Reverberation and Open-fit Hearing Aid Effects on Sound Localization Cues

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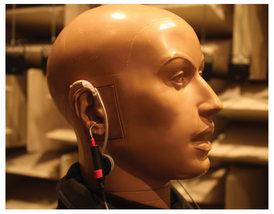
Abstract

Sound localization in the horizontal plane depends primarily on two acoustic cues: interaural time differences (ITD) and interaural level differences (ILD). These cues are susceptible to distortion in the presence of reverberation, which occurs in real rooms. Certain styles of hearing aids may additionally interfere with ITD and ILD cues. Open-fit hearing aids, for instance, mix two copies (processed and acoustic sound) with a slight processing delay (~2-5 ms). Here, we measured binaural recordings of broadband stimuli using probe-tube microphones on an acoustic manikin (KEMAR). KEMAR was fit with low-gain, linear behind-the-ear hearing aids. Noise reduction, microphone directionality and feedback suppression were disabled. Aids were coupled to comply tips with 0-3 vents, or to open domes. Sounds were presented in anechoic and simulated rooms. Binaural cross-correlation and intensity-difference calculation were used to estimate frequency-specific ITD and ILD, respectively. Consistent with previous research, ITD became erratic and ILD diminished in reverberant conditions, compared to anechoic. Effects of hearing aid venting were less clear. ILD cues remained fairly consistent with increased venting, while mid- to low-frequency ITD cues varied across vented conditions in the simulated rooms. [Supported by NIH R01-DC011548]

Methods



Recordings

ER-7 probe-tube microphones
Collected on:
An acoustic manikin (KEMAR)
10 human subjects
23 source locations (~ -61º to +61º)
Broadband noise, 500ms duration
Average of 5 repetitions

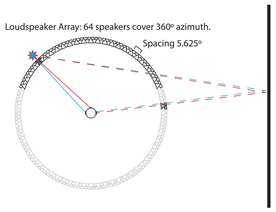
Room Specifications

Anechoic chamber
-64 loudspeakers 360º azimuth
Simulated Room
-four virtual walls (α=0.5)
-5m left/right,
-6.67m front, 3.33m behind

Analysis

ITD - Binaural Cross Correlation
-Gammatone filterbanks
-250-8000 Hz
-1 ERB per channel
-28 frequency bands

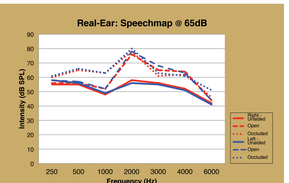
ILD – Intensity Difference Calculation
-Calculated RMS for each right & left waveform
-For each 28 frequency bands:
20 x log10 (rmsRight / rmsLeft)



Hearing Aid Fitting

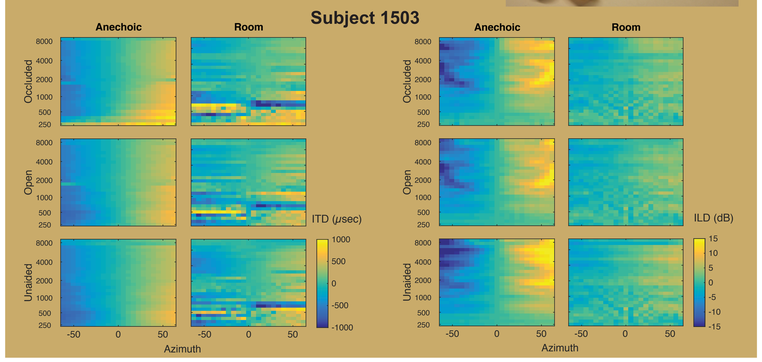
Hearing Aid Settings

-Siemens Motion 700 behind-the-ear hearing aids
-Linear processing
-Low-gain amplification
-Simulating a mild-to-moderate sloping hearing impairment
-Disabled: Noise reduction, microphone directionality, and feedback suppression features
-Verified using AudioScan real-ear measurements

