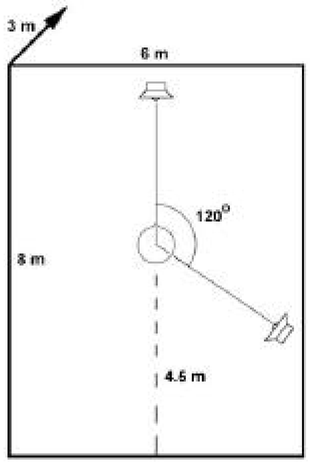
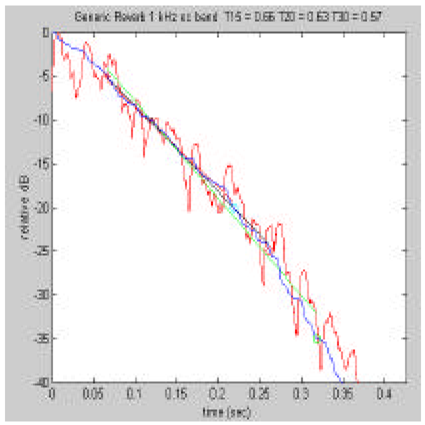
What Audio Engineers Should Know About Human Sound Perception

Part 2. Binaural Effects and Spatial Hearing





AES 112th Convention, Munich
AES 113th Convention, Los Angeles

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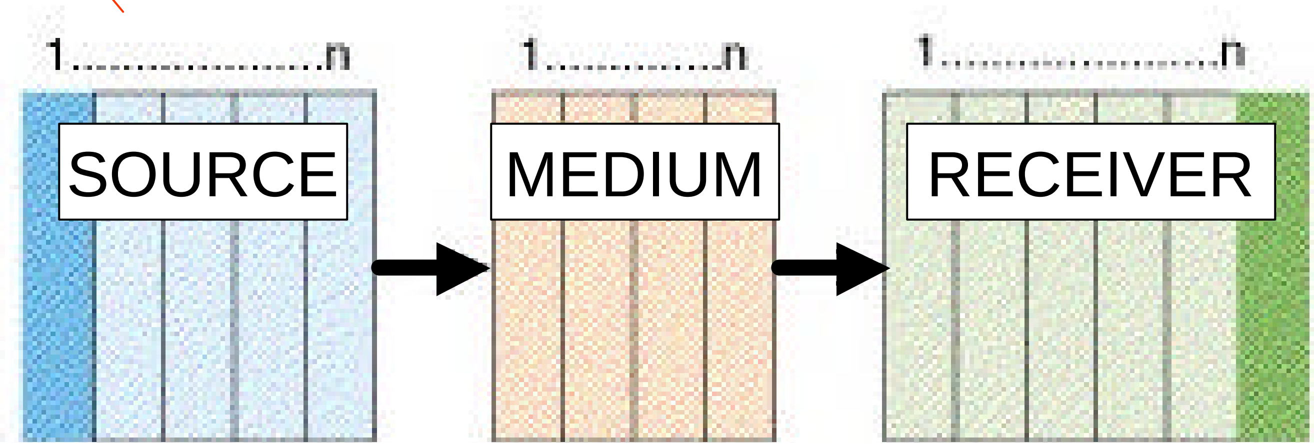
Overview

- ILD, ITD differences and lateralization
- HRTF spectral changes for 3D imagery
- Binaural versus monaural influence of echoes
- Effects of reverberation on perception of the environmental context
- Cues to auditory distance
- Cognitive and multisensory cues

