The effect of head turning on sound localization with hearing-aid satellites

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Introduction

In everyday life, we are constantly localizing sounds in our surrounding environment. This is important to capture target sound sources, like a ringing telephone, which are not necessary in the field of view. Head movements change the main localization cues, interaural time differences (ITD) and interaural level differences (ILD) [11]. Also, a non-centered head orientation can change the head-related transfer functions [2] and therefore the localization cues. For hearing-aid users localization ability is likewise important in everyday life. It is known from previous studies that impairment as well as the used hearing-aids and algorithms have a non-negligible impact on the localization ability [1], [4], [5], [10], [12]. Therefore, the question of this study is, if there is an effect of eccentric head orientations on the localization ability and especially on the front-back reversals in the horizontal plane while using hearing-aid satellites.

To answer this question in this preliminary study a localization experiment was performed in the horizontal plane with different head orientations and behind-the-ear (BTE) hearing-aid satellites. Sounds were played from the frontal as well as from the rear hemisphere to evaluate potential front-back reversals with different head orientations. Results show that with an eccentric head orientation the front-back reversals decrease when BTE satellites were used.

Experimental method

Setup

The sound stimuli were presented from the loudspeakers of the Simulated Open Field Environment (SOFE) chosen from 14 different directions [7]. Three different head orientations, -30°, 0° and +30° were tested in the experiment, where a negative value indicates a head orientation to the left and a positive value to the right. In the range from -60° to +60° relative to a centered head orientation, the loudspeakers were equally distributed in 15° increments. These locations were the same for all three head orientations. For a centered head position there were additional sound sources from behind in the range of -150° to +150° also in 15° increments. The subjects did not know up front that there were no sound directions from behind for the other head orientations.

During the experiment, a marker of an electromagnetic motion tracker (FASTRAK, Polhemus) was mounted on the subject’s head to measure the orientation and position of the subjects' head within 5° tolerance. To position the head to the target orientation, a running light point (“chaser light”) was generated which moved from the actual measured head position to the target head position. Subjects were instructed to follow the chaser light by turning their head until the target position was reached.

All subjects wore during the experiment custom made ITE shells and BTE hearing aid satellites by Phonak. These satellites were connected to a custom-made microphone amplifier. The captured microphone signals were processed with a real-time Simulink model, running on a laptop, to simulate acoustically transparent (no compression or noise reduction) signal processing of a BTE hearing aid with slight amplification. The microphone signal was transformed into the frequency domain using a short-time Fourier transform and bandpass filtered in the range from 200 Hz to 8 kHz. Additionally, the microphone and receiver frequency responses were compensated. Then, the signal was transformed back into the time domain and amplified by 5 dB [3]. In this preliminary study the ITE shells were used to play back the processed signal via the receiver of the ITE hearing-aid satellite.

Stimulus

A white Gaussian broadband noise pulse-train, bandpass-filtered between 200 Hz and 8 kHz, was used as stimulus. It was generated at 60 dB SPL before applying the pulse-train envelope. The overall duration was 500 milliseconds with a pulse duration of 30 milliseconds and an inter-pulse interval of 70 milliseconds with a Gaussian shaped rise and fall times of 10 milliseconds.

Response method

Subjects indicated the perceived direction of the sound source with the Proprioception Decoupled Pointer (*ProDePo*) method [6]. They were instructed to position a light spot, lit up above the loudspeaker ring, to the perceived azimuthal direction with a trackball device. For perceived sound directions from behind, it was possible to indicate the perceived direction at the mirror position in the front and to click the right button on the trackball. With this approach participants do not have to turn their head around. It was left to the subjects whether they use the mirroring approach or turn their head to visually point to rearward stimuli. The mirror axis runs between ±90° in the room and is constant for all head positions.

Localization experiment

Subjects

Four male subjects participated voluntarily in this preliminary study, aged from 25 to 30 years (mean: 27.25 yr.; sd: 2.06). All subjects had self-reported normal hearing. No one was paid for participation and all subjects gave written consent to participate in this study.

