Differences in distance perception for sounds from the front and back with and without hearing aid satellites

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Introduction and Summary

Spectral filtering of the outer ear is important for the spatial perception of sounds, with monaural pinna cues helping to resolve front back confusions and to discriminate differences in elevation. Missing pinna cues are believed to be a major reason for deteriorated spatial perception, internalization and an increased number of front-back confusions. To analyze any effects caused by the hearing aid microphone position, and therefore also by missing pinna cues, we conducted an experiment on distance perception, comparing a reference non-aided condition with two aided conditions, namely an in-the-ear (ITE) hearing aid satellite that still captures pinna cues, and a behind-the-ear (BTE) hearing aid satellite with the microphone placed such that it doesn't capture pinna cues. We played sounds from the front at 30° and the back at 150° in random order at three different distances at 0.75 m, 2 m and 9 m. Stimuli were reverberated sentences of 2-4 seconds length spoken by different male speakers in a virtual room, auralized with the Simulated Open Field Environment's (SOFE) [1] 48 channels loudspeaker ring. Normal hearing participants conducted the experiment in darkness, leaning their heads onto a headrest to restrict head movements. A linear hearing aid algorithm was used in the aided conditions, using a real time Simulink model to process and play back the sounds over the ITE receivers, with a gain of 5 dB compared to the unaided reference condition to mask leaked sounds at lower frequencies due to venting effects.

Preliminary results for six subjects show differing distance perception between conditions (BTE, ITE, unaided) and between the front and back.

Methods

Stimuli

Ten speech sentences spoken by different male speakers of length 2-4 seconds were used as stimuli. The sentences were normalized to 58 dB SPL before convolution with the simulated room impulse responses (RIRs). Stimuli were band pass filtered between 200-10000 Hz.

Room acoustics simulation and stimulus presentation

Room impulse responses for three different distances in the front (30°) and back (150°) were simulated for a room with dimensions (18.5 m x 15.5 m x 10 m) using the SOFE with a reflection order of 30. Stimuli were reverberated by convolution with the simulated RIRs, and were auralized using a loudspeaker ring of 48 horizontally placed speakers. The direct sound and individual reflections were mapped to the nearest loudspeaker in the ring. Late reflections from the 5^{th} order onwards were jittered in time by up to 5%. The experimental room was acoustically damped and the lights turned off.

Hearing aid satellites

BTE and individually manufactured ITE satellites were connected to a custom made microphone amplifier. The signals were input to an RME Fireface UCX soundcard and linearly processed by a real time Simulink model.

Experimental procedure

Six normal hearing participants were seated in the center of the loudspeaker ring with their heads leaned on a head rest to avoid head movements. The unaided condition was tested separately from the aided conditions. All stimuli, distances, presented directions and (aided) conditions were completely randomized. Perceived distance and direction were reported by positioning a marker along two axes displayed in a graphical user interface on a touchscreen device, as shown schematically in figure 1. The touchscreen was the only visible object in the darkened experimental room; the loudspeaker ring was not visible. The experimental supervisor sat in an adjacent control room, monitoring the participants well-being at all times. The experiment was partitioned into runs of 12-15 minutes duration, after which participants were encouraged to take short breaks.

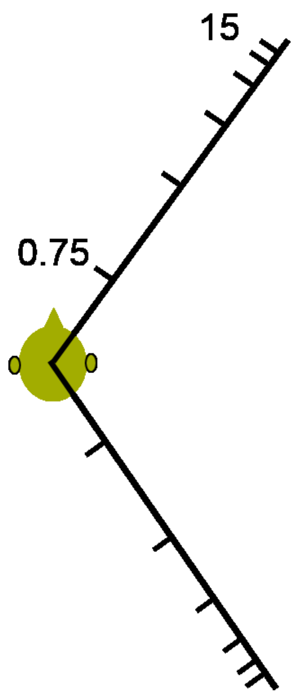

Figure 1: Schematic diagram of the graphical user interface used on the touchscreen device for the input of distance results. The axes were shown at 30° in the front and 150° in the back with logarithmical distance markers. The range was set from 0 – 15 m to avoid boundary effects at larger distances.

