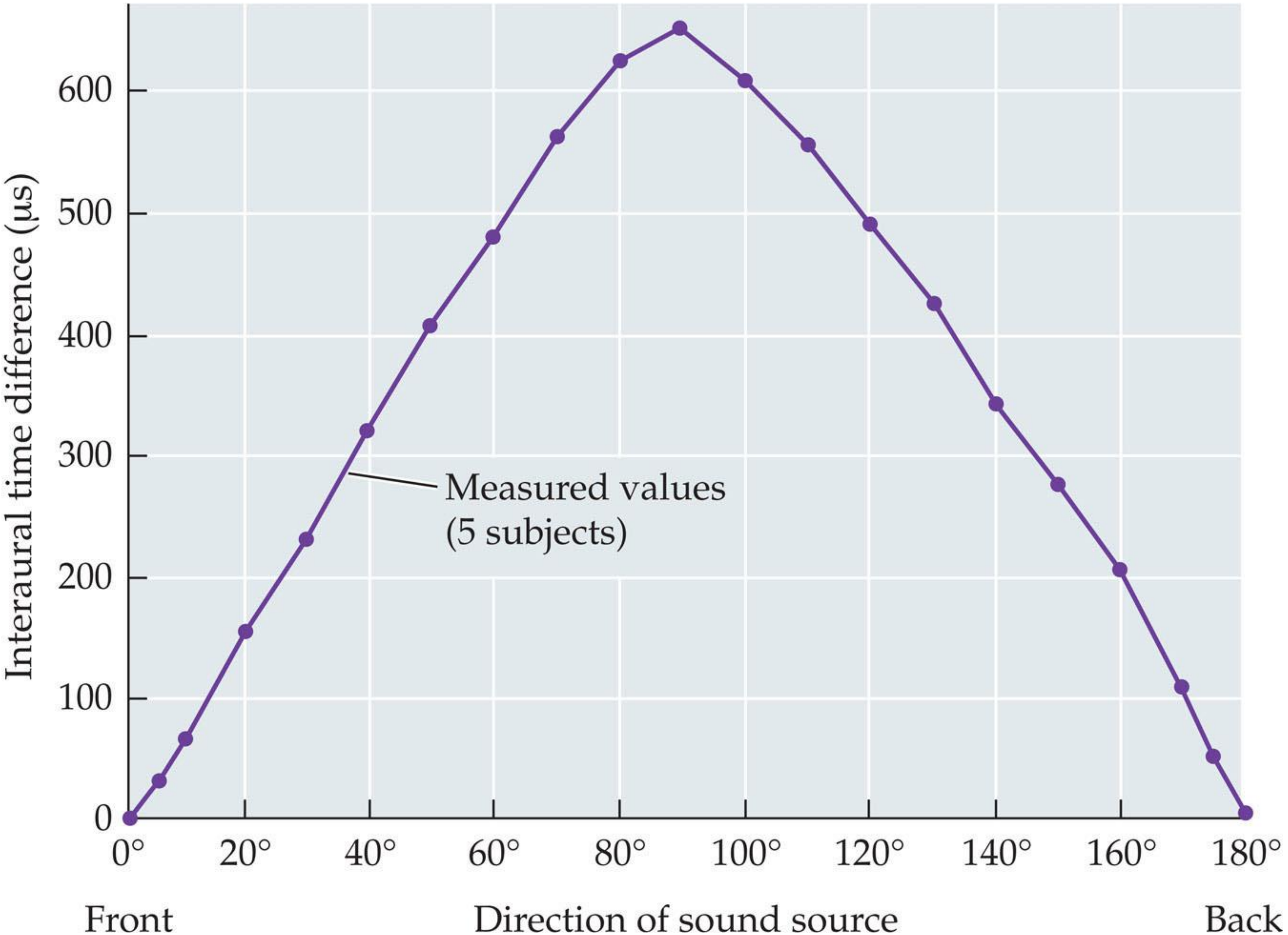
SENSATION & PERCEPTION 4e, Figure 10.1

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

Azimuth: The angle of a sound source on the horizon relative to a point in the center of the head between the ears.

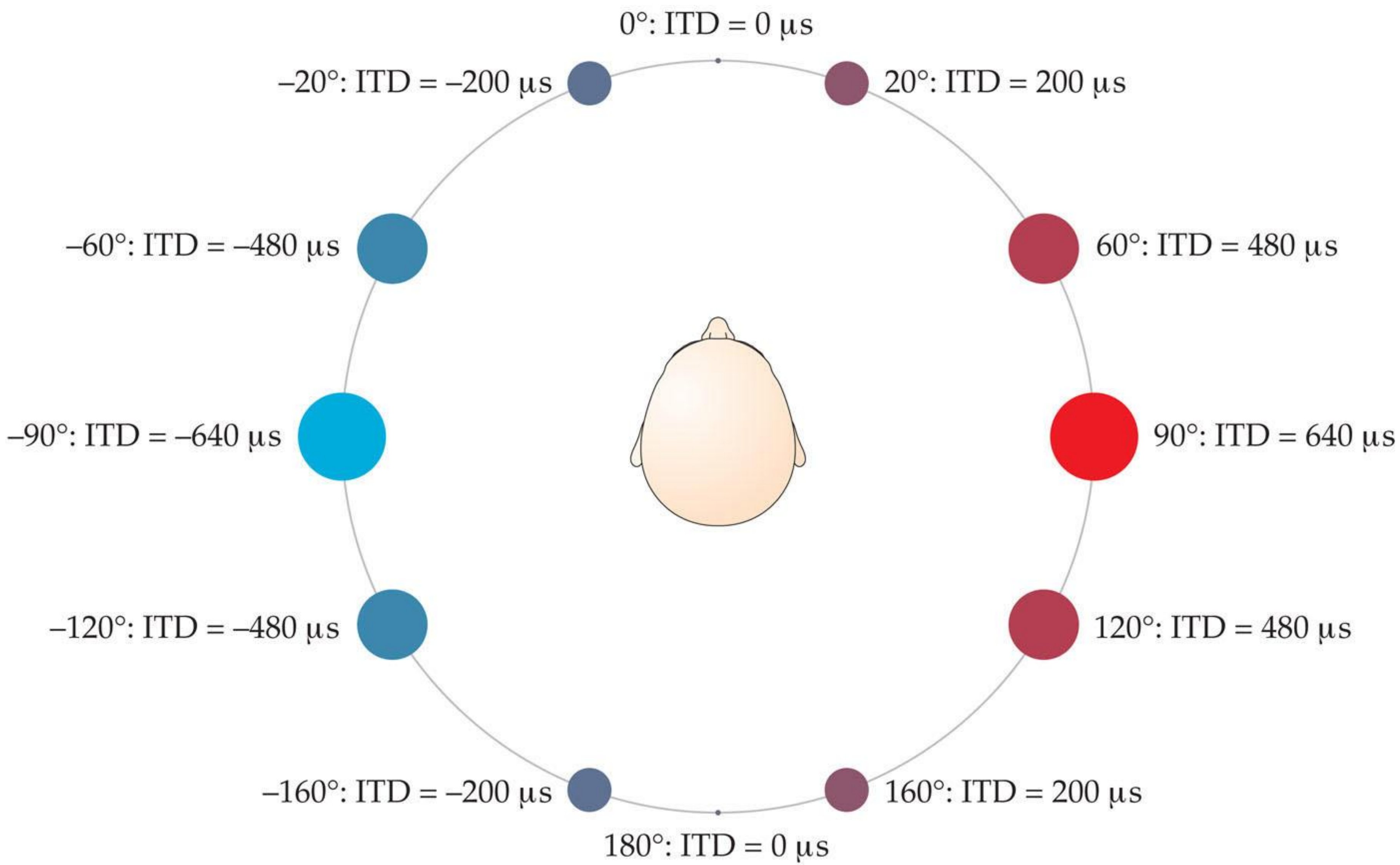
- Measured in degrees, with 0 degrees being straight ahead
- Angle increases clockwise, with 180 degrees being directly behind

Figure 10.3 Interaural time differences for sound sources varying in azimuth



SENSATION & PERCEPTION 4e, Figure 10.3

Figure 10.4 Interaural time differences for different positions around the head



***SENSATION & PERCEPTION 4e*, Figure 10.4**

Physiology of ITD

- Medial superior olive (MSO): A relay station in the brain stem where inputs from both ears contribute to detection of ITDs.
- ITD detectors form connections from inputs coming from two ears during the first few months of life.

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

- For frequencies above 1000 Hz, the head blocks some of the energy reaching the opposite ear.
- ILD is largest at 90 degrees and –90 degrees; nonexistent for 0 degrees and 180 degrees.
- ILD generally correlates with angle of sound source, but correlation is not quite as great as it is with ITDs.

Figure 10.2 The two ears receive slightly different inputs when the sound source is located to one side or the other

