Influence of the Hearing Aid Microphone Position on Distance Perception and Front-Back Confusions with a Static Head

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Introduction and Summary

The spectral influence of the human pinna is of great importance for the spatial hearing of sounds. Missing pinna cues is one of the reasons for deteriorated spatial perception and it leads to increased front-back (f-b) confusions in hearing aid users (Van den Bogaert et al., 2009). This study examined the effect of Behind-The-Ear (BTE) and In-The-Ear (ITE) hearing aid microphone positions on distance perception and f-b confusions, and compared the results of both aided conditions against an unaided reference condition.

Distance perception was tested in a dark room with six experienced normal hearing listeners for a static head position. Nine distances (0.75 – 9 m) were tested each in the front and in the back using 10 different male speech sentences spoken in a virtual room. The reverberated distance stimuli were auralized over the 48 loudspeakers of the Simulated Open Field Environment, a free-field virtual acoustic environment (SOFE v3, Seeber 2010). Preliminary results show a compression (underestimation) of the perceived distances is observed for distances greater than 5 meters, while closer distances are overestimated (Gomez & Seeber, 2015, Zahorik et al., 2005). Significant differences were found between conditions, between distance perception in the front and in the back, between the tested distances and in an interaction with front-back condition. Front-back confusions decrease in both aided conditions while back-front confusions increase with increasing distance. The amount of confusions was much higher in the BTE than in the ITE aided condition, and no confusions were made in the reference condition.

Methods

Subjects: Six male normal hearing subjects (mean age: 30.5, std. dev. 3.27) participated in the study. All subjects had taken part in similar experiments before. Three of the subjects started with the reference, unaided condition, while the other three subjects started with the aided condition.

Hearing-aid satellites and processing: Behind-the-ear (BTE) and custom made In-the-ear (ITE) satellite shells by PHONAK (fig. 1) were connected to a 6 channel microphone amplifier and the signals passed to an RME Fireface UCX audio interface. A laptop running a real-time Simulink model with a total delay between microphone sound pickup and sound playback of 7.7 ms processed the microphone signals. Stimuli were processed as frames of 128 samples each, converted to the frequency domain and band pass filtered (200 – 10000 Hz). The microphone and receiver frequency responses were compensated for and the processed frames converted back to the time domain. A 5 dB gain was applied on top of the gain needed to compensate the attenuation due to the ITE hearing aid shells in the ear canal to equal loudness to the unaided condition.

Environment: The experiment was conducted in the Simulated Open Field Environment (SOFE v3, Seeber 2010), consisting of the playback apparatus and software to simulate and auralize room acoustics. The apparatus consisted of 96 BOSE (Freespace 3) loudspeakers arranged in a circle of 1.29 m radius, of which 48 were used. They were driven by 48 2-channel amplifiers (Samson Servo 120 A). The preliminary test participants sat on a chair with an adjustable head rest in the ring center in the darkened room. Loudspeaker playback was controlled from a standard PC using 3 cascaded 36-channel RME Raydat soundcards. Digital-to-analog conversion was performed by six 16-channel AD/DA converters (Sonic Core A16 Ultra).

Figure 1: Picture of the BTE and ITE satellites worn at the ear.

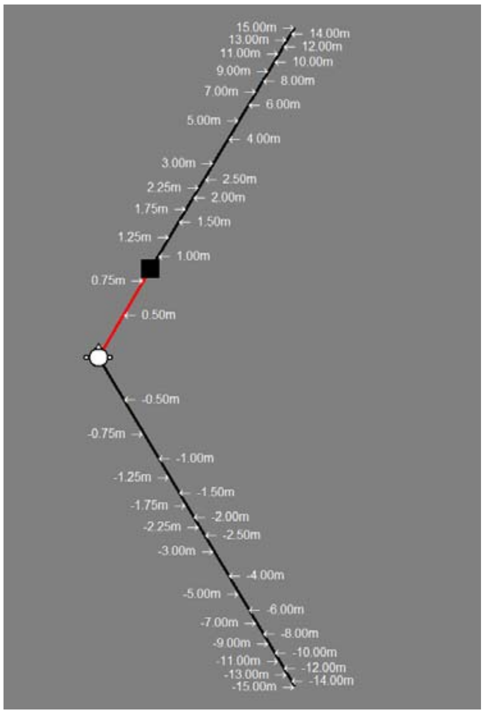

Figure 2: Screenshot of the GUI used for input of distance perception responses.