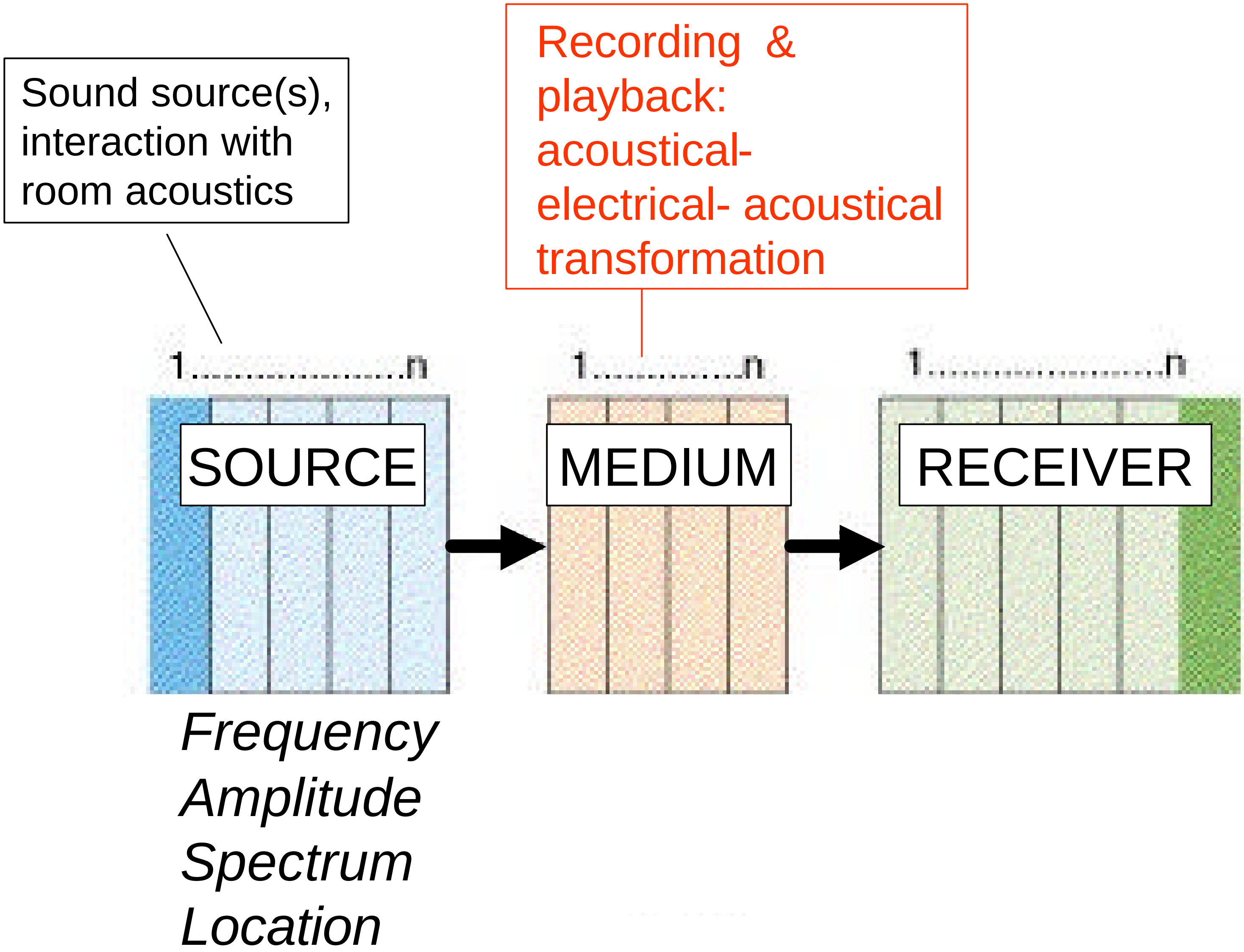
Communication chain for acoustic events

Sound source(s), interaction with room acoustics

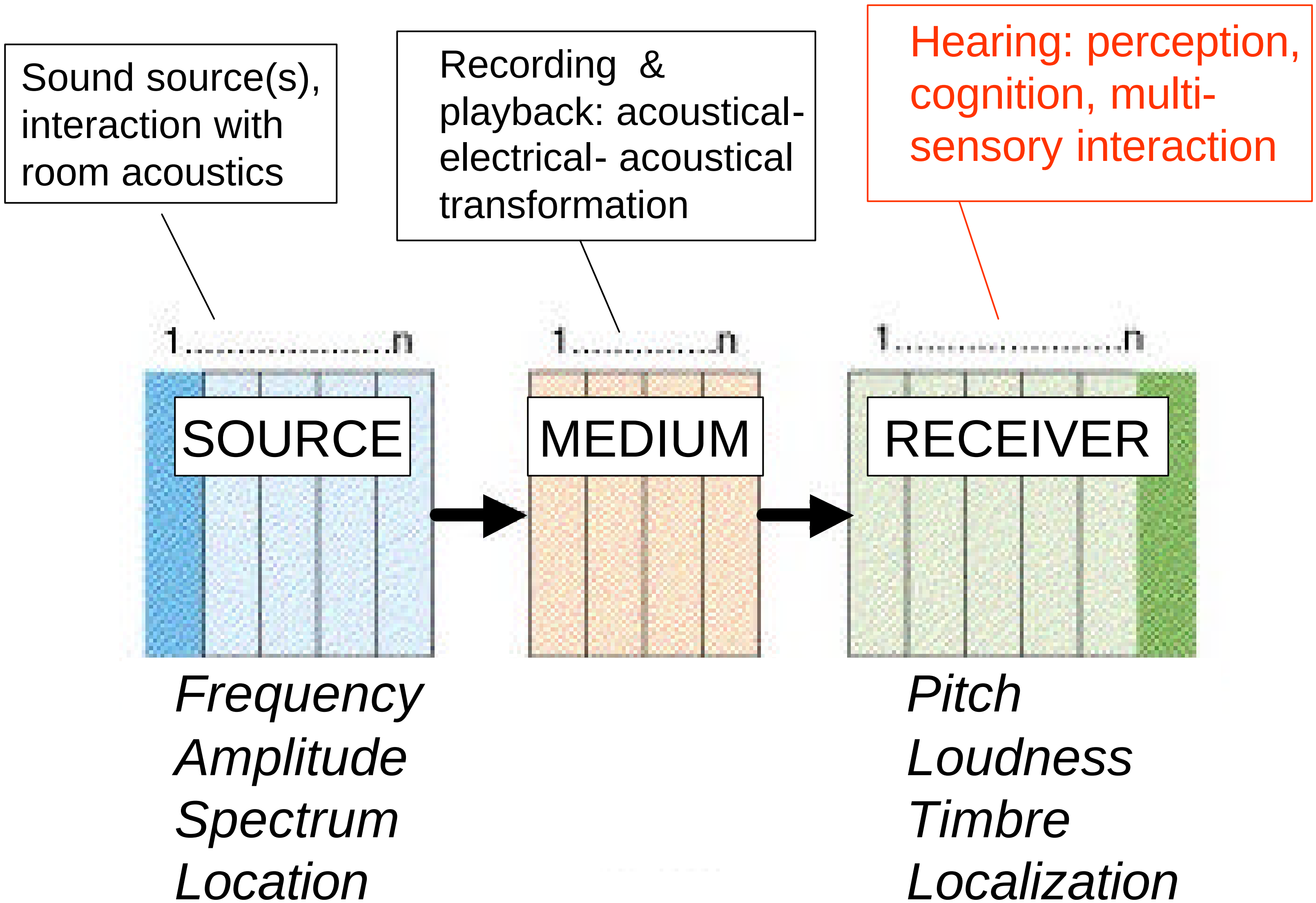


Frequency
Amplitude
Spectrum
Location

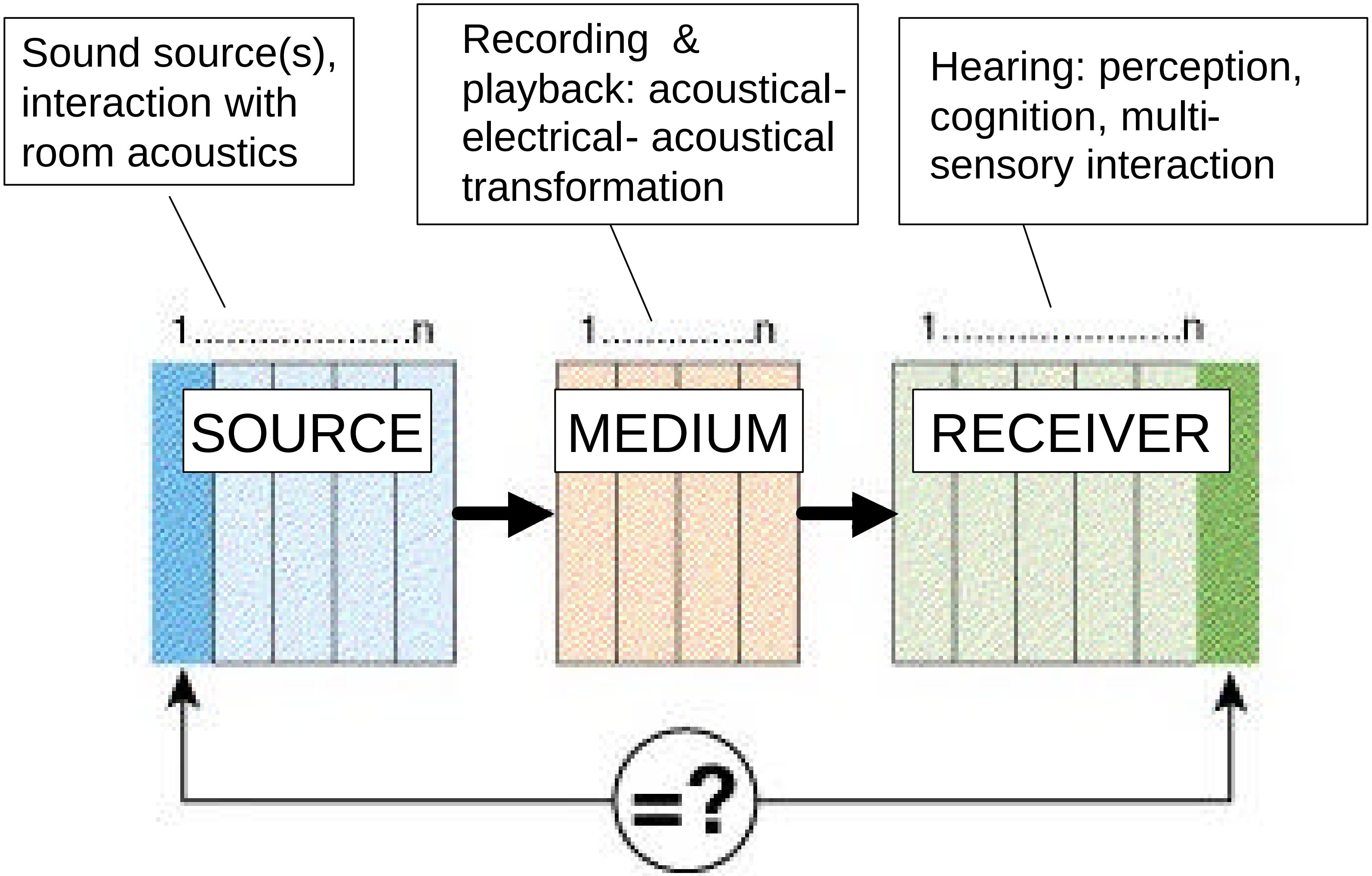
Communication chain for acoustic events



Communication chain for acoustic events

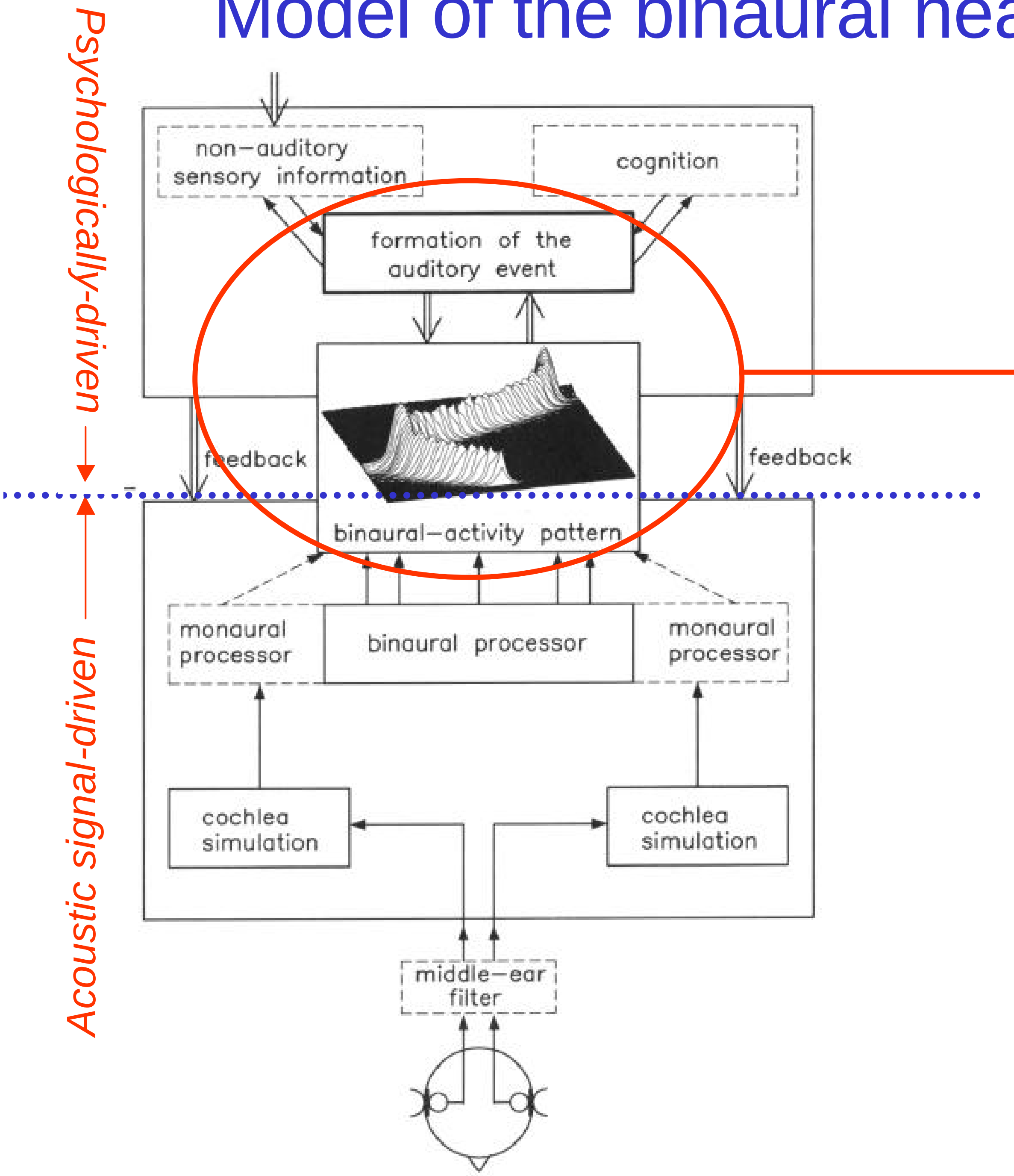


Communication chain for acoustic events



Mismatch between prescribed & perceived spatial events

Model of the binaural hearing system

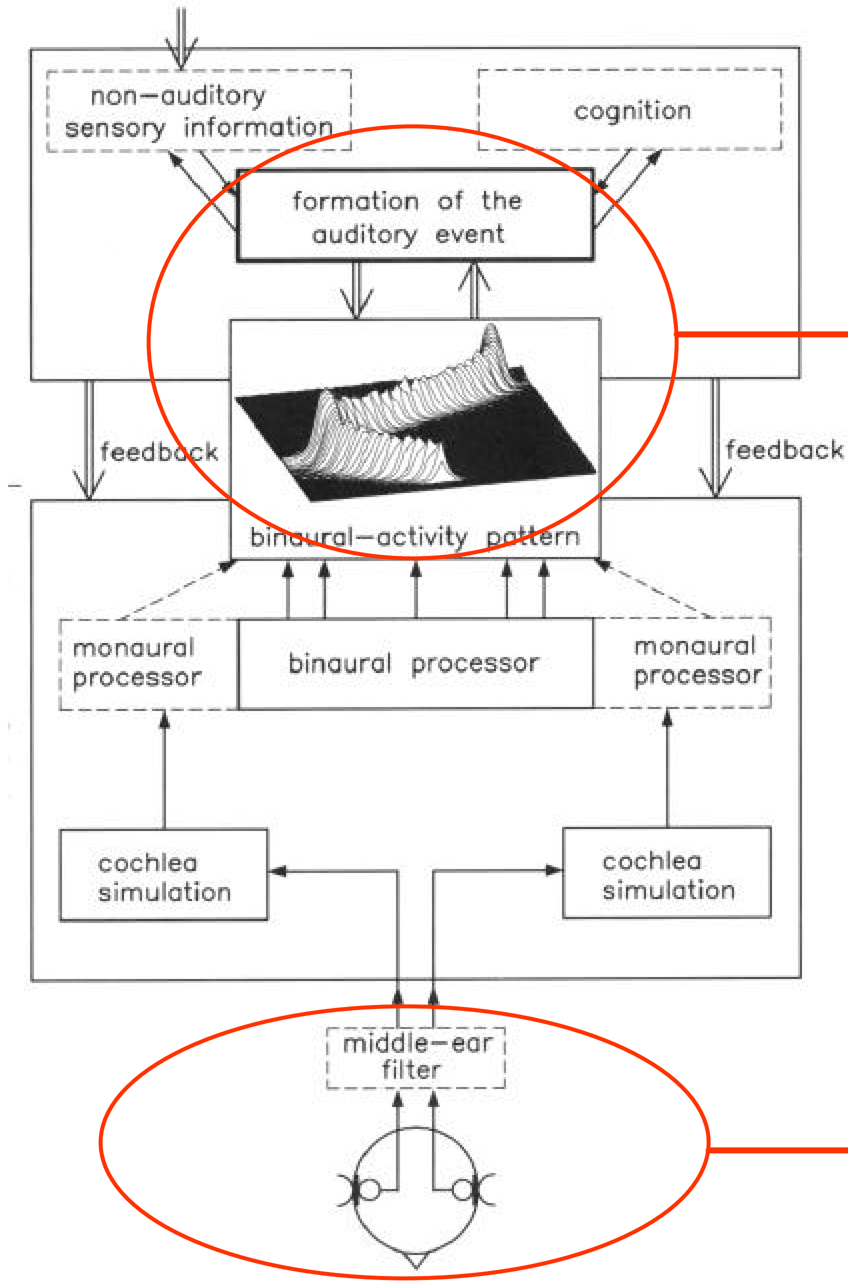


Binaural hearing (localization; signal separation & detection):

forming spatial auditory events from acoustical (bottom-up) and psychological (top-down) inputs

Figure adapted from Jens Blauert, "Spatial Hearing. The Pychophysics of Human Sound Localization. Revised Edition. 1983, MIT Press.

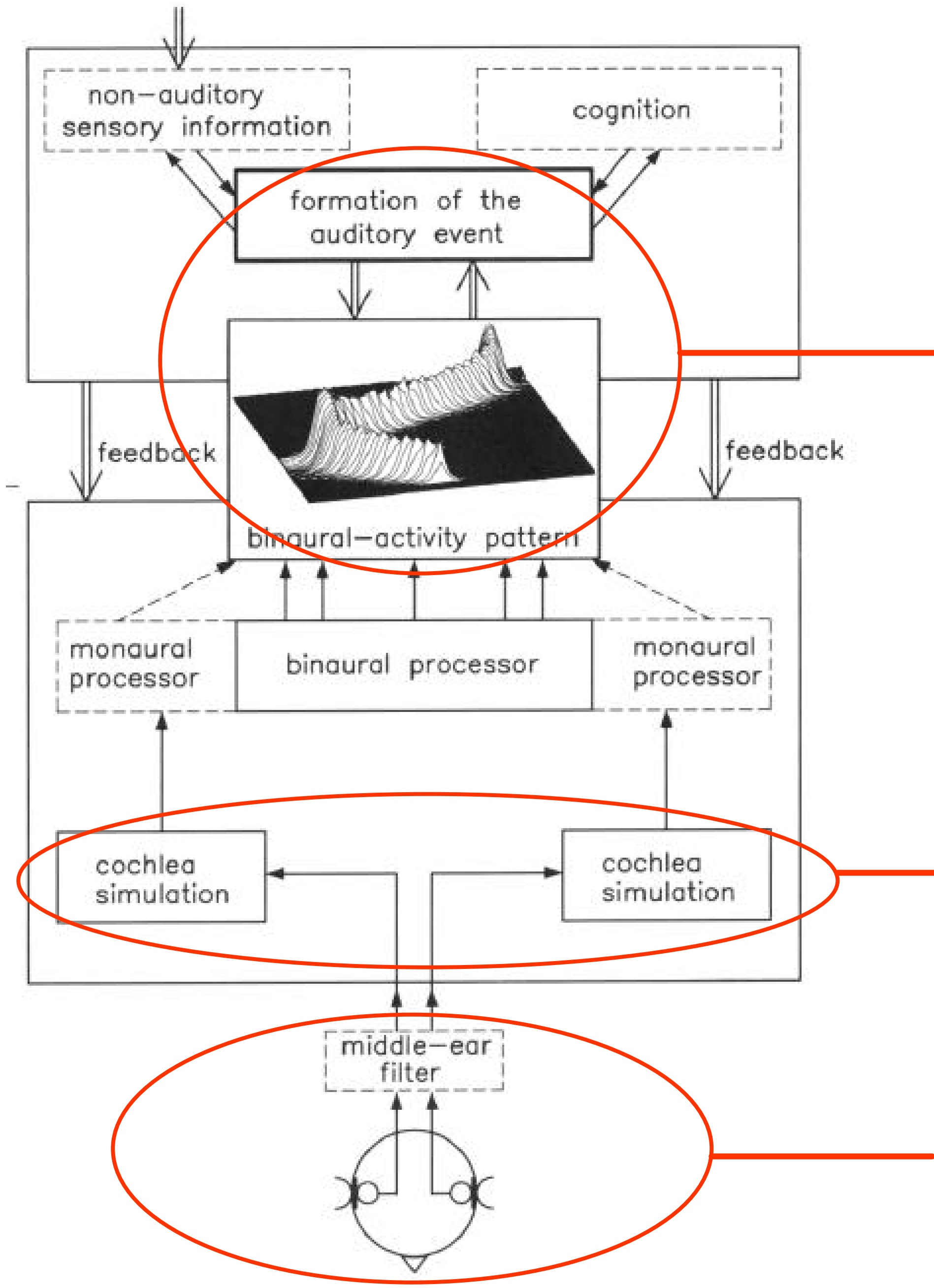
Model of the binaural hearing system



Binaural hearing (localization; signal separation & detection)

Filtering of acoustic signal by pinnae, ear canal

Model of the binaural hearing system

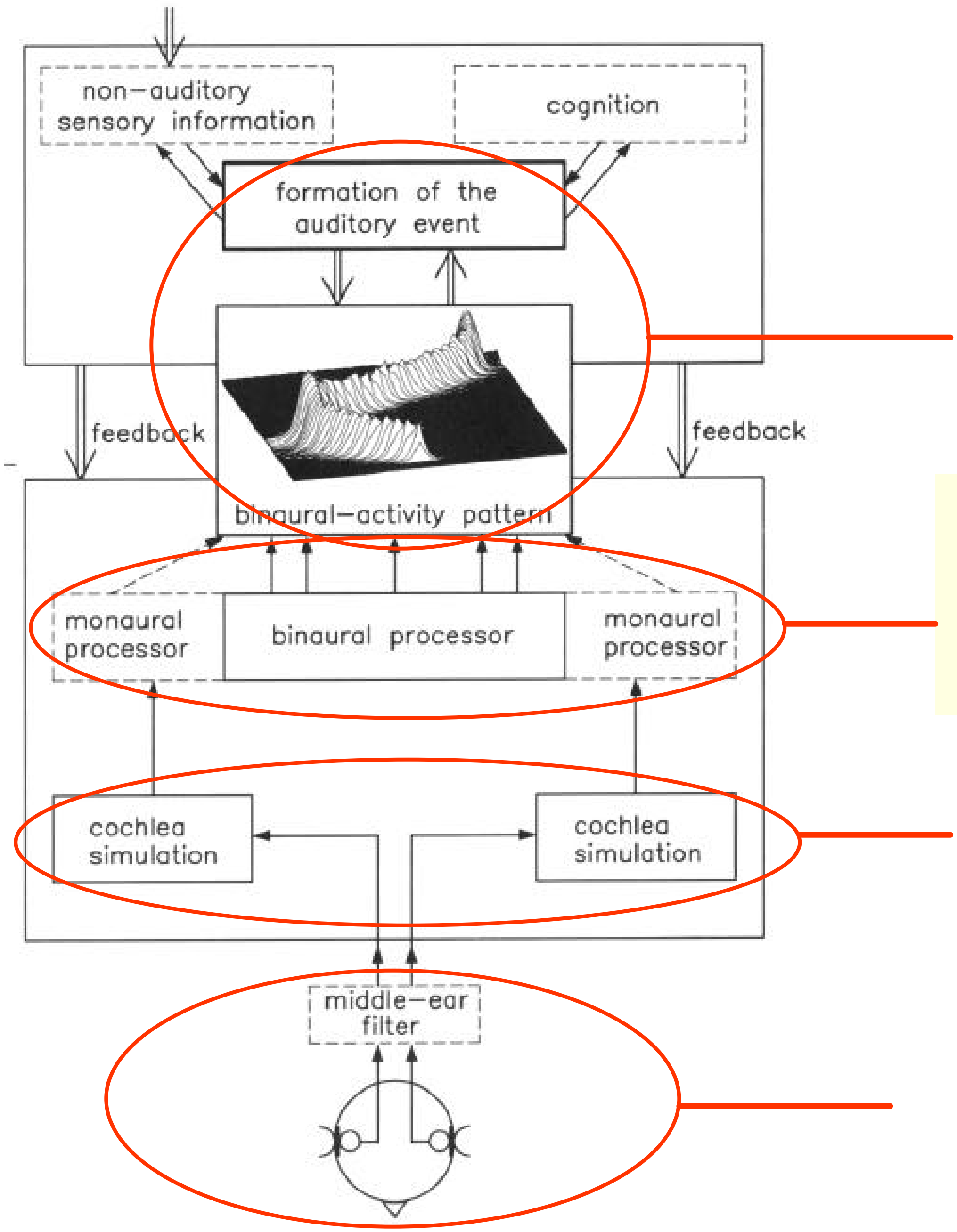


Binaural hearing (localization; signal separation & detection)