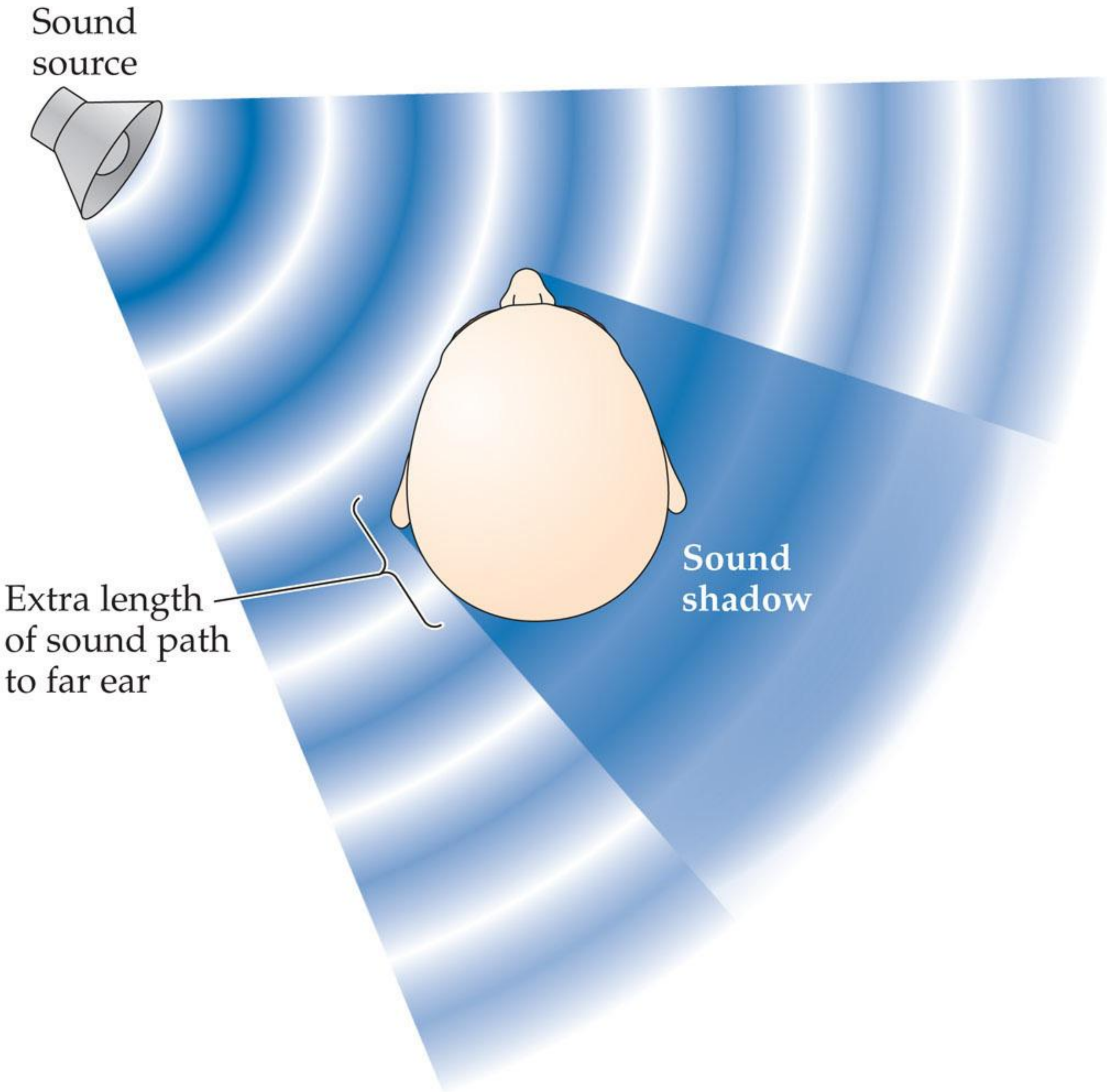
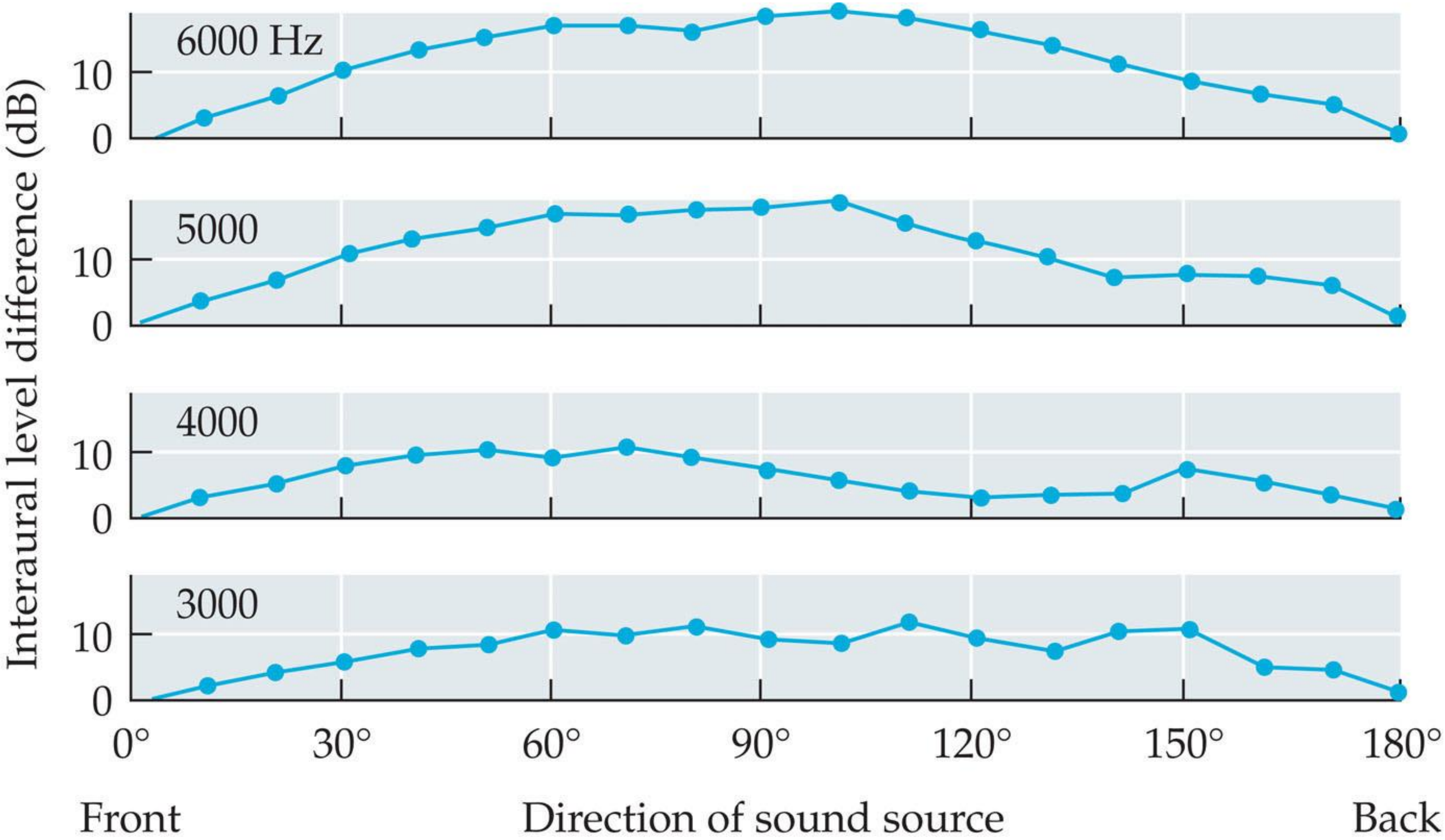
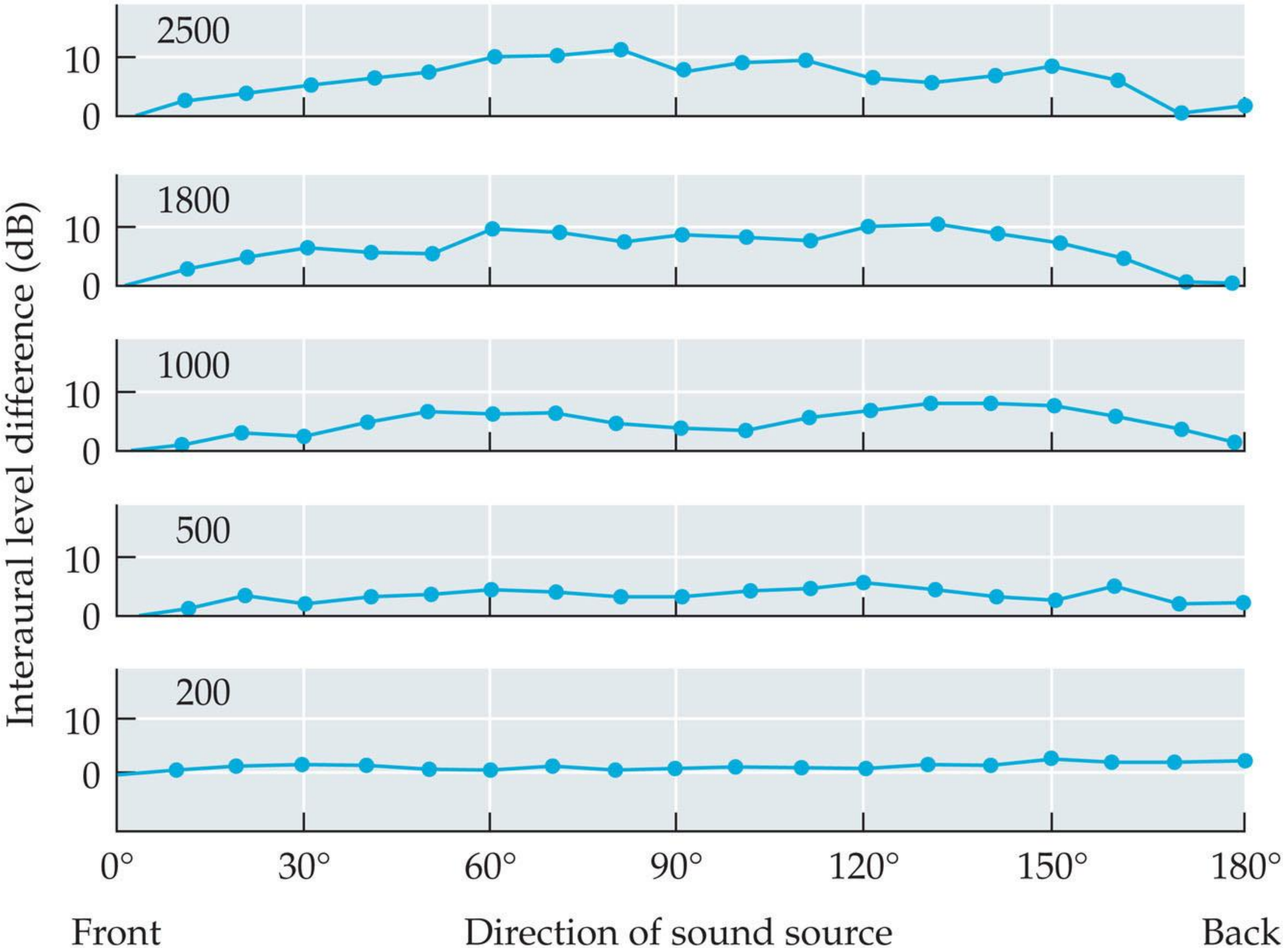


Figure 10.6 Interaural level (intensity) differences (ILDs) for tones of different frequencies presented at different positions around the head (Part 2)



SENSATION & PERCEPTION 4e, Figure 10.6 (Part 2)

Figure 10.6 Interaural level (intensity) differences (ILDs) for tones of different frequencies presented at different positions around the head (Part 1)

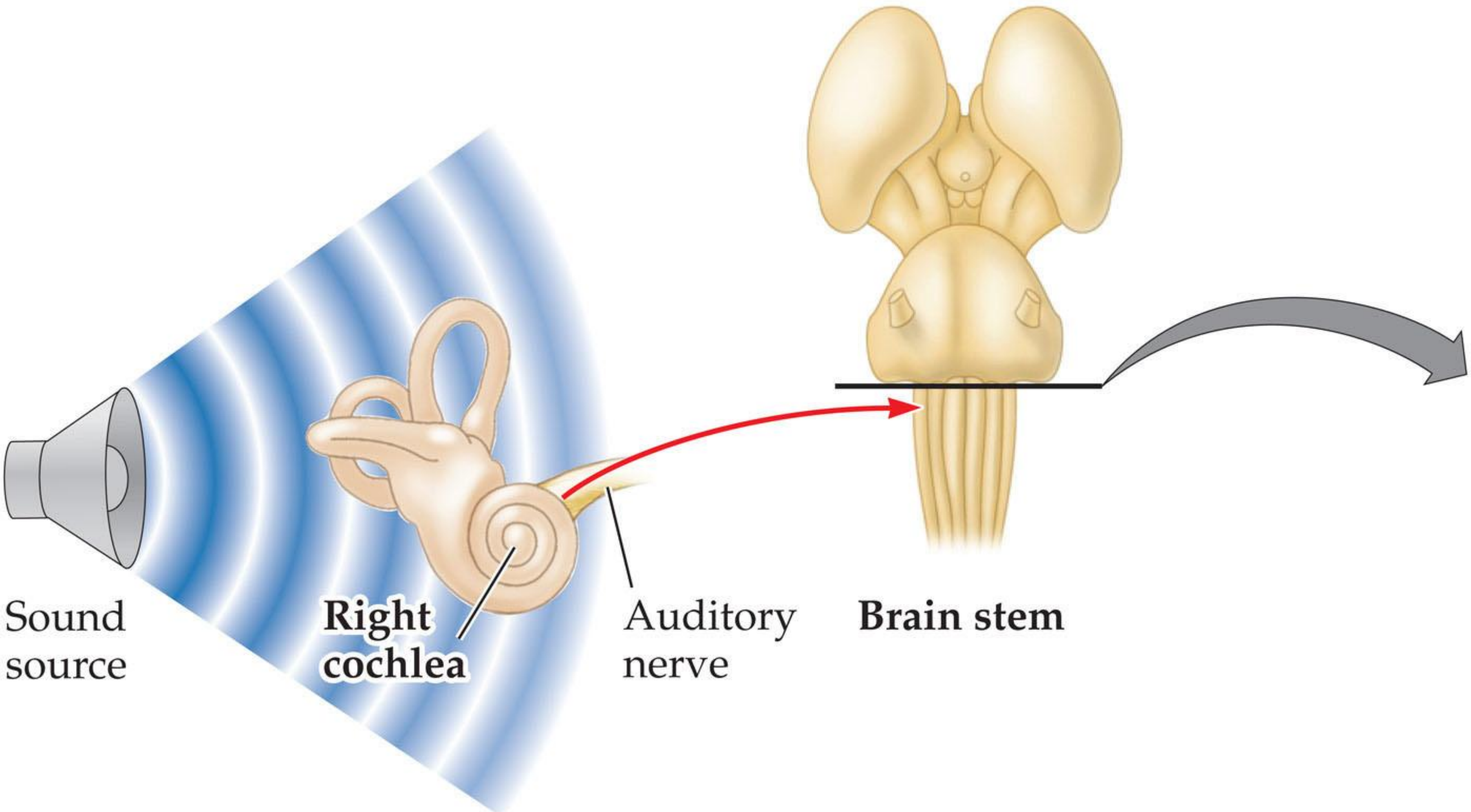


SENSATION & PERCEPTION 4e, Figure 10.6 (Part 1)

Physiology of ILDs

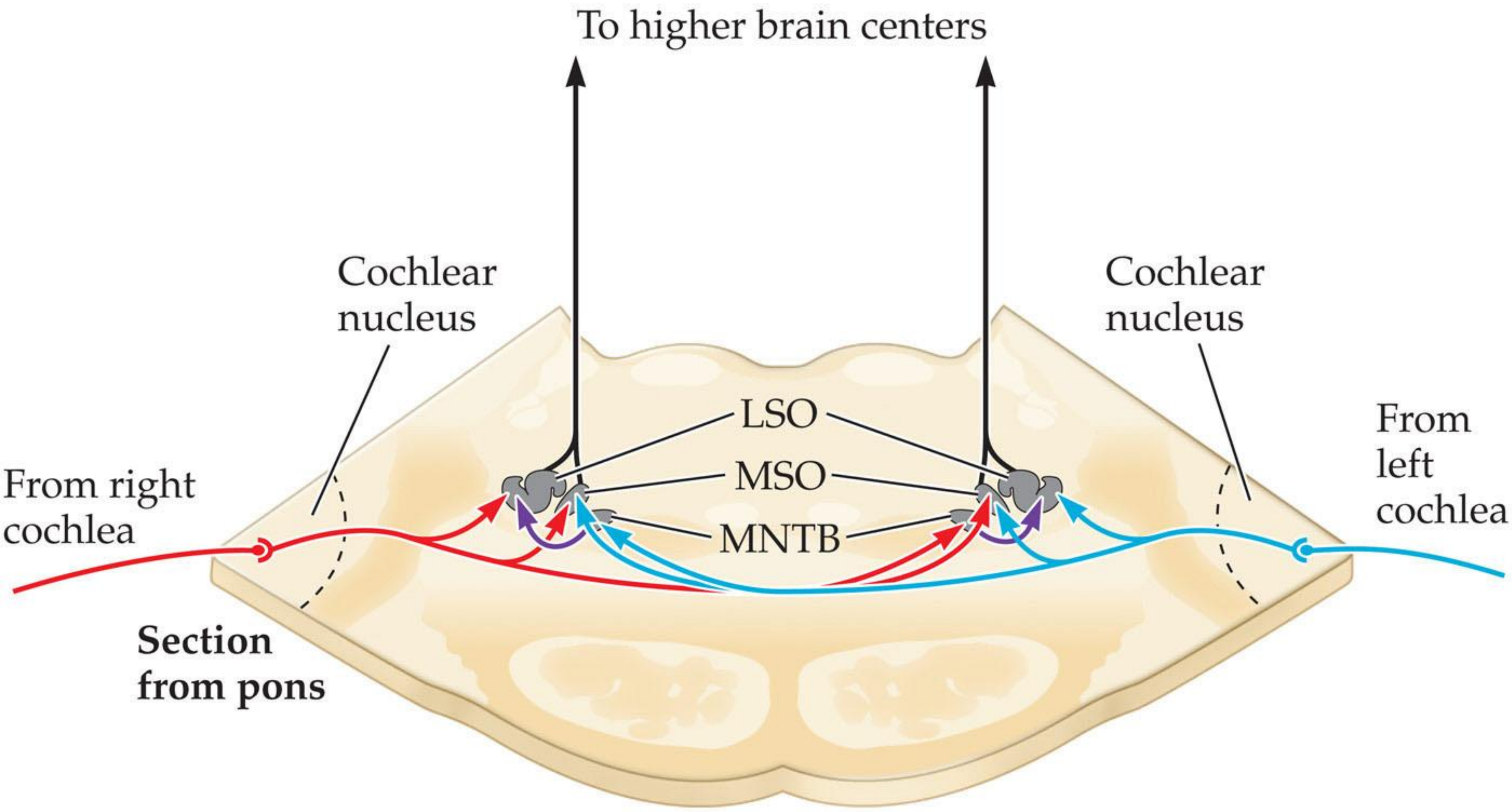
- Lateral superior olive (LSO): A relay station in the brain stem where inputs from both ears contribute to the detection of ILDs.
- Excitatory connections to LSO come from ipsilateral ear.
- Inhibitory connections to LSO come from contralateral ear.