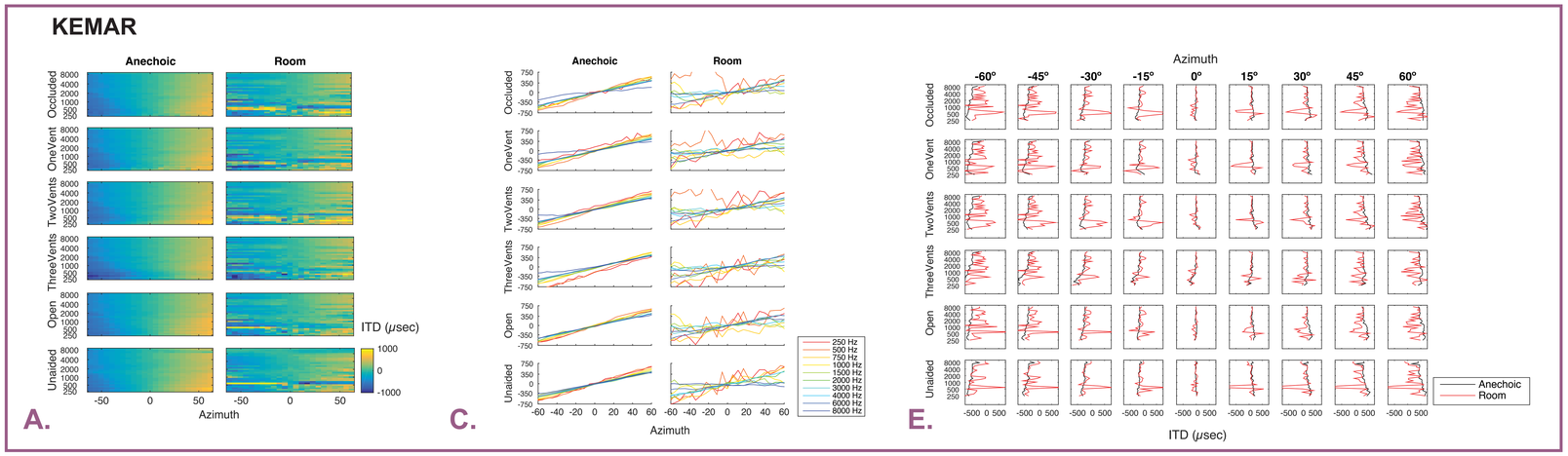


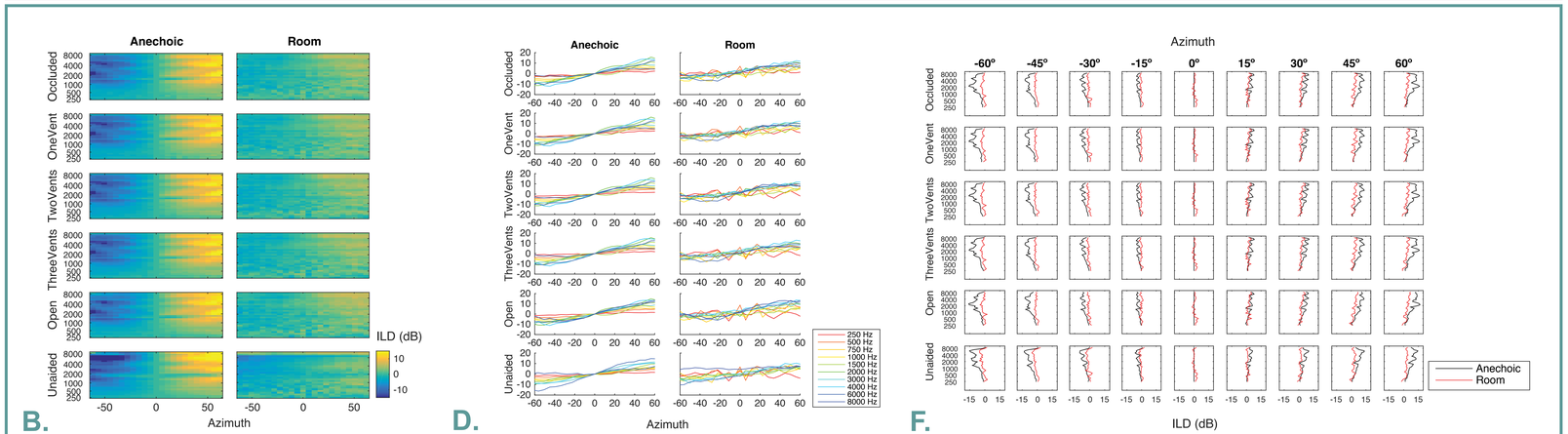
Coupling

-Comply foam inserts with 0-3 vents, comply tube adaptors
-Phonak open domes, attached to size 13 tubing
-Equal tubing length for open-fit and comply inserts



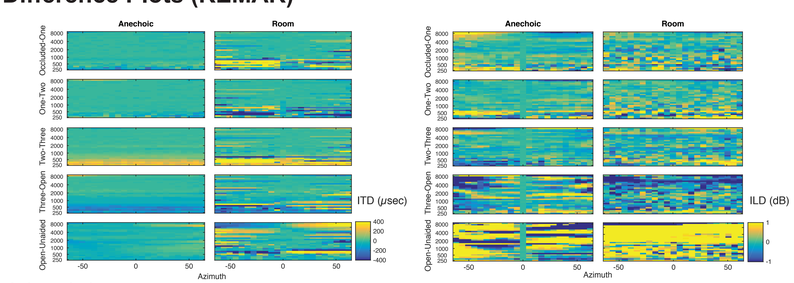
Acoustic Recordings





ITD (top panel) and ILD (bottom panel) data recorded on an acoustic manikin (KEMAR). (A,B,C,D) Panels represent aided (rows) and room (columns) conditions. (A,B) plots ITD or ILD for each 28 frequency bands (y-axis) and 23 speakers (x-axis). (C,D) plots ITD or ILD (y-axis) for 10 of the 28 frequency bands. Frequencies are represented by colored lines (reds/oranges = low frequencies, yellows/greens = mid frequencies, and blue/purple = high frequencies) across 23 speaker locations (x-axis). Individual panels represent each room and hearing aid combination.(E,F) Panels represent aided conditions (rows) across 9 speaker loactions (columns). Lines plots ITD or ILD for each room condition (Anechoic = Black, Room = Red).

Difference Plots (KEMAR)



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Summary & Discussion

Effect of Room

-Diminished ILD cues
-Erratic ITD cues

ITD in low-frequency bands show strong opposing cues. These large ITD distortions are inconsistent with ILD cues within those frequencies.

Effect of Venting

-Results across hearing aid conditions are less clear

This suggests that in most cases spatial deficits of hearing aid listening are mainly caused by signal processing (e.g., wide dynamic range compression, directional microphones, microphone location, etc.) rather than acoustical effects from venting.

While hearing aid venting does not appear to have much of an effect on interaural cues, large ITD distortions in low-frequency bands may be particularly relevant to hearing aid users with normal low-frequency thresholds wearing open-fit devices. Future work investigates behavioral responses to listeners wearing hearing aids with occluded and open-fit coupling.