Filtering by inner ear; frequency-specific neuron firings

Filtering of acoustic signal by pinnae, ear canal

Model of the binaural hearing system



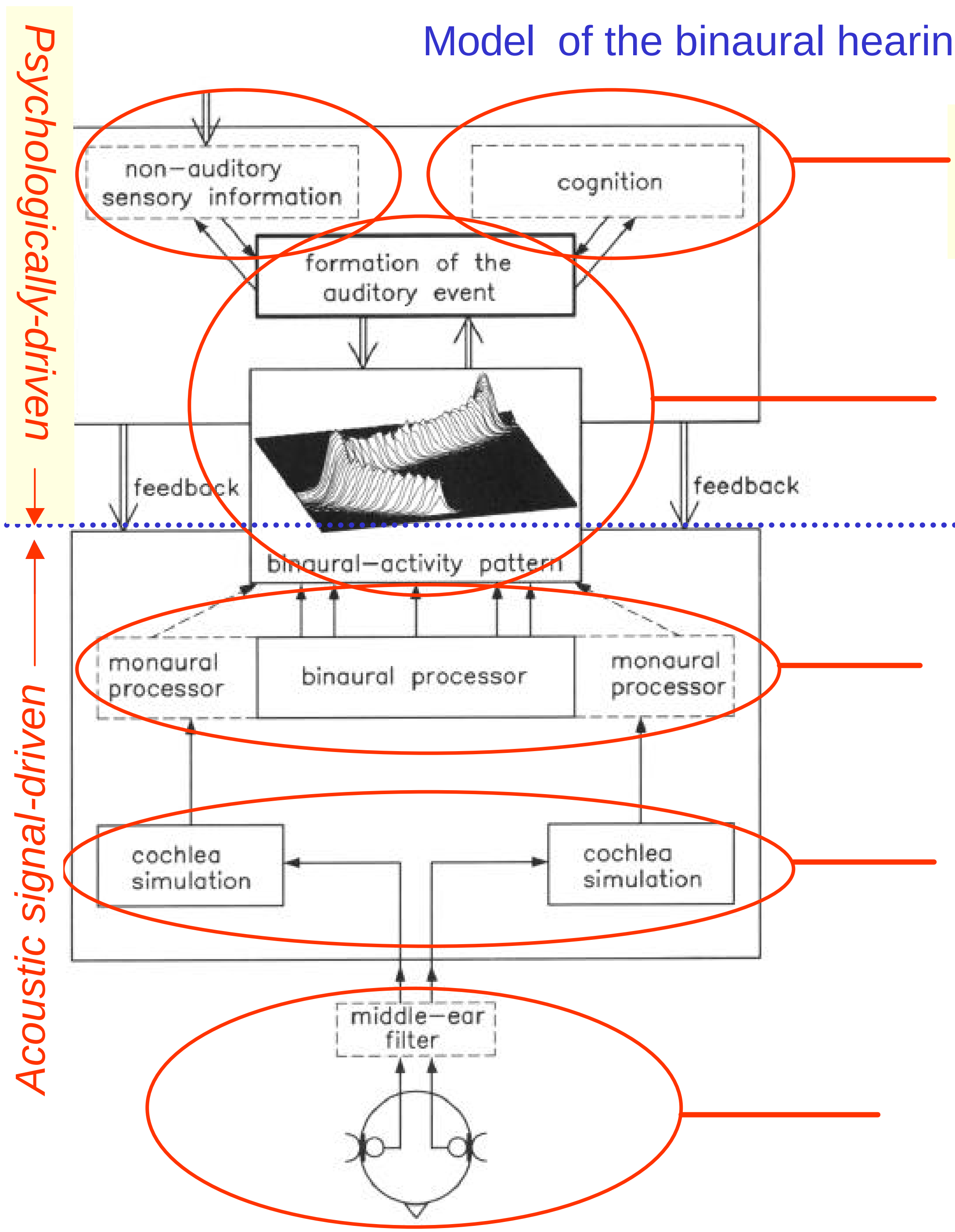
Binaural hearing (localization; signal separation & detection)

Physiological evaluation of interaural timing and level differences

Filtering by inner ear; frequency-specific neuron firings

Filtering of acoustic signal by pinnae, ear canal

Model of the binaural hearing system



Multi-sensory information; cognition

Binaural hearing (localization; signal separation & detection)

Physiological evaluation of interaural timing and level differences

Filtering by inner ear; frequency-specific neuron firings

Filtering of acoustic signal by pinnae, ear canal.

Two important functions of the binaural hearing system for recording engineers*:*

- Localization

  (lateral and 3-dimensional)

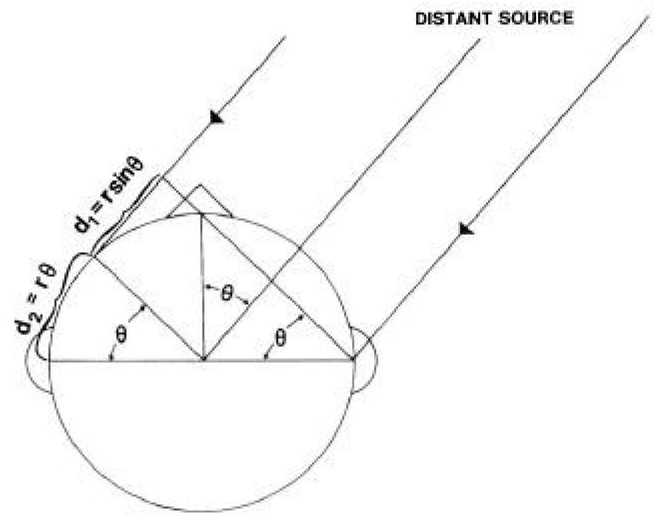
- Binaural masking:

  Echo supression, room perception

Lateral localization of auditory images

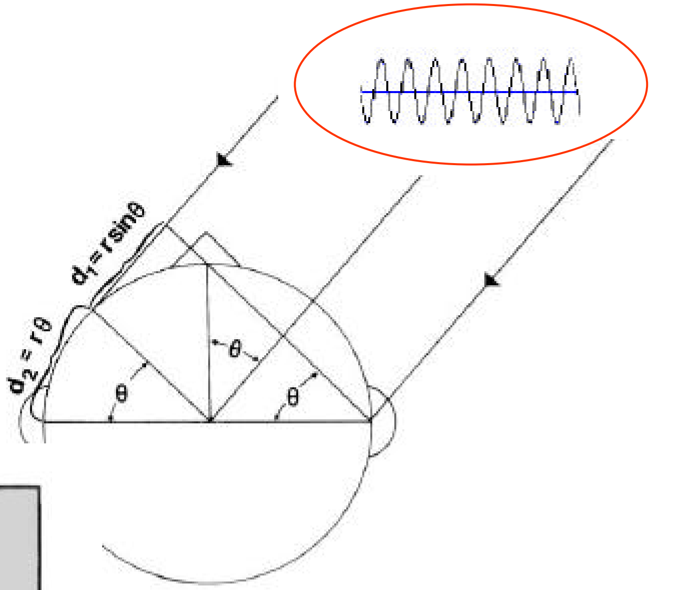
"Duplex" theory of localization

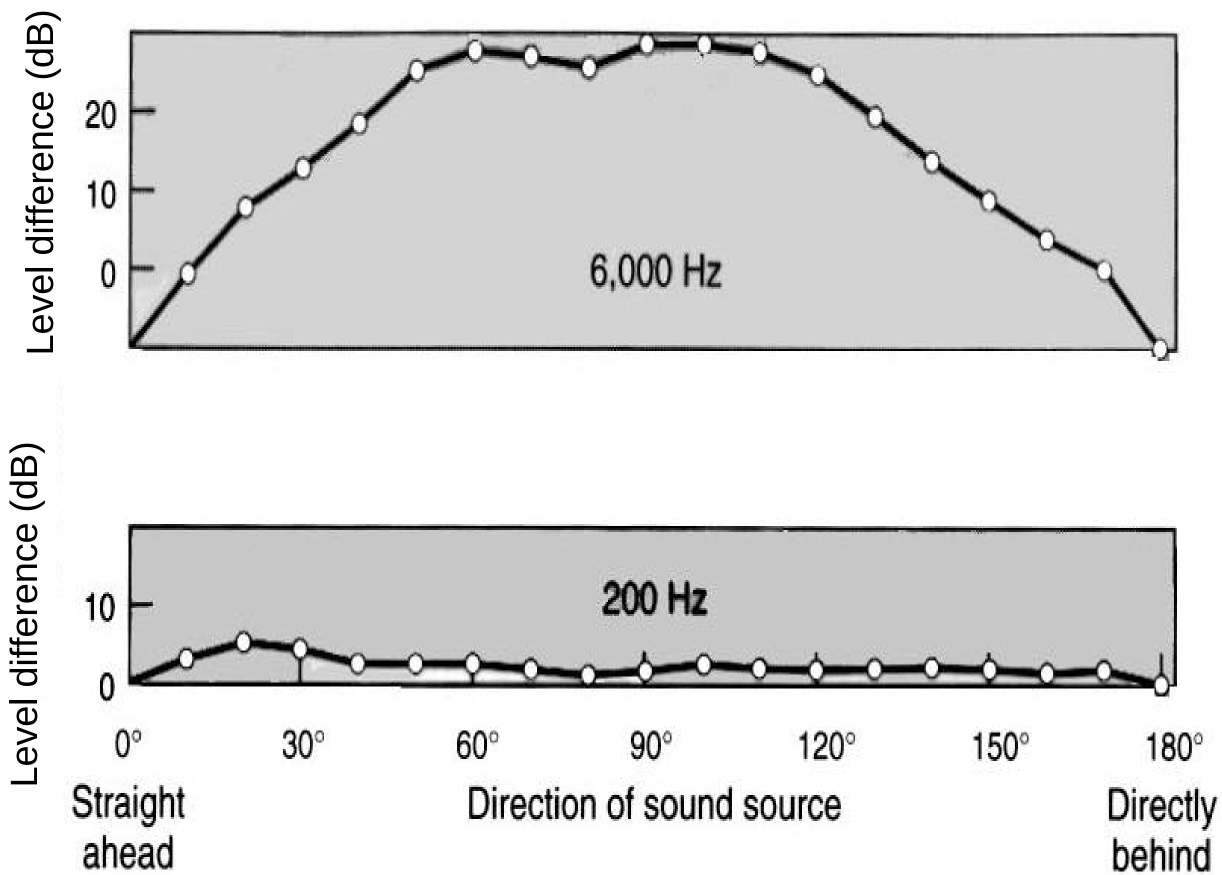
- ILD (interaural level difference)
- ITD (interaural time difference)



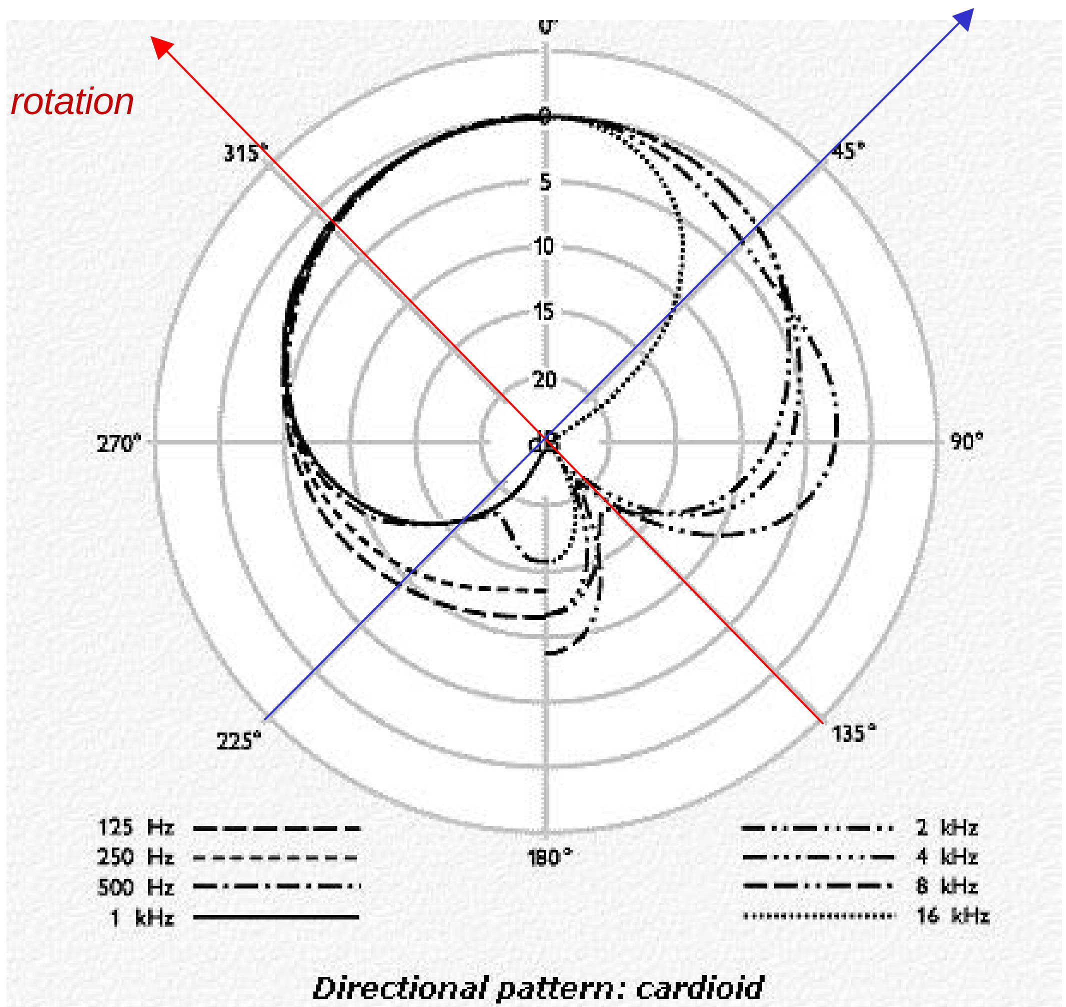
Lateral spatial image shift

- ILD (interaural level difference) caused by head shadow of wavelengths > 1.5 kHz