Stimuli: Ten sentences of 2-4 seconds duration spoken by five English and five German male speakers were convolved with simulated room impulse responses of a room of size 15.5 x 18.5 x 10 m. Nine distances between 0.75 – 9 meters from the virtual listener in the front and back at 30° and 150°, respectively, were tested. All ten sentences were presented for each distance, hemisphere and condition. The speech level of the direct sound was set to 58 dB SPL at the ring center.

GUI**:** Participants registered the perceived distance using a GUI on a touch screen (fig. 2) after stimulus playback. The GUI used logarithmically spaced axis labels in accordance with human resolution in distance discrimination. The axes extend up to 15 meters in the front and back to enable unbounded response opportunity (Gomez and Seeber, 2015).

Results

Figure 3 shows preliminary results of six subjects indicating perceived distance for stimuli with nine different distances presented in the front and the back. Results for the reference condition are given in black, for the BTE-condition in red and for the ITE condition in blue. The green dotted line shows the ideal response. Front-back confusions were not considered for distance perception in figure 3 as distance perception and front-back confusions are analyzed separately. Therefore, we took the absolute value of distance perception responses for the distance data. The black, red and blue thick lines connect the median of the individual median responses, representing a median listener. The error bars represent the median 25^{th} and 75^{th} percentile where 50% of the responses are contained. The data suggests that distance perception in the dark is a difficult task with different individually perceived distance shown by high between subject variance.

In line with the logarithmically labeled axes in the GUI, responses were logarithmically transformed for statistical analysis. 28 out of the 324 data points were discarded as outliers to fulfill ANOVA conditions of equal variance between groups (heteroscedasticity). Normal distribution of residuals was not fulfilled, possibly because of the small number of subjects or because responses were discretized to linear-over-log scaled distances. A multifactorial ANOVA with the factors front/back, distance and condition with the medians of 10 individual answers for six subjects as dependent variables was performed on the data. Statistically significant differences were found between distances ($F_{(8,258)} = 258.32, p < 0.0001$) and v/h*condition ($F_{(2,258)} = 13.4, p < 0.0001$), between back/front ($F_{(1,258)} = 10.75, p < 0.01$) and the condition ($F_{(2,258)} = 4.42, p < 0.05$), but no significant differences between v/h*distance or distance*condition interactions. Post-hoc analysis revealed significant differences specifically between the ITE and the BTE condition, significant differences for front from back with sounds in the back being perceived further away than in the front, and the distances 5, 7 and 9 meters as being a group with no significant differences between each other but different from all the rest.

