

ACOUSTICAL LETTER

Accuracy of subjective straight ahead after passive rotation of listeners: Effects of time interval between visual cue and onset of sound stimulus

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1. Introduction

It is well known that a listener's head movement facilitates sound localization [1,2]. However, several recent studies have revealed that sound localization accuracy may deteriorate during head movement. For example, Cooper *et al.* showed that head movement increases the localization error for a sound stimulus presented during head rotation [3]. Using a virtual sound source, Honda *et al.* showed that the detection threshold of a virtual sound source movement was larger during a listener's active head rotation than under a static condition [4]. However, there have been few studies on such deterioration during listener head rotation and no systematic study of the reason why such deterioration occurs; thus, further clarification of the phenomenon is required. Here, a few possible mechanisms for the phenomenon are given. For example, the blurred memory of a visual cue indicating the direction caused by elapsed time and head rotation may account for some of the deterioration. Moreover, not only bottom-up effects such as the blurring of ear input caused by a listener rotation but also top-down effects such as judgement bias caused by a listener's belief that they are moving should be taken into account. In addition, we must consider phenomena occurring during a listener's rectilinear motion. Teramoto *et al.* reported that the subjective coronal plane shifts in the direction of linear self-motion [5]. A similar phenomenon may occur with head rotation.

With these questions in mind, we conducted two experiments to investigate the detection thresholds of subjective straight ahead (SSA). Previous studies showed that normal listeners demonstrated reasonably accurate judgements of auditory SSA [6], but passive full-body rotation deteriorates the sound localization accuracy of SSA [7]. However, the effects of the time interval between a visual cue and the onset of a sound stimulus were not examined. In the first experiment, the just noticeable difference (JND) of SSA, in comparison with a stimulus presented via a light-emitting diode (LED) located straight ahead, was measured as a function of the time interval between the visual stimulus and the onset of the following sound stimulus. In the second experiment, we examined how the JND of SSA is affected by full-body rotation before the presentation of the sound stimulus.

2. Experiment 1

2.1. Experimental conditions

The listeners were 17 adults (7 women, 10 men; age range, 21–23 yrs.) with normal or corrected vision and normal hearing (including one of the authors). All listeners were tested individually in a dark anechoic room. Each stimulus was a pink noise burst (duration, 30 ms; sound pressure level, 65 dB) and was presented from a loudspeaker in a circular array (1.1 m radius) consisting of 10 loudspeakers located at $\pm 6.875^\circ$, $\pm 4.375^\circ$, $\pm 3.125^\circ$, $\pm 1.875^\circ$ and $\pm 0.625^\circ$ (+, right; −, left). A white LED was placed on the loudspeakers at 0°. Listeners sat still on a chair so that their head coincided with the center of the loudspeaker array and they were asked to look at the LED during the experiment. To begin with, the white LED at 0° flashed for 1 s. After a specified interval, a sound stimulus was presented from one of the loudspeakers. The time interval was randomly chosen as 1 s, 2 s, or 4 s. Listeners were asked to judge whether the stimulus was presented from the left or right of SSA (2AFC). This experiment comprised three sessions and 300 trials in total (3 time intervals × 100 repetitions). Listeners practiced a trial exercise three times before the test.

2.2. Results

For each listener, the rates of responses as "right" were fitted to a cumulative normal distribution function to estimate psychometric functions by maximum likelihood fitting. Then we calculated the point of SSA (PSSA) and JND. PSSA was defined as the 50% point in the psychometric function. JND was defined as the detection threshold for 75% correct responses in the psychometric functions [4]. Data of one male listener was excluded because of a mistake in the experimental procedure. One-way repeated-measures analysis of variance (ANOVA) was applied to PSSA and JND with the time interval (3 levels: 1 s, 2 s, and 4 s) as the factor. The main effects of the time interval were not significant (PSSA: $F(2,47) = 1.0$, $p = 0.37$, JND: $F(2,47) = 1.6$, $p = 0.23$).

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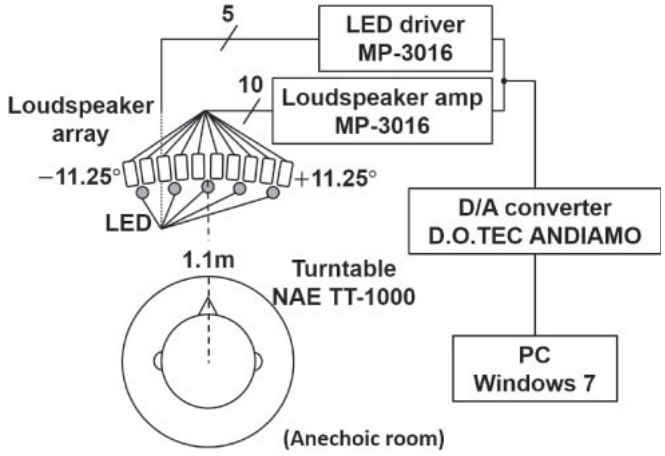

Fig. 1 Experimental setup for experiment 2.

