Binaural-cue weighting in free-field localization of narrowband noises presented with open-fit hearing aids and in simulated reverberation

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Background

Localization in the horizontal plane primarily relies on two acoustic cues: interaural time (ITD) and level differences (ILD). Ideally, listeners receive ITD and ILD cues that are in agreement with one another. In complex environments, however, presence of reverberation will cause ILD cues to diminish and ITD cues to be erratic causing the source to appear in a different or ambiguous (i.e., diffuse) location. Younger listeners tend to perform well in reverberation compared to aged and hearing impaired populations (Helfer 1992, Helfer and Wilber 1990). Such difficulty could occur because of how listeners weight available interaural cues in the presence of reverberation.

Additionally, hearing aids are also known to alter interaural cues. ILD can be altered by dynamic-range compression (Wiggins and Seeber, 2011) and strong directional microphone technology (Picou et al., 2014). ITD cues should be accurately represented through hearing aids, but there is a potential acoustical interaction of direct and processed sound when listening with open-fit hearing aids. This interaction of binaural cues is in addition to reflections from reverberation.

As a result, listeners may adjust their strategies for localizing sounds by weighting available interaural cues differently in complex acoustic scenes. Here, we tested 10 young normal hearing listeners across hearing aid venting and reverberant scenes using narrowband low- and high-frequency noises.

Methodology

Test Conditions

Hearing Aids

1. Occluded foam tip
2. Open-dome
3. Unaided

-Linear, low-gain amplification
-Behind-the-ear (BTE) hearing aids
-Noise reduction, microphone directionality, and feedback suppression turned off

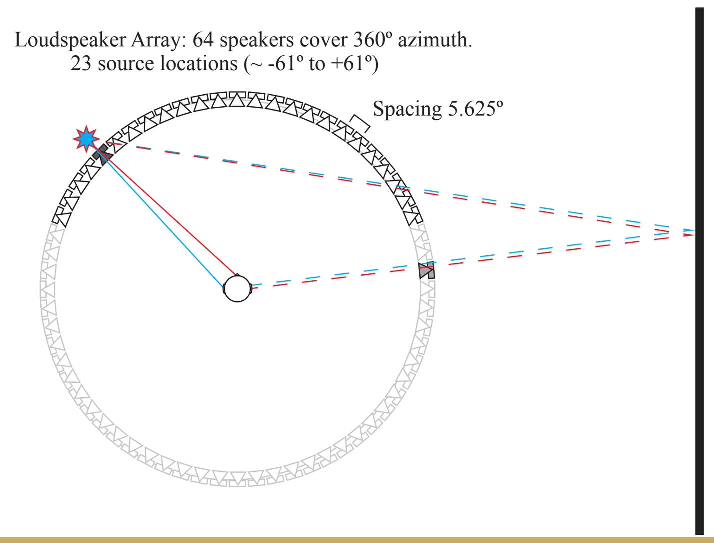
Stimuli

500 Hz
-1/6 octave noise band centered at 500 Hz
4000 Hz
-1/6 octave noise band centered at 4000 Hz
500 + 4000 Hz
-Two simultaneous 1/6 octave noise bands, centered at 500 and 4000 Hz

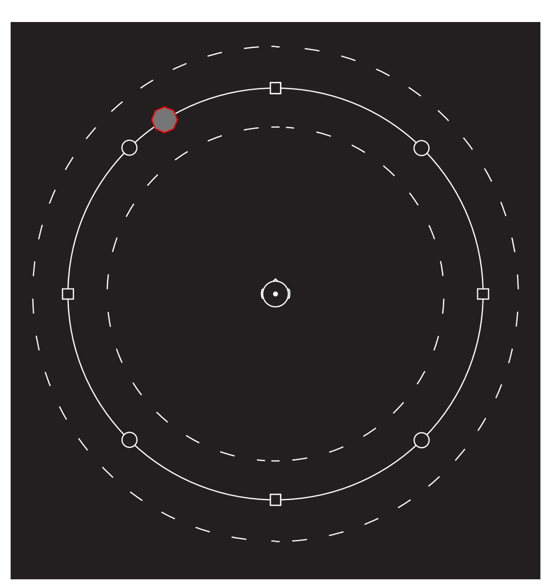
-Duration = 500 ms, ramp = 10 ms

Rooms

1. Anechoic
2. Single Reflective Surface (SRS)
-80% reflective (α=0.2)
-5m to the right, parallel to listeners forward gaze
3. Simulated Room
-four virtual walls (α=0.5)
-5m left/right, 6.67m front, 3.33m behind
-image method (Allen & Berkley, 1979)
-simulated 13 orders of lateral reflection



