Relationship between beamformer patterns, compression, and working memory for different noise configurations.

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Background & Significance

Previous research has shown that speech recognition with wide dynamic range compression (WDRC) is associated with individual working memory (WM) ability, especially in adverse listening conditions[1]. Our recent work[2] has found that combining stronger directional processing (beamformers) with WDRC in hearing aids may reduce the role of WM for speech recognition in ideal spatial conditions when the target signal is presented at 0° and the noise is at 180°. However, under realistic spatial conditions, the noise may arrive from multiple locations, rendering the beamformer less effective if the interfering noise is more diffuse and falls outside the directional null[3]. We need to understand the impact of directional processing on the relationship between WM and speech recognition in realistic spatial conditions.

Objectives: In this project, we extend our work to include different beamformer patterns and multiple noise locations. This work also evaluates the feasibility and conditions under which the current implementation of an open-source device[4] may be applicable to study these relationships.

Methods

Participants

5 individuals (3 males) with hearing impairment in the age range 66-73 years participated in the experiment to date.

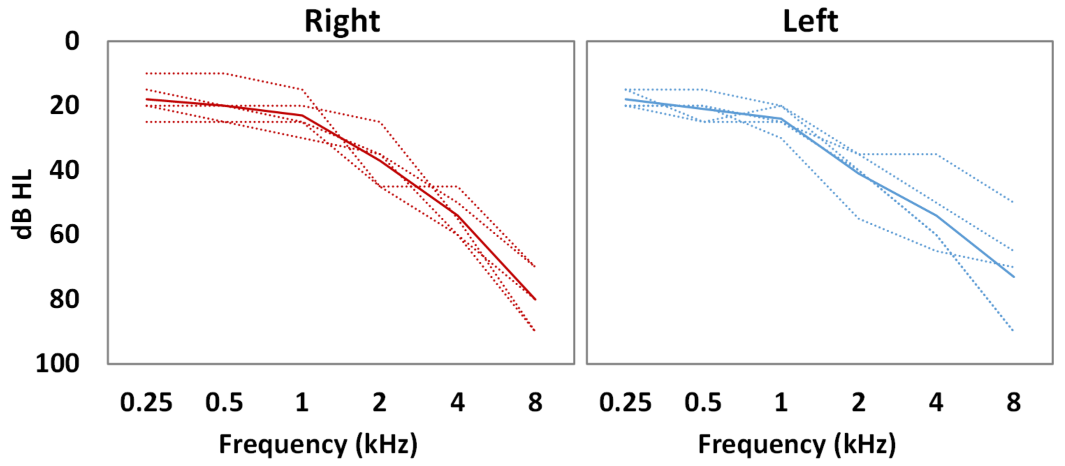


Fig. 1. Individual air conduction thresholds (dashed colored lines; red=right, blue=left). Average thresholds for each ear are represented by the solid lines.

Hearing aids

Signal processing was presented with two types of bil. BTE-RIC hearing aids, each with a different type of beamformer.

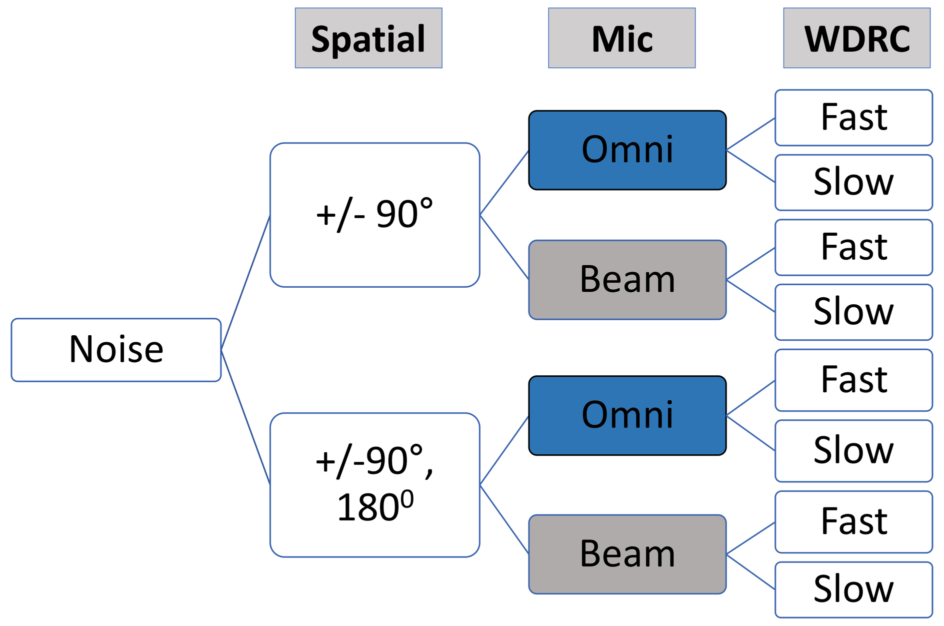
	Device A	Device B
Type	Commercially available	Open-source speech processing platform (OSP)[4]
Bands	48	11[5]
Beamformer	Binaural, narrow beam; 4 mic inputs; wireless NFMI for communication b/w ears	Bi-directional; 2 mic LR adaptive; generalized sidelobe canceller; linearly constrained minimum variance beamformer [6,7]
WDRC Release time	Fast: 70-120 ms Slow: 1400 ms	Fast: 100 ms Slow: 1400 ms
Compression Ratios > 1 kHz	Mean = 2.37 Range = 1.8 to 3.04	Mean = 2.7 Range = 2.22-3.18

