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ACOUSTICAL LETTER

Effects of listener's whole-body rotation and sound duration on horizontal sound localization accuracy

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1. Introduction

Sound localization is an important spatial hearing ability used in daily life. When trying to localize a sound, our head/body movement is known to facilitate sound localization, which creates dynamic changes to the information input to each ear [1–5]. However, earlier reports have described that sound localization accuracy deteriorates during a listener's head rotation [6–8]. Moreover, the facilitative effects of a listener's movement differ depending on the sound features [4,5]. Therefore, the interaction between a listener's movement and sound features remains unclear.

Sound duration, a characteristic of sound, is known to influence the sound localization accuracy. For instance, Frens and Van Opstal [9] showed that sound localization performance deteriorates in elevation when the stimulus duration of broadband noise bursts is shorter than 10 ms. Moreover, Iwaya *et al.* [4] reported that the listener's head rotation improves front–back judgment better when the sound duration is 2 s than when it is 200 ms. Therefore, we anticipated that long sound durations might improve sound localization accuracy during a listener's whole-body rotation because the movement and sound duration can commonly provide rich auditory information to listeners. Nevertheless, few studies have examined whether a listener's movement affects horizontal sound localization performance more for long stimuli than for short stimuli. Therefore, this study examined interaction between a listener's movement and the sound duration.

For this study, we used a digitally controlled spinning chair to assess the effects of a listener's whole-body rotation and sound duration on horizontal sound localization accuracy. As we described earlier, the effects of a listener's movement on sound localization have been studied widely, with mixed results. Our findings might contribute to better understanding of spatial hearing mechanisms and the active listening process.

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2. Method

Listeners were 12 adults (2 women, 10 men; age range, 21–38 years; mean age and standard deviation, 23.3 ± 4.7 years) with normal or corrected vision and normal audition (including one author, AH). Our experiment was conducted in an anechoic room at Tohoku University. All listeners were tested individually in this room. This study was approved by the ethics committee of the Research Institute of Electrical Communication, Tohoku University. Written informed consent was obtained from each listener before participation in the study.

This experiment measured listeners' sound localization accuracy at the horizontal plane from left 30 deg to right 30 deg with respect to the listener in chair-still (0 deg/s) and chair-rotation (10 deg/s) conditions. Stimuli were 1/3-octave band noise bursts (center frequency = 1 kHz, SPL = 65 dB) of 50, 200, and 1,000 ms duration.

Horizontal sound localization is characterized by the listener's interaural time differences (ITDs) and interaural level differences (ILDs). For this study, we used 1/3-octave band noise bursts because future studies are planned to elucidate the roles of the ITD and ILD in spatial hearing during a listener's movement as a function of frequency. In fact, the 1/3-octave band noise has been used in earlier studies to explore the relation between human sound localization, ITDs, and ILDs [10,11]. For instance, Middlebrooks and Green [12] reported that the horizontal sound localization performance was worst at frequencies of 1,500–3,000 Hz because human hearing is insensitive to ITDs higher than 1,500 Hz. Their wavelengths are not sufficiently short to provide adequate ILDs. Considering these points, we selected the center frequency of 1 kHz, at which ITDs effectively work, as the first step.

Each stimulus was presented from a loudspeaker in a circular array (1.2 m radius) with loudspeaker separation of 2.5 deg (total 25 loudspeakers). Listeners were unable to see the loudspeakers because an acoustically transparent curtain was placed between the participant and the circular loudspeaker array while maintaining brighter conditions inside the curtain than outside. We assigned numbers for the azimuth angle at 1.25 degree intervals: the number zero was 31.25 deg to the left; the number 25 was in front of the listener; and the

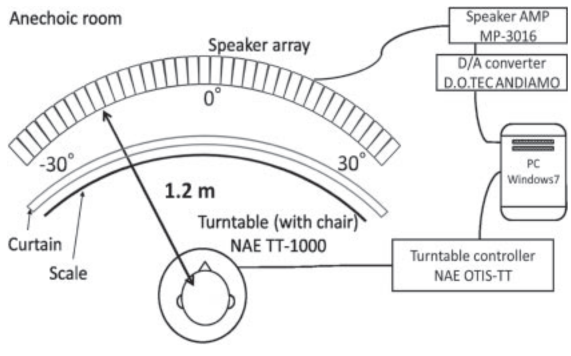

Fig. 1 Outline of the loudspeaker array system.