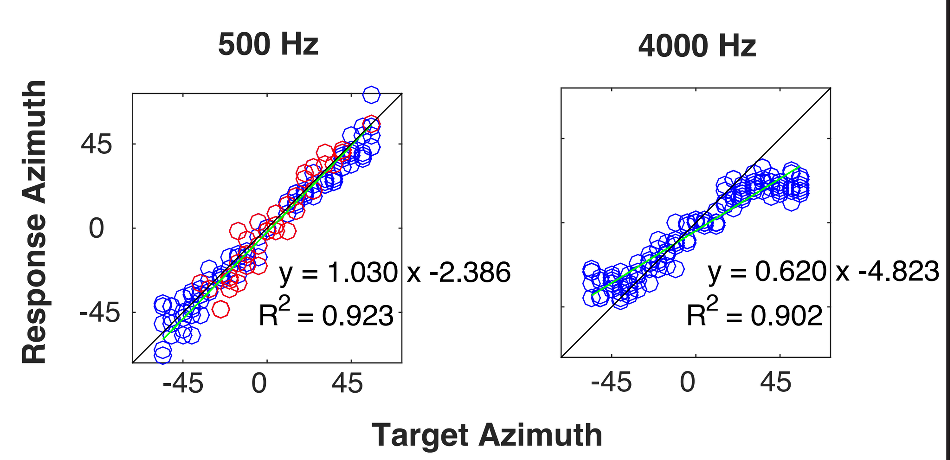
Listener Response



Listener response window - presented on a iPad during testing.

Solid ring represents speaker array with the listener represented at the center of the room. Squares indicate speakers directly in front, behind and parallel to the listener; circles represent +/-45º and +/-135º. Red circle represents a listener response.

Data Analysis



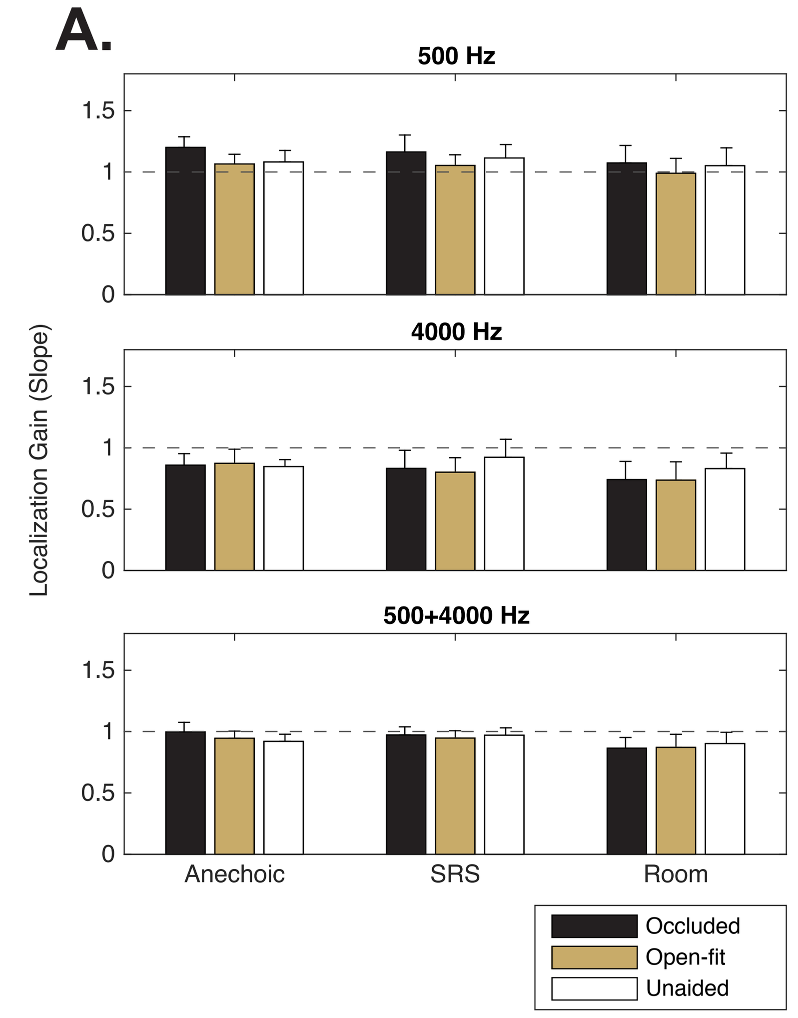
Example plots of individual data for 500 Hz (left) and 4000 Hz (right) stimuli. X-axis represents target speakers, and y-axis behavioral responses. Symbols in scatterplots are individual trials. Red circles indicate front-back confusions, mapped to frontal response azimuths. Green line represents best linear fit (equation shown).