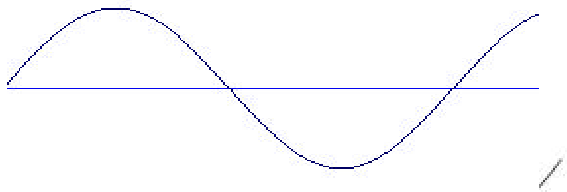




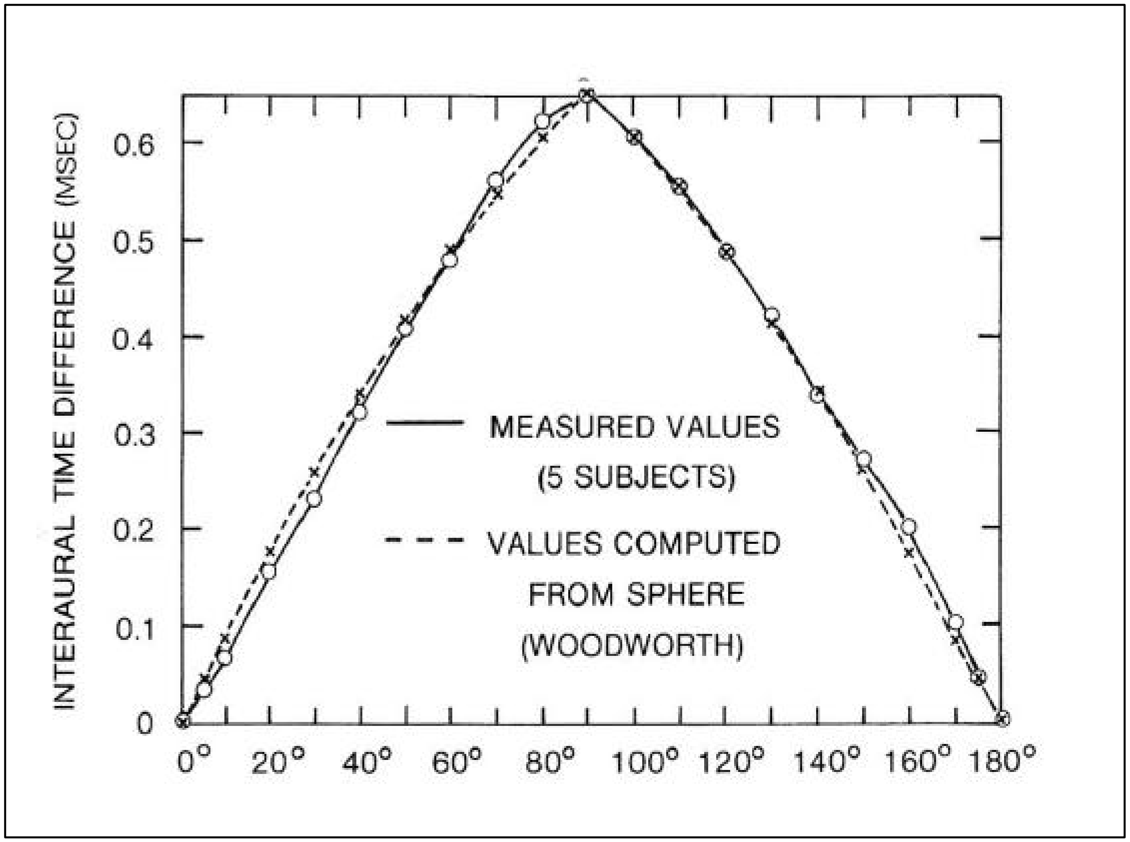
Perceptual decoding of spatial cues in a cross-coincident microphone recording is based on ILDs

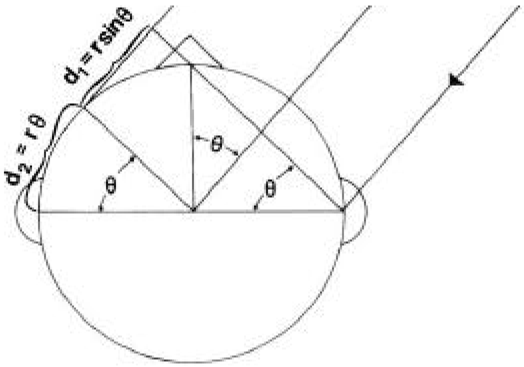


Lateral image shift

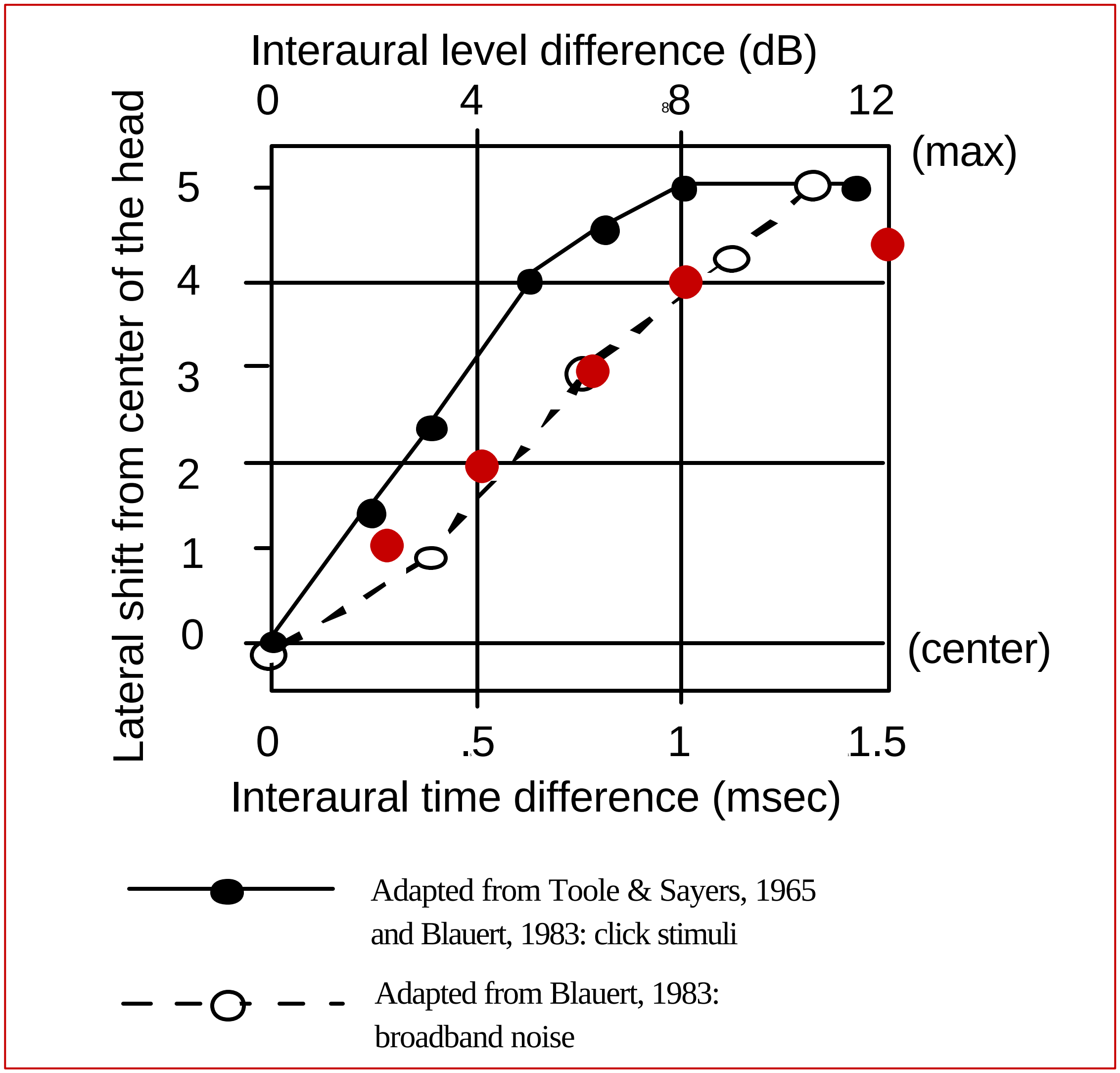


- ITD (interaural time difference)





Lateralization demo. A simple time or level difference can make headphone images move from side to side inside the head.



