# HORIZONTAL LOCALIZATION WITH PINNA-SHADOW COMPENSATION ALGORITHM AND INTER-EAR COORDINATED COMPRESSION

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## INTRODUCTION

The physical presence of pinna attenuates high frequency sounds that originate from the back and sides by an average of 5 dB from 2 kHz to 8 kHz. This attenuation provides an important acoustic cue for normal hearing individuals to localize sounds along the median plane. For sounds arriving from the sides the acoustic paths from the sound source to the two ears are not identical. This results in interaural time difference (ITD) or interaural level difference (ILD) cues between the two ears. Normal hearing listener may use these cues to aid localization for sounds arriving from the sides.

The use of BTE hearing aids with omnidirectional microphone placed on top of the pinna may eliminate the pinna localization cues. If aided localization is the primary consideration in a hearing aid, we could correct for the absence of the pinna shadow so that, despite using a BTE with an omnidirectional microphone, the wearer will still have the "normal" localization cues. Digital pinna hearing aid feature was developed to compensate for the difference in input measured between an unaided ear and an aided ear with an omnidirectional BTE hearing aid. The natural attenuation of sounds originating from behind the listener was created by using a hypercardioid polar pattern above 2 kHz while not altering the in-situ directivity below 2 kHz.

For sounds arriving from the sides, the use of wide dynamic range compression (WDRC) hearing aid may reduce the magnitude of the natural ILD cue. WDRC hearing aid may apply less gain on the side of the sound source, while providing more gain at the opposite side where the traversing sound has been attenuated by the natural head shadow. The natural ILD can be restored by coordinating the gain between the two hearing aids. The hearing aid used in the current study included functionality, where each input received by one hearing aid was shared wirelessly with the other hearing aid at a rate of 21 times per second. The gain calculated for the target sound side was used in both hearing aids.

The current study examined the localization performance of hearing impaired listeners when using a behind-the-ear (BTE) hearing aid incorporating the digital pinna feature and the inter-ear coordinated compression.

## SUBJECTS

Fifteen listeners aged 28 – 83 yr (mean = 71 yr) with bilateral sensorineural hearing loss ($PTA_{right}$ = 48.6 dB HL, $PTA_{left}$ = 50.1 dB HL) participated in the study. Symmetry of the hearing loss between ears was on average within 15 dB at any frequency, with the exception of two listeners who had a threshold difference of 20-25 dB at a single frequency. On average, the participants had worn hearing aids for 9.2 yr (SD = 6.1 yr).

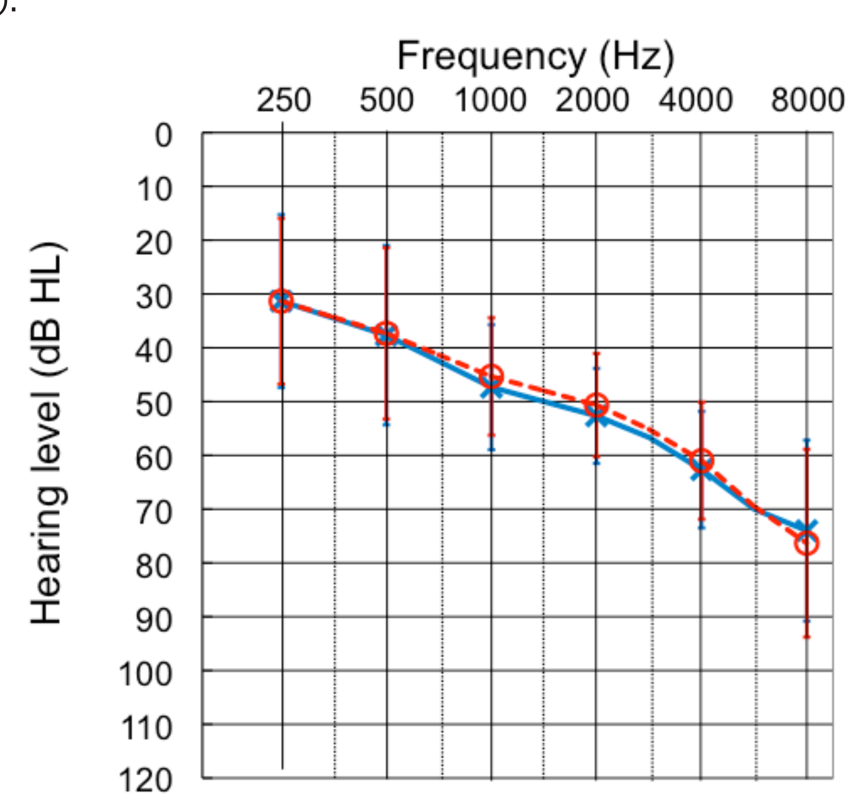



Figure 1. Average pure-tone audiometric thresholds for right (red) and left (blue) ears for participants (N=15). Error bars show ±1 SD.

