The Effect of Head Turning on Sound Localization in the Horizontal Plane

Norbert Kolotzek, Gabriel Gomez, Bernhard U. Seeber

Audio Information Processing, Technische Universität München, Arcisstraße 21, 80333 München

Introduction

Localization of sound sources is important in our everyday life. It allows us to capture targets which are not necessarily in the field of view, turn toward a speaker or evade dangers. We can move our head (in limits) freely in the azimuthal and median planes and thus produce important dynamic cues for sound localization [8]. When a sound arrives at the listener, it is not always that the head is oriented to the front. Therefore, the listener has to localize the sound direction with a non-centered head-above-torso orientation to get an idea from where the sound comes from. Brinkmann et al. [2] have shown that a non-centered head position influences the head-related transfer functions (HRTF) and that these changes are audible. Lewald and Ehrenstein [4] investigated that head turning causes shifts when lateralizing sounds. The present study asks whether the head-to-trunk orientation has an impact on the perceived sound direction in the horizontal plane and thus aims to reproduce the localization shifts observed by Lewald and Ehrenstein [4] with different methods.

To answer these questions a localization experiment was performed in the horizontal plane with different head turning directions. Rare for this kind of experiments, sound directions were presented not only from the front but also from rear directions to investigate potential effects on localization in the back. Results show that for head-above-torso positions of ±30° small shifts in the frontal horizontal plane occur compared to a centered head position of 0°. Larger shifts were observed in the rear horizontal plane.

Experimental method

Setup and procedure

Sound stimuli were presented from the loudspeakers of the Simulated Open Field Environment (SOFE) chosen from 28 different directions [6]. Three head orientations, -30°, 0°, and +30° were used. In the range from -30° to +30° relative to the head orientation, the loudspeakers were equally distributed in 7.5° increments; otherwise they were equally distributed in 15° increments. In Figure 1 the loudspeaker configuration for a centered head position is shown. For both non-centered orientations the setup was rotated by the same angle as the head was turned.

During the experiment subjects wore an electromagnetic motion tracker (FASTRAK, Polhemus) to measure the actual head orientation and to position the subjects' head to a target head position 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.

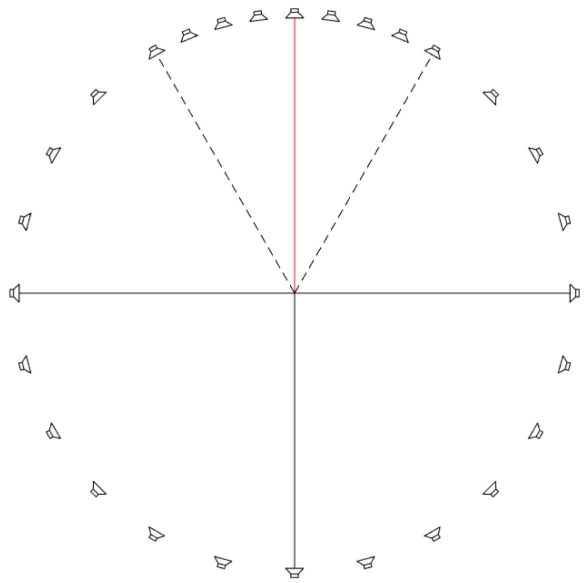

Figure 1: Loudspeaker setup for the localization experiment with a 0° head-above-torso orientation. The red line indicates the head position, the dashed lines indicate ±30°.

Stimulus

A broadband noise pulse-train was used as stimulus. It was a bandpass-filtered white Gaussian noise pulse-train, ranging from 200 Hz to 8 kHz, with a total duration of 500 ms, pulse duration of 30 ms, inter-pulse interval of 70 ms and a rise and fall time of 10 ms with a Gaussian-shaped ramp. The noise signal was generated at 60 dB SPL before applying the pulse-train envelope.

Response method

The perceived direction of sound was indicated with the Proprioception Decoupled Pointer (ProDePo) method [5]. Subjects positioned with a trackball device a light spot projected above the loudspeakers to the perceived direction. Additionally, to report perceived positions in the back without turning the head around, participants were instructed to indicate the perceived direction at the mirror position in the front and to click the right button on the trackball. It was left to the subjects themselves whether they use the mirroring approach or turn their heads to follow the light source. The mirror axis runs between ±90° in the room and is constant for all head positions (i.e. mirroring at the shoulders).

Localization experiment

Subjects

In total five subjects (4 male) participated in this experiment, aged from 23 to 25 years (mean: 24.20 yr.; sd: 1.10). All of them were students and no one was paid for participation. All subjects participated voluntarily in this experiment and gave written consent for their participation.

Procedure

The subject was sitting in the middle of the loudspeaker ring in complete darkness on a non-rotating chair with a short backrest. Before the stimulus started, the target head orientation was shown with a chaser light running from the current head orientation to the target head orientation. This target orientation had to be held for one second before the stimulus was played; if not, the head orientation was readjusted. Subjects were not allowed to move their head during stimulus playback. This was also ensured with the head tracker. After the stimulus finished, a light point was displayed randomly in a range of ±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 10 times during the whole experiment. In total 840 trials were presented to each subject (28 sound directions, 3 head orientations, 10 repetitions). The experiment was blocked in 10 runs in which all trials were presented in completely randomized order. All subjects completed the whole experiment in about 2 hours. Short brakes were taken between the runs.