Figure 10.5 After only a single synapse in the cochlear nucleus, information from each ear travels to the medial superior olive and lateral superior olive (Part 1)



SENSATION & PERCEPTION 4e, **Figure 10.5 (Part 1)**

Figure 10.5 After only a single synapse in the cochlear nucleus, information from each ear travels to the medial superior olive and lateral superior olive (Part 2)



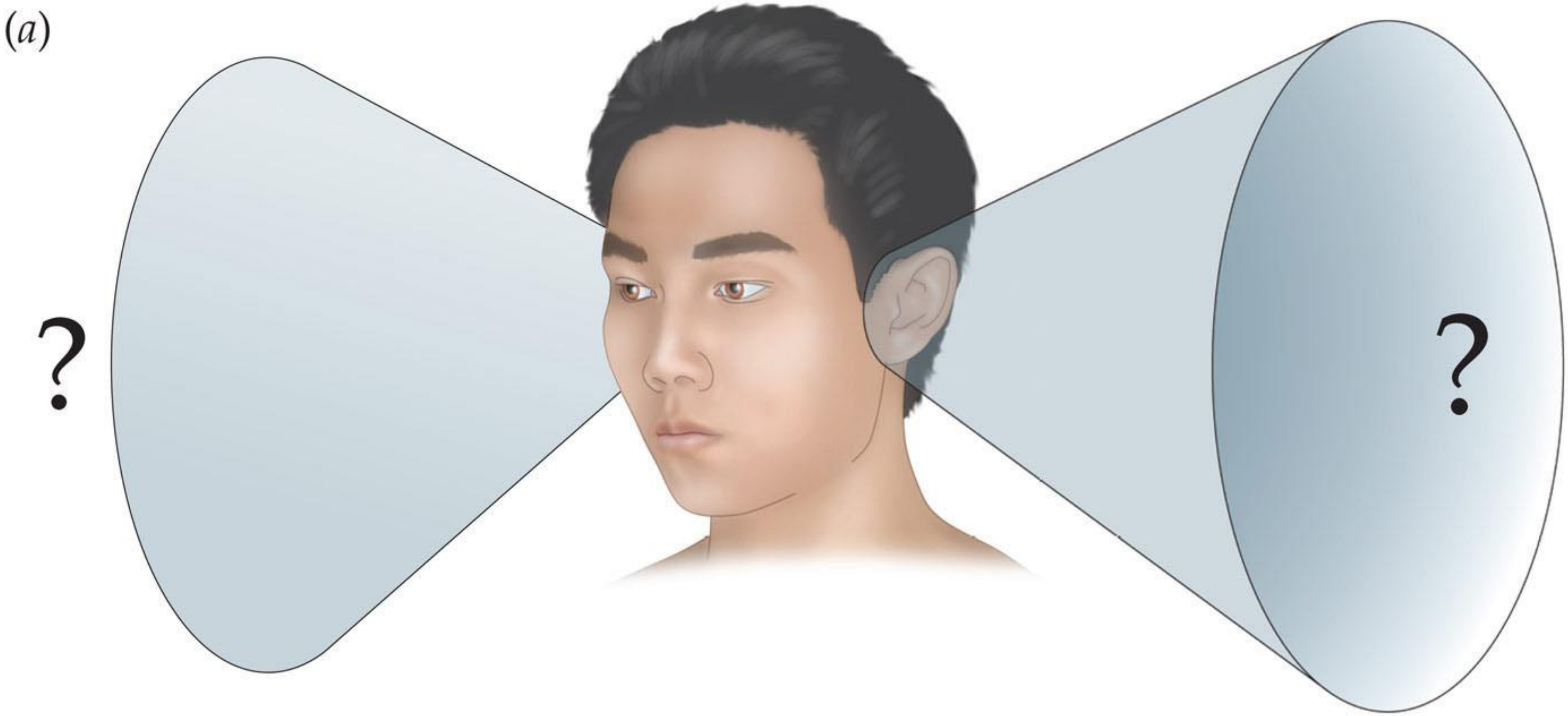
SENSATION & PERCEPTION 4e, **Figure 10.5 (Part 2)**

Sound Localization

Potential problem with using ITDs and ILDs for sound localization:

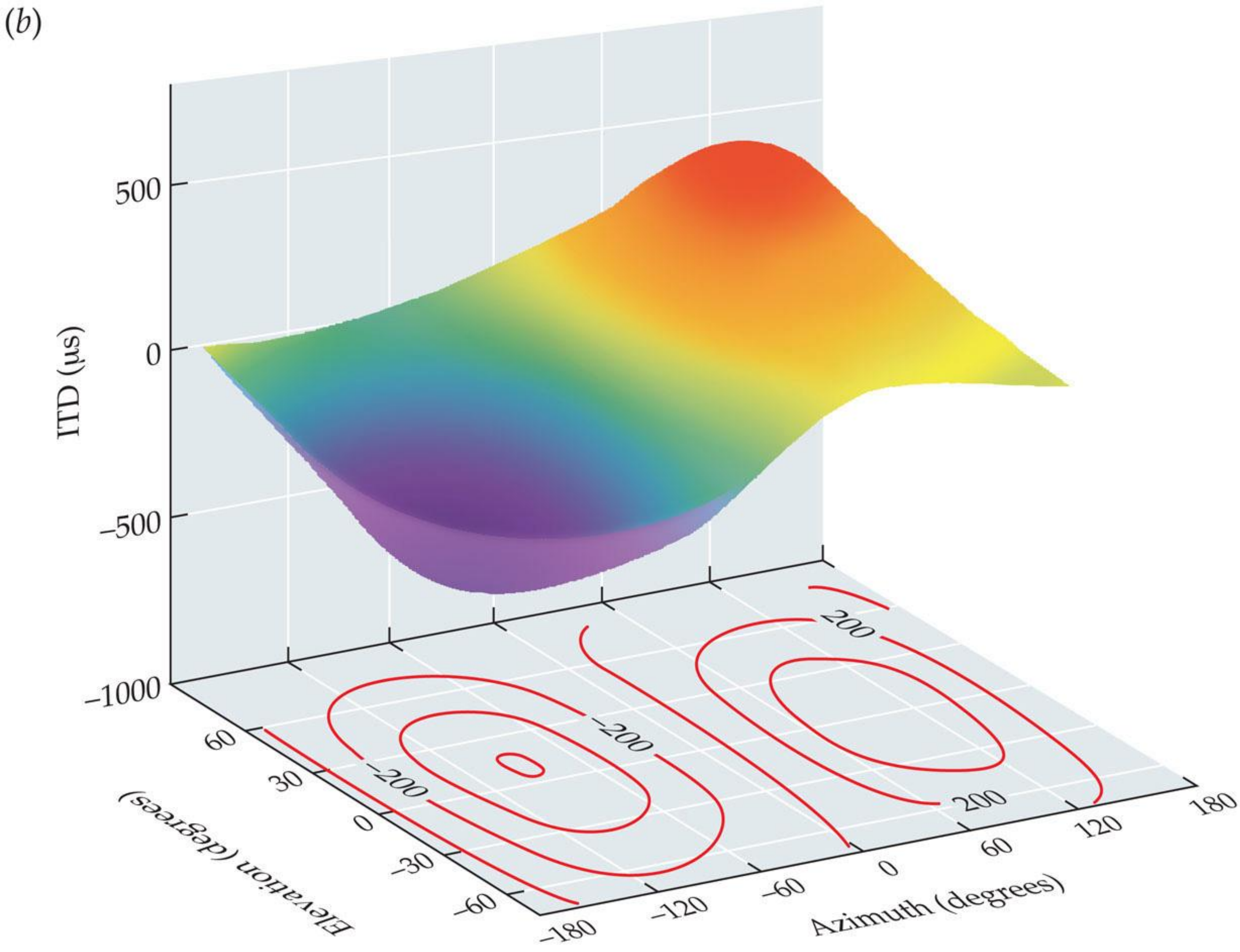
- Cone of confusion: A region of positions in space where all sounds produce the same ITDs and ILDs .

Figure 10.7 Elevation adds another dimension to sound localization (Part 1)



SENSATION & PERCEPTION 4e, Figure 10.7 (Part 1)

Figure 10.7 Elevation adds another dimension to sound localization (Part 2)

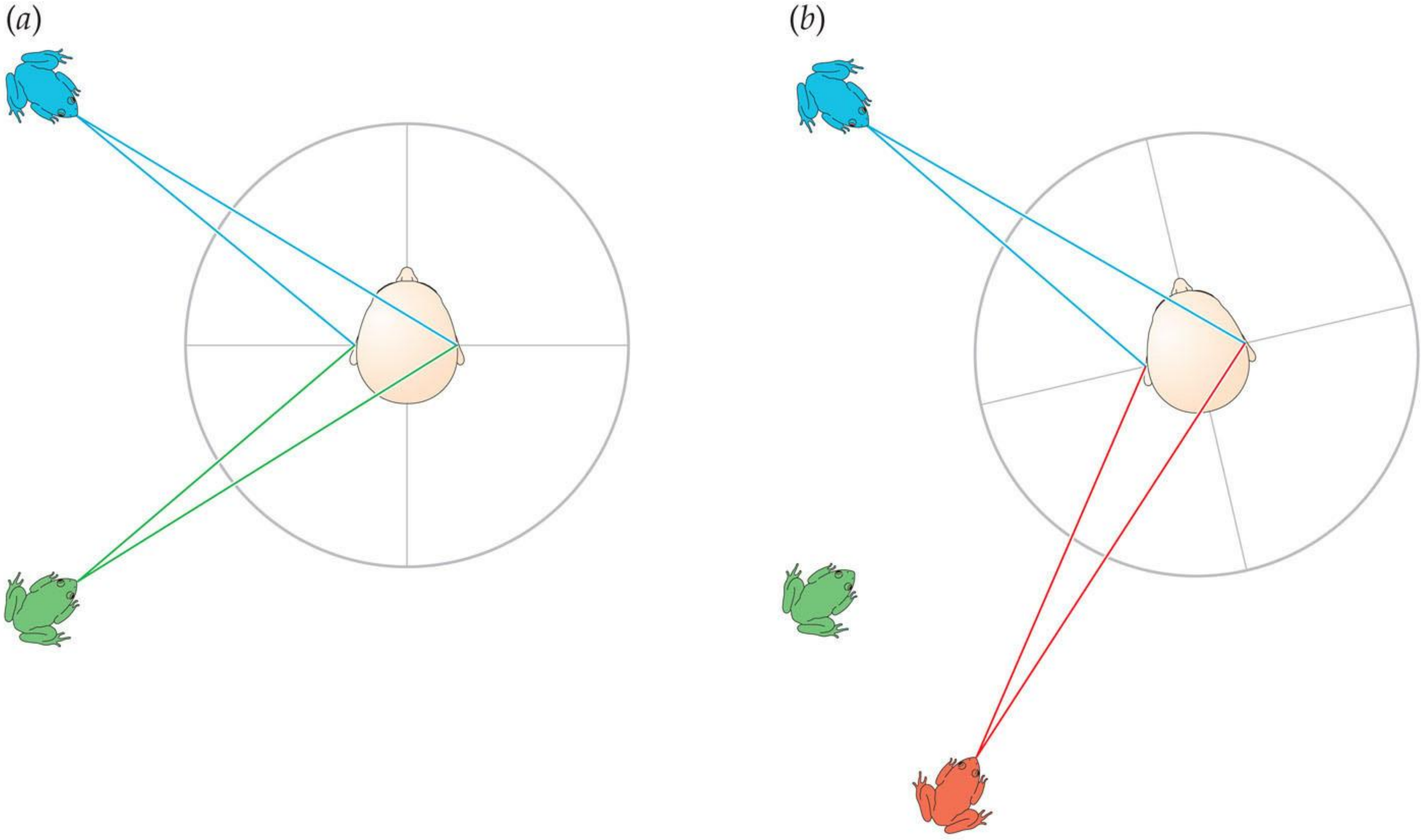


SENSATION & PERCEPTION 4e, Figure 10.7 (Part 2)

Overcoming the cone of confusion

- Turning the head can disambiguate ILD/ITD similarity.