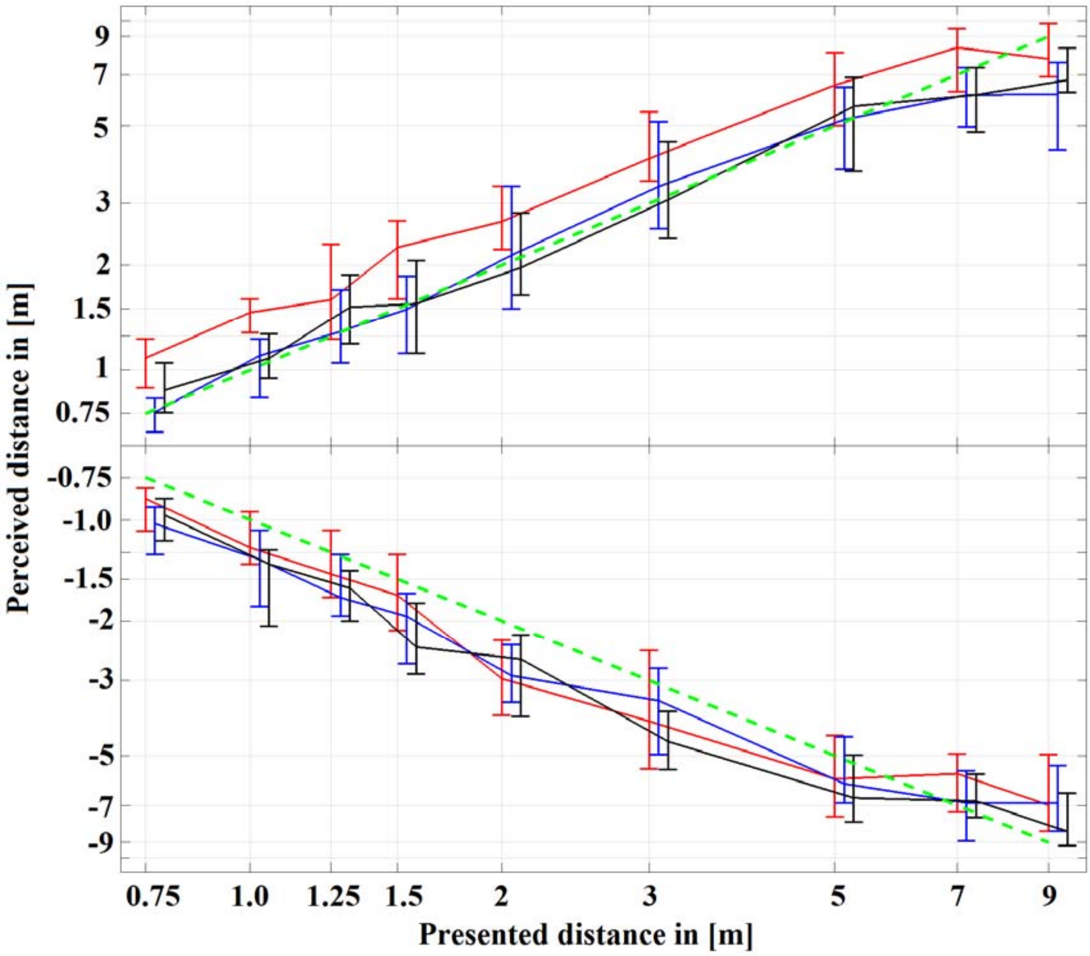

Figure 3: Distance perception results for six subjects (double-logarithmic axes). The green dotted line shows the ideal response, the error bars show the median of the 25th and 75th percentiles. The thick lines connect the median of individual medians for the reference (black), BTE (red) and ITE (blue) conditions. Front back confusions are disregarded here by taking the absolute value of the perceived distance responses.

The mean σ value of 1.713 discrete linear steps was similar for all subjects and all distances. It was calculated after logarithmic transformation of the data. This standard deviation is equal to less than two discrete steps in the input from the mean. That of course transforms to higher σ in the distance if looked at linearly, since for near distances one discrete step represents a much smaller distance step in the response than for distances farther away, as shown in table 1.

σ \ dist.	0.75	1.0	1.25	1.5	2	3	5	7	9
Mean front σ	0,25	0,38	0,59	0,75	1,07	1,56	1,97	1,99	1,80
Mean back σ	0,31	0,45	0,68	0,72	1,24	1,65	1,91	1,78	2,05
Mean σ	0,28	0,41	0,63	0,73	1,15	1,61	1,94	1,89	1,92

Table 1: Mean standard deviations σ of the distance results averaged over six subjects and over all three conditions for the front, back and back-front combined, for all nine tested distances. Units are given in [m].

