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Analysis of head rotation trajectories during a sound localization task

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Abstract

Dynamic changes of the Head-Related Transfer Function renderings as a function of head movement have been shown to be an important cue in sound localization. To investigate the cognitive process of dynamic sound localization, quantification of the characteristics of head movements is needed. In this study, trajectories of head rotation in a sound localization task were measured and analyzed. Listeners were asked to orient themselves towards the direction of active sound source via localization, being one of five loudspeakers located at 30° intervals in the horizontal plane. A 1 s pink noise burst stimulus was emitted from different speakers in random order. The range of expected head rotations (EHR) for a given stimulus were, therefore, from 30° to 120°. Head orientation was measured with a motion capture system (yaw, pitch, and roll). Analysis examined angular velocity, overshoot, and reaction time (RT). Results show that angular velocity increased as EHR increased. No relationship between overshoot and EHR was observed. RT was almost constant (≈260 ms) regardless of EHR. This may suggest that dynamic sound localization studies could be difficult for a short stimulus with duration less than 260 ms.

Keywords: Dynamic sound localization, Head rotation, Reaction time

1 INTRODUCTION

Sound localization of human beings can be accomplished via the Head-Related Transfer Functions (HRTFs) empirically [1] in our daily lives. When we can move our head, the accuracy of sound localization improves [2, 3, 4]. This tendency can be observed in virtual conditions with dynamic binaural renderings [5]. In consequence, it can be concluded that dynamic cues in sound localization are important in addition to HRTFs. Several previous studies have investigated the perceptional process of dynamic sound localization using the notion of 'active listening' [6, 7]. However, the details of these dynamic cues has not been sufficiently detailed. In this study, therefore, the cognitive process of dynamic sound localization was quantitatively investigated with regards to head rotation specifically. In previous studies [5], front-back confusions in sound localization were analyzed. We observed that front-back confusion rates decreased when the duration of test stimulus was long. This result indicates that head rotation in dynamic sound localization tasks needs sufficient time to be beneficial. In other words, we must be aware of the existence of a sound and roughly localize the corresponding direction of the sound before we rotate our head. In this paper, the time trajectories of head rotation in a sound localization task were measured and analyzed.

2 METHOD

Six university students (in their 20's with normal hearing) participated in the study. Five loudspeakers (C50A, Beringer) were arranged on the horizontal plane at a radius of 2 m at −60° intervals to 60°, where 0° indicated the direction in-front of a listener. A listener sat on a chair at the center of the circle. The height of listener's ear entrance and center of loudspeakers were 1.2 m. A 1 s pink noise at 70 dBA was emitted randomly through one of the five loudspeakers, via a USB audio interface (UR824, Steinberg) controlled by a PC1 (Microsoft Windows 10, Core i7-4790, 16GB Memory). Five markers were placed on a headband attached to the listener enabling monitoring of and head movement, captured via a motion capture system (V120 Trio, OptiTrack) on another PC2 (Microsoft Windows 10, Core i7-4790, 16GB Memory). The electric signal of the stimulus from a loudspeaker was fed back to a USB audio interface (UR824, Steinberg) attached to PC2, while the stimulus and head movement data were simultaneously recorded (Motive, OptiTrack). The update rate of the motion capture system was $1/120$ s.

The listener was asked to localize sound direction by facing (nose pointing protocol) to the direction of the source. In each trial, three stimuli were emitted continuously at 1 s intervals. For each listener, 35 trials were performed, with a total of 105 localizations.

3 RESULTS AND ANALYSIS

3.1 Abstract of head movement

An exmaple of a typical head movement data log is shown in Fig. 1. Head rotation (yaw, pitch, and roll) and the recorded sound envelope are plotted in Fig. 1. We observed small overshoot in roll and yaw angle. Furthermore, start time is delayed from sound emitted time. These tendencies were observed for all participants. Therefore, we analyzed, overshoot, reaction time (RT), and angular velocity of roll.

3.2 Reaction Time

We defined reaction time as followings: First, we calculated the amount of angle change of roll angle between five frames, as shown in Fig. 2 (one frame is $1/120$ s). Small changes were eliminated as data noise using threshold processing. Subsequently, a tangent line was drawn at the time of 2°, when we decided the participant started movement. Finally, the moment of the 0° crossing of the tangent was calculated as the starting time for head movement. The difference between the calculated start time and the sound envelope rise time was defined as the reaction time.

The five loudspeakers were arranged at 30° intervals. The range of expected head rotations for a given stimulus was, therefore, from $-120°$ to 120°. Table 1 shows the average RT for expected amount of head rotation. Positive and negative angular signs indicate right and left rotations, respectively. From Table 1, it can be observed that RT is almost constant, ≈0.26 s.