Individualized gains and CRs for Device B were obtained from the NAL-NL2[12] standalone software

Devices were coupled with power domes. All advanced signal processing features except automatic feedback suppression were turned off.

Methods

Stimuli & Conditions



Speech: IEEE sentences (50 keywords/condition)[8]; 2 male and 2 female talkers from a local-talker database; presented at 65 dB SPL

Noise: 6 talkers; 3 male and 3 female spontaneous speech recordings from the ALLSTAR database[9]; 10 s lead time and 1 s lag time

SNR: 3 & 8 dB

Room Setup

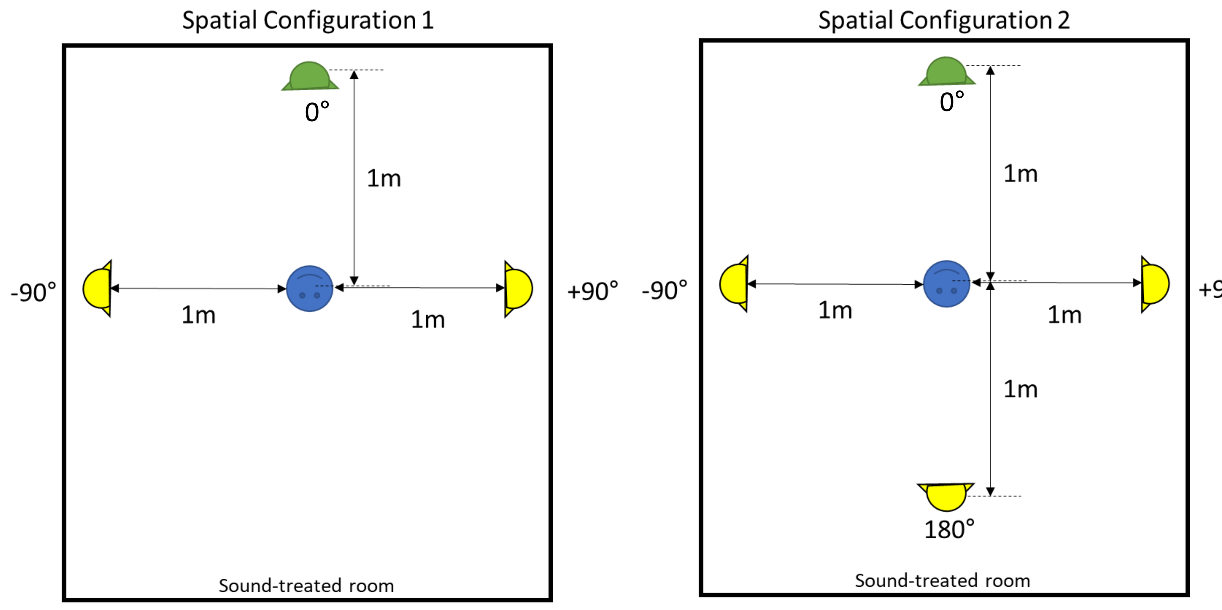


Fig. 2. Configuration of speakers in the test space. Speakers were placed at a distance of 1 m around the listener. Speech was always presented at 0°. Spatial config 1: 3 talkers per speaker, located at +/-90°; Spatial Config 2: 2 talkers per speaker, located at +/-90° and 180°. Stimuli were always presented at ear level.

