3-D SOUND IMAGE LOCALIZATION BY INTERAURAL DIFFERENCES AND THE MEDIAN PLANE HRTF

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ABSTRACT

A new 3-D localization method by simulating interaural differences and the HRTF in a sagittal plane is proposed. This method is based on the supposition that the spectral cues would be common in any sagittal plane. Localization tests were performed to examine the method. The results infer that a sound image of any directions can be localized using the HRTF in the median plane and interaural differences. Furthermore, localization tests in which ITD or ILD is simulated separately indicate that ITD is dominant on the perception of the lateral angle.

1. INTRODUCTION

Morimoto and Ando [1] have shown that 3-D localization can be attained, if HRTF are accurately simulated. Almost of the recent studies on 3-D localization are based on this principle. However, there are still several problems that occur in practice. One of the most serious problems is that a number of HRTF are required to represent the entire 3-D auditory space. In this paper, a new sound image localization method, which requires less number of HRTF is proposed.

2. NEW SOUND IMAGE LOCALIZATION METHOD

Morimoto and Aokata [2] have demonstrated that the lateral angle α and vertical angle β of a sound image are determined by the binaural disparity cues and the spectral cues, respectively, by using the coordinate system shown in Fig. 1. They also clarified that the directional bands proposed by Blauert [3] are observed in any sagittal planes. According to these findings, they suggested that the spectral cues would be common in any sagittal planes.

If the supposition is credible, sound localization in any directions would be possible by simulating the HRTF in a sagittal plane, for instance the median plane, and interaural differences. This method requires less amount of HRTF. Furthermore, this method could focus the issue of individual difference in HRTF on the median plane.

3. LOCALIZATION TESTS

3.1. Localization accuracy of the proposed method

Localization tests were carried out to confirm the localization accuracy of the proposed method.

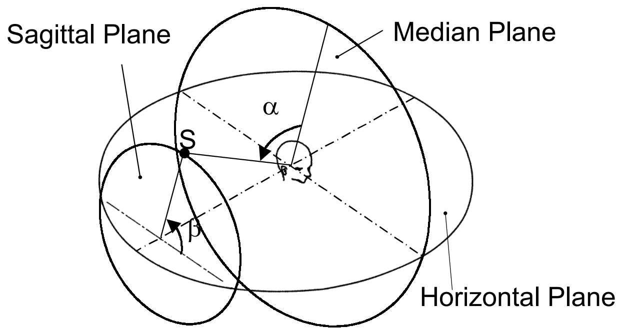

Figure 1. *Definition of the coordinate system. α is the lateral angle and β is the vertical angle of a sound source, S.*

3.1.1. *Procedure of localization tests*

The HRTF of the subjects in the upper median plane were measured at every 30° from the front to the rear. Interaural differences were also measured at the four lateral angles (0, 30, 60, and 90°) in the right side of the horizontal plane. The source signal was the band-limited white noise (280Hz - 11.2kHz). Stimuli were prepared by convolving the noise with the subject's own median plane HRTF, and adding interaural differences to them. Twenty-eight kinds of stimuli (7 HRTF x 4 interaural differences) were prepared. The presentation system of the stimuli consists of DSP and near-ear loudspeakers (AKG K1000). The DSP was used for convolution of the white noise and the HRTF. Besides it, the DSP compensated the transfer function from the near-ear loudspeakers to the entrance of ear canals of the subjects, and the cross-talks between two ears were negligible small. Each stimulus was presented 10 times in random order. The duration of the stimuli was 1s and the interval between two stimuli was 9s. The tests were carried out in an anechoic chamber. The task of the subjects was to mark down the perceived elevation of a sound image on the recording sheet. They were transformed into α and β after the experiment. Subjects were four males with normal hearing sensitivity.

3.1.2. *Results and discussions*

The subjects reported that they perceived all sound images outside the head. The responses of one subject were not adopted into analysis regarding he could not localize a sound image with this experimental system, since his localization accuracy was not enough even for the stimuli, which provided the measured his own HRTF in the median plane to his ears.

Figure 2 shows the responses of one of three subjects. The circular arcs denote the lateral angle α, and the straight lines from the center denote the vertical angle β. The most outside arc denotes the median plane (α = 0°), and the center of the circle denotes the side direction (α = 90°). The simulated α and β are shown in bold lines. The intersection of two bold lines indicates the simulated direction. The diameter of the circle is proportional to the number of responses.