Results

For the three head positions the tendencies for localization ability were comparable. To analyze the differences between the three head turn orientations, data from all subjects were pooled. From these data sets, containing 50 data points per condition, the median was calculated. To determine shifts in the localized sound directions, the median localized sound directions for non-centered head turn orientations were subtracted from those for 0° head orientation for each sound source direction relative to the head position. Figure 2 shows the resulting differences for both non-centered head-above-torso positions.

The results show that head orientation has a small but measureable impact on localizing sound sources in the horizontal plane. For sound directions in front of the listener small shifts can be observed for both non-centered head positions. Between ±60° relative to the head position, the median shift for a head orientation of -30° to the left was +0.53° (Q1: -0.13°; Q3: +1.69°) compared to a centered head position. For a head orientation of +30° to the right the median shift was -1.29° (Q1: -1.96°; Q3: -0.79°). It is noteworthy that these shifts were opposite to the head turning direction, i.e. to the body center. Analysis of variance (ANOVA) with head orientation and sound direction as factors and subject as a random factor showed that head orientation not to be a significant main effect. In the rear horizontal plane shifts were observed only on that

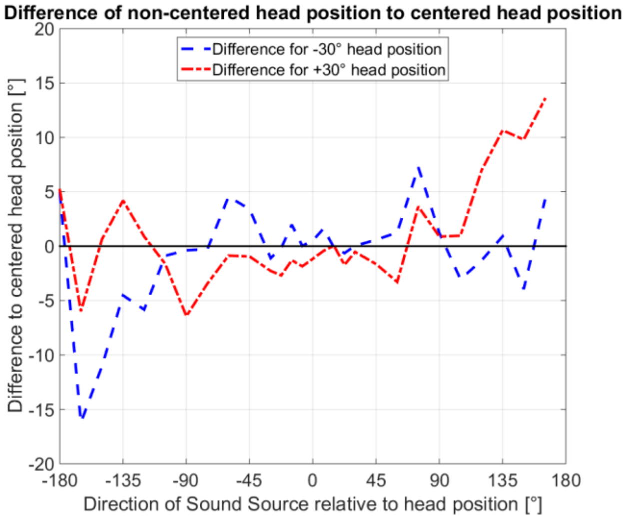

Figure 2: Differences of median localization results for non-centered head orientations (blue, dashed line: -30°; red, dash-dotted line: +30°) to 0° head-above-torso orientation.

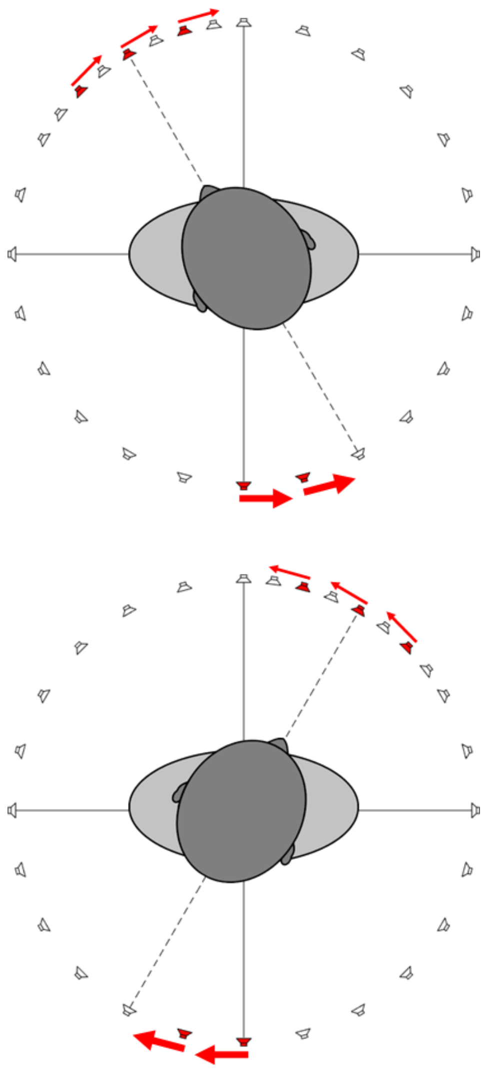

Figure 3: Observed localization shifts, indicated by arrows, for exemplary sound directions, marked in red. The upper drawing visualizes observed shifts for -30° head orientation and the lower drawing for +30° head orientation. The black dotted line indicates the median axis.

side to which the head was turned and these shifts were towards the median plane, meaning sound directions were overestimated and perceived more at the rear. For -30° head orientation the median shift was -4.53° (Q1: -9.73°; Q3: -0.51°) whereas the median shift for +30° head orientation was +8.38° (Q1: +0.96°; Q3: +10.65°). On the side opposite to the head turn orientation no shifts were observed in the rear horizontal plane (median for -30° head orientation: -0.20°; median for +30° head orientation: +0.64°). Figure 3 illustrates exemplarily for selected sound directions where shifts occurred and in which direction, indicated by the arrows, for both head orientations of ±30°. Analysis of variance showed that head orientation has a significant main effect [$F(1,5)=8.76$; $p<0.05$] when evaluated between -165° and -90° sound direction relative to the head orientation, when head was turned to -30°, while it is not significant in this range for +30° head orientation. The opposite can be observed for sound directions between +90° to +165° relative to head orientation where head orientation shows a significant main effect [$F(1,5)=43.5$; $p<0.01$] for a head orientation of +30°, but no significance for -30°.