## METHODS

### Hearing instrument

Each subject was fitted binaurally with Widex Clear440 m-CB BTE hearing aids using custom earmolds.

**Hearing aid features:**
15-channel wide dynamic range digital hearing aid. 32 kHz sampling rate of the A/D stage with 20-32 bit resolution. Frequency response from 100 Hz to 8350 Hz (ANSI, 2003). Slow-acting compression with attack time of up to 2 sec in each of the 15 channels.

**Hearing aid programs/test conditions:**

i. Digital-Pinna off, Inter-ear compression off **(Omni)**
ii. Digital-Pinna on, Inter-ear compression off **(Omni+DP)**
iii. Digital-Pinna off, Inter-ear compression on **(Omni+IE)**
iv. Digital-Pinna on, Inter-ear compression on **(Omni+DP+IE)**
v. Unaided **(Unaided)**

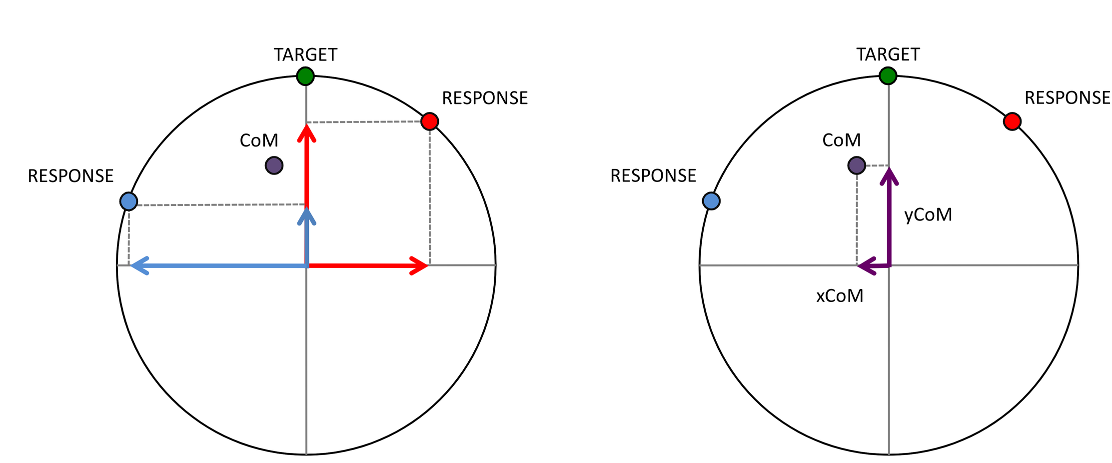
### Procedures

**Horizontal localization** performance was measured using a 12-loudspeaker array distributed evenly on 360° horizontal plane around the listener with 30° resolution. The listeners were seated 1 meter from the loudspeakers. The target stimulus was a three second duration speech sample "Search for the sound from this speaker". The targert stimulus was presented in a random order from one of the loudspeakers. The task was to indicate the perceived location of the target by touching a corresponding loudspeaker on a touch screen monitor. The stimulus was presented from each test azimuth a total of three times during each test trial.

**Localization training** was provided prior to localization evaluation. In-lab and take-home training programs with adaptive difficulty were used. These training programs incorporated feedback and learning opportunities. The stimuli used during the training was different from the target stimulus used in the current study.