Figure 10.8 Evaluating ITDs and ILDs from two different head positions helps in sound localization



SENSATION & PERCEPTION 4e, Figure 10.8

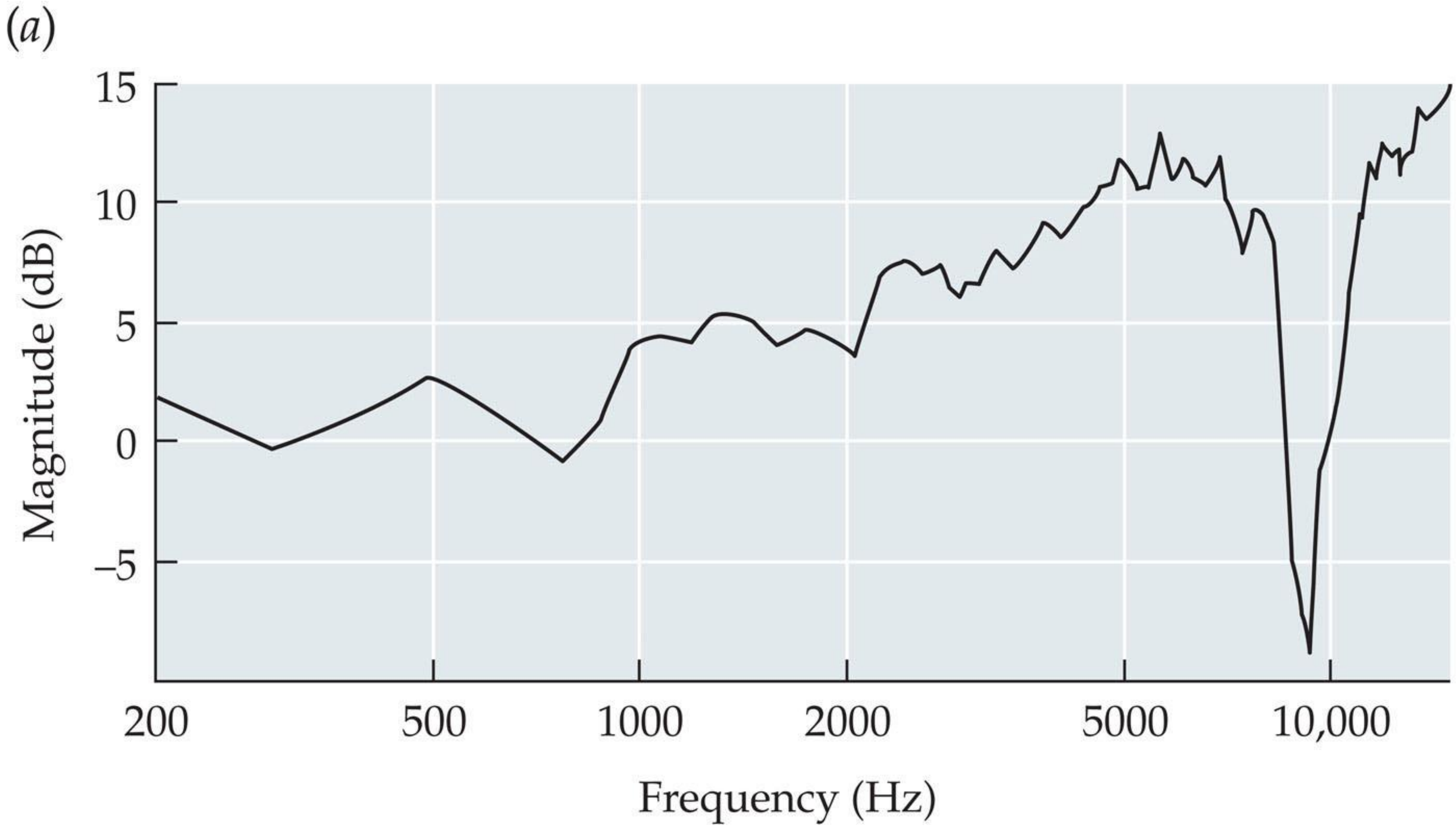
Sound Localization

Shape and form of pinnae help determine localization of sound.

- Directional transfer function (DTF): A measure that describes how the pinna, ear canal, head, and torso change the intensity of sounds with different frequencies that arrive at each ear from different locations in space (azimuth and elevation).
- Each person has their own DTF (based on their own body) and uses it to help locate sounds.

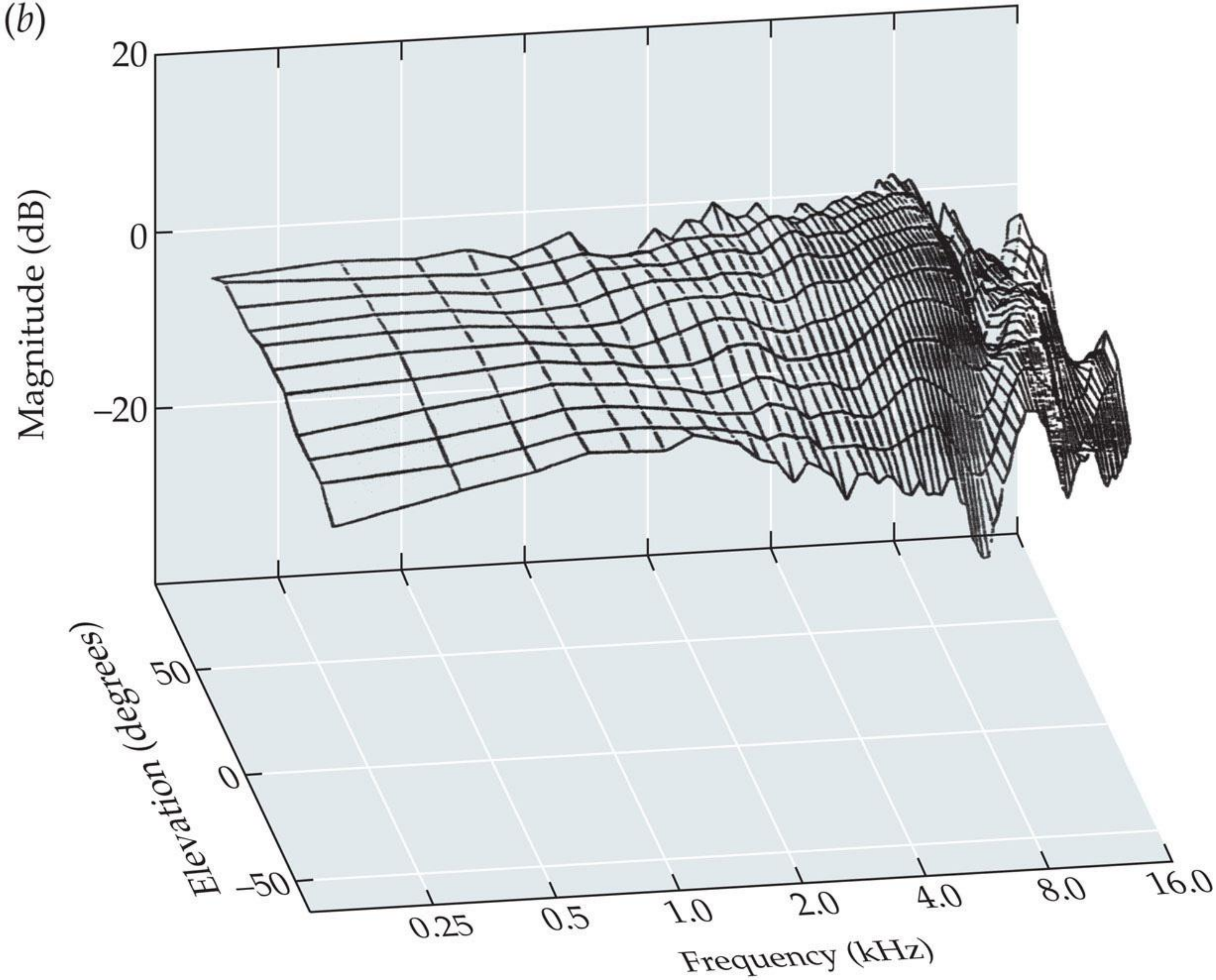
Figure 10.9 Pinna shapes vary quite a lot between people

Figure 10.10 Directional transfer functions (DTFs) (Part 1)



SENSATION & PERCEPTION 4e, **Figure 10.10 (Part 1)**

Figure 10.10 Directional transfer functions (DTFs) (Part 2)



SENSATION & PERCEPTION 4e, Figure 10.10 (Part 2)

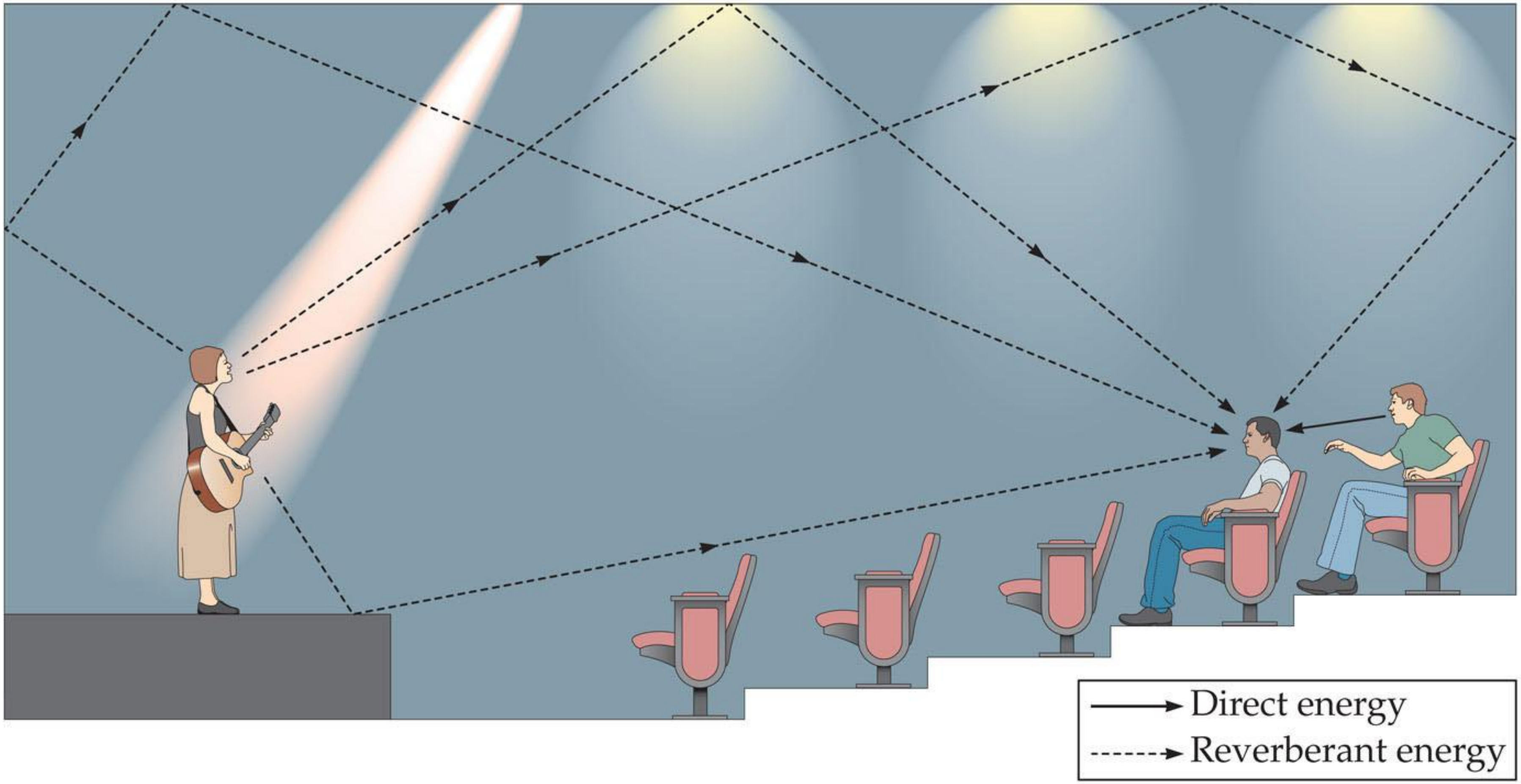
Auditory distance perception

- Simplest cue: **relative** intensity of sound
- **Inverse-square law:** Decrease in intensity is equal to the distance squared.
  - As distance from a source increases, intensity decreases faster.

Auditory distance perception (*continued*)

- Spectral composition of sounds: Higher frequencies decrease in energy more than lower frequencies do as sound waves travel from source to one ear.
- Relative amounts of direct versus reverberant energy

Figure 10.11 The relative amounts of direct and reverberant energy coming from the listener's neighbor and the singer provides the relative distances of the two sound sources