Results

For comparison of distance perception results, we show preliminary median results for six subjects for the aided and unaided conditions for frontal sound presentation (fig. 2) and presentation from the back (fig. 3).

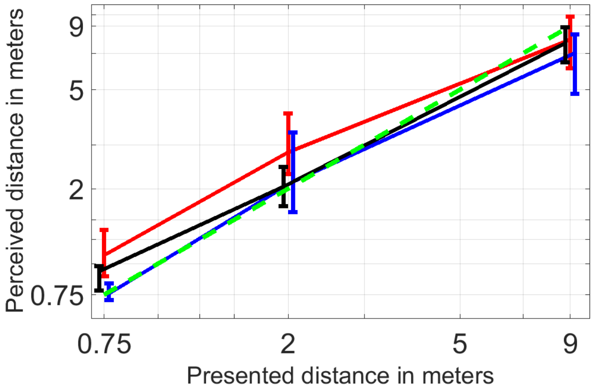

Figure 2: Preliminary median distance results for six participants for the front for the aided and the unaided conditions: BTE (red), ITE (blue) and unaided (black). The green line represents the ideal distance response. Errorbars show the across-subject median of individual interquartile ranges.

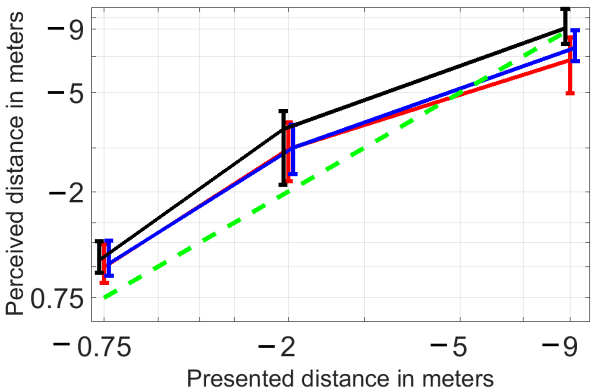

Figure 2: Preliminary median distance results for six participants for the back for the aided and the unaided conditions: BTE (red), ITE (blue) and unaided (black). The green line represents the ideal distance response. Errorbars show the across-subject median of individual interquartile ranges.

As can be seen from the distance responses in figures 2 and 3, there seems to be a difference in distance perception between the front and back. Especially the unaided reference condition in the back differs from the front, with perceived distance being heard further away than in the front. For the BTE distance perception, the opposite seems to be the case, with distances from the front being heard further away than in the back. In the ITE distance perception, we notice differences mainly for near distances between the front and back. The quantiles at 2 meters sound presentation look greater than at 0.75 meters or 9 meters. Also, there is a difference in distance perception when comparing the aided and unaided conditions.

Discussion

The greatest differences in distance perception can be seen between the unaided condition and the BTE condition. While in the unaided condition the distances are perceived further away from the back than in the front, the opposite is the case for the BTE condition, where distances from the front are perceived as being further away than in the back. On the other hand, the opposite is the case in the unaided condition, there is a discrepancy between both conditions. In the ITE condition, we see similar results for the front and back at the furthest distance, but differences at near distances. These results suggest that the pick-up of sound at different microphone positions has an important effect on distance perception for normal hearing listeners that are used to listening with their own ears without hearing aids. Future experiments should take these effects into account when comparing distance perception results with hearing impaired listeners. Interestingly, our results differ from the averaged distance perception results over many different studies as described by Zahorik [2]. The given average curve, described by a power function, overestimates distance results for near distances and underestimates results for far distances. One main difference in our case compared to most previous studies is the setting in complete darkness. Although the physical room was known to the subjects from when they entered the laboratory, its visual influence on the results should be minimal since distances were only determined by the acoustical changes in the simulated room auralized over the SOFE loudspeaker ring. Our results are more comparable to the results found by Mershon and Bowers [3] in a physical room in the dark, suggesting an important effect of visual cues on auditory distance perception.

Literature

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