All hearing aid, room and stimulus conditions were evaluated for:
-Localization variance (R^2)
-Localization gain (slope)
-Localization accuracy (RMS error across speakers)
-Number of front-back confusions

Results

Localization Gain

A.



RMS Error

B.

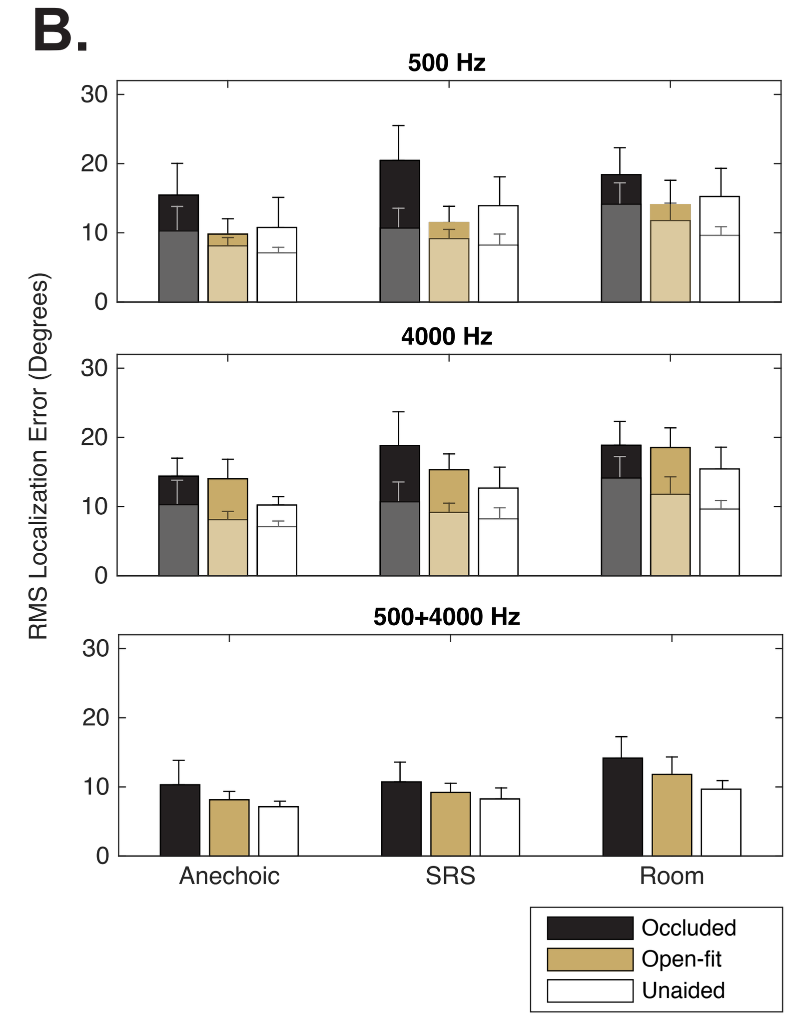


Figure (above). Bars represent mean data and standard error for 10 subjects.
Panel A shows localization gain for each stimulus type (500, 4000, 500+4000 Hz). Dashed line plots slope of 1.
Panel B represents RMS localization error across 23 target locations. Results for 500+4000Hz are superimposed onto the 500 and 4000 Hz subplots.