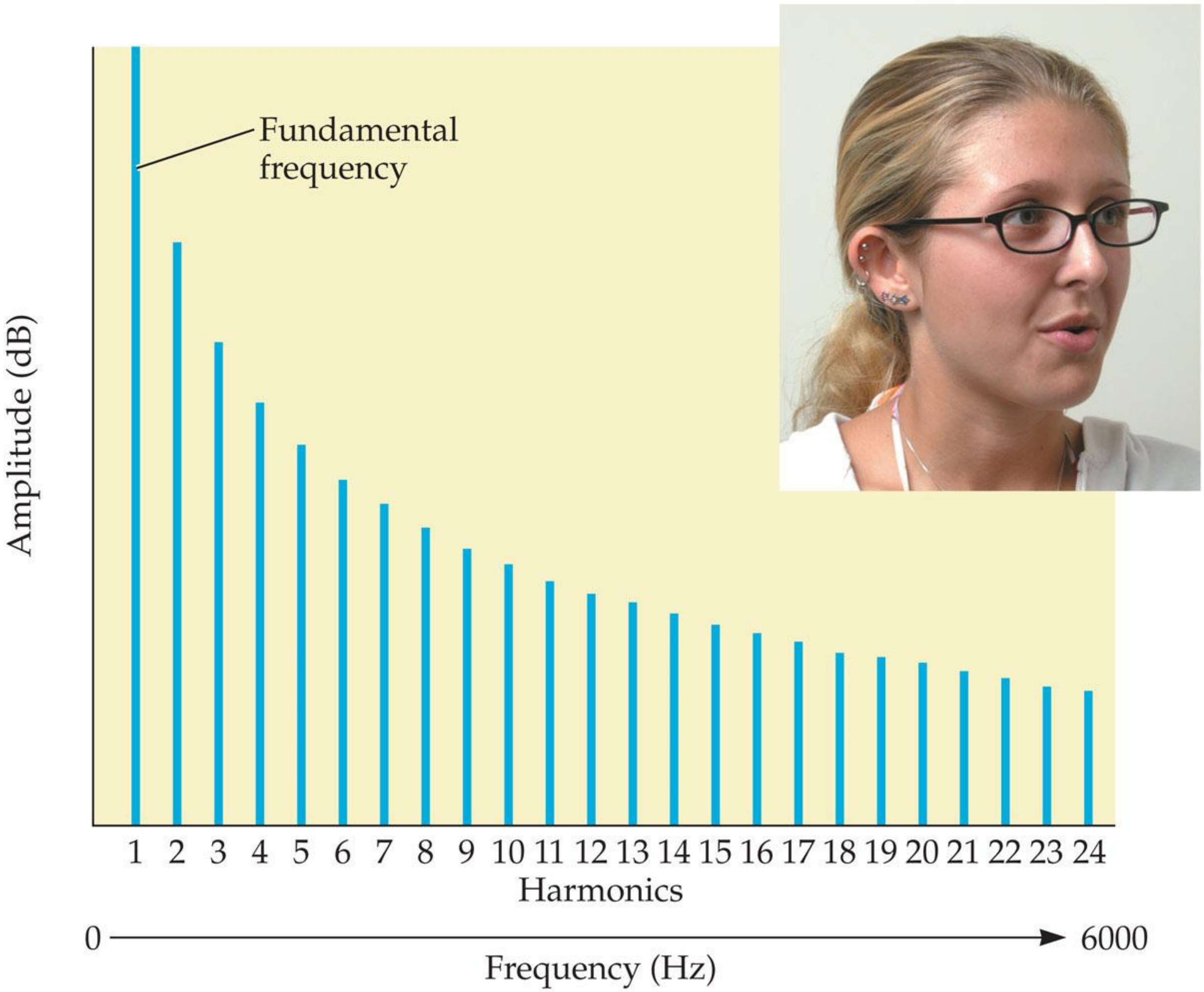


SENSATION & PERCEPTION 4e, Figure 10.11

Harmonics

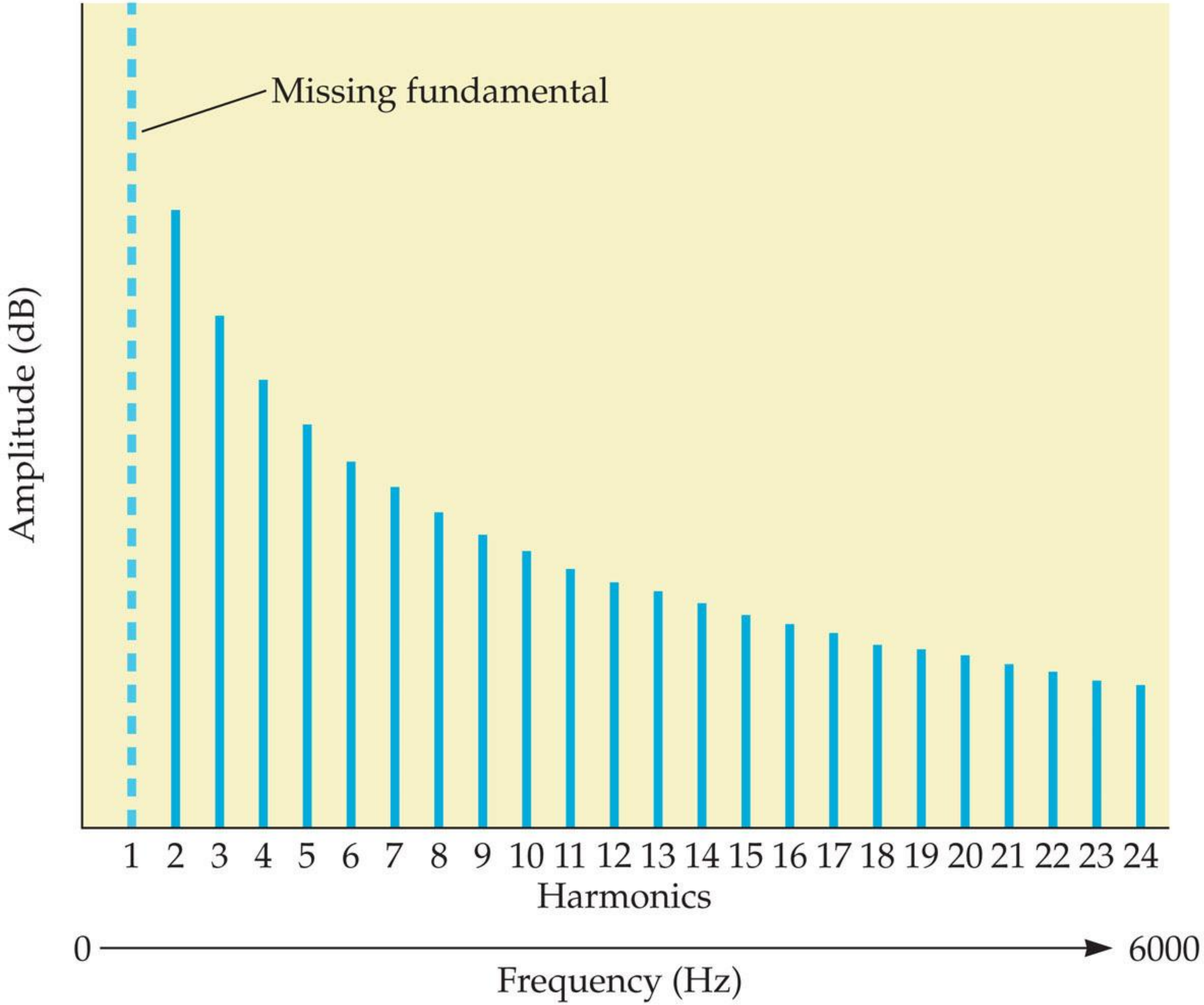
- **Fundamental frequency:** Lowest frequency of harmonic spectrum.
- Auditory system is acutely sensitive to natural relationships between harmonics.
- What happens when first harmonic is missing?
  - Missing-fundamental effect: The pitch listeners hear corresponds to the fundamental frequency, even if it is missing.

Figure 10.12 Many environmental sounds, including voices, are harmonic



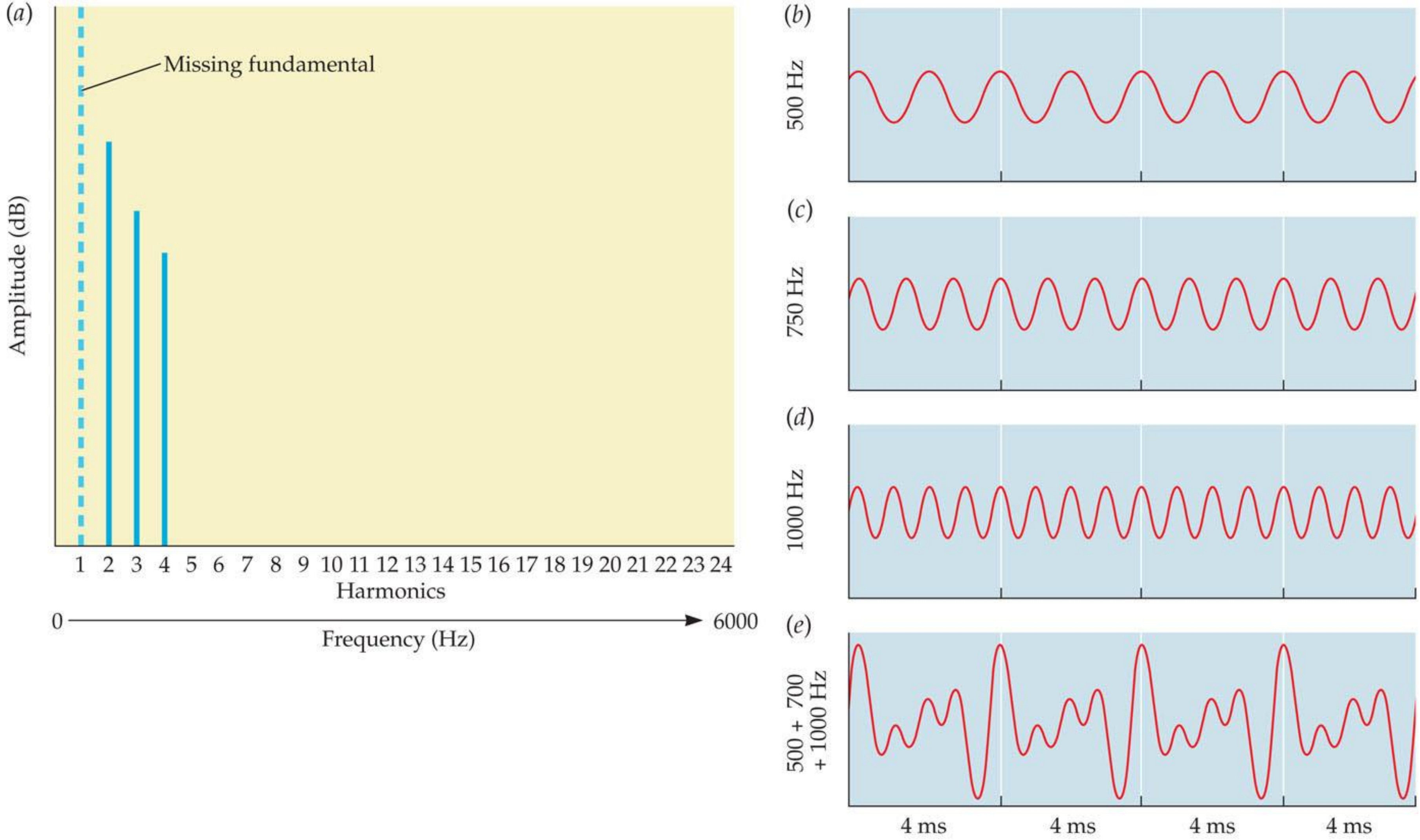
SENSATION & PERCEPTION 4e, Figure 10.12

Figure 10.13 If the fundamental of a harmonic sound is removed, listeners still hear the pitch of this "missing fundamental"



SENSATION & PERCEPTION 4e, Figure 10.13

Figure 10.14 The missing fundamental



SENSATION & PERCEPTION 4e, Figure 10.14

Complex Sounds

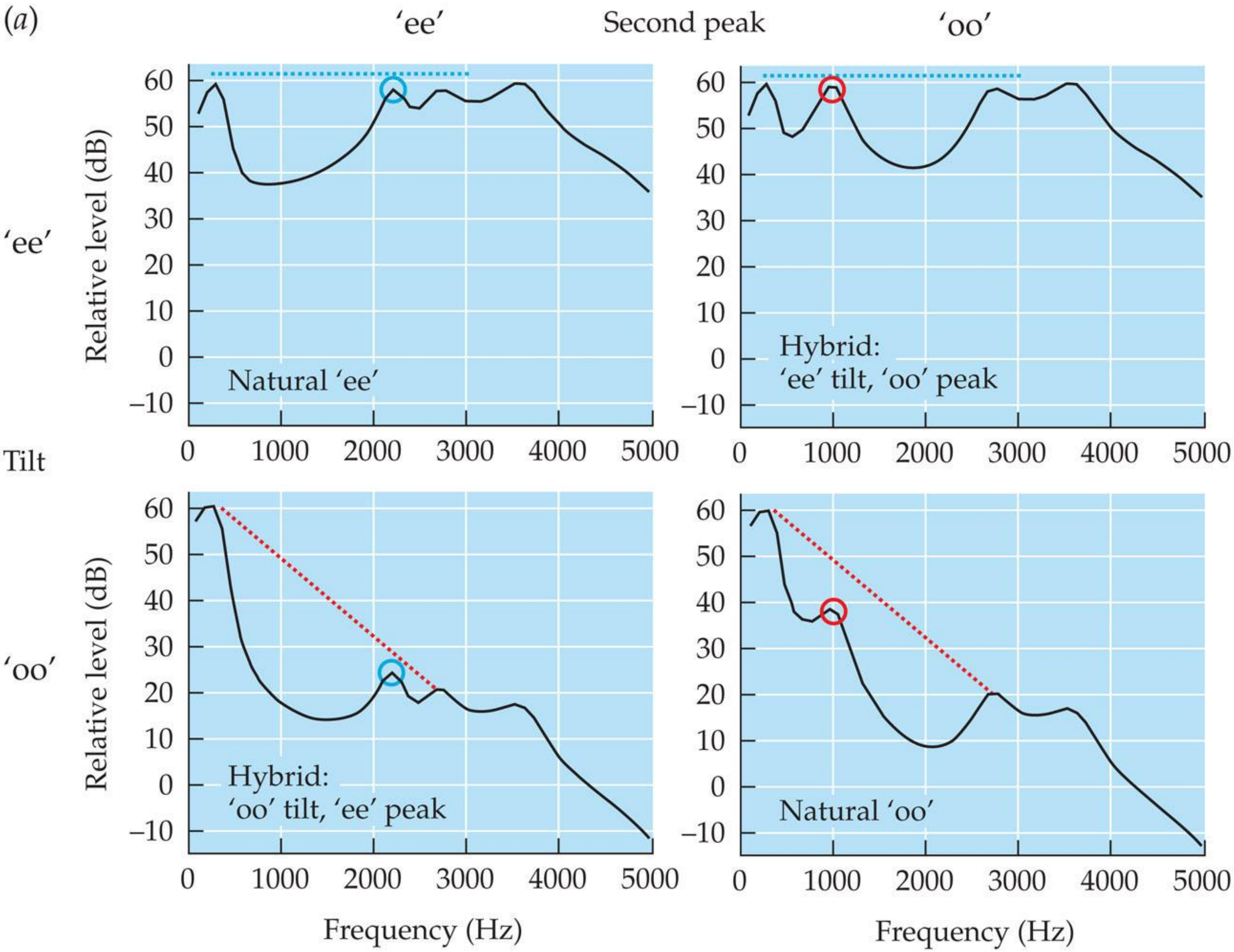
Timbre: Psychological sensation by which a listener can judge that two sounds with the same fundamental loudness and pitch are dissimilar.