1. ILD DEMO:

2 dB

4 dB

6 dB

8 dB

12 dB

2. ITD DEMO:

0.00 ms

0.25 ms

0.50 ms

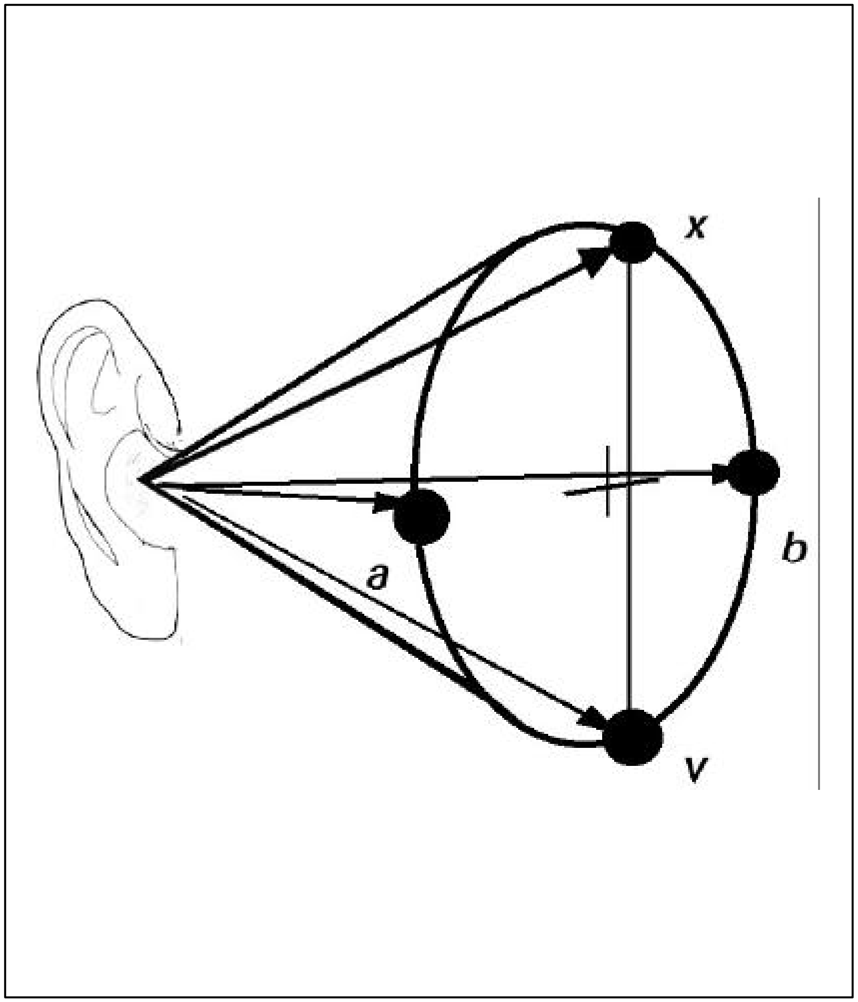
0.75 ms

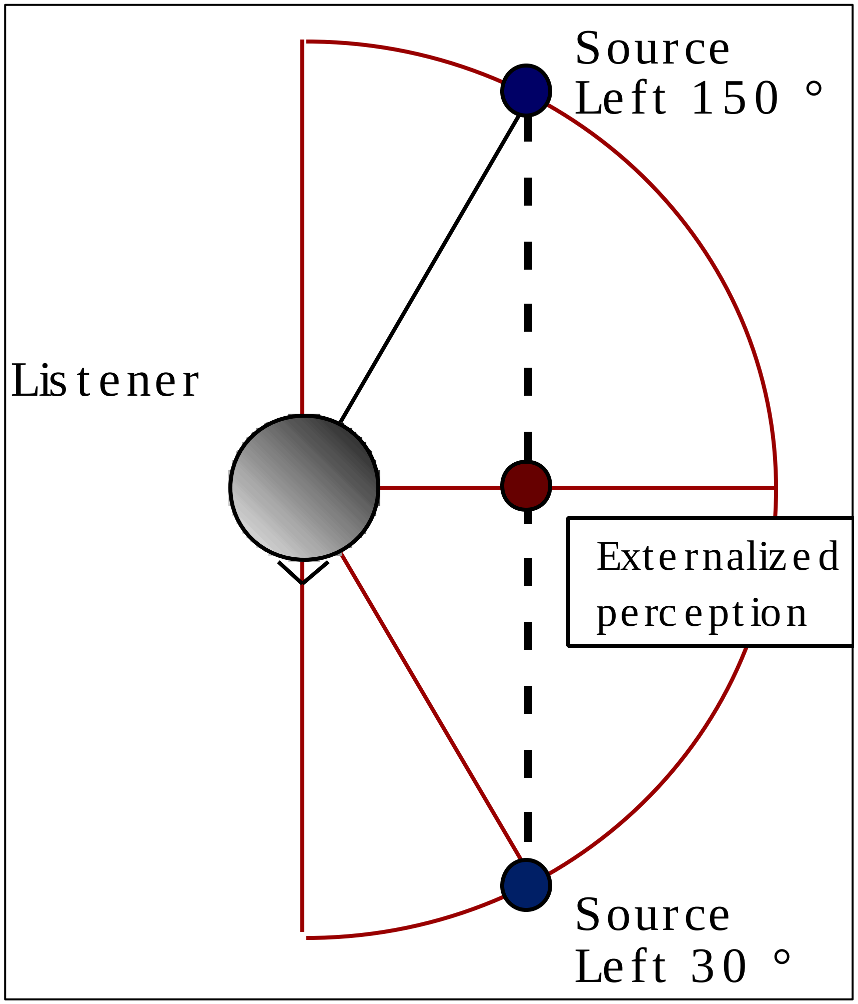
1.00 ms

1.50 ms

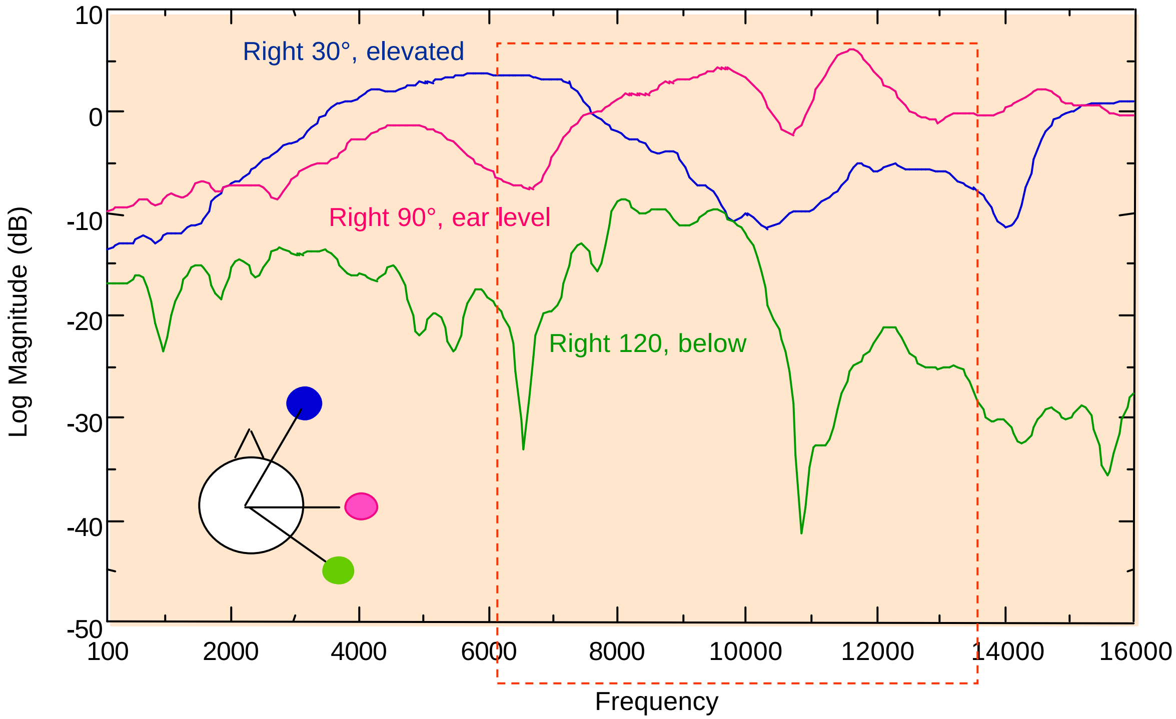
Elevation and front-back discrimination: HRTF, pinnae cues

The cone of confusion causes reversals for virtual sources with identical or near-identical ITD or ILD

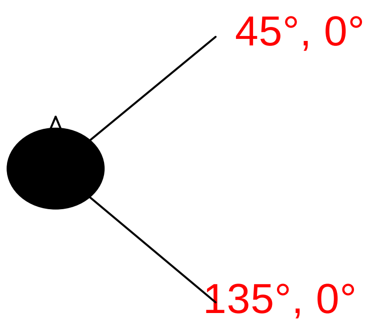


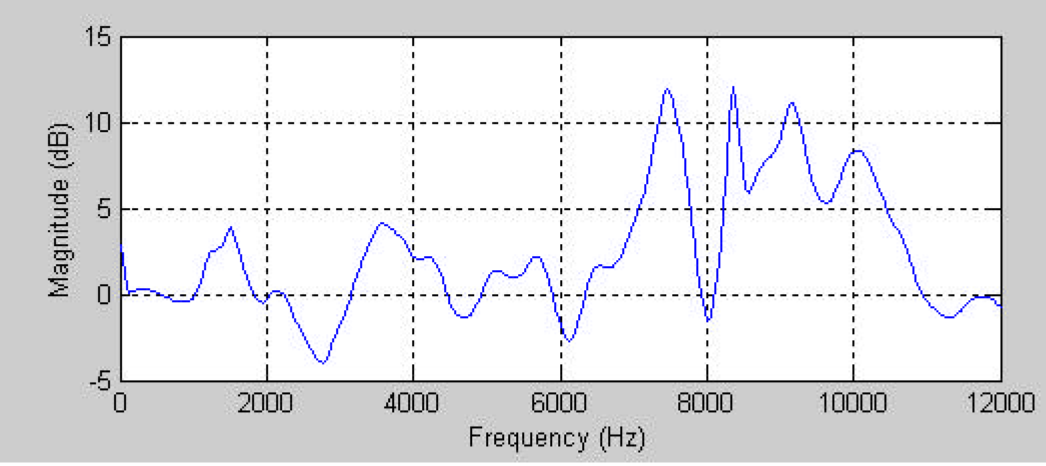


Head-related transfer function cues (HRTFs) provide cues for front-back discrimination and elevation

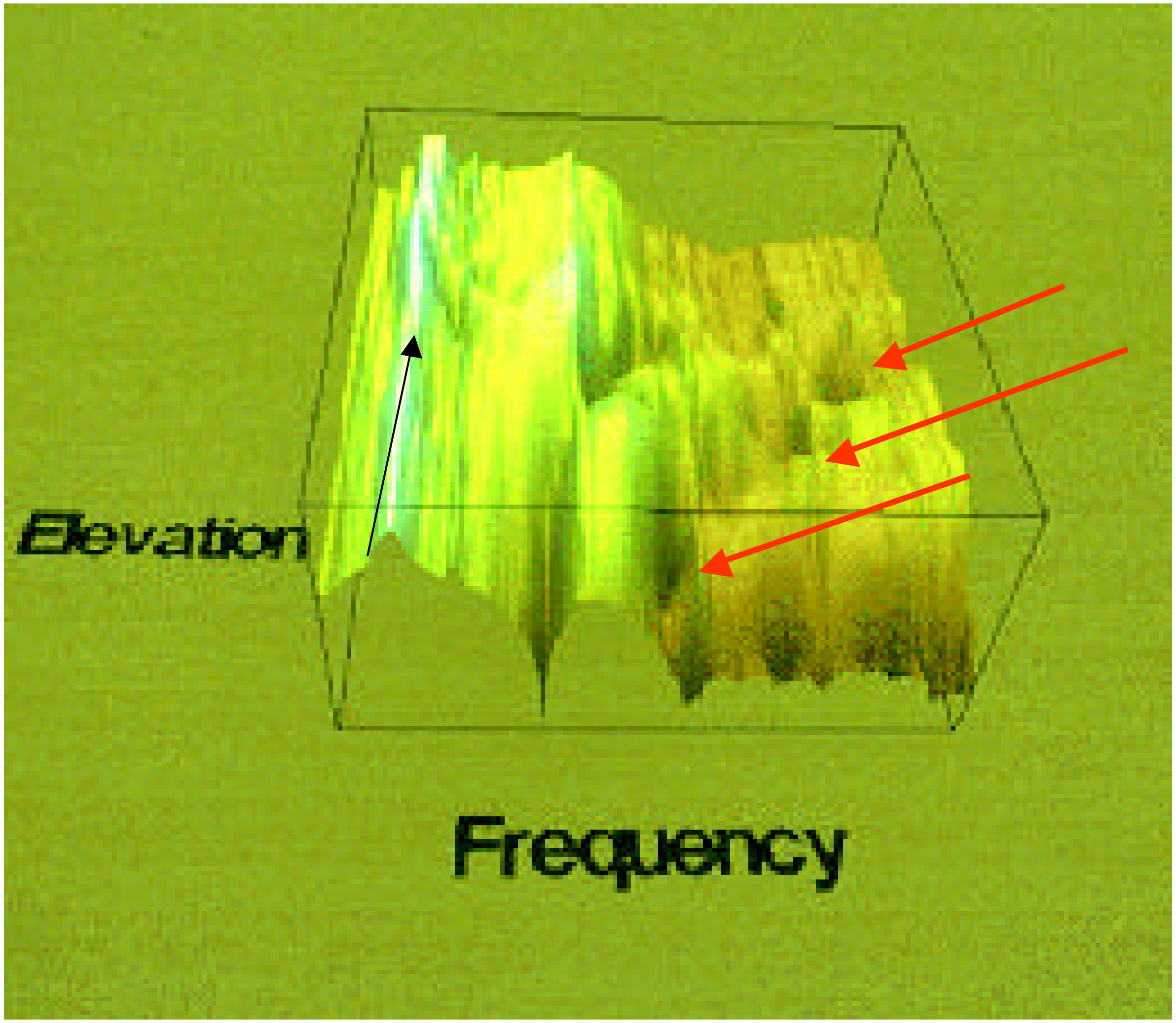


3. audio example: HRTF "clock positions"





Variation in HRTF magnitude with elevation at one azimuth



4. Audio example:

120 degree azimuth: at

+36,

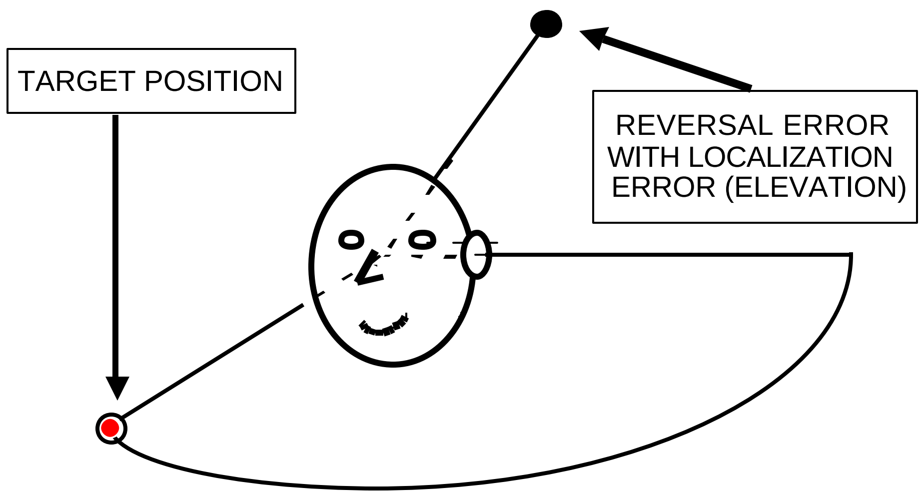
0 ,

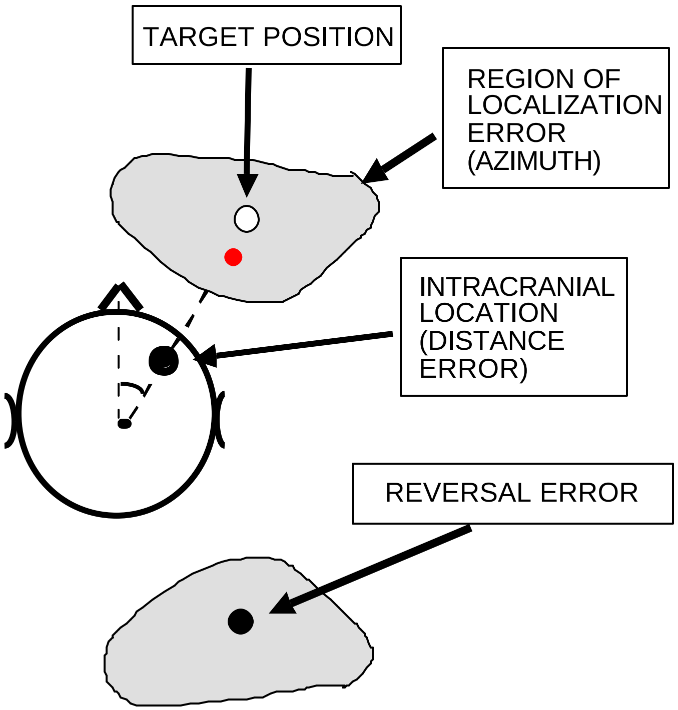
-36 degrees

elevation

Graphic by William L. Martens, University of Aizu

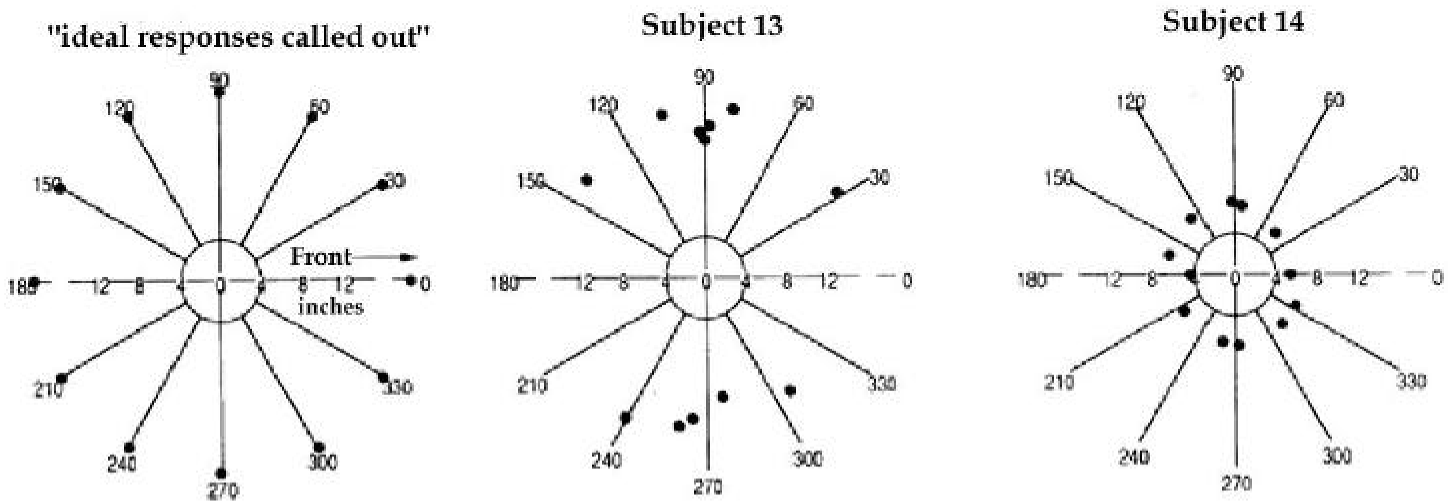
Perceptual errors with headphone 3-D sound include inside-the-head localization (solution: reverberation cues) and reversals (solution: head tracking)