The first discussion concerns the localization accuracy in lateral angle α. In case the target lateral angle α is 0 degrees (the median plane), the subject localized a sound image in the median plane. In case the target lateral angle α is 30 degrees, the perceived lateral angles agree with the target lateral angles for the target vertical angle β of 0, 30, and 180 degrees, however, the subject localized a sound image to the median plane slightly and the perceived lateral angles are a little bit scattered for the target vertical angle β of 60, 90, 120, and 150 degrees. In case the target lateral angle α is 60 degrees, the perceived lateral angles scattered a little for all of the target vertical angle β. The subject localized a sound image to the median plane for the target vertical angle β of 90, 120, 150, and 180 degrees. In case the target lateral angle α is 90 degrees (side direction), the subject localized a sound image to the median plane for the target vertical angle β of 90, 120, 150, and 180 degrees.

To sum up the results mentioned above, the subjects perceived the lateral angle of a sound image around the target lateral angle. However, the larger the target lateral angle becomes, the more the dispersion of the perceived lateral angle becomes. This phenomenon agrees with the findings that the differential limen of the lateral angle perception becomes large as lateral angle of a sound source increases [4].

The next discussion deals with the localization accuracy in vertical angle β. In case the target lateral angle α of 0 degrees (the normal localization tests in the median plane), the perceived vertical angles agree with the target ones, however, the responses scattered for the target vertical angle β of 120 and 150 degrees. This behavior is similar to the responses for the actual sound source [4]. For the lateral sound sources position (α = 30, 60, and 90°), the localization accuracy in vertical angle is similar to that in the median plane. In addition, no front-back confusion is observed. These results indicate that the vertical angle of a sound image in any sagittal plane can be perceived with the HRTF in the median plane. This supports the hypothesis of Morimoto and Aokata [2], that is, the spectral cues would be common in any sagittal planes.

Furthermore, the mean localization error was obtained by Eq. (1).

$$e = \overline{| R - S |} \qquad (1)$$

where R is the perceived angle, and S is the target angle.

Table 1 shows the errors in lateral and vertical angles for each target lateral angle of the stimuli. The mean localization error in lateral angle becomes large, as the target lateral angle increases. This tendency agrees with that of the differential limen of the lateral angle perception for the actual sound source [4], however, these values are a little bit larger than the differential limen.

Table 1. *Mean localization error in degrees when ITD and ILD are simulated as interaural differences.*

Error	Simulated angle α (deg)			
	0	30	60	90
Perceived angle α	1	7	16	23
Perceived angle β	15	13	21	-

The vertical angle error is almost the same as that of normal localization in the median plane [4]. However, the vertical angle error shows relatively large for the target vertical angle α of 60 degrees. This reason seems to be that a change of vertical angle along a circular arc in the lateral sagittal plane is sensitive when its radius is small.

These results infer that a sound image of any directions can be localized using the HRTF in the median plane and interaural differences.

3.2. Effects of ITD and ILD on the perception of lateral angle

The interaural differences consist of interaural time difference (ITD) and interaural level difference (ILD). Localization tests were performed to examine the effect of each interaural difference on the perception of the lateral angle.

3.2.1. Procedure of localization tests

The method is the same as that in section 3.1, with the exception that either ITD or ILD is simulated as interaural difference. In case only ITD was simulated, ILD was set for 0dB, and in case only ILD was simulated, ITD was set for 0μs.

3.2.2. Results and discussions

Figures 3 and 4 show the responses of one subject to the stimuli, in case that only ITD or only ILD was used as interaural difference, respectively. Tables 2 and 3 indicate the mean localization error in each case, respectively.

The perceived lateral angles almost agree with the target lateral angles when only ITD was simulated as interaural difference (Fig. 3). The mean localization error is almost the same as that for the stimuli in which both ITD and ILD were simulated.

