inter.noise 2011
Osaka Japan September 4-7

Head movements during horizontal sound localization

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ABSTRACT

We measured subject's head movements during horizontal sound localization experiments to determine how little the people move their heads in a head-still condition, and how they move their heads in a head-movement condition. The head movements of eight subjects in a head-still condition were measured while localizing six kinds of band-pass noises, and the head movements of five subjects in a head-movement condition were measured while localizing 500-Hz low-pass noise, 12-kHz high-pass noise, and white noises. In the experiments, all stimuli were presented from one of loudspeakers placed 30º apart in a circle of 1 m radius. In the head-still condition, we confirmed that all subjects kept their heads fairly still. The maximum head movement was 1° in roll angle, 3° in pitch angle, and 1.5° in yaw angle. These results suggest that the subjects followed the instruction of not moving their heads while the stimuli were being presented in the head-still condition. In the head-movement condition, all subjects turned their heads toward the presented sounds, yet they did not necessarily turn their heads to face the sound. The maximum head movement angle in yaw angle among the subjects was about ±60°. The head movement patterns, however, were different among subjects, suggesting that each subject seemed to have his/her own strategy.

Keywords: Head Movement, Sound Localization, Head-still Condition, Head-movement Condition

1. INTRODUCTION

We move our heads when we listen to the sound because we implicitly know sound localization becomes more accurate by moving our head. The impact of head movement on sound localization has been known since Wallach [1-11]. However, it is not clear how we move our heads when we localize sound.

Thurlow *et al.* reported that there are many horizontal head rotations when we locate sound directions [11]. Blauert reported that people move their heads so that the difference limen of sound localization may decrease [10]. This means that they face the sound source because the minimum audible angle is smallest [12]. Iwaya *et al.* reported that subjects tended to move their heads more dynamically when the sound was presented away from front (0°), trying to capture it directly in front of them [5]. Recently, Nojima *et al.* reported that subjects moved their heads toward the sound image on the lateral sides and they can localize the sound even when they do not face the sound image [13]. Toshima *et al.* noted that subjects do not necessarily turn their heads to capture the sound in front of them [6].

To clarify how we move our heads when we localize sound, we measured subject's head movements during horizontal sound localization experiments with real sound sources in the head-still and head-movement conditions. We first show data on how little the subjects moved their head in accordance with the experimenter's instructions of not to move their heads during the experiment. Next, we present data on how much the subjects moved their heads to localize sound when head movement was allowed. Finally, we discuss the head movement strategy on sound localization.

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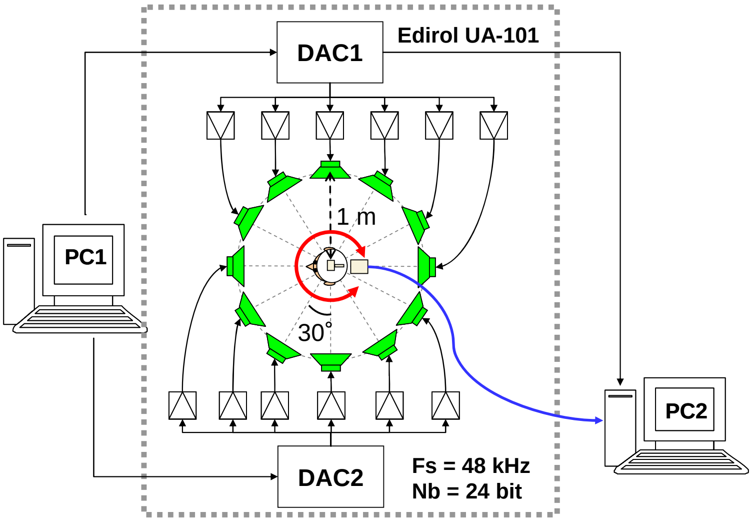
2. METHODS

Three-dimensional positions and Euler angles of a subject's head were measured using a motion sensor (Flock of Birds, Ascension Technology) placed on top of the head. The accuracy of the motion sensor was static positional accuracy 1.8 mm RMS and static angular accuracy 0.5° RMS. Figure 1 depicts a block diagram of the experimental system. Two PCs were used; one for controlling the sound localization experiment and the other for simultaneously recording the stimuli sound and head movement data to confirm their synchronization. Sampling frequency of the sound was 48 kHz and that of the Flock of Birds was 128 Hz.