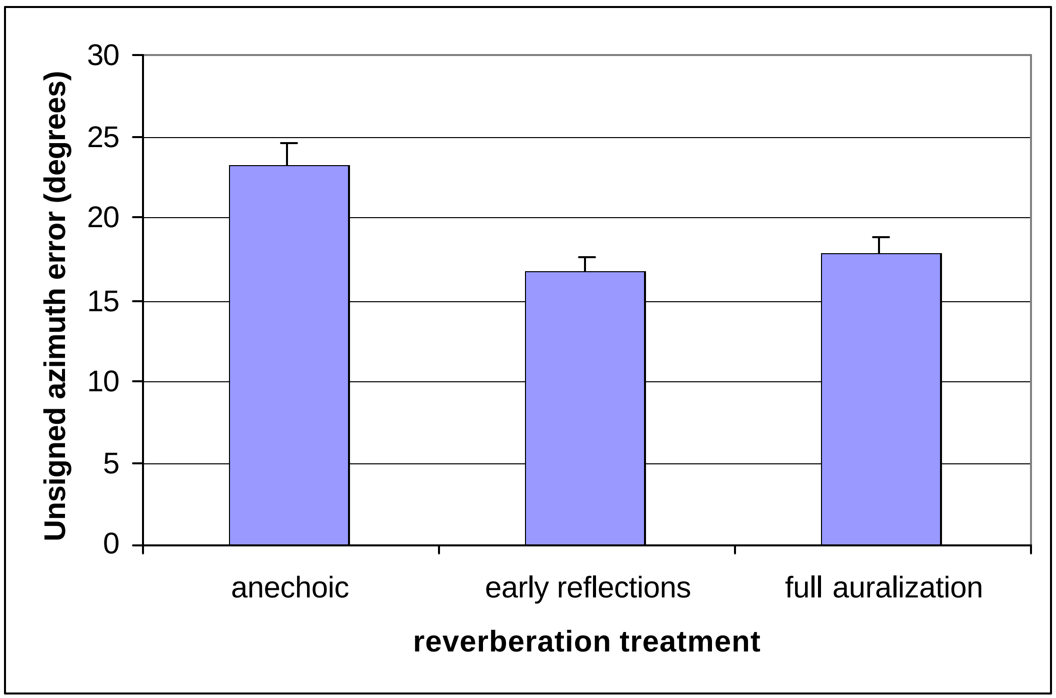


Localization error for headphone stimuli (azimuth)

Anechoic Speech: Individual differences

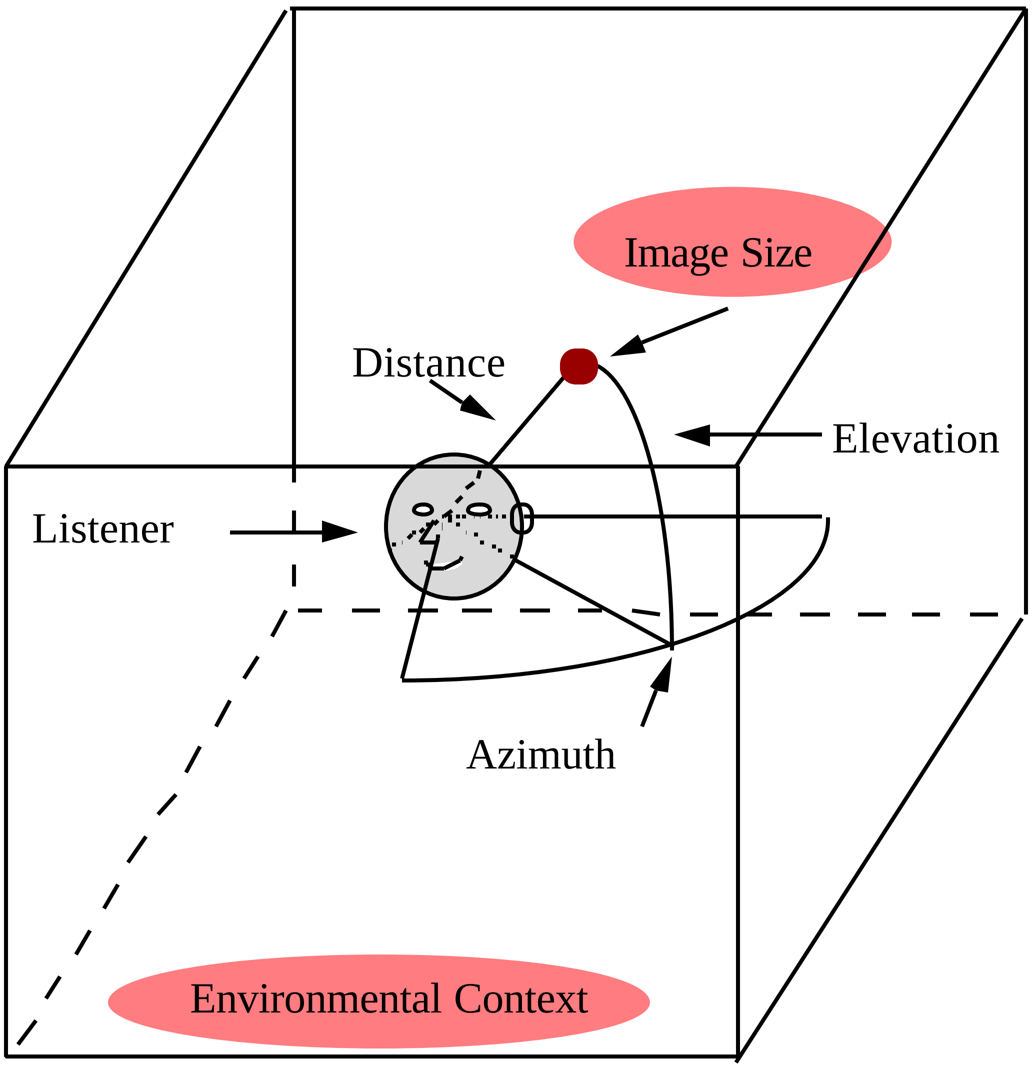


Mean values for different reverberation conditions



Echoes, reverberation and background sound: perception of the environmental context

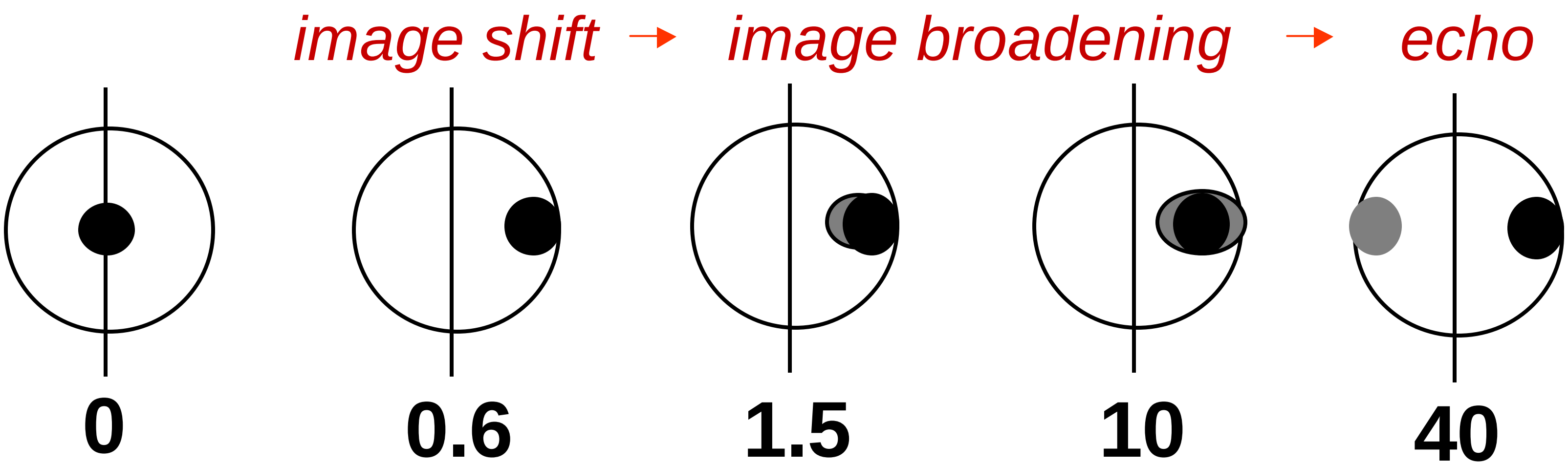
Spatial hearing fundamentally involves perception of the location of a sound source at a point in space (azimuth, elevation, distance).



But a sound source simultaneously reveals information about its environmental context.

-reverberation
-image size & extent

Effect of delay time for a single echo

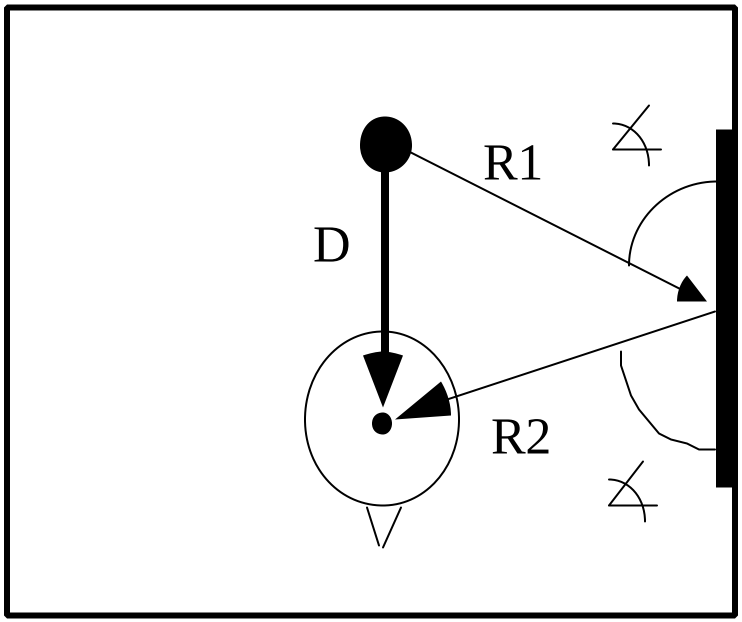


Approximate delay time to left channel (msec)

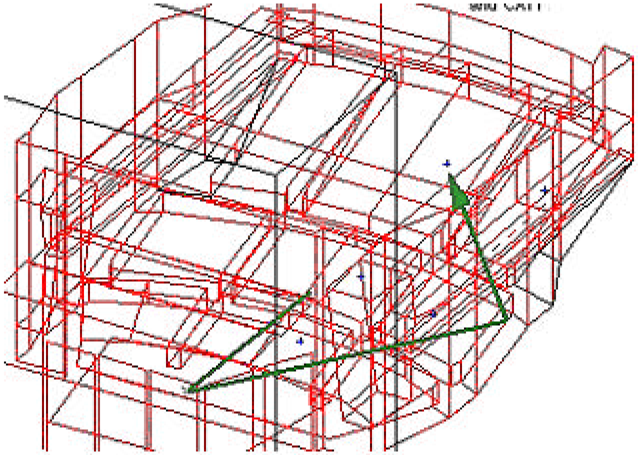
Sound examples: 5. stereo echo- 6. monaural echo

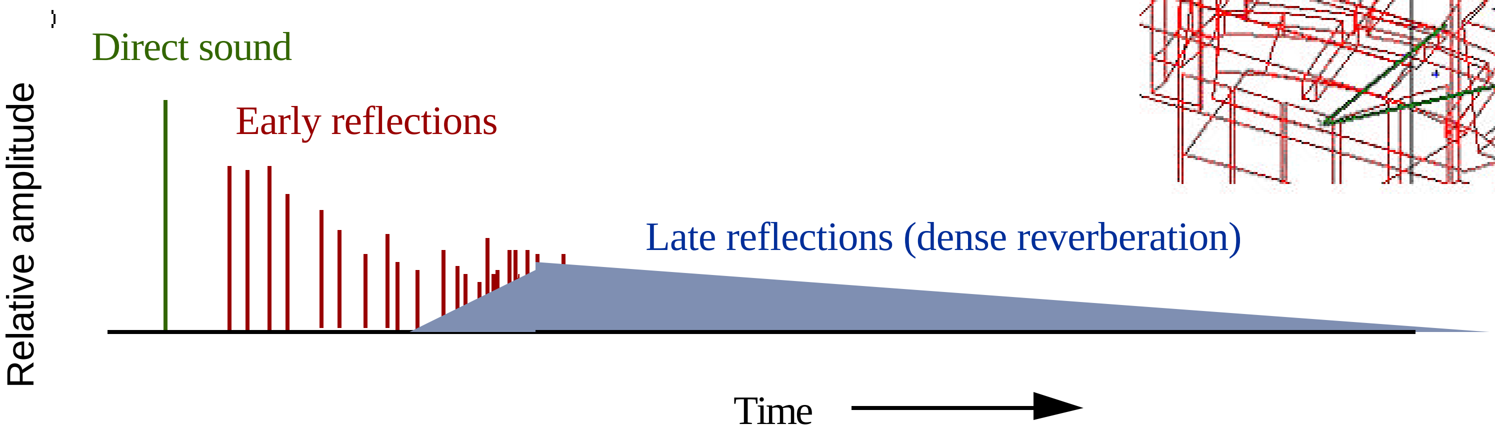
Relative to the reference condition,
spatially separated echoes create spatial percepts;
non-spatially separated echoes create timbral effects