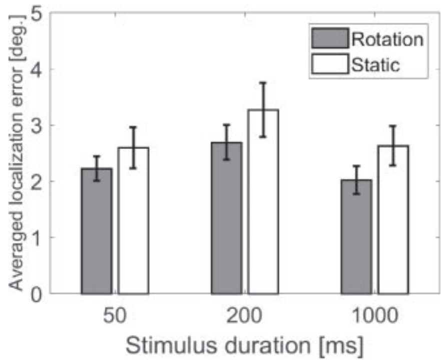

Fig. 2 Results of angular error in the horizontal planes.

number 50 was 31.25 deg to the right. These numbers were presented on the curtain to facilitate responses. Listeners sitting on the spinning chair set at the circle center were asked to report the number corresponding to the position of the presented stimulus (see Fig. 1).

In the chair-still condition, listeners faced forward with the head aligned frontward (0 deg). Then the stimulus was presented from one loudspeaker of the circular array. In the chair-rotation condition, listeners faced forward with the head 15 deg left or 15 deg right. Then, the chair rotated for 30 deg clockwise or counterclockwise respectively when the listener first faced 15 deg left or right. During the rotation, when listeners faced forward with the head front at 0 deg, the stimulus was presented from one of the loudspeakers in the circular array.

The chair-still condition comprised four sessions and 600 trials in all (3 sound durations $\times$ 25 loudspeaker positions $\times$ 8 trials). The session structure of the chair-rotation was identical to the chair-still condition. The stimuli and the sessions were presented in fully randomized order. Before the test trials, listeners completed 75 practice trials for each condition.

3. Results

We analyzed the angular errors in the horizontal planes. The angular errors were calculated as the difference between the perceptually localized position and the physical target position. Figure 2 depicts the mean horizontal sound localization performance. Two-way analysis of variance (ANOVA) was applied to angular errors with the rotation condition and the sound duration as factors. The rotation condition includes two levels (chair-still (0 deg/s) and chair-rotation (10 deg/s)). The sound duration includes three levels (50 ms, 200 ms, and 1,000 ms). Results show that the main effect of rotation condition was significant ($F(1, 11) = 4.93$, $p < 0.05$). The chair-rotation condition ($Mean$ (M) $= 2.31$) showed better horizontal sound localization performance than the chair-still condition did ($M = 2.83$). A significant main effect of the sound duration was also found ($F(2, 22) = 7.31$, $p < 0.005$). Post-hoc analysis (Ryan's method, ps < 0.05) revealed larger horizontal angular errors for 200 ms ($M = 2.98$) than those for 50 ms ($M = 2.41$) or for 1,000 ms ($M = 2.32$). Interaction between the condition and the sound duration was not significant.

4. Discussion

We investigated the effects of a listener's whole-body rotation and sound duration on horizontal sound localization accuracy. Earlier studies demonstrated that a listener's head/body movement facilitates sound localization [1–5], but the interaction between the listener's movement and sound duration of the stimuli remains unclear. Furthermore, the effects of a listener's movement on sound localization have been widely studied, yielding mixed results.

Our results demonstrated superior sound localization accuracy of the chair-rotation condition to that of a chair-still condition. Moreover, a significant effect of sound duration was observed; the accuracy for 200 ms stimuli seems worst among the durations used. However, the interaction of the test condition and the sound duration was not significant. A listener's head movement might influence the localization performance more for long stimuli than for short ones, but our results indicate that the effects of a listener's whole-body rotation on the angular errors in the horizontal planes were not linearly dependent on the sound duration.

These findings suggest that the sound localization performance might be improved if listeners are able to obtain dynamic auditory information from their movement. Furthermore, the duration difference of target sound was not crucially important for their sound localization accuracy. Of course, other explanations are possible. For instance, listeners might be better able to localize the sound using shorter sound (less than 50 ms), although a halfway longer duration such as 200 ms would not provide effective dynamic information to facilitate sound localization. Irrespective of the interpretation, our results provide valuable suggestions for future studies undertaken to elucidate the interaction between a listener's movement and sound duration.

Several limitations of this study must be acknowledged. Frens and Van Opstal [9] reported that sound localization performance deteriorates in elevation when the sound duration is shorter than 10 ms. In addition, Strybel and Fujimoto [13] reported that the effect of sound duration is generally stronger in the vertical plane than in the horizontal plane. Future studies are expected to investigate differences between vertical and horizontal planes and to confirm whether the observed phenomenon is limited to the horizontal sound localization accuracy. Moreover, Lewald and Karnath [14] reported a slight but significant influence of rotation on sound lateralization during passive whole-body rotation. Whereas they used headphones, we applied loudspeakers around the spinning chair. Although the loudspekers were not visible, listeners were able to use visual and positional cues by numbers from zero to fifty related to the sound source. Future studies must investigate whether these visual cues related to auditory information contribute to sound localization accuracy during passive whole-body rotation.

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