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

Auditory “color” constancy

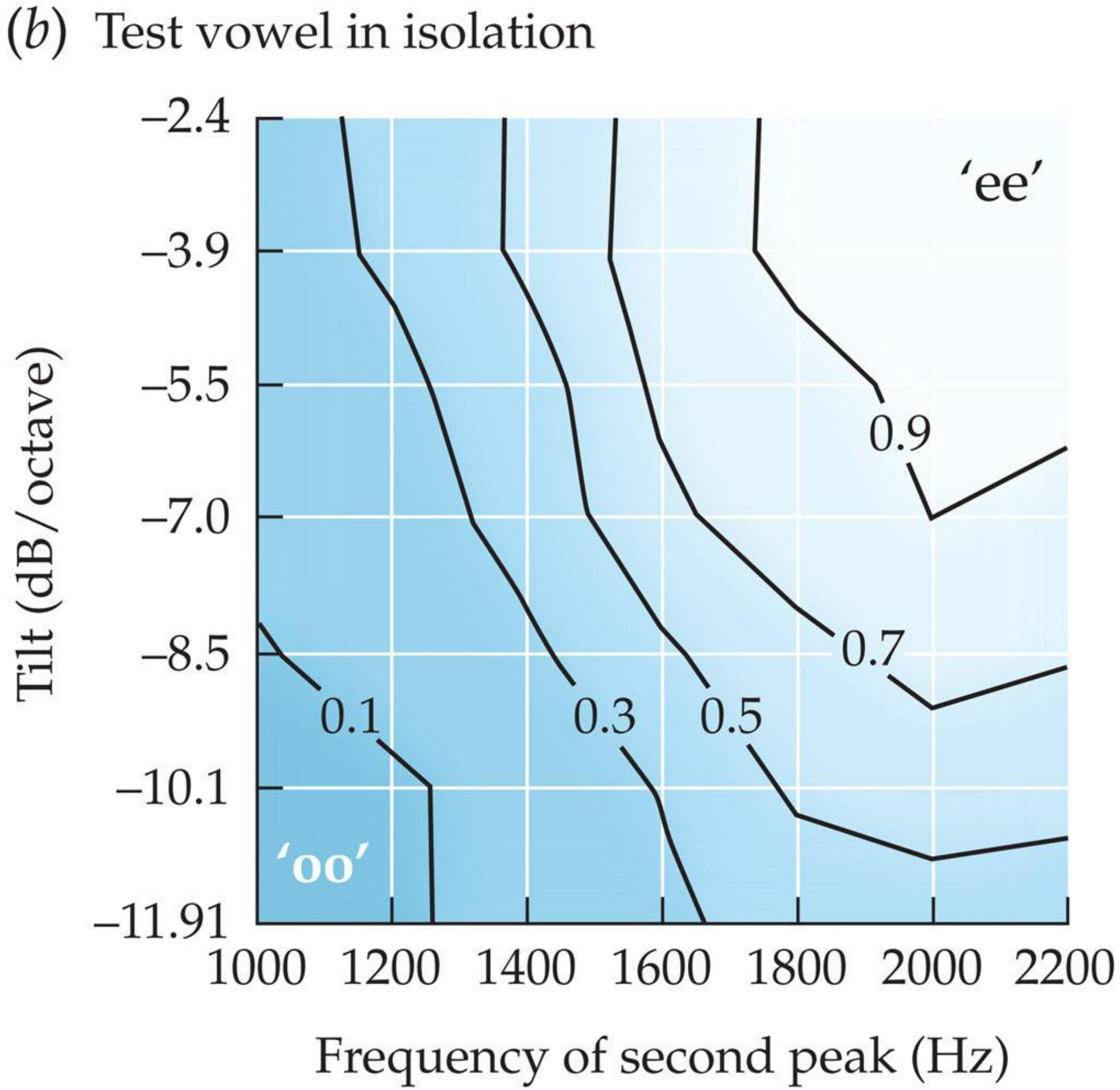
- Phonemes should sound the same regardless of the acoustic characteristics of the signal.
- Surfaces in the environment reflect and absorb energy at different frequencies.
- We use sound context to interpret phonemes.
- Kiefte and Kleunder (2008) experiment looked at tilt and frequency of vowel sounds.

Figure 10.16 Listeners use both spectral tilt and the frequencies of spectral peaks to identify vowels (Part 1)



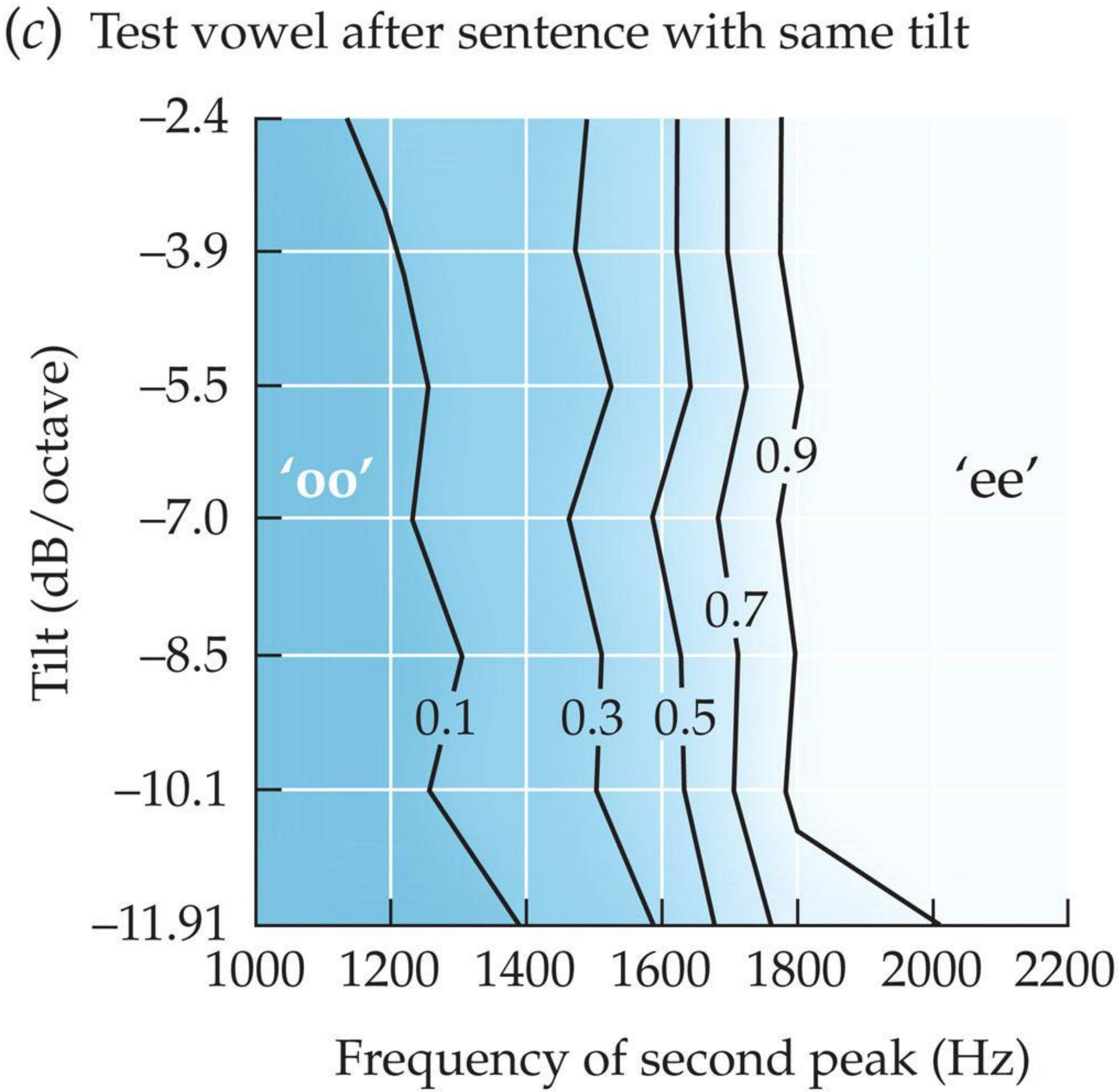
SENSATION & PERCEPTION 4e, Figure 10.16 (Part 1)

Figure 10.16 Listeners use both spectral tilt and the frequencies of spectral peaks to identify vowels (Part 2)



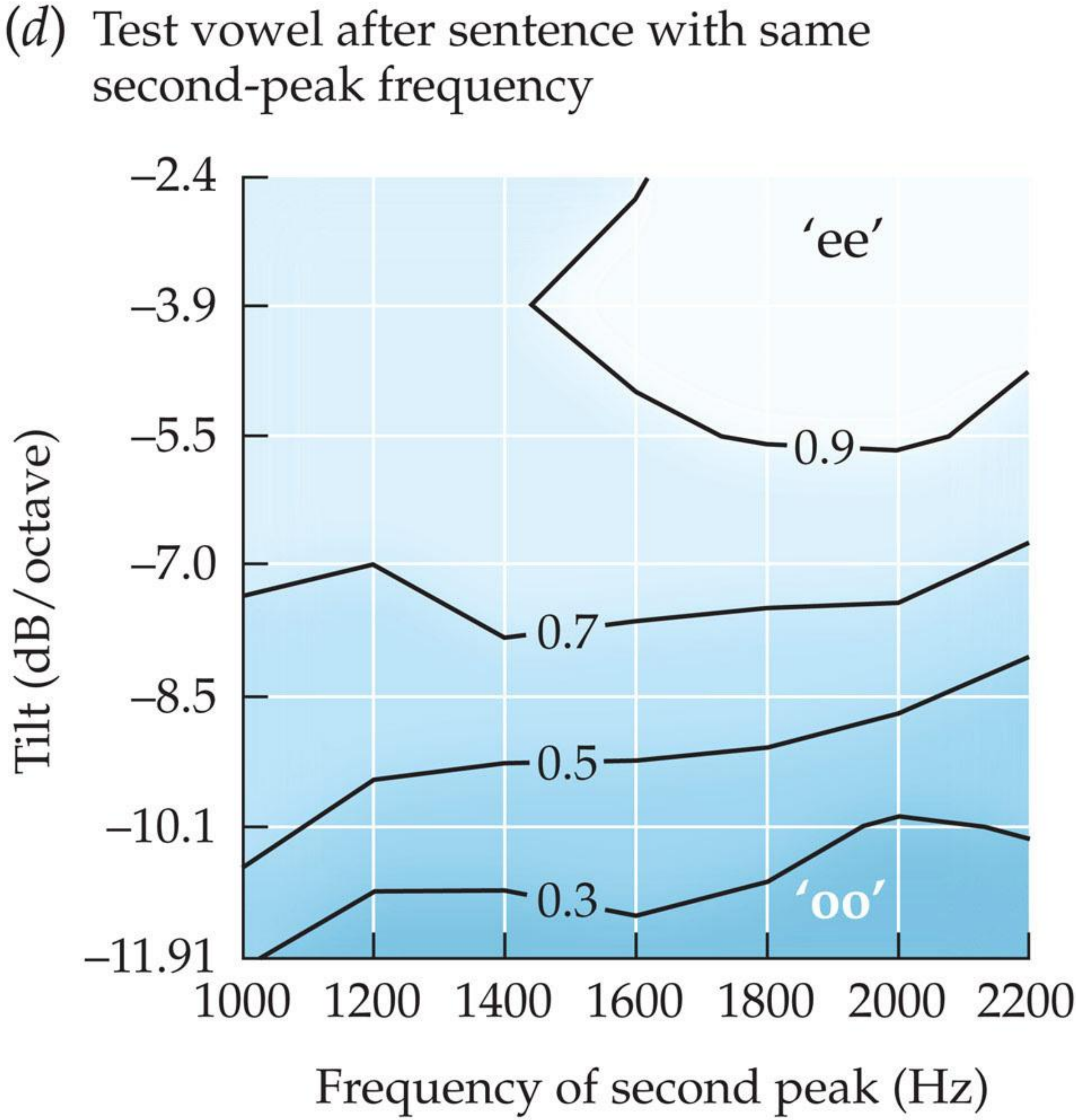
SENSATION & PERCEPTION 4e, Figure 10.16 (Part 2)

Figure 10.16 Listeners use both spectral tilt and the frequencies of spectral peaks to identify vowels (Part 3)



SENSATION & PERCEPTION 4e, Figure 10.16 (Part 3)

Figure 10.16 Listeners use both spectral tilt and the frequencies of spectral peaks to identify vowels (Part 4)