Summary & Discussion

Effect of stimulus type

Localization gain
500 Hz - slope > 1 (expansion)
4000 Hz - slope < 1 (compression)
500+4000 Hz - slope ~1

Localization error
Less RMS error for 500+4000 Hz vs. either 500 or 4000 Hz in isolation

Front-back confusions
Fewer front-back for 500+4000 Hz vs. either 500 Hz alone

Localization variance (R^2)
Less residual variance for 500+4000 Hz vs. either 500 or 4000 Hz in isolation

Effect of hearing aid venting across room type

Localization gain
500 Hz - Occluded > Open & Unaided for Anechoic condition
4000 Hz - Occluded & Open < Unaided with reverberation (SRS & Room)
500+4000 Hz - These differences were resolved in the 500 + 4000 Hz condition.

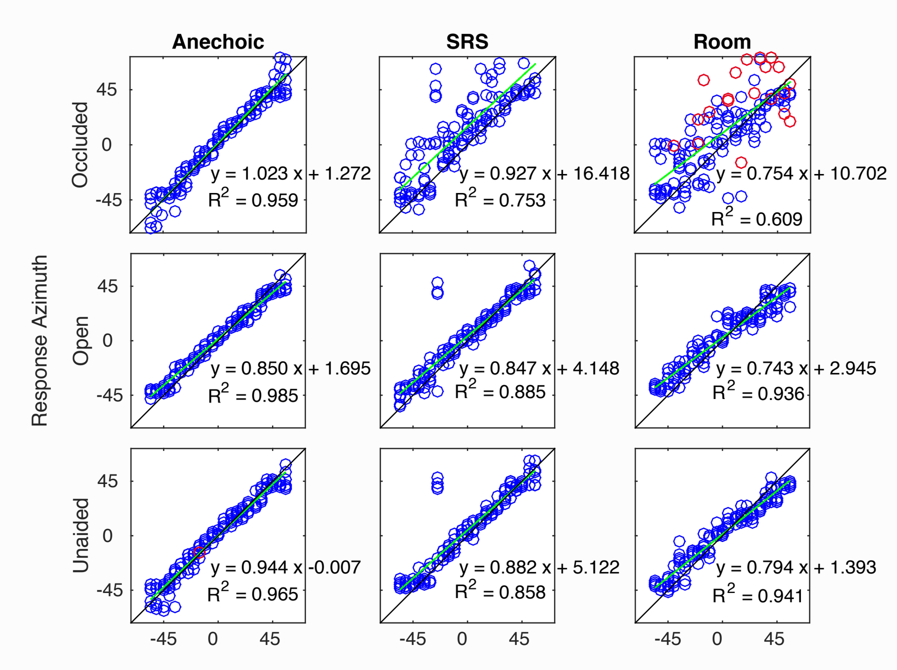
Localization error
500 Hz - Occluded > Open for all room conditions
4000 Hz - Occluded & Open > Unaided for all room conditions
500+4000 Hz - These differences were resolved in the 500 + 4000 Hz condition for Anechoic and SRS.

Young, normal-hearing listeners have most *difficulty listening with occluding hearing aids* likely because this condition doesn't allow access to unprocessed acoustic cues and BTE microphone placement eliminates pinna cues.
Additionally, listeners tested here show *compressed high-frequency localization* of narrowband noise in reverberation when wearing BTE hearing aids, regardless of venting.
These results were *mostly resolved* when low- and high-frequency noises were played simultaneously (i.e., with broadband stimulation).