Table 2. *Mean localization error in degrees when only ITD is simulated as interaural difference.*

Error	Simulated angle α (deg)			
	0	30	60	90
Perceived angle α	1	13	22	29
Perceived angle β	13	14	16	-

Table 3. *Mean localization error in degrees when only ILD is simulated as interaural difference.*

Error	Simulated angle α (deg)			
	0	30	60	90
Perceived angle α	1	15	33	67
Perceived angle β	15	15	21	-

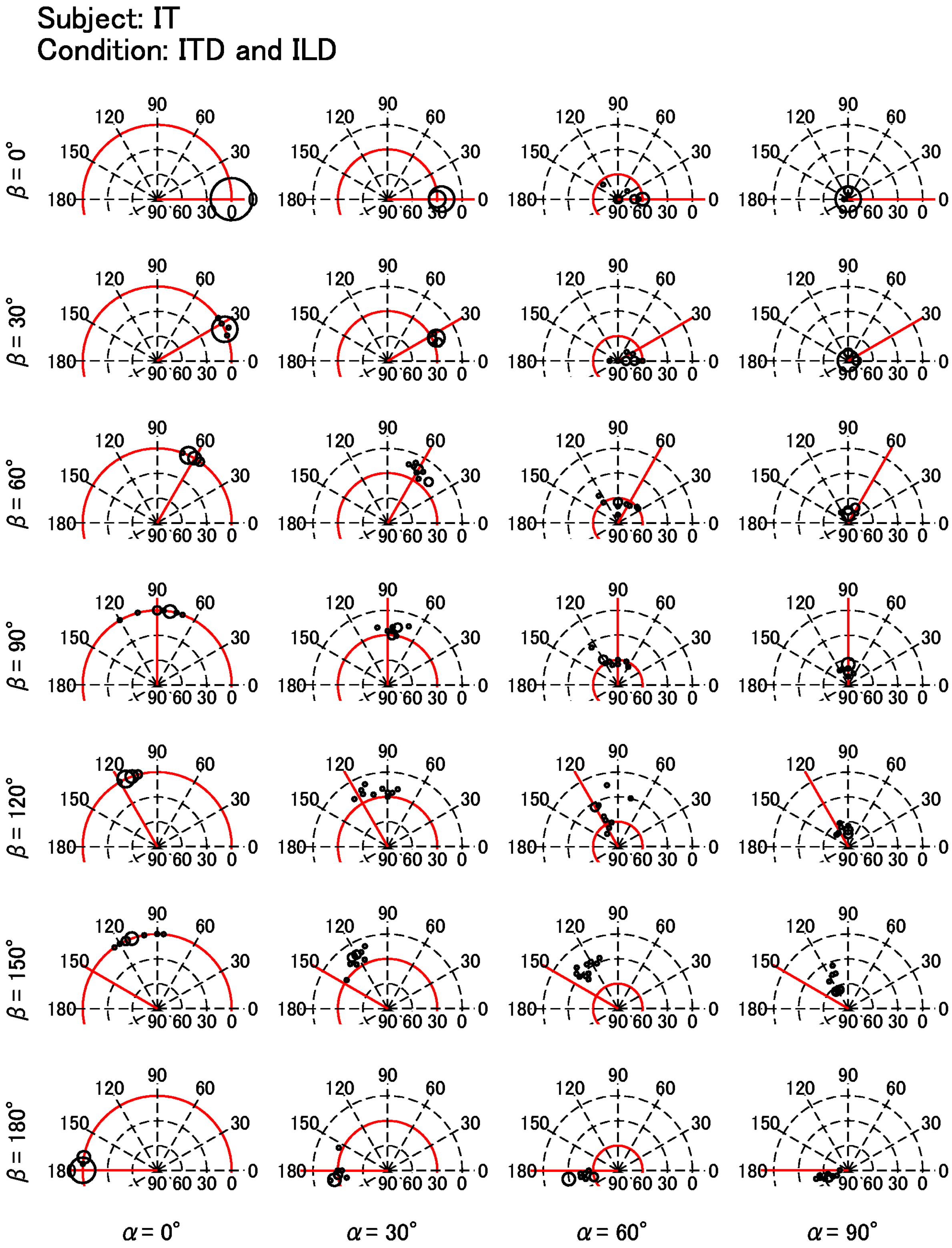

Figure 2. *Responses to the stimuli, which simulated ITD, ILD as interaural differences. The circular arcs denote the lateral angle α, and the straight lines denote the vertical angle β. The simulated lateral angle and vertical angle are shown in bold lines.*