**Center of Mass (CoM)** method (Edmondson-Jones et al. 2010) was used to report the error characteristics of sound localization performance. The CoM analysis is represented visually with a unit circle centered at the origin in the Cartesian coordinate system in the Euclidean plane. Coordinates for a single error response of θ are defined as X = (sin θ, cos θ) and for a sample of N observations sample mean is defined as:

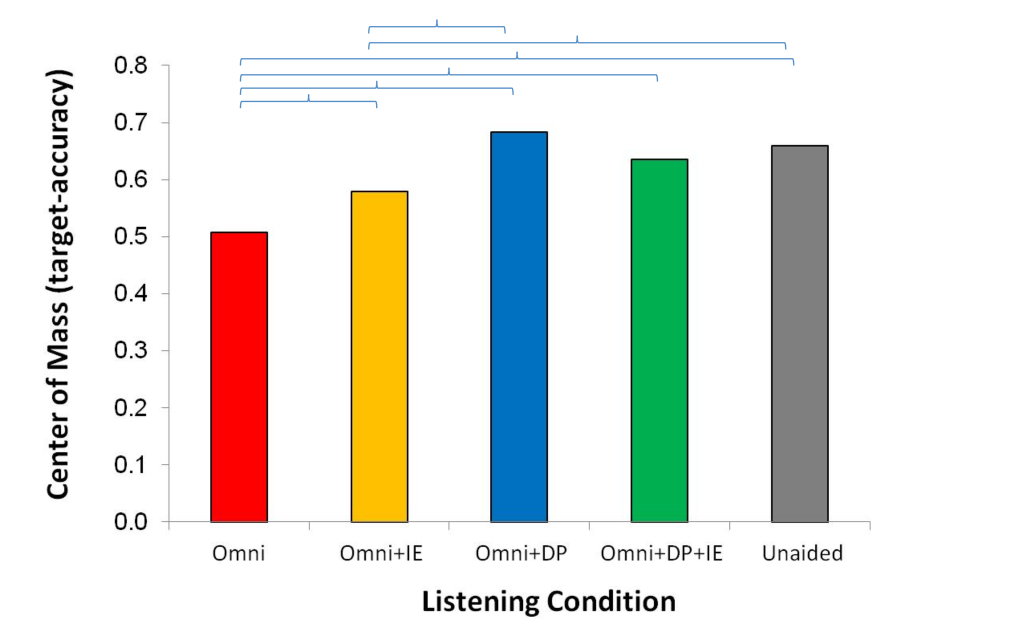
$$\bar{X}=\left(\frac{1}{N}\sum_{i=1}^{N}\sin\theta_i,\frac{1}{N}\sum_{i=1}^{N}\cos\theta_i\right)$$




The center of mass (CoM) is the average location of all the data points having an equal weight of a unit mass. When the responses are perfectly correct the yCoM will be 1 while xCoM will be 0. Thereby, yCoM is a measure of the target accuracy indicating how close the responses are from the perfect reponses, and xCoM is a measure of lateral accuracy indicating the responses distance from the origin.

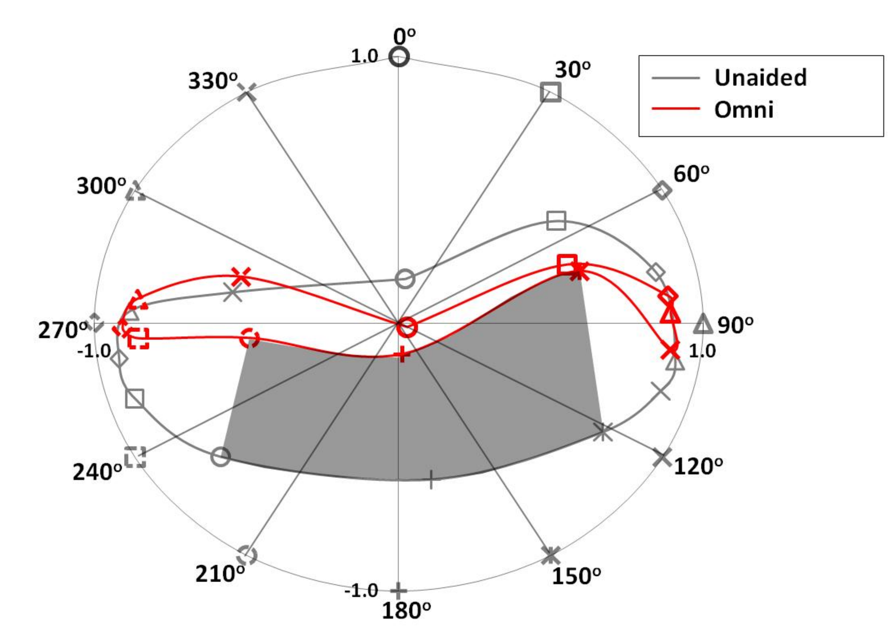
## RESULTS

The averaged localization (target-accuracy) for all participants under the five test conditions were 0.51 (Omni), 0.58 (IE), 0.68 (DP), 0.64 (IE+DP), 0.66 (Unaided) (Figure 3). The localization performances (i.e., target accuracy at different loudspeakers) between two listening conditions were compared with one-way ANOVA.