Acoustic Analyses

Audibility

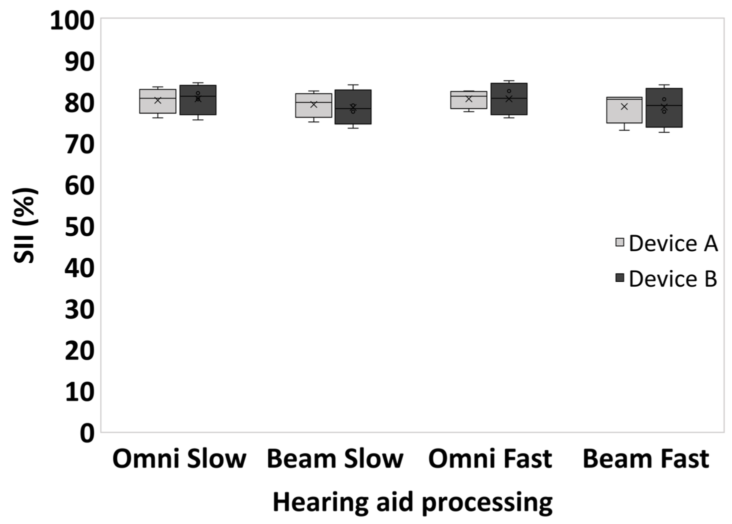


Fig. 3 Box-plots showing the SII range across hearing aid processing conditions for a 65 dB SPL input (test box).

Audibility across hearing aid processing conditions was matched to NAL-NL2 targets within +/- 5dB between 0.25-4 kHz in a test box.

5-10 dB gain was added between 0.5-2kHz in the Beam conditions for Device B across fittings to match targets.