Procedure

The participant was sitting in the middle of the loudspeaker ring in complete darkness on a non-rotating chair with a short headrest. All participants wore during the experiment an electromagnetic head tracker, BTE satellites and custom made ITE satellites for playback of the processed microphone signal. Before the stimulus was presented, the target head orientation was indicated with a light spot running from the current measured head orientation to the target position. The head target orientation had to be held for one second before the stimulus was played, if not, the running light spot reappeared to readjust head orientation. Subjects were instructed not to turn the head during the stimulus presentation, which was ensured with the head tracker. Next, the sound stimulus was played. Afterwards, a light spot was displayed at a random azimuthal location ±30° around the sound direction. For sound directions from behind the light point was displayed around the corresponding mirrored position in the front of the listener. The subjects had to indicate the perceived sound direction by moving the light spot to the perceived location or to its mirrored location in the front. Each combination of sound direction and target head position was repeated 4 times during the whole experiment. In total 128 trials were presented to each subject in completely randomized order. The experiment was blocked in 6 runs and the participants were recommended to take short breaks in between. All subjects completed the whole experiment in about 20 minutes.

Results

The amount of front-back reversals for frontal sound directions is plotted in Figure 1. The different head orientations are plotted in different colors. Results show that for BTE devices most front-back confusions occur in the range from 0° to +15° sound direction relative to the head orientation except for a head orientation of +30°. There, most of the front-back reversals occur between +15° and +30° sound direction. It can be seen that the amount of front-back confusions with a head orientation of 0° is higher for all sound directions than for an eccentric head orientation. The mean amount of front-back reversals for a centered head orientation is 22.2% whereas for -30° head orientation the mean amount is 12.2% and for +30° head orientation 13.3%. These data show that for a centered head orientation the number of front-back reversals are higher when using BTE devices.

Discussion

The results show that front-back reversals occur less often for an eccentric head orientation for BTE devices. These observations lead to the assumption that an eccentric head orientation seems to have a slightly improving influence on front-back reversals with BTE hearing aids. It was shown in other studies [2] that head turn relative to the torso can audibly influence the head-related transfer functions. Also, the position of the microphone of a hearing device also influences the transfer function [8]. One can assume that because of the eccentric head orientation the reflections from the shoulders are more dominant for lateral sound sources and may thus provide helpful cues to resolve front-back confusions with BTE devices.

Conclusion

This preliminary study asked the question how a static eccentric head orientation affects the localization accuracy of normal hearing listeners while using BTE hearing aid satellites. The results suggest that the head orientation is a factor for resolving front-back confusions if BTE hearing-aid devices are used.

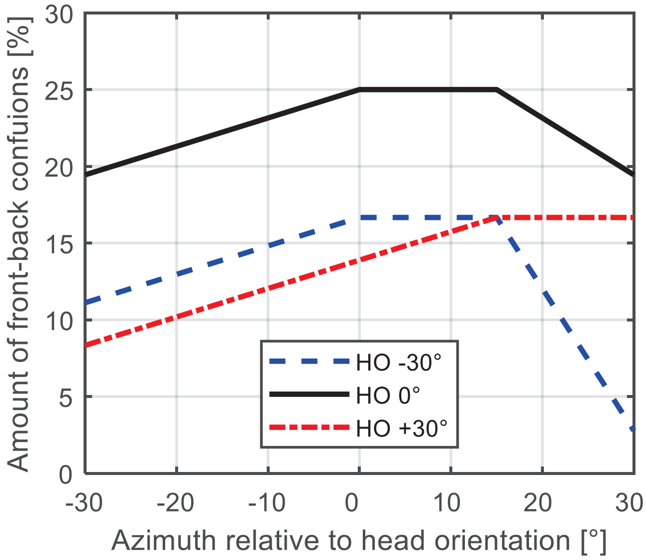

Figure 1: Amount of front-back confusions for all different head orientations (HO) depending on the direction of sound source relative to the HO for BTE hearing-aid satellites (black line: 0° HO; blue dashed line: -30° HO; red dashed dotted line: +30° HO).

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