The stimulus duration and inter-stimulus interval were both 3 s. Stimuli were presented from one of loudspeakers placed 30° apart in a circle of 1 m radius. Each session consisted of 60 trials, and the stimuli were presented in random order from the 12 loudspeaker. One experiment consisted of four sessions. Subjects sat on a chair placed at the center of the speaker array without using any head fixing device. Their head movements were measured during horizontal sound localization experiments in the head-still and head-movement conditions.

In the head-still condition, six kinds of band-pass noises (BPNs) were used as stimuli for sound localization. Their pass-bands were 2-12, 2-8, 2-4, 4-12, 4-8, and 8-12 kHz. Broad-band BPNs can be localized easily while narrow-band BPNs are difficult to localize in the head-still condition [14]. The subjects were instructed to close their eyes and keep their heads still while each stimulus was presented. When each stimulus was stopped, they opened their eyes and marked the perceived sound-image location at one of the 12 horizontal directions on an answer sheet. Eight males in their 20s participated in this experiment.

In the head-movement condition, white noise (WN), 500-Hz low-pass noise (LPN), and 12-kHz high-pass noise (HPN) were used as stimuli for sound localization. WN can be localized easily while LPN and HPN are difficult to localize because many front-back errors occur. The subjects were instructed to close their eyes and were encouraged to rotate their heads freely while each stimulus was presented. Five males in their 20s participated in this experiment.



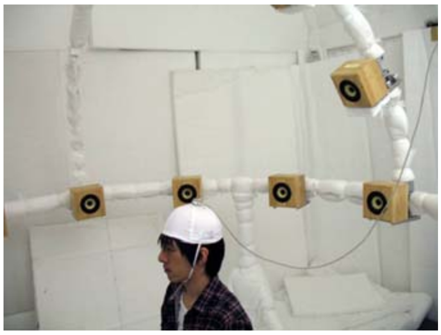


Figure 1 – Block diagram of experimental system (left) and photograph of experiment room (right). PC1 was used to for stimuli presentation for sound localization experiment. PC2 was used to simultaneously record sound stimuli and subject's head movement data.

3. RESULTS

3.1 Head-still condition

Figure 2 shows an example of the typical head movement of the subject in the head-still condition. The gray lines represent the stimulus waveform. In Figure 2(a), the blue, green and red lines respectively represent the x, y, and z directions of the head. In Figure 2(b), the blue, green and red lines respectively represent the roll, pitch, and yaw angles of the head. The subject kept his heads fairly still while each stimulus was presented. When each stimulus presentation ended, he moved his head downward to mark the perceived location on the answer sheet. Thus, the x direction increased, the y direction decreased, and pitch angle decreased. Then, he returned his head back to the listening position for the next stimulus, but these returned positions were not always the same. The head positions while listening to stimuli differed by up to 8.2 cm in the x direction and 20º in pitch angle. However, the variation in the yaw angle, which should largely impact horizontal sound localization, was less than 2.6° for each subject.

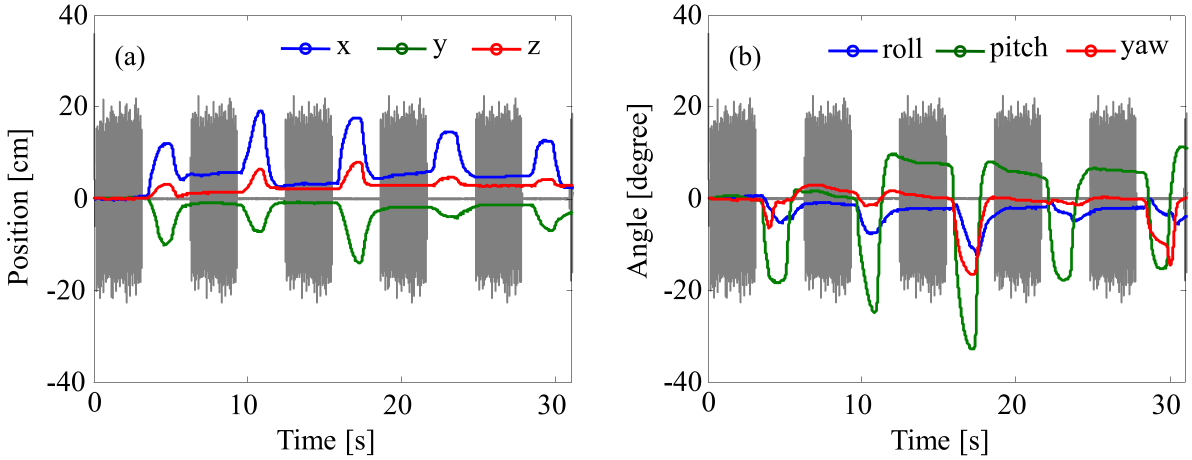


Figure 2 – Example of typical head trajectories of subject in head-still condition;
(a) three-dimensional positions data and (b) Euler angles data.