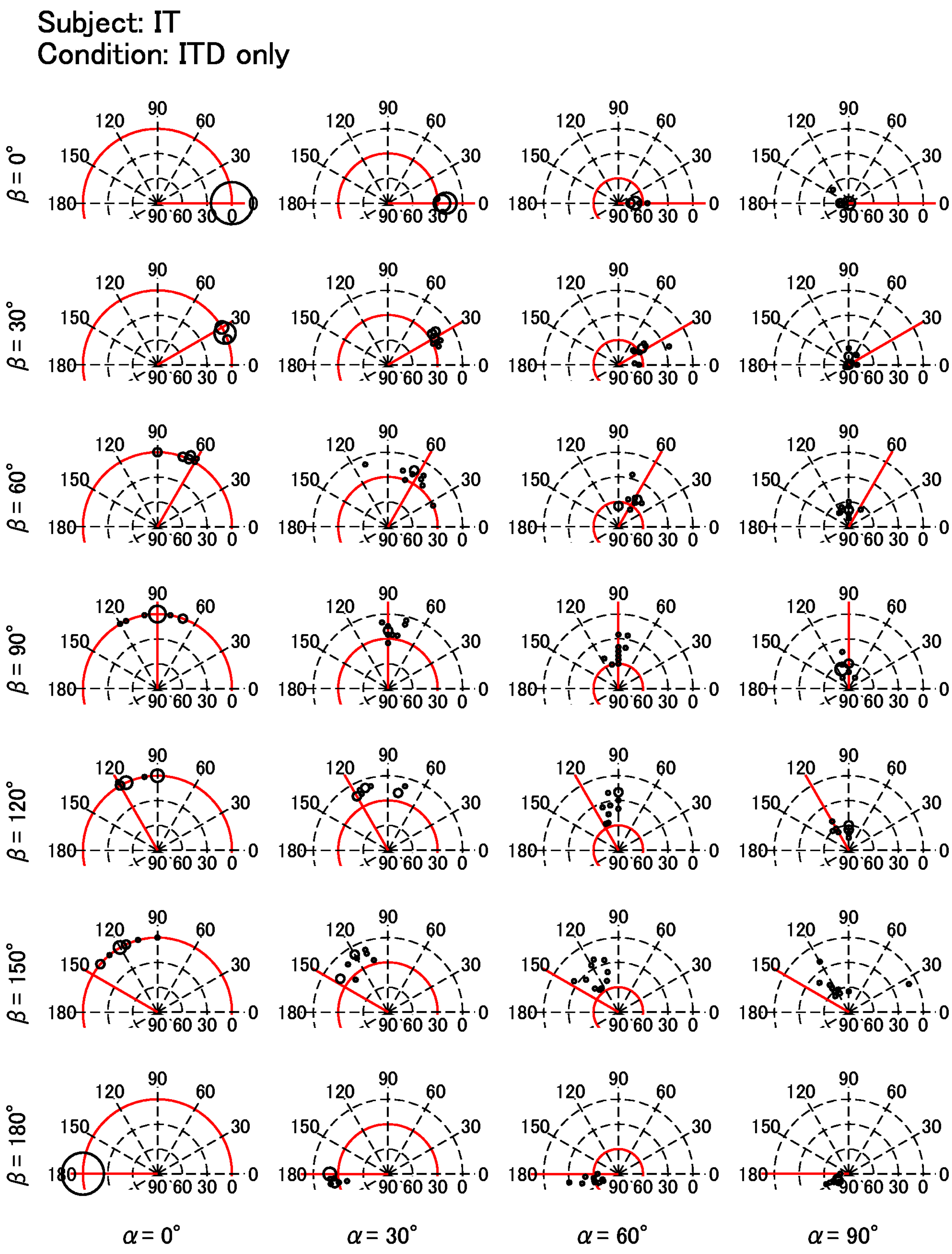

Figure 3. *Responses to the stimuli, which simulated only ITD as interaural difference. The circular arcs denote the lateral angle α, and the straight lines denote the vertical angle β.*