Early and late reverberant sound fields



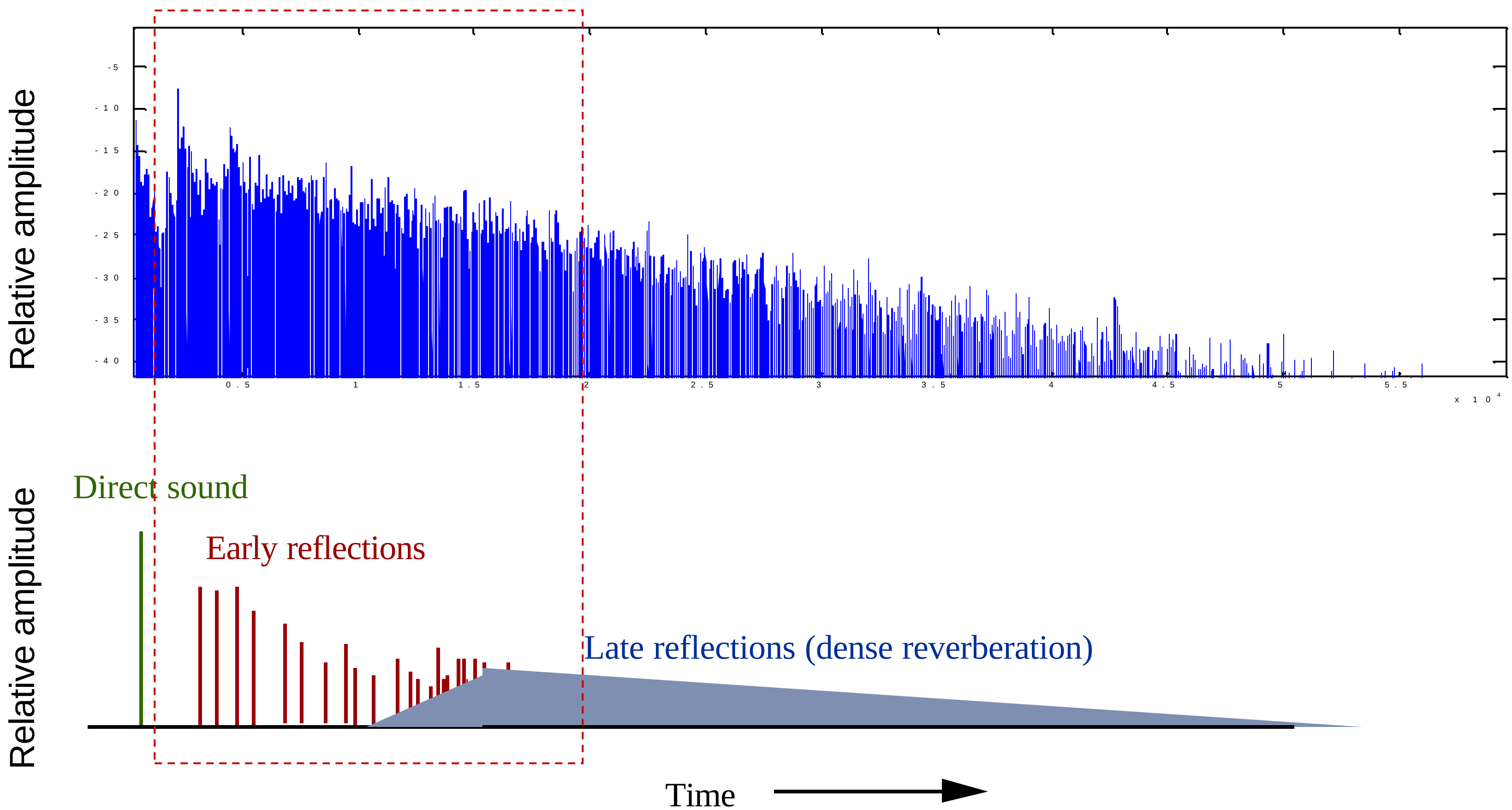
7. Audio examples:
-direct sound
-direct w/ 1st, 2nd order ERs
-direct with full auralization





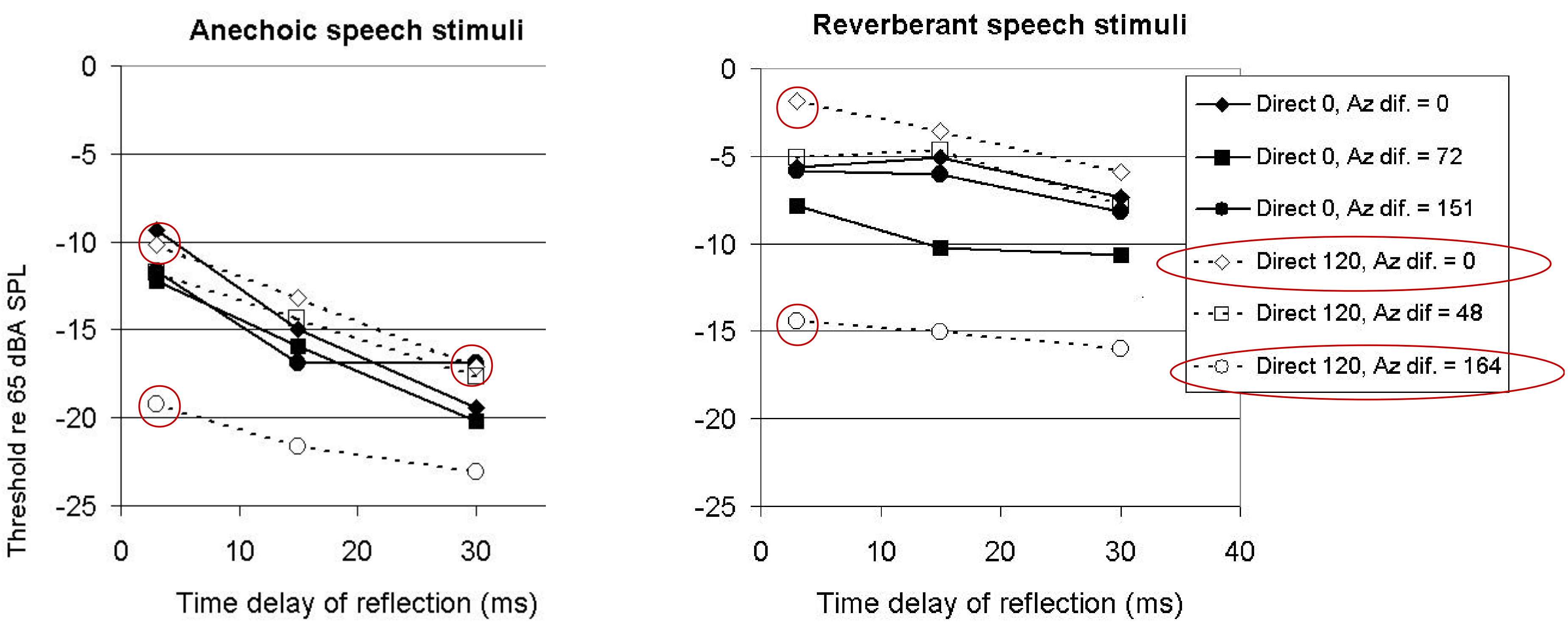
Early and late reverberant sound fields

8. audio examples: normal and 0.25 speed impulse response

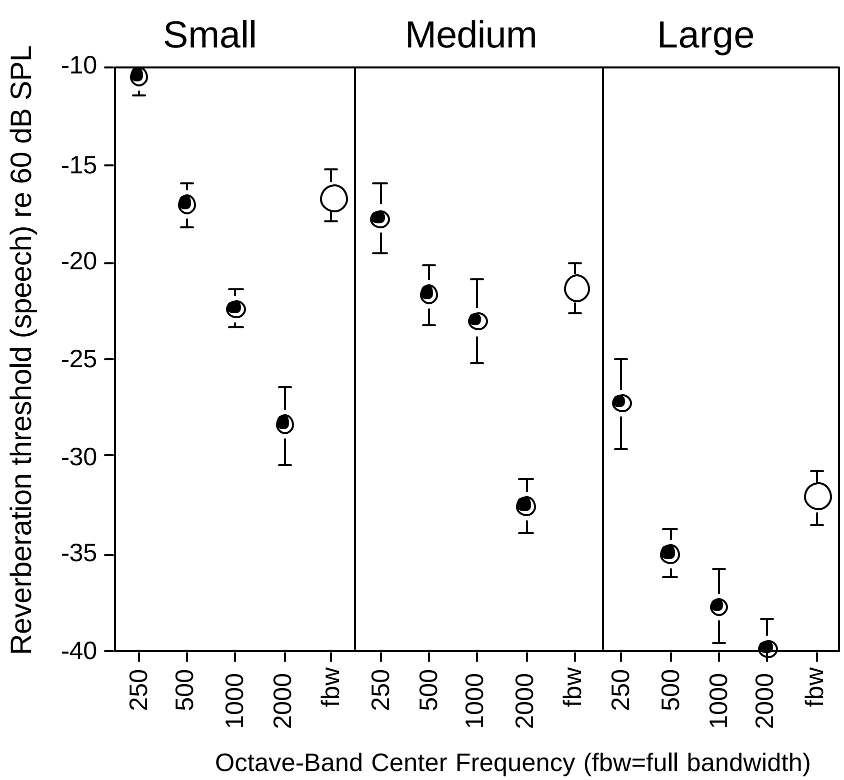


Echo thresholds

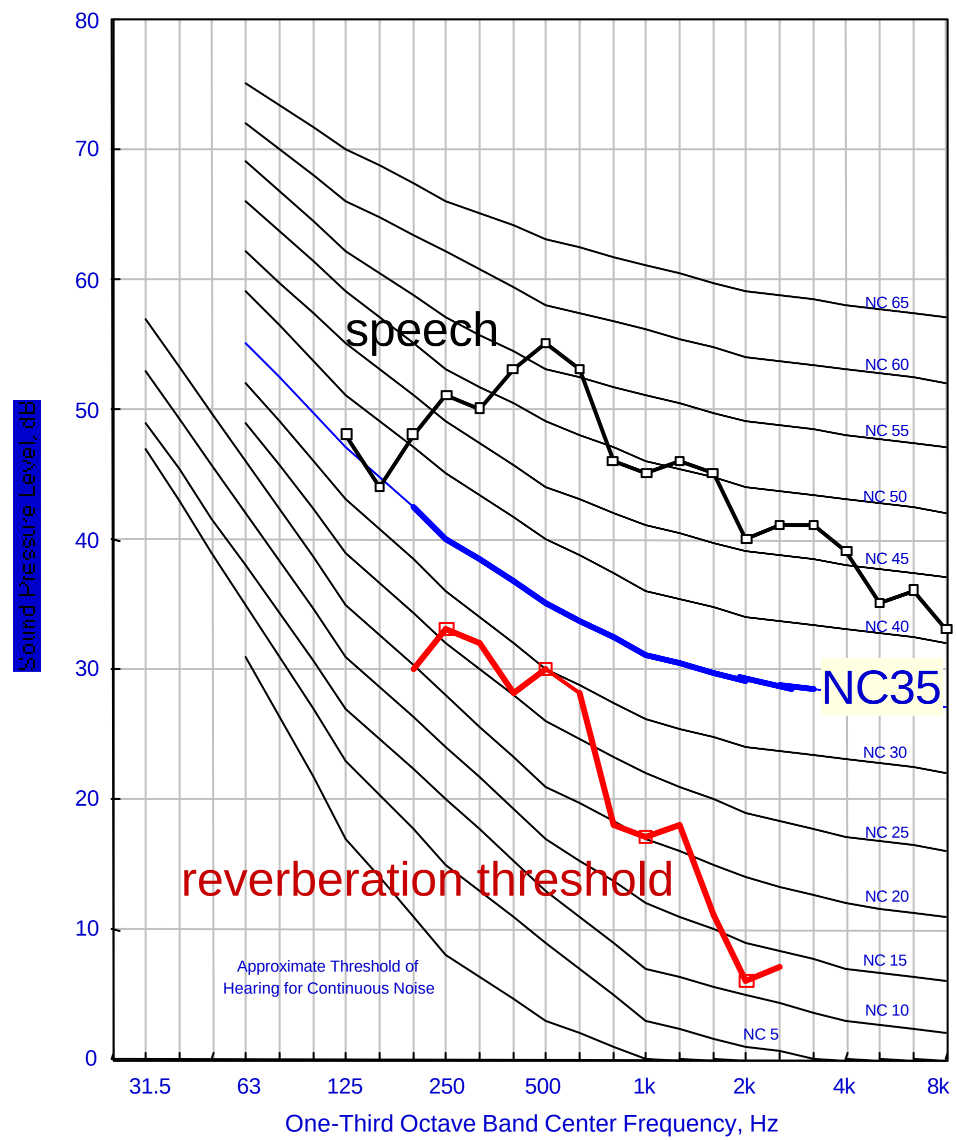
- Sensitivity can increase as much as 10 dB if echoes occur at different locations
- Late reverberation can decrease sensitivity
- Sensitivity increases with increasing time delay



Although thresholds for reverberation are relatively low, background noise (e.g., NC 35) can mask the reverberant decay.