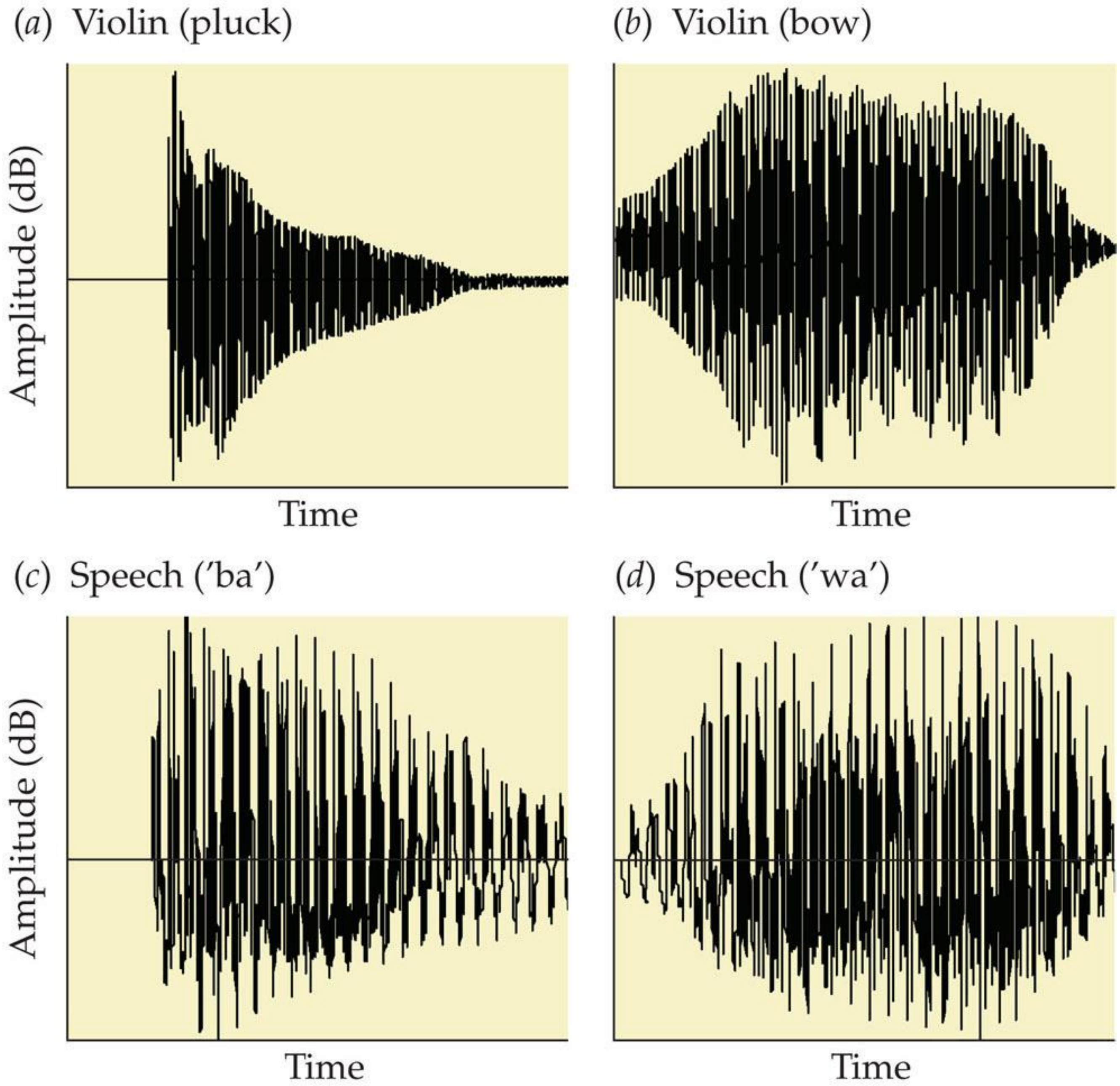
SENSATION & PERCEPTION 4e, **Figure 10.16 (Part 4)**

Complex Sounds

Attack and decay of sound

- Attack: Part of a sound during which amplitude increases (onset).
- Decay: Part of a sound during which amplitude decreases (offset).

Figure 10.17 We use the onsets of sounds to identify them



SENSATION & PERCEPTION 4e, **Figure 10.17**

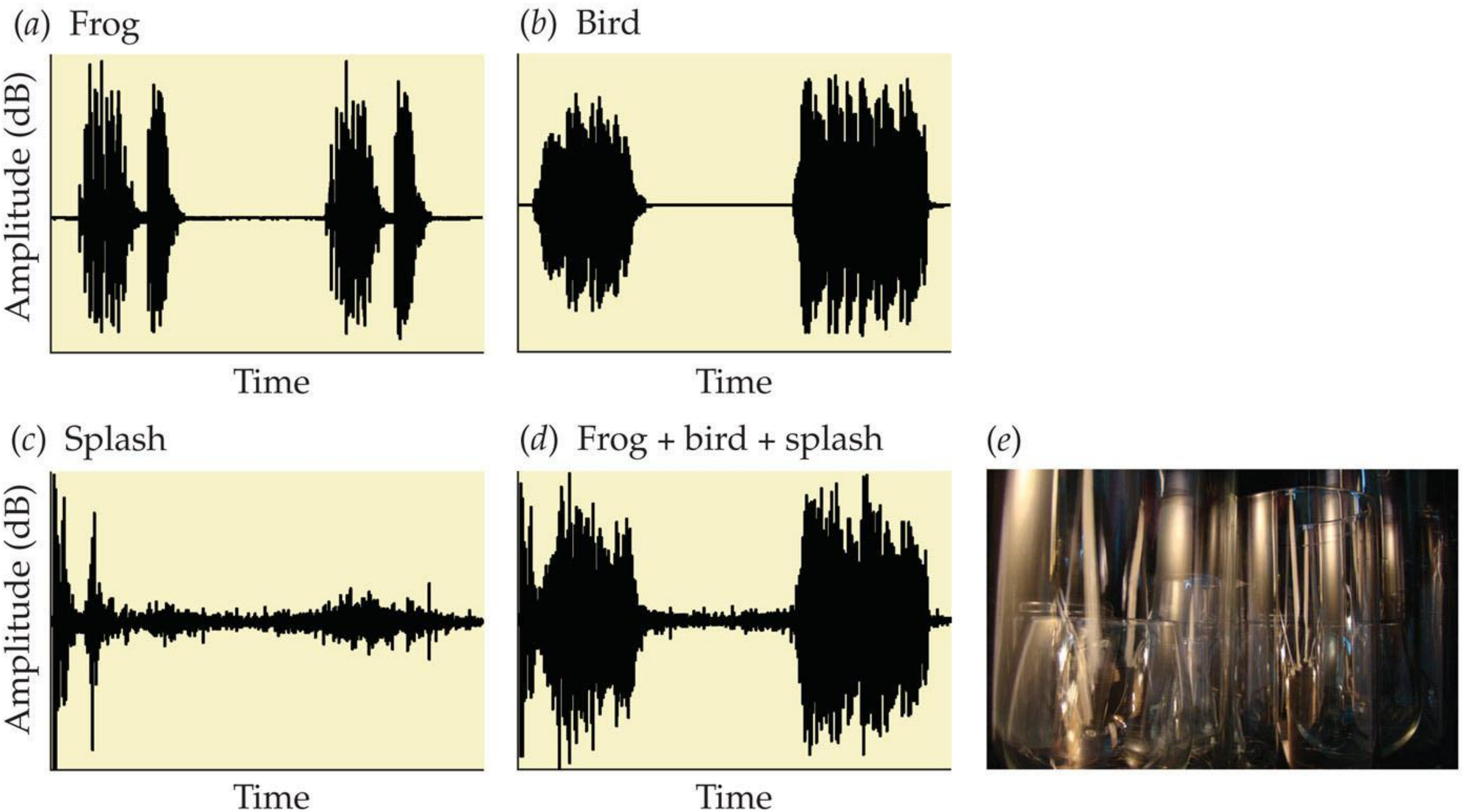
What happens in natural situations?

- Acoustic environment can be a busy place with multiple sound sources.
- How does the auditory system sort out these sources?
  - Source segregation (or auditory scene analysis): Processing an auditory scene consisting of multiple sound sources into separate sound images.

A number of strategies to segregate sound sources (Spatial, Spectral, Temporal):

- **Spatial separation** between sounds
- Separation based on sounds' **spectral or temporal qualities**
- **Auditory stream segregation**: The perceptual organization of a complex acoustic signal into separate auditory events for which each stream is heard as a separate event.

Figure 10.18 All the waveforms from all the sounds around us are summed into a single waveform arriving at the ears

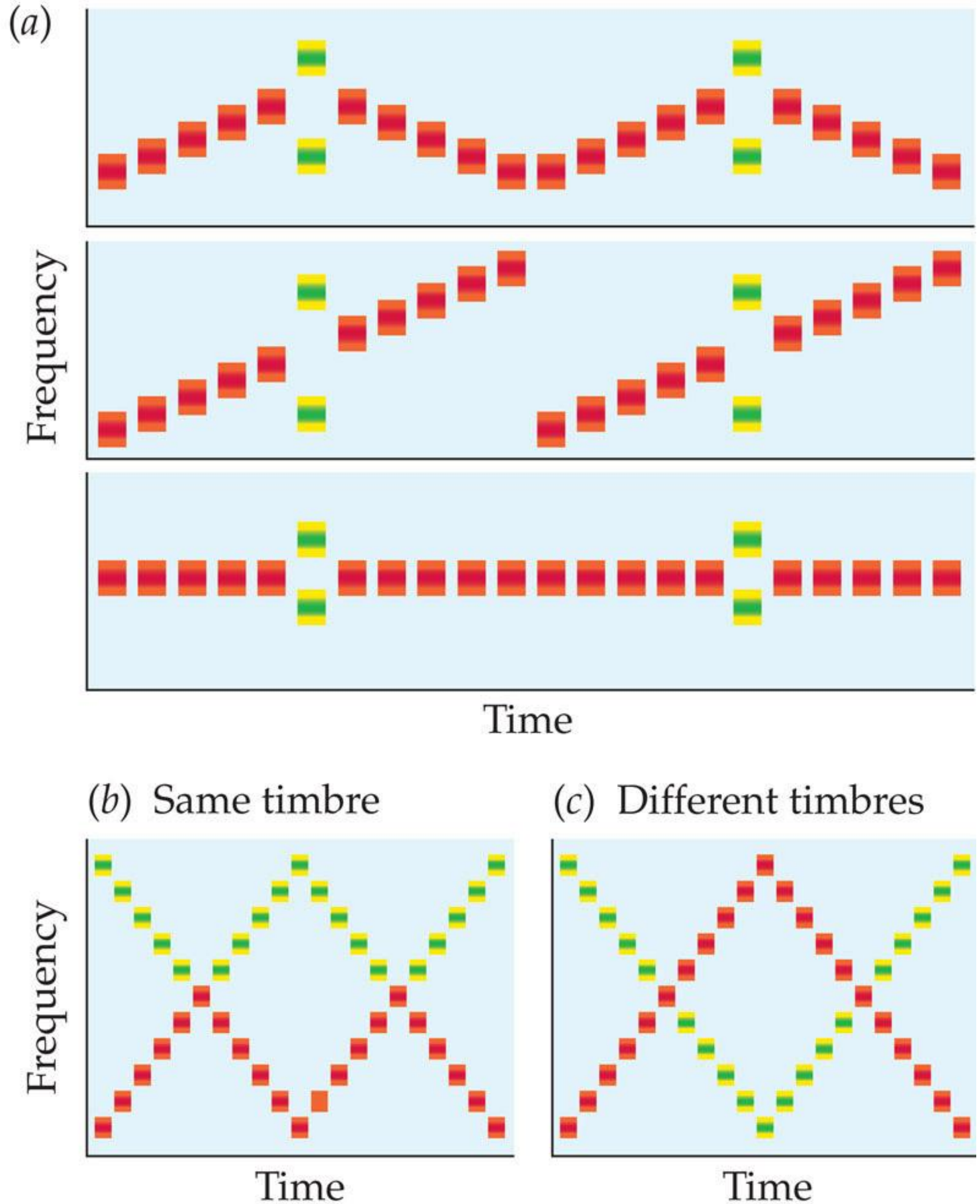


***SENSATION & PERCEPTION 4e,* Figure 10.18**

Grouping by timbre

- Tones that have increasing and decreasing frequencies, or tones that deviate from a rising/falling pattern “pop out” of the sequence

Figure 10.21 Timbre affects how sounds are grouped

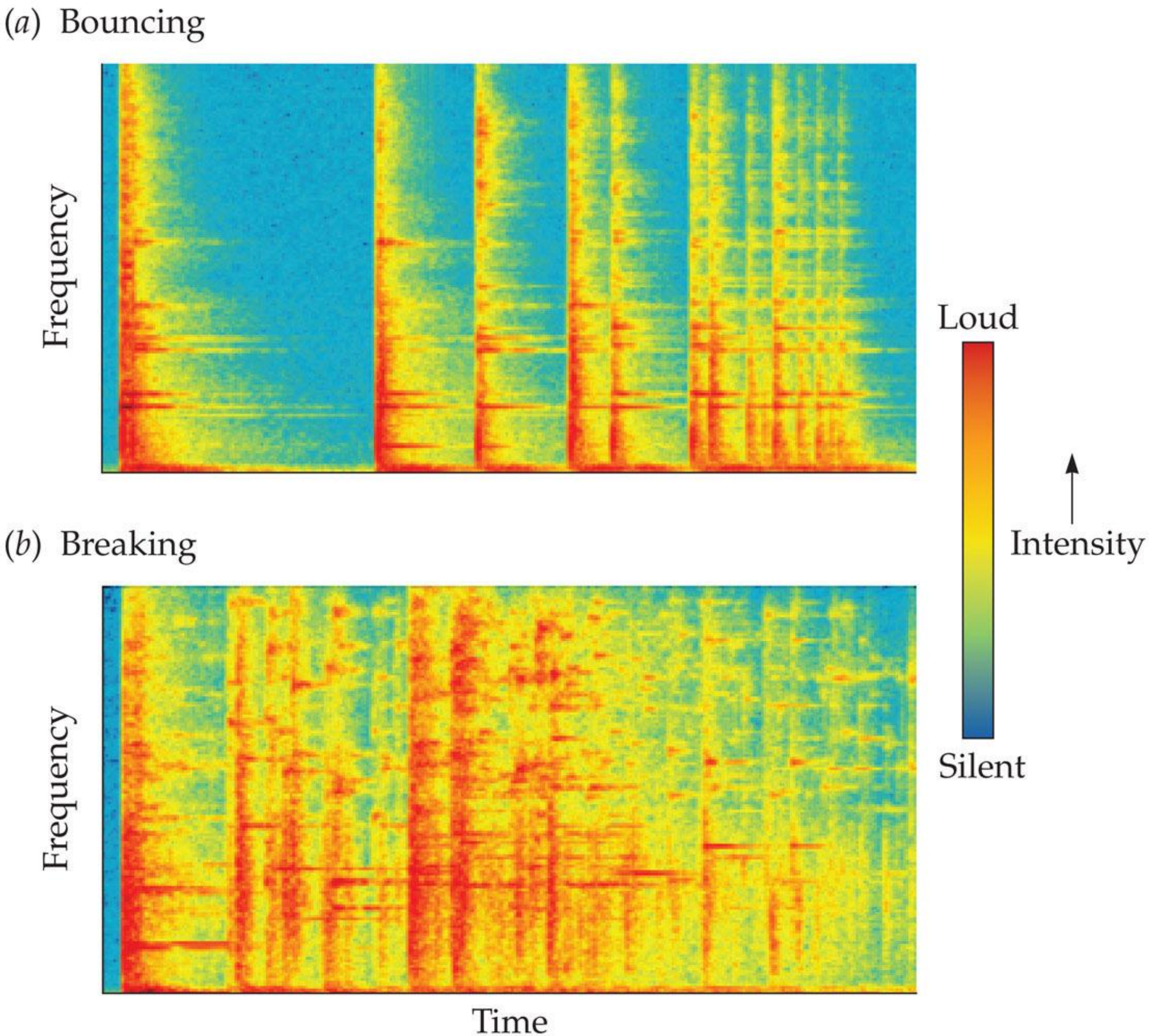


SENSATION & PERCEPTION 4e, Figure 10.21

Grouping by onset

- When sounds begin at the same time, or nearly the same time (< 30ms), they appear to be coming from the same sound source.
  - This helps group different harmonics into a single complex tone.
- Consistent with the Gestalt law of common fate