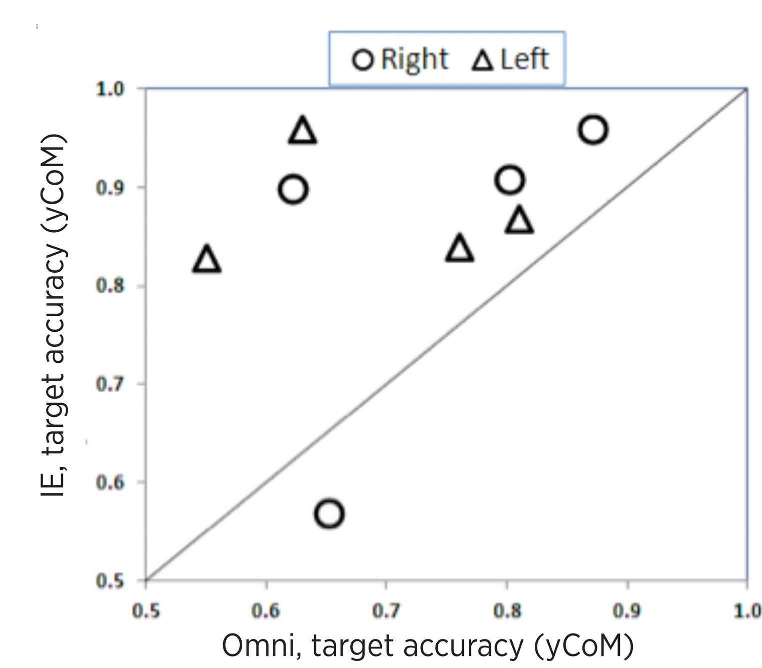

Averaged localization performance for all participants (N = 15). Test conditions included omnidirectional microphone with digital pinna "off" and "on" in combination with inter-ear compression "on" and "off" and unaided. Comparisons where statistical significance was reached (p < .05) were shown with a connector.

### Unaided vs. Aided localization with Omni




Localization performance unaided (gray) and with omnidirectional microphone (red). The gray area indicated the quadrant with significant (p < .05) difference between the test conditions. The use of omnidirectional microphone in a BTE hearing aid may eliminate the natural pinna cue used for front-back localization. In fact, significant difference in performance between the unaided and Omni conditions was observed in the back quadrant.

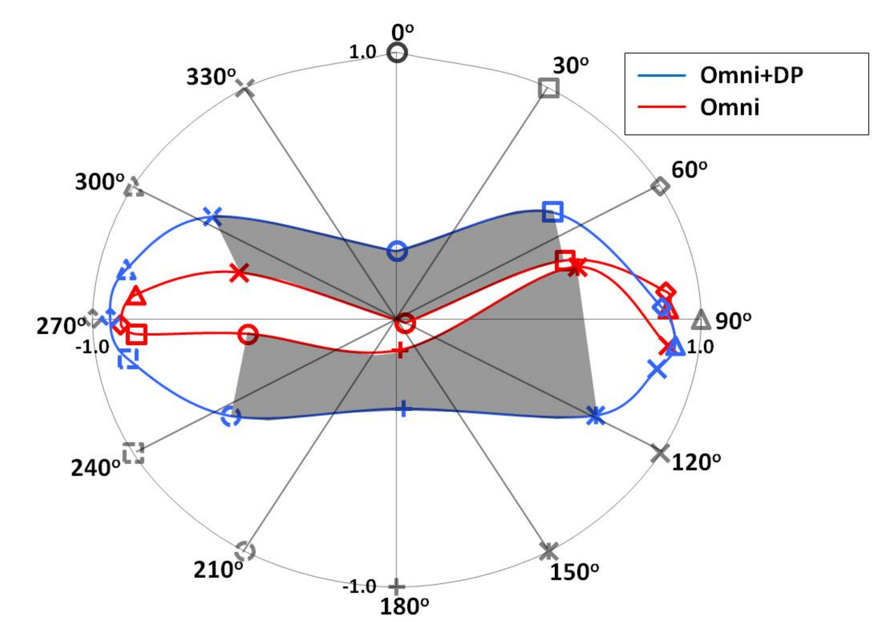
### Effect of coordinated compression




Most participants reached a high level of accuracy for sounds arriving from the sides. Individual differences however existed. We looked at the individual performance of the listeners with lower level of performance. Scatter-plot comparing individual localization performance between the Omni (x-axis) and IE (y-axis) conditions for sounds arriving from the left and right quadrants for the four poorest performers (yCoM < 0.87) was shown. Performance was in general better with the IE than the Omni condition ($F(1,14) = 5.81$, $p = 0.03$, $\eta^2 = 0.29$, power =0.6).