Discussion

Lewald and Ehrenstein [4] reported on shift of the subjective auditory median plane in their lateralization experiment. Their outcomes showed a significant shift of the subjective auditory median plane to the opposite side of head turning orientation of about 0.017 dB per degree of head rotation in an ILD adjustment. Results of the current localization experiment show a similar behavior for sound sources in front of the listener. The observed shifts when localizing a sound direction with a non-centered head position, compared to a head orientation of 0°, also occurred to the side opposite to the head's orientation but these shifts where close or below of the just noticeable difference (JND) of about 1° in the frontal horizontal plane [3]. Lewald and Ehrenstein [4] investigated the effect in a lateralization experiment by adjusting the interaural level difference (ILD), in contrast to this experiment which was performed with sound sources located in a room so that not only ILDs have an impact on localization, but interaural time differences (ITD) and monaural spectral cues were also available for subjects to localize the sound source. However, shifts for head-above-trunk orientation of ±30° where in [4] about 0.5 dB which is also very close to the JNDs of ILDs [3] which were reported to be about 0.5 dB. The current study also presented sounds from behind to investigate if localization ability changes in the rear horizontal plane depending on an eccentric head orientation. The results for sound directions presented from behind show that shifts only occurred on that side to which the head was turned. These shifts were far larger than those in the frontal plane and rise up to 15°. Senn et al. [7] measured minimum audible angles (MAA) for normal hearing listeners in the horizontal plane. They reported the MAA of 1° to 4° for sound sources from behind. The shifts in the back observed in the current study exceed the MAA with a median shift of -4.53° for -30° head orientation and +8.38° for +30° head position. Noteworthy is that these differences only occurred because of an eccentric head-above-torso orientation. The statistical analysis with an ANOVA also indicates that shifts in the back are due to head orientation, since the main effect of head orientation becomes significant. A possible explanation for these shifts, both in the frontal and the rear horizontal plane, lies in the body centered perception of the environment and the impact of proprioceptive information from muscles, as discussed in [4]. Another possibility for such shifts is different shoulder and torso-reflections based on the eccentric head-above-torso orientation. It was shown by Brinkmann et al. [2] that head orientation has an impact especially on monaural cues. However, changes in ITD and ILD, predominantly relevant for localization, where below the JND. It is nevertheless possible that changes in monaural spectral cues have an impact on perceived sound direction in horizontal plane.

Conclusion

The present study demonstrated that head turning marginally affects the localization of sound sources in the horizontal plane. The observed localization shifts were only small, but the direction of these shifts was consistent and similar to previous studies. Additionally, sound directions from behind were included in this experiment. Shifts in the back were observed as larger and above MAA. The head orientation significantly affected reported sound directions from sources from behind. Therefore, it can be summarized that the head-above-torso orientation is a factor when localizing sound in the horizontal plane. Because static head orientation influences the localization ability, it can be assumed that azimuthal head movement also has an impact on sound localization.

Acknowledgments

NK's participation at the DAGA conference was supported by a DEGA student grant. GG is funded by Phonak AG and BS by BMBF 01 GQ 1004B.

Literature

[1] Blauert, J., Spatial Hearing: The Psychophysics of Human Sound Localization, The MIT Press, Cambridge, Massachusetts, 1999

[2] Brinkmann, F., et.al.: Audibility of head-above-torso orientation in head-related transfer functions. IEEE Journal of Selected Topics in Signal Processing 9(5) (2015), 931-942

[3] Hartmann, W.M.: How We Localize Sounds. Physics Today 52(11) (1999), 24-29

[4] Lewand, J. and Ehrenstein, W.H.: Influence of head-to-trunk position on sound lateralization. Exp. Brain Res. 121(3) (1998), 230-238

[5] Seeber, B.U.: Eine neue Messmethode für Lokalisationsuntersuchungen (A new measurement technique for localization tests). Fortschritte der Akustik - DAGA '01, Dt. Ges. f. Akustik e.V. (DEGA), (2001)

[6] Seeber, B.U., Kerber, S., and Hafter, E.R.: A system to simulate and reproduce audio-visual environments for spatial hearing research. Hearing Research, 260, 1-10

[7] Senn, P. et.al.: Minimum Audible Angle, Just Noticeable Interaural Differences and Speech Intelligibility with Bilateral Cochlear Implants Using Clinical Speech Processors. Audiology and Neurotology 10(6) (2005), 342-352

[8] Wallach, H.: The role of head movements and vestibular and visual cues in sound localization. Journal of Experimental Psychology 27(4) (1940), 339-368