Influence of the low-frequency acoustic bypass on distance perception with hearing-aids

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Introduction and Summary

With the advent of new hearing-aid technology, more and more hearing-aid users wear their devices with an open fit, avoiding unwanted occlusion effects. Open fitting allows for the direct acoustic sound from the outside to pass through to the ear drum. But also for closed fitted hearing aids there is a part of the direct acoustic sound from the outside that can pass through the vent, especially at low frequencies, depending on vent size. Any sound from the outside that reaches the ear drum will be superposed to the sound played back by the hearing aid, thus allowing for effects such as comb filters that may deteriorate the perceived sound.

In this study, the effect of the acoustic bypass on distance perception was analyzed for speech stimuli. We conducted one experiment with two parts. In the first part, participants wearing behind-the-ear (BTE) and in-the-ear (ITE) hearing aid satellites were seated in a virtual sound field of a room that was auralized in the Simulated Open Field Environment (SOFE v3; Seeber et al., 2010). Short sentences by male speakers were presented from three different distances (1.5 m – 9 m) in the front and the back at 30° and 150°. The BTE and ITE microphone signals were processed by a linear hearing aid algorithm and played back over the ITE receivers. Normal hearing participants with their heads fixed were asked to rate the direction and distance of the stimuli in the dark room. Simultaneously, the digital signals sent to the receiver were recorded for an identical playback situation in the second part of the experiment. The second part of the experiment was identical to the first part with the exception that the outer sound field by the loudspeaker ring of the SOFE was absent, leaving only the ITE receiver playback. Since no external sound field was present, any effects due to leaked sounds through the ITE vents could be discarded. Preliminary results for 5 subjects show no statistically significant effects of the acoustic bypass on distance perception when comparing the recording and the loudspeaker playback results. This finding suggests that the influence of the acoustic bypass, that is particularly present at low frequencies, can be neglected and does not play an important role in distance perception.

Methods

Seven sentences of 2-3 seconds duration, spoken by different male speakers, were used as stimuli. Sentences were convolved with simulated room impulse responses at three different distances (1.5 m, 6 m and 9 m) for a horizontal source position at 30° azimuth in the front and 150° azimuth in the back. The simulation and auralization was done with the Simulated Open Field Environment (SOFE v3; Seeber et al., 2010) using a loudspeaker ring of 48 channels. Five participants took part in the experiment and were seated in the middle of the loudspeaker ring, with the head on a head rest to minimize head movements. The experiment took part in complete darkness, except for the light emanating from the touchscreen used to input the perceived distance results in a GUI. Participants wore custom made ITE shells and generic BTE shells connected over cables to a PC, on which a real time Simulink model linearly processed the sounds with a short processing delay of 7.8 ms. All stimuli, distances and microphone selection (ITE or BTE) were presented in a random order to avoid learning effects. This experiment was partitioned into two parts with the exact same presentation order of the stimuli and conditions. The difference between both parts was that the first part used sound presentation over the loudspeaker ring of the SOFE, during which the signals to the ITE receivers were simultaneously recorded. The second part used the recordings instead of the loudspeaker playback for sound presentation, with no external sound field. Both conditions were exactly identical except for the influence of the direct acoustic bypass from the loudspeaker playback arriving at the eardrum. Preliminary data for five normal hearing participants are presented.