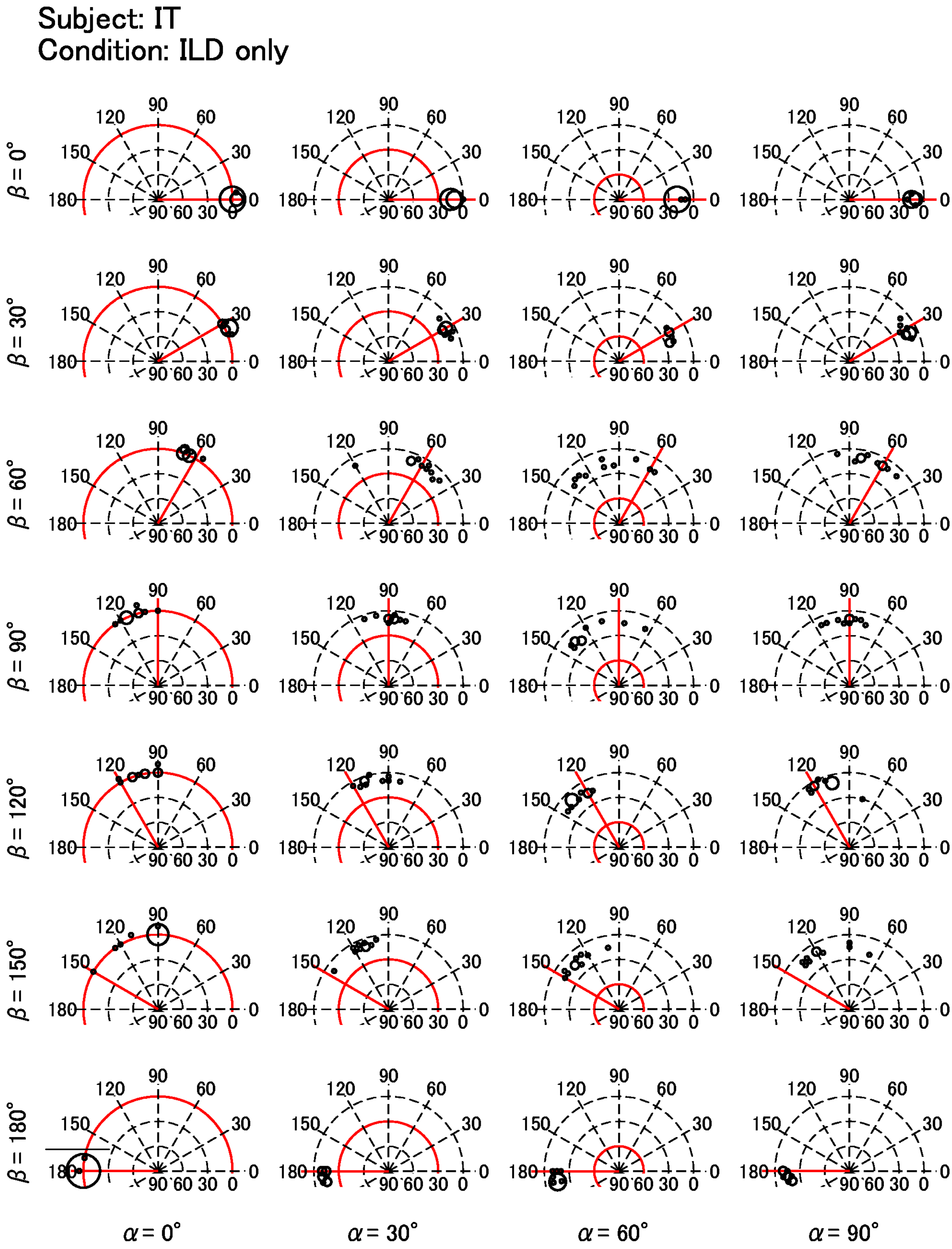

Figure 4. *Responses to the stimuli, which simulated only ILD as interaural difference. The circular arcs denote the lateral angle α, and the straight lines denote the vertical angle β.*

On the other hand, the perceived lateral angles do not agree with the simulated lateral angles, and all responses distribute near the median plane when only ILD was simulated as interaural difference (Fig. 4). The mean localization error becomes larger as the simulated lateral angle increases. Namely, the subject tends to perceive the lateral angle to the median plane. A proper explanation for this tendency is that ITD was set for zero when only ILD was simulated. These results agree with the findings of Wightman and Kistler [5] that ITD is dominant to other cues when the signal contains low frequency components.

The perceived vertical angles almost agree with the target ones in both cases. However, in case of only ILD was simulated as interaural difference, the responses of the subject scattered for the target vertical angles β of 60 and 90 degrees when the target lateral angles α are 60 and 90 degrees.

In conclusion, localization tests in which ITD or ILD is simulated separately indicate that ITD is dominant on the perception of the lateral angle.

4. CONCLUSIONS

A new 3-D sound image localization method by simulating interaural differences and the HRTF in a sagittal plane was proposed. The results of the localization tests indicate that the perceived lateral and vertical angles agree with the simulated ones. In addition, the localization tests, which examine the effect of each interaural difference on the perception of the lateral angle, clarified that ITD is dominant on the perception of the lateral angle.

5. REFERENCES

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