PERCEPTUAL EVALUATION OF A BINAURAL BEAMFORMING ALGORITHM

Jumana Harianawala, Au.D., Susie Valentine, Ph.D. and Ivo Merks, Ph.D.

Starkey Hearing Technologies

Introduction

One of the most common ways to improve listening in background noise is by using directional microphone arrays *within one hearing aid* (termed bilateral hearing aids). Additionally, with the advent of wireless technology, microphone arrays *across two hearing aids* (termed binaural beamforming hearing aids) have been used to provide an increased SNR.

The binaural advantage for speech recognition in reverberant environments and a background of noise is very well documented for both listeners with and without hearing loss (Bronkhorst & Plomp, 1992). The magnitude of this binaural advantage (~3 dB) remains unchanged with bilateral omnidirectional or bilateral directional hearing aids (Ricketts, 2001). However, binaural beamforming hearing aids may be able to provide additional benefits for speech recognition.

Adding signals from two coherent sound sources provides a 3 dB sound pressure advantage (Speaks, 1999). Therefore it is reasonable to expect that adding the input signals of the binaural hearing aids will result in gain improvements of about 3 dB when compared to bilateral hearing aids. One limitation of a binaural beamforming is that often the end result is a *single* signal with an improved speech-to-background ratio. This single signal is then presented diotically. This means that the benefits normally obtained from binaural processing, which are needed for spatial hearing are lost, such as interaural time difference (ITD) and interaural level difference (ILD) (Desloge *et al*., 1997).

The goal of this study was to investigate the perceptual performance of a binaural beamforming hearing aid compared to bilateral hearing aids.

Methods & Results

BINAURAL BEAMFORMING ALGORITHM

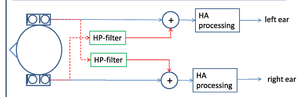


Figure 1: Schematic of an implementation representing a high-pass binaural beamformer.

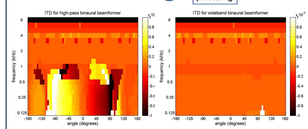


Figure 2: Shows the interaural time difference map, ITD as a function of frequency and angle, between the high-pass implementation of a binaural beamformer (left panel) and a wideband implementation of the binaural beamformer (right panel).

- The individual signals are high-passed in order to preserve any interaural cues needed for binaural processing, that would otherwise be lost in a wideband implementation (Desloge *et al*., 1997).
- Information from each individual hearing aid is first high-passed at cutoff of 750 Hz
- The filtered signal from each hearing aid is added to the hearing aid processing from the contralateral ear
- The combining of the signals from two different microphones produces a narrow polar directional pattern.

PARTICIPANTS

- 7 participants with normal hearing sensitivity

Hearing in Noise Test (HINT)

- Adaptive HINT was administered using 3A insert earphones
  - Speech = 55 dBSPL (adapted)
  - Noise = 65 dBSPL (fixed)
- The hearing aids were programmed to a linear version of eStat Starkey's proprietary fitting formula for a flat 40 dBHL hearing loss.
- To simulate the noise field, impulse responses were measured from an 8 loudspeaker array using standard BTE placed on KEMARs ears. Correction filters were applied such that the ear-canal response of the stimuli played over the 3A insert earphones matched the hearing aid response measured on KEMAR.

HINT Results

- RMANOVA showed a significant main effect of hearing aid condition ($F(2,12) = 66.288$, $p < 0.001$). Suggesting an improvement in speech recognition with changing hearing aid condition.
- The pairwise comparison (Tukey Test) revealed a significant difference between omnidirectional and both directional conditions.
- The difference between fixed directional and binaural conditions was 1.6 dB, but not significant.

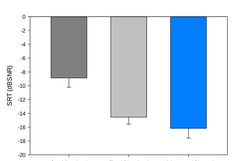


Figure 3. Average HINT scores for 7 participants in dBSNR as a function of hearing aid conditions. Error bars show one standard deviation.

Methods & Results

Localization

- Participants were fit with standard BTE with an occluded earmold.
- The hearing aids were programmed to a linear version of eStat Starkey's proprietary fitting formula for a flat 40 dBHL hearing loss.
- Four hearing aid conditions were tested
  - Bilateral Omnidirectional (OD)
  - Bilateral Fixed Directional (FD)
  - Wideband Binaural Beamformer (WB BB)
  - High-passed Binaural Beamformer (HP BB)

Frontal Field Localization

- 13 speaker array
- Single words
  - Fixed level of 65 dBSPL
  - Roved +/- 3dB around 65dBSPL
- 273 trials per hearing aid condition

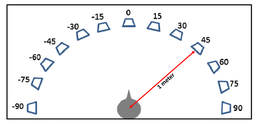


Figure 4. Diagram of the frontal field localization array of 13 loudspeakers spaced in 15° intervals. Participants were seated in the center of the array at a distance of 1 meter from each loudspeaker.

Front-Back Localization

- 7 speaker array
- Single words at 65 dBSPL
- 49 trials per side per hearing aid condition
- Participants identified the target speaker using a laptop for both localization tasks. Training and Reference were provided for each condition.

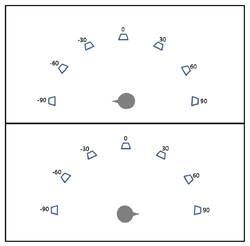
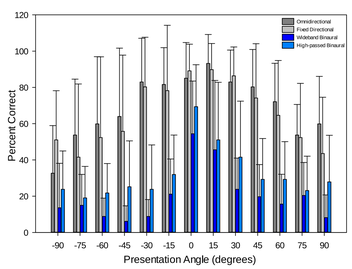


Figure 5. Diagram of the front back localization array of 7 loudspeakers spaced in 30° intervals. Participants were seated in the center of the array at a distance of 1 meter from each loudspeaker. Test was conducted with array to the right & left for each condition.