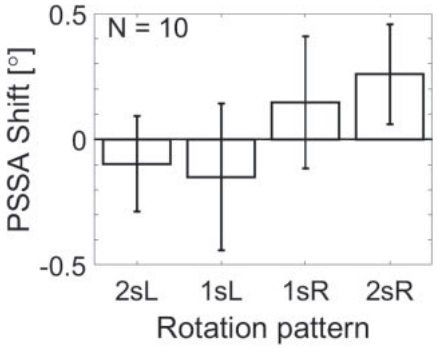

Fig. 2 PSSA shift induced by rotation before stimuli presentation. Here, "1 s" and "2 s" indicate the rotation duration, and L and R respectively indicate counter-clockwise and clockwise rotation.

3. Experiment 2

3.1. Experimental conditions

The listeners were 17 adults (6 women, 11 men; age range, 21–22 yrs.) with normal or corrected vision and normal hearing, two of them participated in Exp. 1. The experimental setup is shown in Fig. 1. Each stimulus was presented from a loudspeaker in a circular array (1.1 m radius) consisting of 10 loudspeakers ranging from -11.25° to $+11.25^\circ$ with 2.5° separation. Five white LEDs were set on the loudspeakers at 0°, $\pm 5^\circ$, and $\pm 10^\circ$. The sound stimulus was the same as that used in Exp. 1. Listeners sat on a digitally controlled spinning chair. They faced 0° and then the chair sometimes spun and back to face forward again, and visual and sound stimuli were presented. The experiment comprised 5 rotation patterns (0 s, 1 s clockwise, 1 s counterclockwise, 2 s clockwise, and 2 s counterclockwise). In each trial, the chair turned 0° (0 s), 5° (1 s), or 10° (2 s) clockwise or counterclockwise. Then the white LED in front of the listener flashed for 1 s. Listeners were asked to look at the LED. One second after the extinction of the LED, the chair turned in the opposite direction to face 0°. The rotation speed was fixed at 5°/s. The sound stimulus was presented from one of the 10 loudspeakers 1 s after the rotation. Listeners were asked to judge whether the stimulus was presented from the left or right of SSA (2AFC). This experiment comprised four sessions and 400 trials in total (5 patterns $\times$ 80 repetitions). Pattern selection was fully randomized. Listeners practiced a trial exercise three times before the test.

3.2. Results

PSSA and JND for each listener were calculated by the same procedure as that in Exp. 1. Data of seven listeners (6 males, 1 female) were excluded because their PSSA and JND could not be estimated. One-way repeated-measures ANOVA was first applied to PSSA and JND with the rotation pattern (5 levels: 0 s, 1 s clockwise, 1 s counterclockwise, 2 s clockwise, and 2 s counterclockwise) as the factor. As a result, the main effects were not significant (PSSA: $F(4, 49) = 2.6$, $p = 0.49$, JND: $F(2, 29) = 3.6$, $p = 0.35$). This result suggests that the accuracy of auditory SSA judgement does not deteriorate if stimuli are presented at least 1 s after the rotation.

In addition, we analyzed the PSSA shift induced by a listener rotation before stimuli by calculating the difference between PSSAs without and with rotation (see Fig. 2). Two-way repeated-measures ANOVA was applied to the PSSA shift with the rotation duration and direction as factors. The result shows no significant effects of the rotation time ($F(1, 36) = 0.16$, $p = 0.92$) and the head rotation ($F(1, 36) = 1.7$, $p = 0.13$) on the direction of PSSA.

4. Discussion

The results of the present study suggest that the accuracy of horizontal sound localization is unaffected by full-body rotation before listeners listen to the sound stimulus, irrespective of the time interval between the rotation and stimulus. In contrast, as described in the introduction, previous studies showed the deterioration of sound localization accuracy during listener head rotation. Therefore, rotation of the listeners at the time of sound presentation and localization might be a necessary condition for the rotation to affect/deteriorate sound localization accuracy. However, there seems to be no experimental evidence in previous studies including ours, that supports this hypothesis. Thus, further investigation should be conducted to clarify the effects of listener rotation on sound localization performances.

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