Figure 4 shows the average front-back and back-front confusions in percent for the BTE and ITE conditions. In the reference condition none of the subjects had any confusion. The mean percentage of confusions is shown by the horizontal lines, with the BTE condition in red and the ITE condition in blue. Error bars are not shown here for clarity, since some subjects experienced almost only front-back confusions, while others experienced almost only back-front confusions in agreement with (Wightman & Kistler 1999). There is a tendency towards decreasing confusions with increasing distance for frontal sources. For sounds played from the back, confusions increased with increasing distance. Confusions in the BTE conditions occurred about 4-5 times more often than in the ITE position, confirming the importance of monaural spectral pinna cues in sound source localization (Wightman & Kistler 1997).

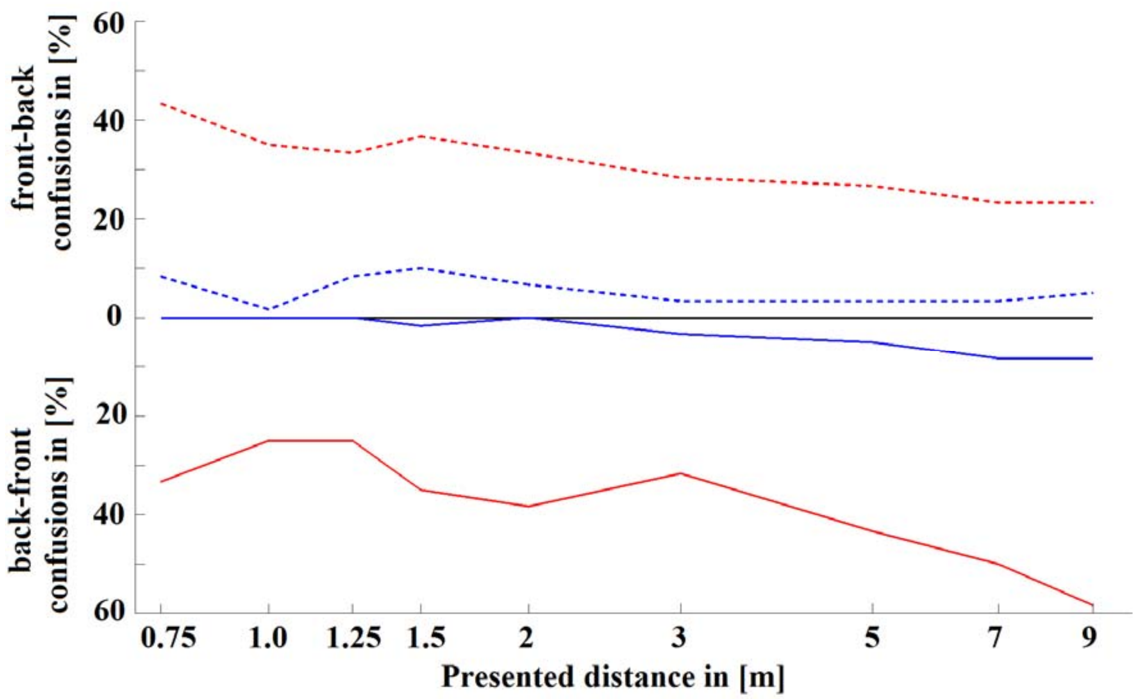

Figure 4: Front-back and back-front confusions in percent. The upper part of the figure shows sound presentations from the front, where the sounds were perceived as coming from the back. The lower part shows confusions for sound presentation from the back. The horizontal lines connect the mean percent of confusions for all distances. Error bars are not shown here for clarity.

Conclusions

In this study the effect of the hearing aid microphone position on distance perception and front-back confusions was tested using virtual acoustics in a dark room with a fixed head position. Distance results show an overestimation of close distances and an underestimation for distances further away than 5 meters. We found significant differences between front and back distance perception and between the BTE and ITE conditions. The individual data show large between subject variance in distance perception, while the small standard deviation of less than 2 discrete steps suggests quite good response reproducibility. We found a decrease of front-back confusions and an increase of back-front confusions with increasing distance. This latter finding will be further examined for different rooms to analyze room acoustic effects on front-back confusions. We will continue collecting data from additional subjects in order to gain more reliable measures.

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Literature

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