Signal Fidelity

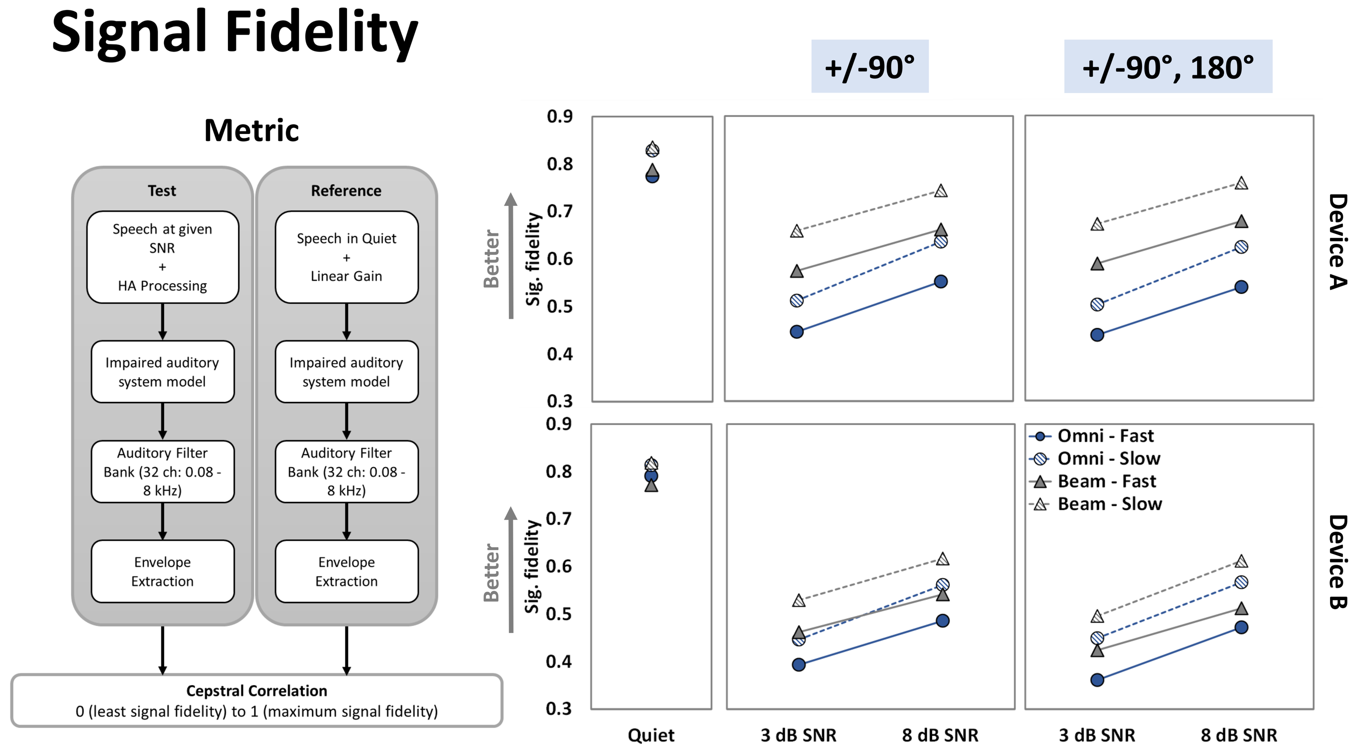


Fig. 4. Signal fidelity (cepstral correlation[10]) across conditions for a representative audiogram with mild-mod. sev. HL[13]. Test & ref. signals recorded on KEMAR (occluded).

Key observations: Signal fidelity with Slow WDRC > Fast WDRC, Beam > Omni with both devices. Effects in quiet are comparable between devices; overall improvement in fidelity is greater for the binaural Beam (Device A) vs the bi-directional Beam (Device B) across conditions.

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Results

Behavioral (Device A)

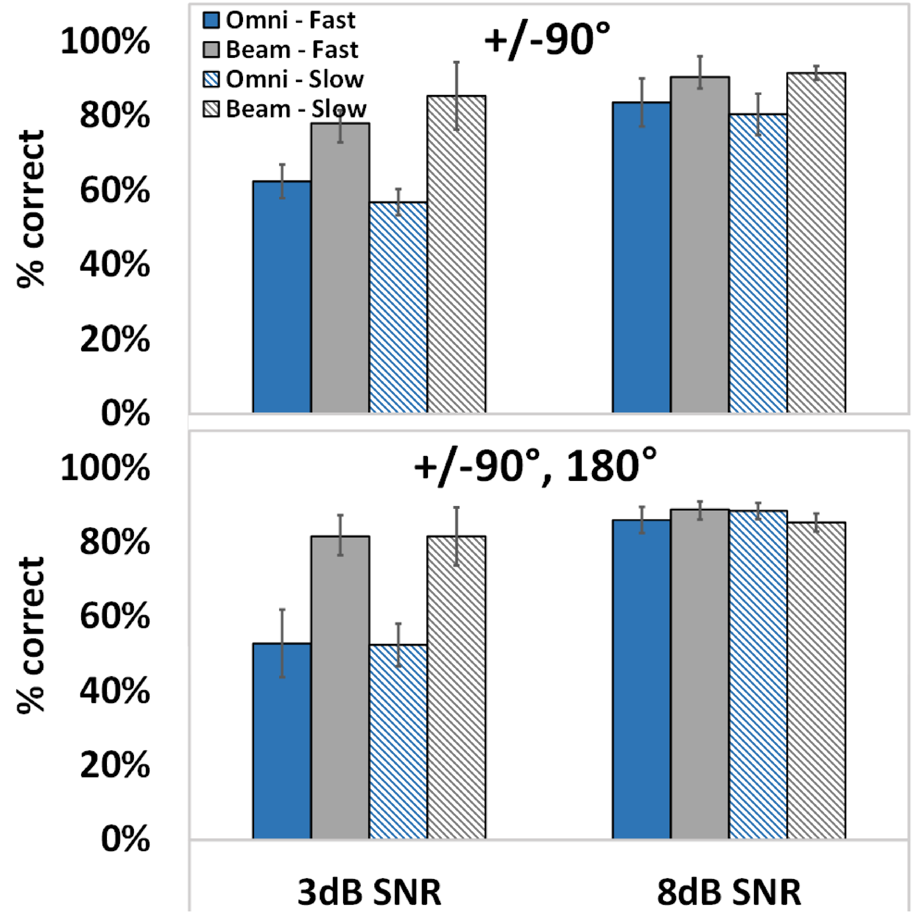

Fig. 5. Percent correct scores at each SNR. Colored bars represent hearing aid processing conditions (legend). Results are grouped by spatial config. Error bars - SE of mean. Note ceiling performance at 8 dB SNR.