Table 2 shows the results of RT averaged across trials for each participant. Subject B was the fastest (0.18 s) with Subject C the slowest (0.30 s). As a result, it can be assumed that there may be individual difference among individuals.

Table 1. Average RT to amount of head rotation.

Expected amount of head rotation (°)	RT (s)
30	0.31
–30	0.27
60	0.27
–60	0.27
90	0.24
–90	0.24
120	0.22
-120	0.23
Average	0.26

3.3 Maximum Angular velocity.

We calculated the time to the maximum value of each movement in Fig. 2 and the slope at the time was used to determine the maximum angular velocity.

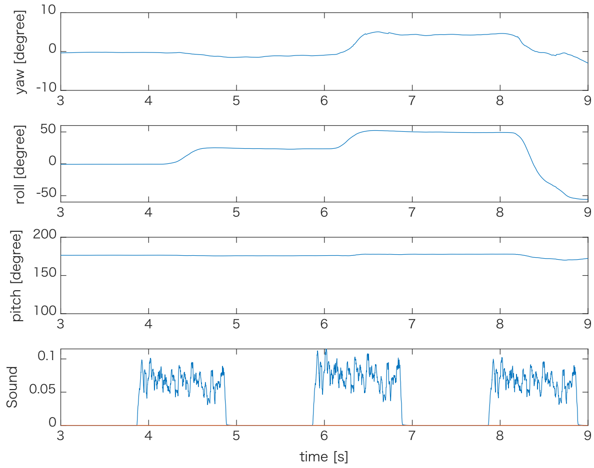

Figure 1. Example of head movement (yaw, pitch, roll, and sound envelope) data log. Target angles were 30°, 60°, and $-60°$.

Table 2. Average RT of each participant.

Participant	RT (s)
A	0.29
B	0.18
C	0.30
D	0.29
E	0.24
F	0.22
Average	0.26

From Table 3, the maximum angular velocities were larger than that of expected amount of head rotation in 1 s. It was observed that as the total amount of head movement increased, the maximum angular velocity tended to increase.

Table 3. Maximum angular velocity to expected head rotation

Expected amount of head rotation (°)	max. angular velocity of rotation (°).
30	139.8
-30	143.6
60	200.1
-60	189.6
90	251.8
-90	239.5
120	300.6
-120	288.1

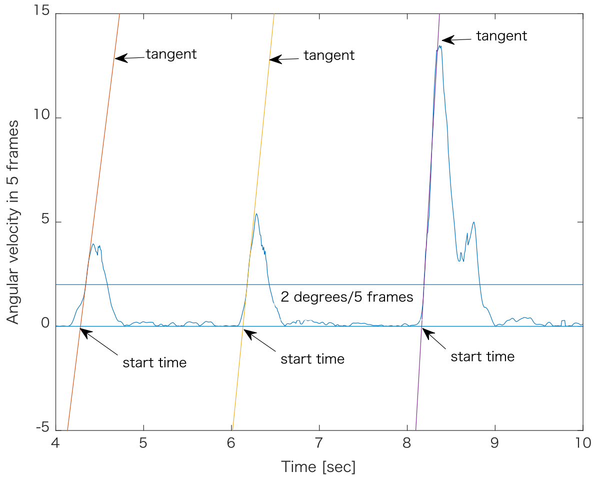

Figure 2. Example of amount of change of roll angle in 5 frames.

3.4 Overshoot

Participants did not always face the emitted speaker correctly. To quantify this, the difference between the angle of the peak in one localization and the angle at the start time of the next localization was calculated as the overshoot.

Average overshoot for each expected amount of head rotation is shown in Table 4. No systematic change in overshoot was observed as a function of the target position.

Table 4. Maximum angular velocity to expected head rotation.

Expected amount of head rotation (°)	average overshoot (°).
30	2.4
-30	0.4
60	2.4
-60	1.8
90	2.6
-90	2.4
120	2.6
-120	1.7

4 SUMMARY

In this paper, the time trajectories of head rotation in a sound localization task were measured and analyzed. Reaction time, overshoot, and maximum angular velocity of the head rotation were investigated. From the results, reaction time was more than 0.2 s, irrespective of the expected amount of rotation. Results show that angular velocity increased as the angular distance to the target increased. No relationship was observed between overshoot and rotation. Reaction time was almost constant (about 260 ms) regardless of expected rotation. This may suggest that dynamic sound localization studies could be difficult for a short stimulus. However, further investigations are needed because the duration 260 ms in this paper might be a task dependent result.

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