Frontal Field Localization Results

- RMANOVA showed a significant main effect of hearing aid condition ($F(3,18) = 26.147$, $p < 0.001$). Suggesting that localization ability changed with changing hearing aid condition.
- The pairwise comparisons (Tukey Test) revealed a significant difference for OD vs. both WB BB and HP BB; FD vs. both WB BB and HP BB. No significant differences were noted.
- There was no significant interaction between hearing aid condition and presentation levels.

Figure 6: Comparison of mean frontal field sound localization ability of 7 participants for all four hearing aid conditions (omnidirectional, fixed directional, wideband binaural beamformer and the high-passed binaural beamformer). Results are collapsed between fixed level and roved level, because no significant difference was found. Error bars show one standard deviation.



Methods & Results

Frontal Field Localization Results

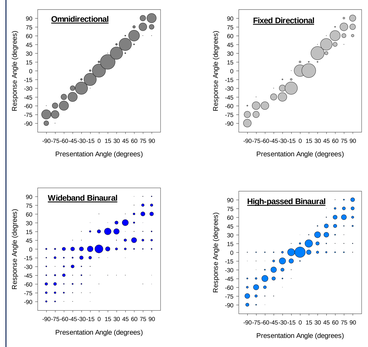


Figure 7: The average response patterns produced by 7 participants when tested with all four hearing aid conditions. Data are pooled across levels. Points along the diagonal shows accurate localization performance . Positive and negative azimuths represent right and left plane, respectively.

Front-Back Localization Results

- RMANOVA showed a significant main effect of hearing aid condition ($F(6,18) = 13.657$, $p < 0.001$). Suggesting an effect of hearing aid conditions on front-back localization performance.
- The pairwise comparison (Tukey Test) revealed a significant difference between OD vs. both binaural conditions (WB BB and HP BB); FD vs. both binaural conditions (WB BB and HP BB). However, no significant difference was noted for OD vs. FD, as well as, WB BB vs. HP BB.

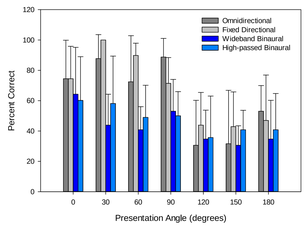


Figure 8: Comparison of mean front back sound localization ability of 7 participants for all four hearing aid conditions (bilateral omnidirectional, bilateral fixed directional, wideband binaural beamformer and the high-passed binaural beamformer). Error bars show one standard deviation.

Spatial Release from Masking (SRM)

- Female talkers from the coordinate response measure (CRM) corpus (Bolia et al., 2000).
  - Target fixed = 65dBSPL
  - Combined maskers (adapted)= 45dBSPL
- One-up, one-down adaptive tracking procedure to estimate a 50% correct point
- 1 interval 4 (color) X 8 (numbers) alternative forced choice
- Participants selected target color and number via touch screen
- SRM = SNR $_{Separated}$—SNR $_{Collocated}$

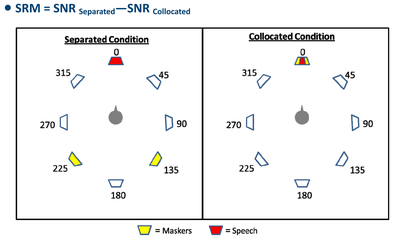


Figure 9. Diagram of the spatial release from masking task showing the speech and masker locations for both the separated and collocated conditions. Participants were seated in the center of the array at a distance of 1 meter from each loudspeaker.

Methods & Results

Spatial Release from Masking Results

- RMANOVA showed a significant main effect of hearing aid condition ($F(3,18) = 12.5$, $p < 0.001$).
- The pairwise comparison (Tukey Test) revealed a significant difference for OD vs. all directional conditions (FD, WB BB and HP BB). No significant differences were found between the three directional conditions (FD, WB BB and HP BB).
- These results suggest that all directional systems led to more spatial release from masking than the omnidirectional system.

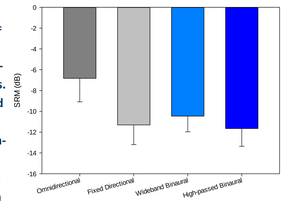


Figure 9: Average SRM scores (dB) as a function of hearing aid condition from 7 participants. Error bars show one standard deviation.

Discussion & Conclusions

- Results show that speech reception thresholds in noise are improved when compared to OD for both a FD and a HP BB.
  - A post-hoc power analysis showed that for a power of .8, approximately 20 subjects would be needed to achieve significance between the two directional systems.
  - It is likely that the inclusion of a binaural beamformer may address some of the complaints of listeners with sensorineural hearing loss regarding understanding speech in noise that fixed directional systems have not.
- Both the OD and FD system performed better in the localization tasks than either of the binaural beamformer conditions.
  - It was expected that localization performance would suffer from the use of a WB BB system, due to the loss of interaural cues needed during localization.
  - There is a consistent trend (albeit not significant) that participants did have better localization performance with the HP BB, indicating that providing ITD cues to the participants though high-pass filtering is beneficial in localization performance.
  - Additional participants will likely lead to a significant differences between WB BB and HP BB.
- Spatial release from masking was better in the three directional conditions (FD, WB BB and HP BB) compared to the OD condition.
- No significant difference existed between the three directional conditions.
  - Separation between the target stimulus and the maskers may have been too great to tease out any benefits of the binaural beamformers and specifically the high-pass binaural beamformer.

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