Figures 3(a) and (b) show the mean maximum head movement positions and angles during the stimulus presentation for each subject. References for measuring the maximum head movements were the positions and angles at the beginning of each stimulus. The blue, green, and red lines respectively represent the x, y, and z directions of the head (Fig. 3(a)), and the blue, green, and red lines respectively represent roll, pitch, and yaw angle of the head (Fig. 3(b)). The mean maximum head movement of all subjects was less than 1.3 cm in each direction and less than 3° in each Euler angle. The maximum pitch of head movement was largest among Euler angles because the subject's heads moved downward when they marked their answers on the answer sheet. These data suggest that all subjects kept their heads fairly still when each stimulus was presented in the head-still condition.

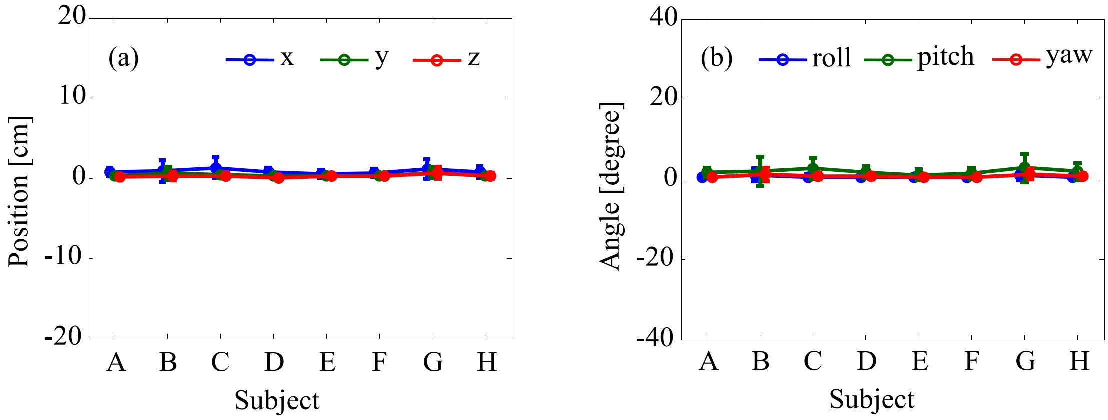


Figure 3 – Maximum head movement for each subject during stimulus presentation in head-still condition;
(a) maximum head position movement and (b) maximum head angular movement.

3.2 Head-movement condition

Figure 4 shows the typical head-yaw angle trajectory of the subject head for LPN. The gray line represents the stimulus waveform and the red line represents the head-yaw angle trajectory. The blue and green circles respectively represent the presented and perceived azimuthal angle of the stimulus. All stimuli were localized correctly.

In most cases, the subject turned his head towards the presented stimulus direction, then he sometimes swung his head. For the first stimuli, presented at the front-right (60°), he turned his head right and swung it to right. For the third stimuli, presented at the right (90°), he turned his head right once. For the 5th stimulus, presented at the rear left (-120°), he turned his head left and swung it to both sides. For the 7th stimuli, presented at the front left (-30°), he turned his head left and swung it to left. For the 8th stimulus, presented at the front (0°), he turned his head right once. Usually, the maximum yaw angles at which he turned his head were smaller than the stimulus angles.

These head movements were classified into two patterns; single-side head swing and both-side head swing. The single-side head swing pattern is when a subject turned and swung his head once or twice to either the right or left. The both-side head swing pattern is when a subject swung his head both to the right and left. Stimuli numbers 1, 3, 4, 6, 7, 9, and 10 resulted in a single-side head swing pattern and stimuli numbers 2, 5, and 8 resulted in a both-side head swing pattern.