Working Memory

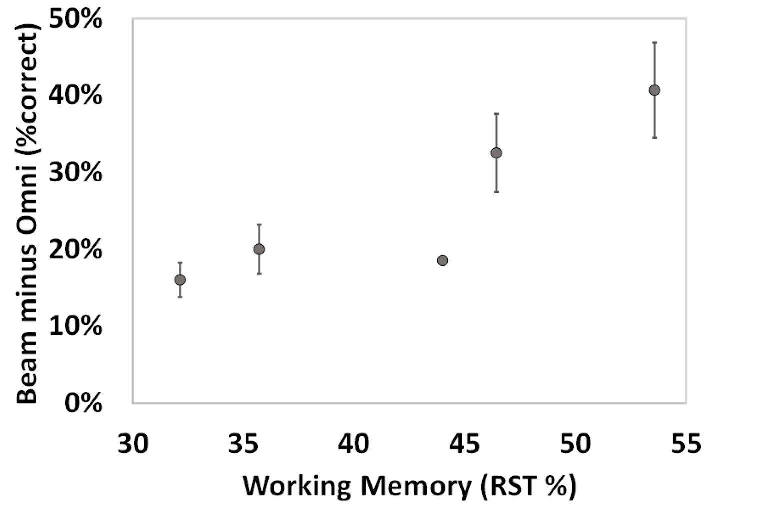

Fig. 6. Beam-benefit at 3 dB SNR as a function of WM measured using the reading span test[11] (RST %). Scores averaged across spatial configurations & WDRC.

Key results to date from statistical analyses (LME model):

- ***SNR*Mic:*** Omni < Beam only at 3 dB SNR ($p < 0.001$)
- ***RST*Mic*** ($p < 0.01$): See Fig. 6
- No sig. effect of WDRC, WDRC*RST, or spatial config.

Behavioral (Device B: Omni only)

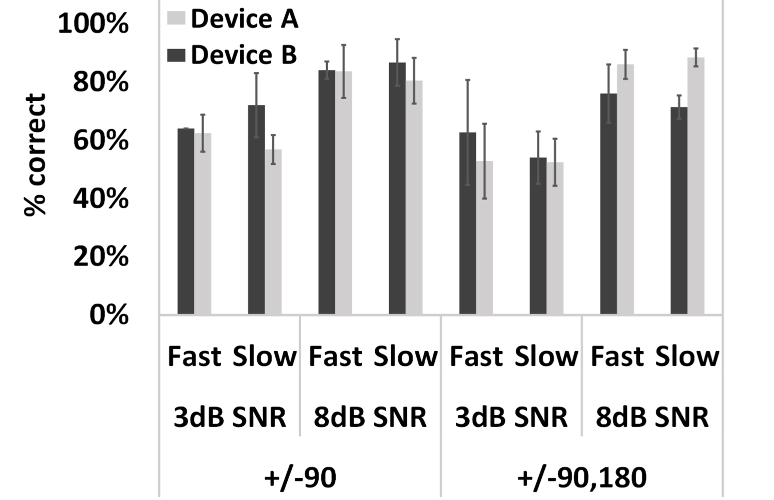

Fig. 7. Percent correct scores with Device B (OSP) in omnidirectional mic condition averaged across three listeners. Device A scores are shown for comparison (legend). Error bars represent the SE of mean. LME model showed no significant main effect of device or interactions with other test conditions on % correct scores (p > 0.05).

Summary & Future Directions

Results to date suggest the following trends:

- WM ability may impact speech recognition benefit with the binaural beamformer (narrow) in the presence of multiple talker-interferers from 2 or 3 spatial locations.
  - Individuals with higher WM ability may show greater benefit with beamformers
- Regardless of WM ability, speech recognition may not be impacted by WDRC release time, despite lower signal fidelity with fast WDRC than slow WDRC.
- A larger sample size is needed to appropriately interpret the behavioral results.
- Adequate audibility (SII and match-to-targets) is achieved in quiet across signal processing settings with the OSP (Device B)
  - Speech recognition in noise does not reveal any systematic differences between devices with omnidirectional processing
  - Relatively smaller improvement in signal fidelity with the bi-directional beamformer in the +/-90°, 180° condition is as expected because the interferer at 180 ° is within the region of beam sensitivity. However, the small effects of the bi-directional beamformer in the +/-90° condition need further investigation. Different test conditions may need to be considered to evaluate the full effects of the beamformer.

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