Figure 10.22 Spectrograms of a bottle bouncing (*a*) or breaking (*b*)

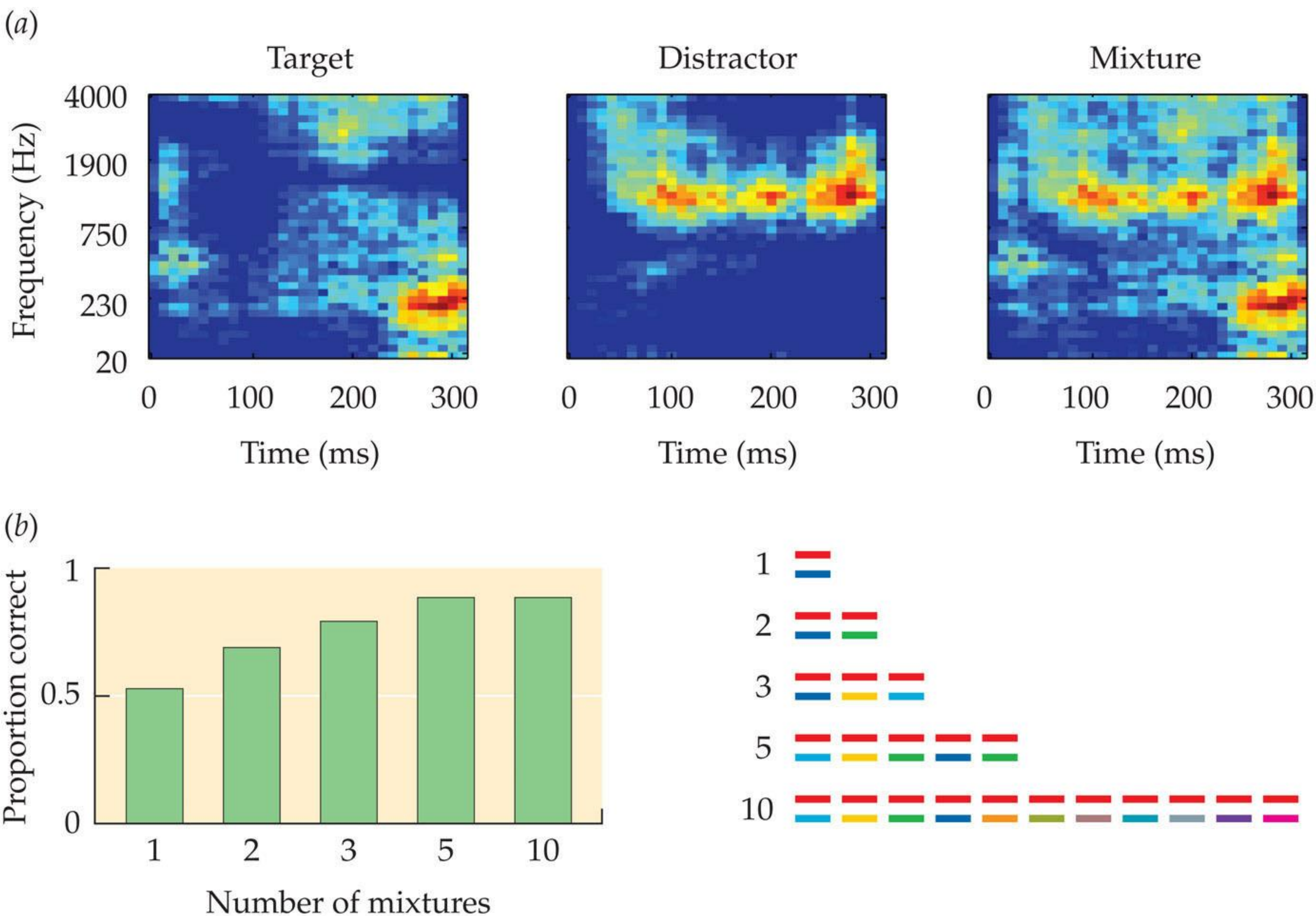


SENSATION & PERCEPTION 4e, Figure 10.22

People are surprisingly good at learning how to recognize a completely new sound.

- McDermott, Wroblewski, & Oxenham (2011)
  - Created novel sounds and played them many times in combination with other novel sounds that did not repeat.
  - Listeners needed very few repetitions to learn the new sounds, even though they never heard them in isolation.

Figurer 10.23 Listeners' tasks



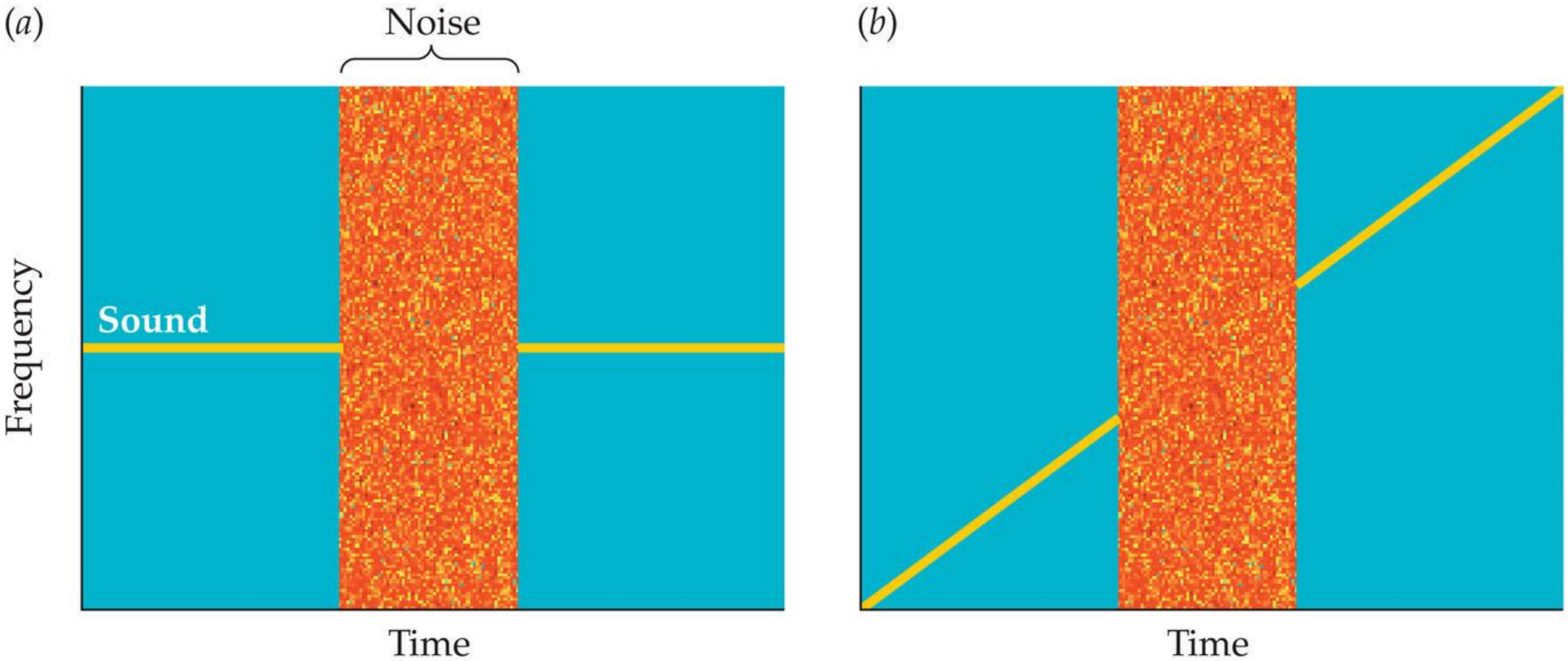
SENSATION & PERCEPTION 4e, Figure 10.23

Continuity and Restoration Effects

How do we know that listeners really hear a sound as continuous?

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

Figure 10.24 When a sound is deleted and replaced with a loud noise, listeners will hear the sound as if it continues through the noise



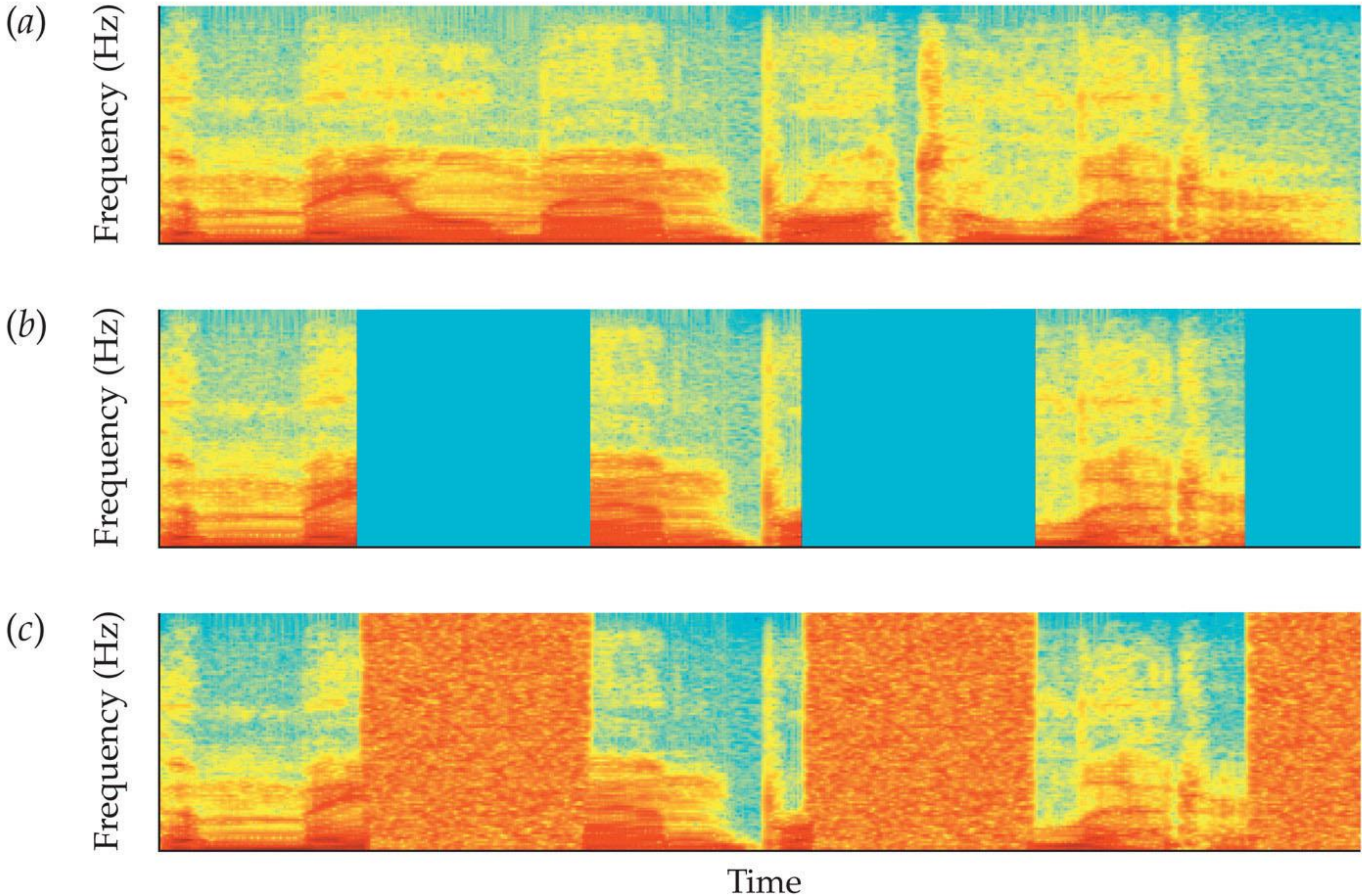
SENSATION & PERCEPTION 4e, Figure 10.24

Continuity and Restoration Effects

Restoration of complex sounds (e.g., music, speech)

- Listeners use "higher-order" sources of information, not just auditory information, to restore missing segments.
- Gaps in a sound stream are less detrimental if filled with noise rather than with silence.
  - With noisy gaps, listeners can't even reliably specify where the gaps were.

Figure 10.26 Adding noise improves comprehension



SENSATION & PERCEPTION 4e, Figure 10.26

Auditory Attention

Hearing is the primary sense for maintaining vigilance.

Acoustic startle reflex: The very rapid motor response to a sudden sound.

- Very few neurons are involved in the basic startle reflex, so responses are very fast (<10 ms!).
- Emotional state affects startle reflex.

Auditory Attention

We can attend to some sound sources and not others, even though all sounds come through the same two ear canals.

Difficult or impossible to attend to more than one auditory stream at once.

- Inattentional deafness