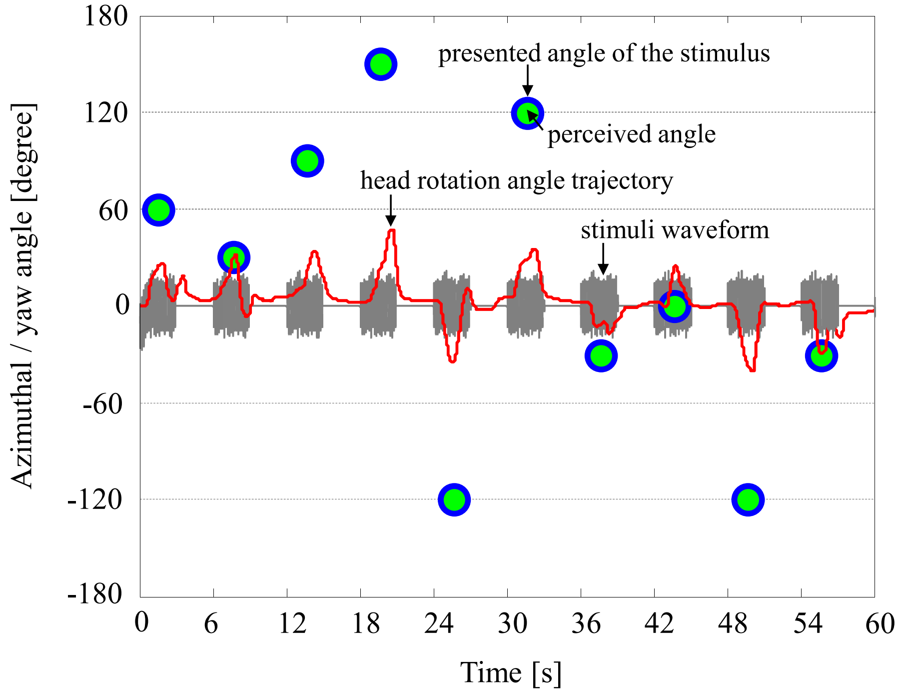


Figure 4 – Example of typical head-yaw angle trajectory of subject for LPN. Head movement can be classified into two patterns; single-side head swing and both-side head swing patterns.

Figure 5 shows the mean, maximum, and minimum angles of the head-yaw angle in single-side head swing (upper panel) and both-side head swing (lower panel) patterns for each angle of the presented stimuli. N represents the number of single-side or both-side head swings. The blue, red, and green circles respectively represent the mean, maximum, and minimum yaw angles. There are some points where data is not drawn for the single-side head swing, indicating the subject always swung his head to both sides. In the single-side head swing pattern, the maximum or minimum yaw angle was not necessarily 0°, because the subjects did not return his head to the initial position punctually when each stimulus presentation began.