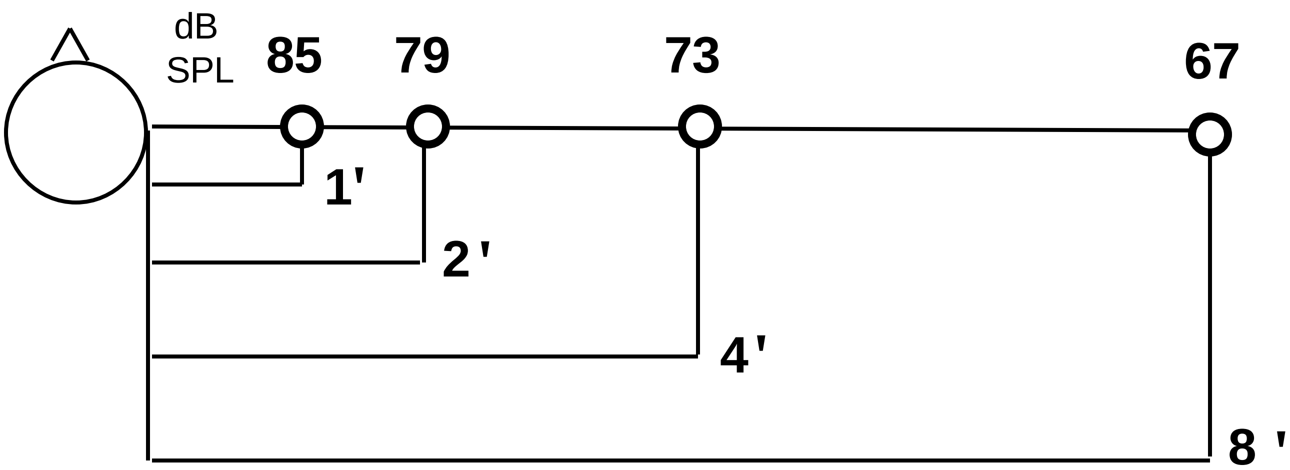


Noise Criteria (NC) curves



Distance perception: amplitude cues

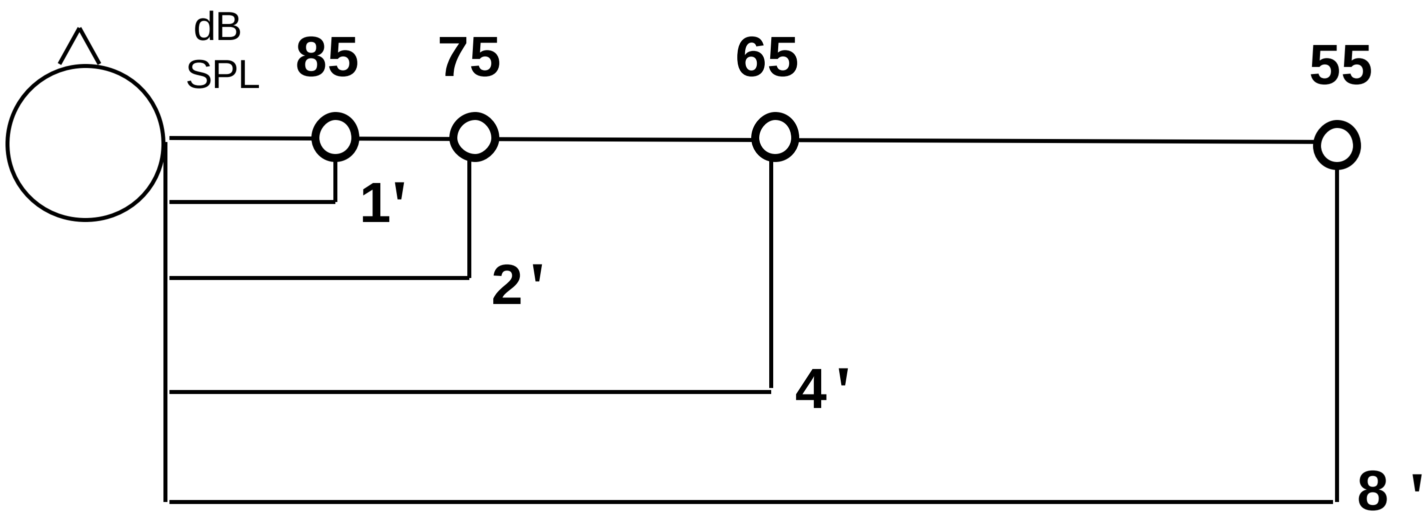
- The inverse square law states that sound decays 6 decibels per doubling of distance in a reflection-free environment.



9. sound example

Distance perception: amplitude cues

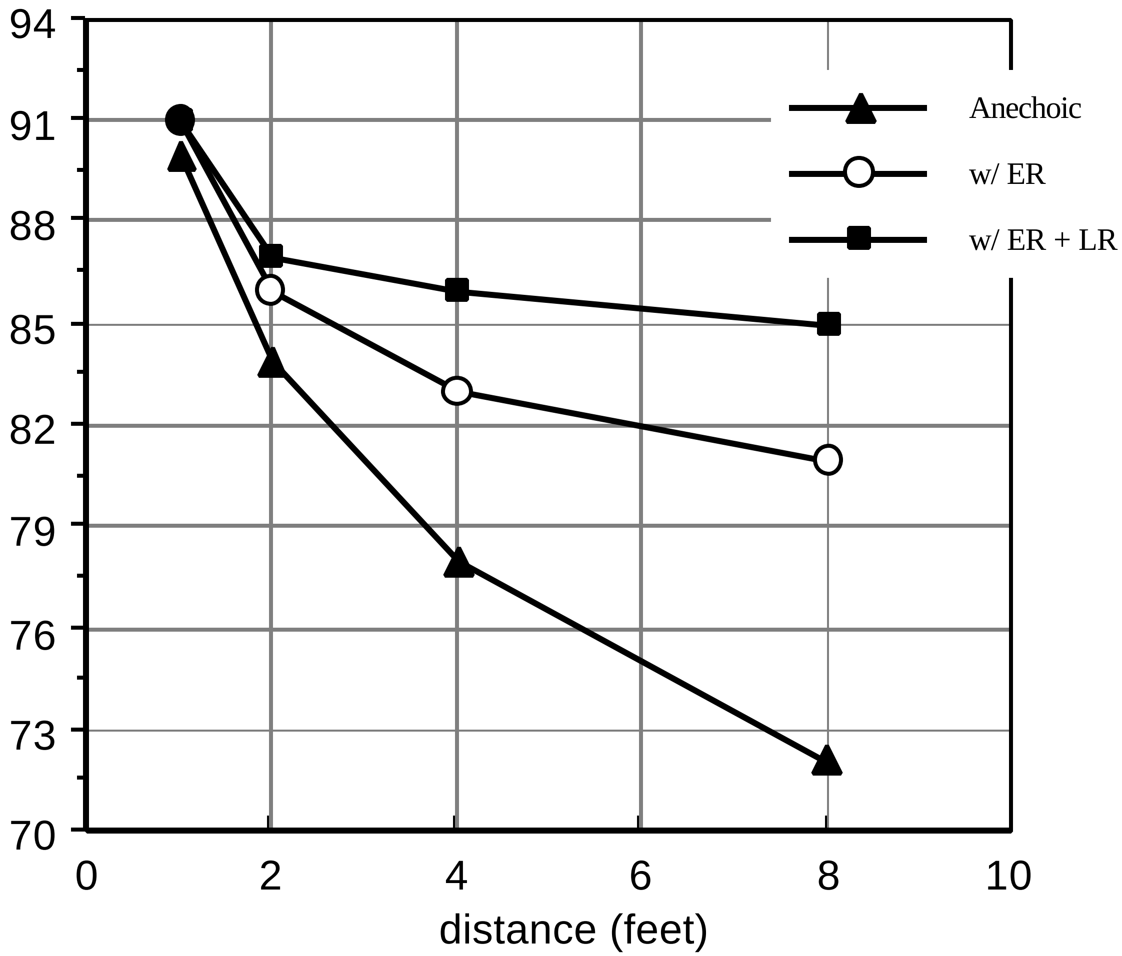
However, “half-as-loud” corresponds to a 10 dB reduction in level with distance



10. sound example

Distance perception: reverberant ratio cues

An increase in reverberant level indicates movement into the diffuse sound field

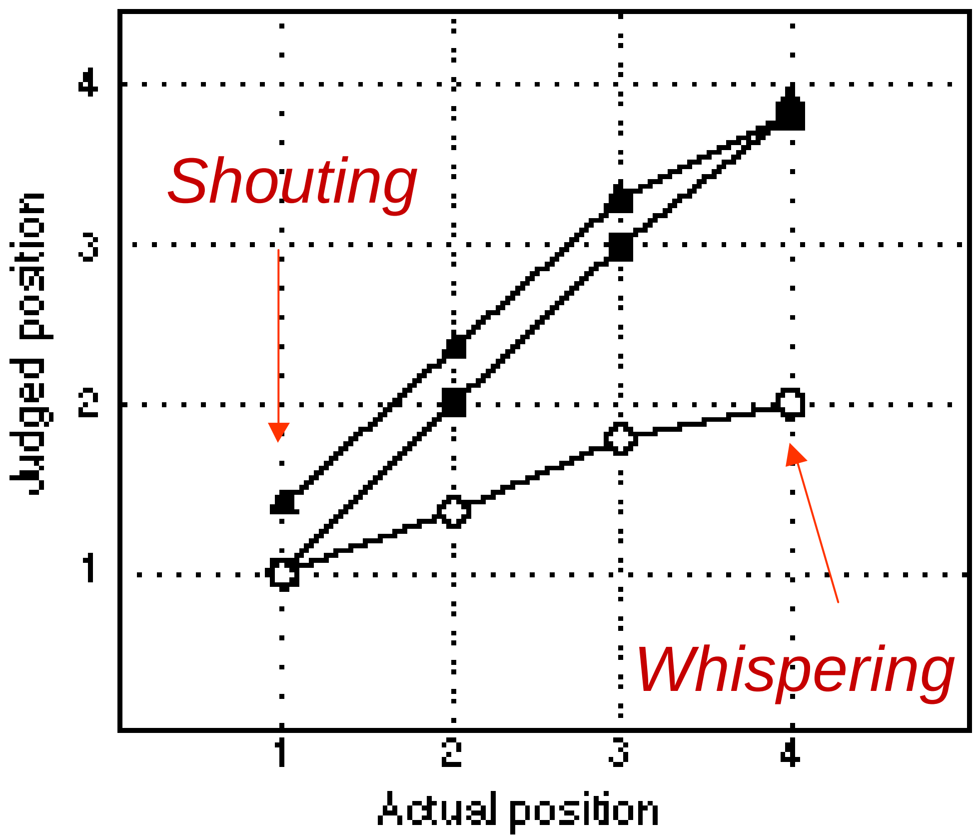


Concert Hall reverberation physical-perceptual parameters

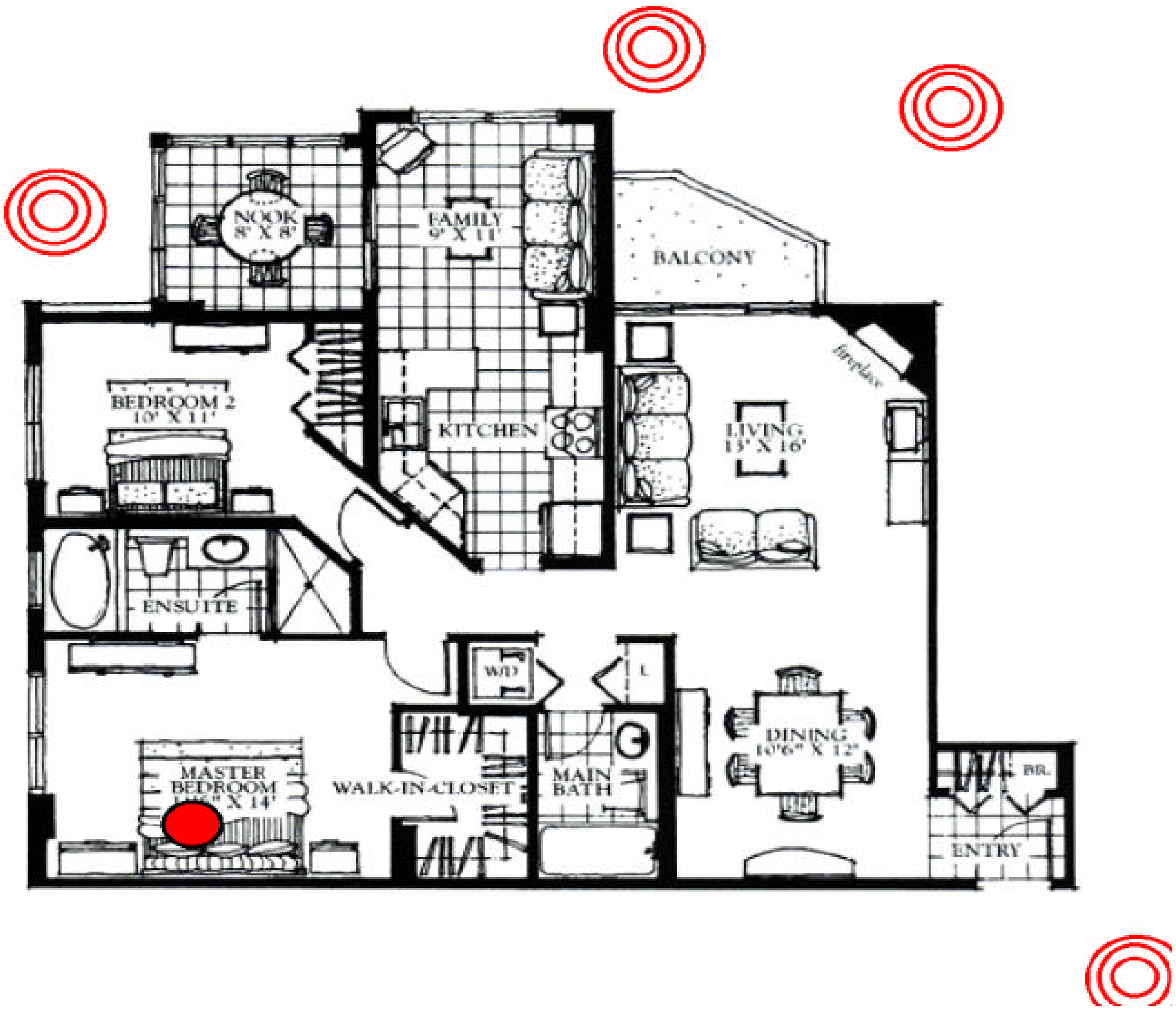
- Reverberance *(reverberation time, strength)*
- Apparent source width (ASW) *(interaural cross-correlation)*
- Envelopment *(spatial diffusion of reflections from all around)*
- Clarity *(ratio of first 50-80 ms of early sound to late sound)*
- Warmth *(ratio of bass frequency RT to mid-band RT)*

Cognitive cues; multisensory cues

Cognitive cues to distance perception



Auditory localization can be influenced or biased by cognitive mapping



Influence of visual, vibratory cues

Helicopter fly-overs

Explosions & crashes

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