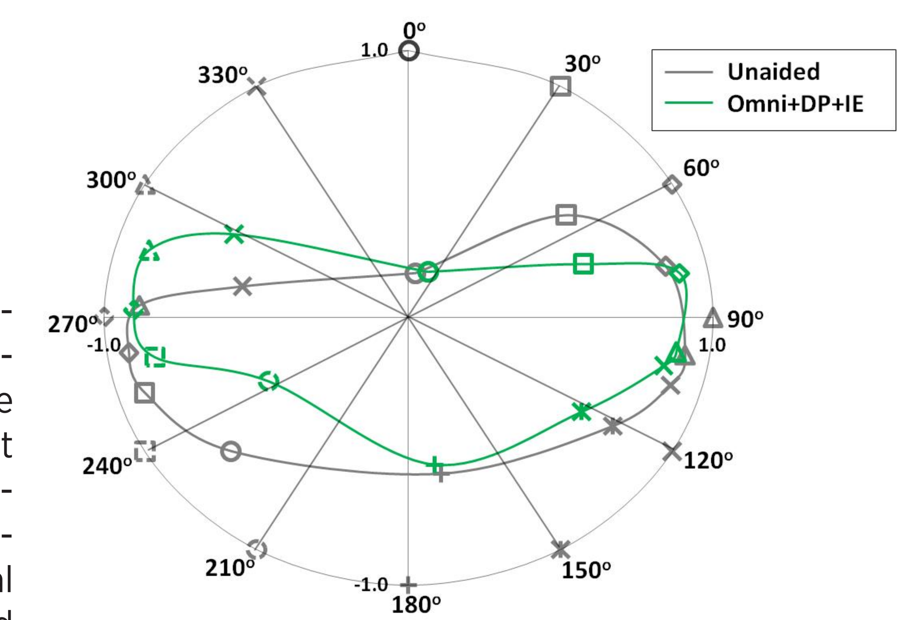
## RESULTS (CONT.)

### Effect of Digital Pinna




Localization performance with omnidirectional microphone (red) and with omnidirectional microphone with DP (blue). Digital pinna was designed to correct for the absence of the pinna shadow in a BTE hearing aid with an omnidirectional microphone. In fact, the localization performance was better (p < .05) with the DP than with the Omni condition in the front and the back quadrants.

### Unaided vs. Aided localization with DP and IE




Localization performance unaided (gray) and with omnidirectional microphone with DP and inter-ear coordinated compression (green). Unlike the Omni condition, no difference (p < .05) was seen in performance between unaided and the DP+IE conditions for any quadrant. In other words, the use of the digital pinna and inter-ear coordinated compression in a BTE fitting retained the localization performance achieved unaided.

## CONCLUSIONS

The present study showed that the use of digital pinna feature, as implemented on the hearing aid in the current study, improved front-back localization accuracy in the horizontal plane over a BTE hearing aid with and omnidirectional microphone. We also demonstrated that inter-ear coordinated compression was providing a helpful cue for localization for those listeners who had poorer aided localization performance for sounds arriving from the sides. It is worth noting that the effect of the coordinated compression on localization may have been lessened by the slow acting compression used in the study hearing aid. The unaided localization performance was better than aided performance when using an omnidirectional microphone alone. However, the use of digital pinna feature together with inter-ear coordinated compression was succesful in restoring the compromized aided performance. Improved localization ability may lead to improved speech understanding in the real world as the listener can turn her head and focus the auditory and visual attention to the direction of the speaker. Also, the improved localization ability has safety benefits, such as the capability to locate vehicles in traffic.

## REFERENCES

Edmondson-Jones M, Irving S, Moore DR, Hall DA. (2010) Planar localization analyses: A novel application of a centre of mass approach. Hear Res 267:4-11.