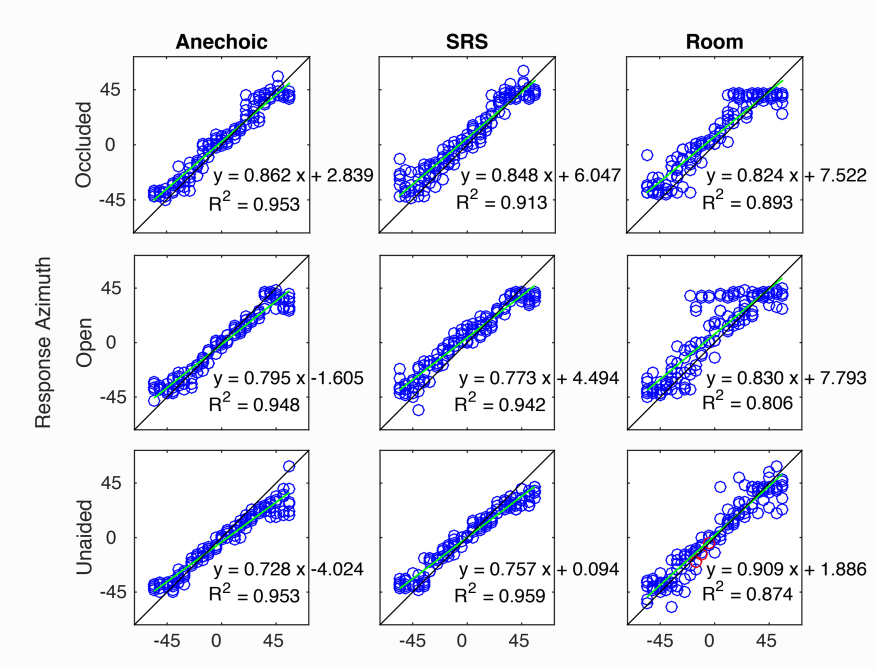
Future Directions - Compare behavioral results with measured ITD, ILD.
Evalute open-fit hearing aid candidates (normal low-frequency hearing, mild to moderate 4000 Hz hearing).

Example Individual Data

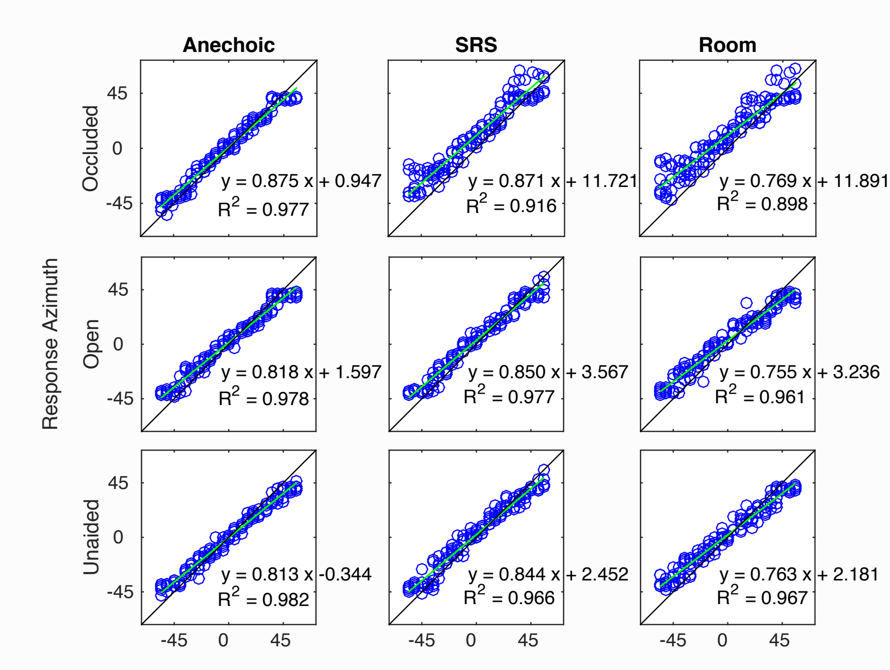
500 Hz



4000 Hz



500+4000 Hz



Figures show listener 1406's individual responses for 500 Hz (left), 4000 Hz (middle), and 500+4000 Hz (right). Each set of plots show data for room (columns) and aided (rows) conditions.

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References:
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Wiggins & Seeber (2011), *JASA* 130(6):3939-3953