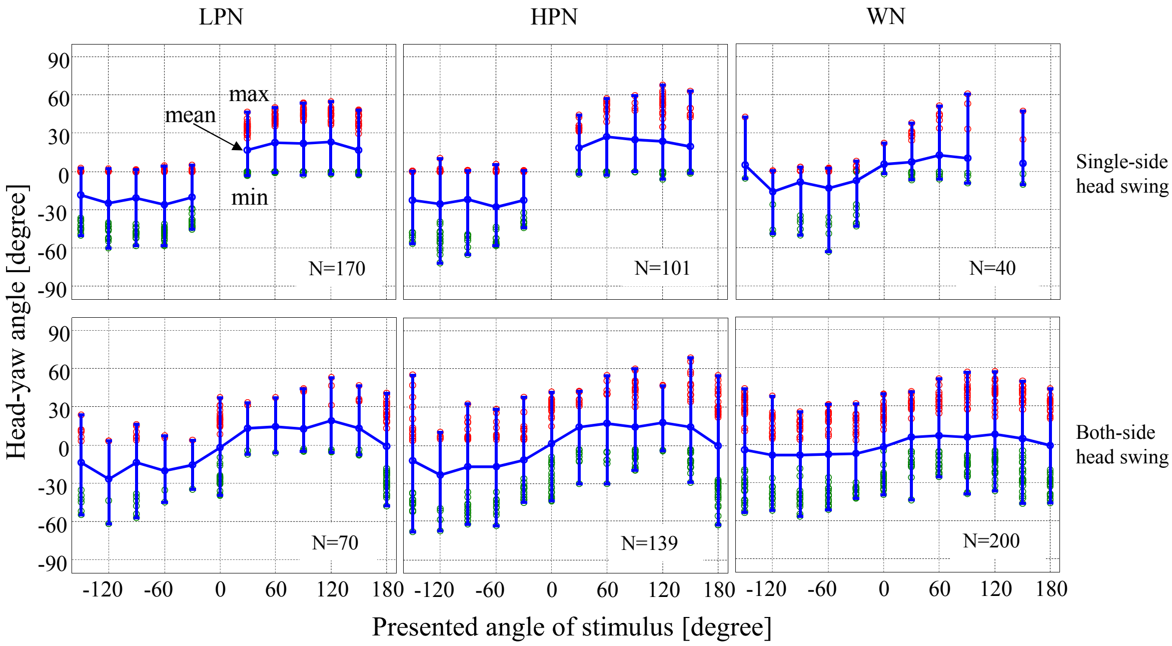


Figure 5 – Mean, maximum, and minimum head-yaw angle of subject for LPN, HPN, and WN. Upper panels show those of single-side head swing pattern and lower panels show those of both-side head swing pattern.

When stimuli were presented from front (0°) or behind (180°), the subjects always swung their heads to both sides. When stimuli were presented from the lateral sides, the subjects turned their heads toward the stimuli. However, the maximum head-yaw angle was about ±60°. The subjects did not turn their heads to face the stimuli when they were presented over ±60°.

Among LPN, HPN, and WN, the mean head-yaw angle for each stimulus was smallest for WN. WN was almost perfectly localized by all subjects even in the head-still condition because it contained rich acoustical cues for localization. The dynamic acoustical cues provided by the head movement are probably not necessary. Small head movements should be enough to confirm the sound direction for WN. By contrast, the correct localization performances of LPN and HPN were less than 75% in the head-still condition. The performances improved more than 17% when head movement was allowed because front-back confusion disappears due to head rotation. Obviously, the dynamic cues from head movement play important roles in localizing LPN and HPN, which only contain either inter-aural time difference (ITD) or inter-aural level difference (ILD). Thus, a larger amount of head movement is necessary for localizing LPN and HPN than that for WN.

All five subjects showed similar head-movement strategies. They did not turn their heads to capture the sound stimuli in front of them, the maximum head-yaw angles were about ±60°, and the amount of head rotation was small for WN compared to that for LPN and HPN. Detailed head movement strategies, however, differed by subject. For example, one subject always swung his head a certain amount despite the stimulus presentation azimuthal angle in the single-side head swing pattern. Another subject preferred to use the single-side head swing pattern than the both-side head swing pattern.

4. DISCUSSION

The results of the head-still condition showed that the subjects kept their heads still during the stimuli presentation without using any head fixing devices and that they returned their heads to the right position no later than the start of the next stimulus. The subjects followed the experimenter's instructions very well. These results confirm the validity of the experimental procedures for the sound localization tests we have been conducting. It must be, however, very difficult to keep the head still for longer the sessions.

The results of the head-movement condition showed that the subjects did not turn their heads to capture the stimulus in front of them. The yaw angles at which they turn their heads were always smaller than the stimulus azimuthal angles. Even though the maximum yaw angle at which humans can turn their heads is about 70° [9], the subjects did NOT turn their heads to this extent. Presumably, they can obtain enough information for sound localization with smaller head yaw angles. Namely, they did not face the sound stimuli, suggesting that they do not move their heads in order to decrease the difference limen of the sound localization. They all swung their heads while localizing the sound. The variation in ITD and ILD, *i.e.* ΔITD and ΔILD or time derivative of ITD and ILD, must be used as dynamic cues to localize sound. In fact, the sound image of the stimuli swings around the head when rotating the head, resulting in a dramatic reduction in the ambiguity of sound image location.

5. CONCLUSIONS

We measured subject's head movements during horizontal sound localization experiments in the head-still and head-movement conditions.

In the head-still condition, subject's maximum head position movements and maximum head angular movements were small when each stimulus was presented. Therefore, all subjects kept their head fairly still when they were instructed to do so.

In the head-movement condition, subjects turned their heads toward the stimuli when each stimulus was presented. The head movement patterns were either single-side head swing or both-side head swing. The maximum head-yaw angle, however, was less than ±60° despite the stimulus direction. The subjects did not turn their heads to capture the stimulus in front of them over ±60°. The amount of head rotation was small for WN compared to that for LPN and HPN, suggesting that the less acoustical cues are involved in a stimulus, the more head movements are necessary to localize it. Detailed head movement strategies, however, differed by subject.

ACKNOWLEDGEMENTS

Part of this work was supported by KAKENHI (22300061).

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