Distance Perception Results

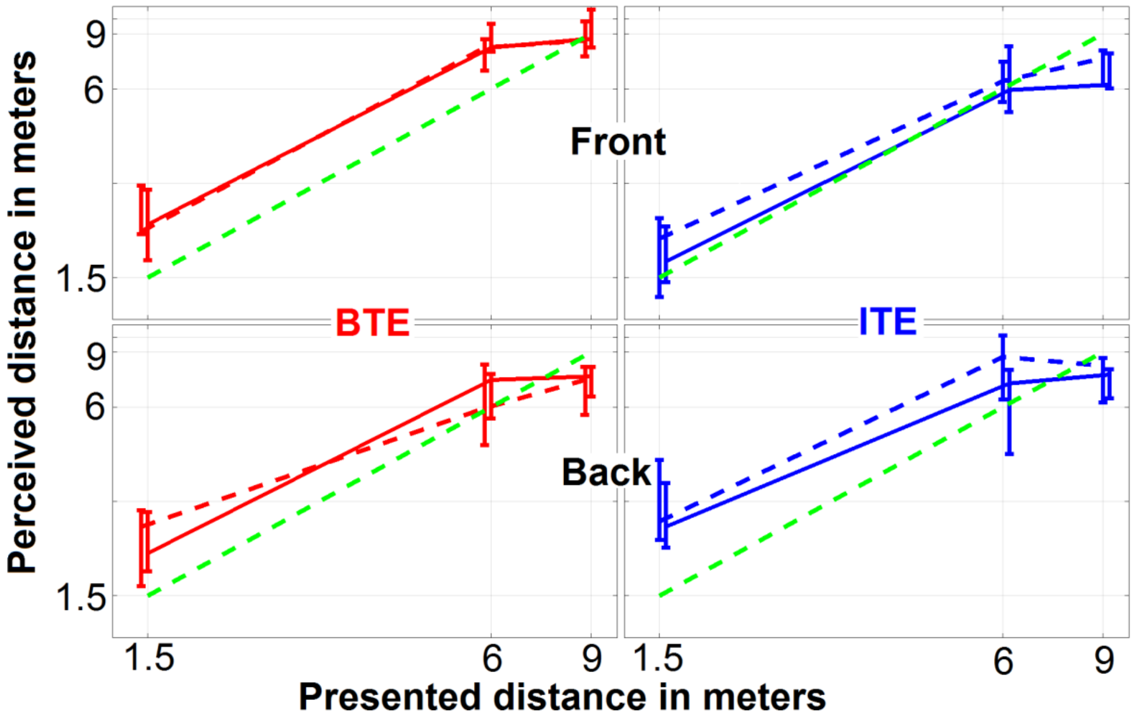

Figure 1: Preliminary results for five subjects representing perceived distance as a function of source distance simulated in a moderately reverberant room with speech sounds (double-logarithmic axes). The green dotted line shows the ideal response, the error bars show the median of the individual 25th and 75th percentiles, for which the absolute values of the responses were used. The lines connect the median of individual medians for the BTE (red) and ITE (blue) conditions. The continuous red and blue lines stand for the results of the loudspeaker playback. The dotted red and blue lines stand for the results of the recording condition.

Figure 1 shows preliminary results for five participants, showing reported perceived distance as a function of presented distance. From the figure we see that there are only small differences between the loudspeaker presentation (continuous red and blue lines) and the recordings (dotted red and blue lines) for the BTE (red, left side) and ITE (blue, right side) microphone positions.

Differences in distance perception between the loudspeaker and recording sound presentation were tested with a multifactorial ANOVA with a mixed model using front/back, distance, condition (BTE, ITE) and LS/rec as factors and the sentences and subjects as random factors. No significant differences were found regarding distance comparing the loudspeaker and the recording sound presentation ($p = 0.42$), nor in the interaction with other factors.

Discussion and Conclusion

We compared distance perception in two identical situations, one being a real time processing with playback over the loudspeaker ring of the SOFE, and the other one being recordings thereof. Comparing preliminary results from five participants we did not observe statistically significant differences between both presentation conditions. This indicates that the leaked sound through the vent (acoustic bypass) at low frequencies, where attenuation due to the shells is low, does not affect distance perception. Possible effects that could have been expected are differences in front-back confusions or distance perception due to the deterioration of sound when leaked from the outside and superposed with the amplified sound. Considering distance perception, we did not observe differences between loudspeaker playback and recordings that cannot be explained by natural variability. The results are similar to the ones found by Gomez and Seeber (2015) and Mershon and Bowers (1979), but differ from the average results by Zahorik et al. (2005). Zahorik and colleagues found a higher degree of compression leading to an underestimation of distance perception for distances greater than 2 m, possibly due to visual influences. An audible difference between the recording condition and that with real-time processing of the external sound field was a slightly higher noise floor in the recordings due to the incoherent addition of the recorded noise and the microphone noise that was still present, since we left the linear amplification turned on in the recording playback part of the experiment to avoid silence between stimulus presentation, trying to make both conditions as similar as possible even in the pauses. Keidser et al. (2007) found that even when vent-transmitted sound dominated the low frequencies, it had no effect on speech recognition or horizontal localization. They further came to the conclusion that there is no need to increase low frequency gain to compensate for vent effects to achieve benefit from directionality and noise reduction over a wider frequency range. These findings complement our claim, that low frequency leakage of sound through the hearing aid vents has little or no effect on distance perception.

Acknowledgements

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Literature

Seeber B U, Kerber S & Hafter E R (2010) A system to simulate and reproduce audio–visual environments for spatial hearing research. Hearing Research, 260(1), 1-10.

Gomez G, Seeber B U (2015) Influence of the Hearing Aid Microphone Position on Distance Perception and Front-Back Confusions with a Static Head. Proc. 18. Jahrestagung Deutsche Gesellschaft für Audiologie e.V. (DGA), Dt. Ges. f. Audiologie, 2015, 1-5

Mershon D H, Bowers J N (1979) Absolute and relative cues for the auditory perception of egocentric distance. Perception, 8(3), 311-322

Zahorik P, Brungart D S & Bronkhorst A W (2005) Auditory distance perception in humans: A summary of past and present research. Acta Acustica united with Acustica, 91(3), 409-420.

Keidser G, Carter L, Chalupper J, Dillon H (2007) Effect of low-frequency gain and venting effects on the benefit derived from directionality and noise reduction in hearing aids, International Journal of Audiology, 46:10, 554-568