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Feature Analysis of spectral cues and loudness for perception of sound direction by people with unilateral hearing loss

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Abstract

Persons with Unilateral Hearing Loss (UHL) commonly have difficulty judging the direction of the sound arrival because of a lack of interaural time difference (ITD) and interaural level difference (ILD), whereas some previous studies have reported that some persons with UHL are able to judge direction to some extent. Here, UHL is the loss of hearing in only one side. In this research, we aim to overcome the difficulty through the analysis of perception of direction of sound arrival. We carried out experiments of direction recognition for persons with UHL with Gaussian white noises. A stimulus was delivered at 30-75 dB SPL, where the sound level is randomly-selected. The experimental results suggest the following: Persons with UHL are able to perceive sounds from a specific direction (hearing side and front side), while they have some difficulties to judge the depiction of deafness side and rear side. In addition, we discuss the spectral cue and loudness in each direction. On this examination, we found the possibility that relationship of spectral cue and loudness influences the perception of direction of sound arrival for persons with UHL.

Keywords: unilateral hearing loss, sound locarization , spectral cue

1 INTRODUCTION

Person with unilateral hearing loss (UHL) has obvious hearing loss on one side and does not have hearing loss on the other side. In Japan, those have been considered to have almost no problems in daily life. It is also thought that the commonly performed hearing test does not reflect the handicap in the communication of a person with UHL. Therefore their handicap has been neglected despite having a potential handicap on hearing.

Problems related to the hearing of a person with UHL can be summarized as (1) listening to the sound coming from the hearing loss side, (2) listening under noise, and (3) difficulty in recognizing the direction of the sound. The “cross hearing aid” is known as a system which is a hearing aid for people with UHL, in which a sound collector is attached to the affected ear, and collected sound is transferred to a regenerator attached to the hearing ear. It is effective for the problem of (1) and (2). However, "cross hearing aids" are not effective for problem (3) difficulty in recognizing the direction of sound.

The human recognition of the direction of sound is considered to be perceived by three clues; interaural level difference (ILD), interaural time difference (ITD), and spectral cue. Generally speaking, because ILD and ITD is not available to the persons with UHL, it is considered difficult for them to recognize the direction of the sound. Although some researchers have been reported for the perception of sound space by the person with UHL[4, 5, 6, 7, 8], the details of the cognitive mechanism in only one ear have not been clarified, and no findings have been reported to improve the difficulty in recognizing the direction of sound. That is, problem (3) is unsolved at present.

In this study, we aim to improve the problem (3). For that purpose, it is necessary to elucidate the direction recognition mechanism of the sound of a person with UHL. In this paper, the direction recognition experiment is conducted with the person with UHL as a subject and the characteristics are discussed. Furthermore, we measure the head related transfer function (HRTF) of subjects and compare them with the features of direction recognition to discuss the conditions necessary to improve the problem (3). In addition, a fundamental investigation is performed to explore the possibility of a hearing aid system based on our findings.

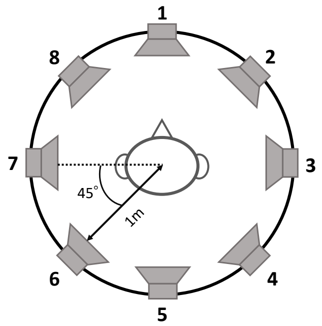

Figure 1. Arrangement of sound sources in the first experiment.

2 THE SOUND DIRECTION RECOGNITION EXPERIMENT

2.1 Experiment environment

Figure 1 shows the layout of the loudspeakers in the direction recognition experiment. The experiment is performed in an anechoic chamber, and eight loudspeakers are used as shown in the figure. The loudspeakers are 1.1 [m] in height, and are installed at 45 [deg] intervals on a horizontal circumference of 1 [m] in radius, all facing the center.

2.2 Subject

Three subjects with UHL participated, two men and a women, ranging in age from 18-25 years. They have hearing loss with left ear. Table 1 shows the degree of deafness of the subjects

Table 1. About subjects

	Hearing Loss Side	Hearing Loss Level	Duration of Hearing Loss
subject A	Left	High	Congenital
subject B	Left	middle	seven years
subject C	Left	unkown	Congenital

2.3 Procedure

In the direction recognition experiment, stimulation sounds are randomly presented from loudspeakers in eight directions. The subjects verbally answer the direction from the number 1 to 8 that are close to the recognized direction. During the stimulus sound presentation, it was decided to face the front and keep the head stationary. After the stimulus sound was presented, it was kept silent for 4 seconds, which is given for the answer. In addition, when the direction could not be determined, it was decided for them to answer number 0. The results are shown in the figure for a total of 80 responses for each subject when the stimulus sound was presented 10 times from each direction.

2.4 results of hearing person

Figure 2 shows the results of a direction recognition experiment performed on one hearing person. The horizontal axis shows the angle of the loudspeaker, where the front of the subject is 0 deg. The vertical axis shows the angle that subjects answered. The red circle (filled) is recognized, and the red circle (unfilled) is not recognized (subjects answered 0). The area size of the red circle corresponds to the number of answers. The

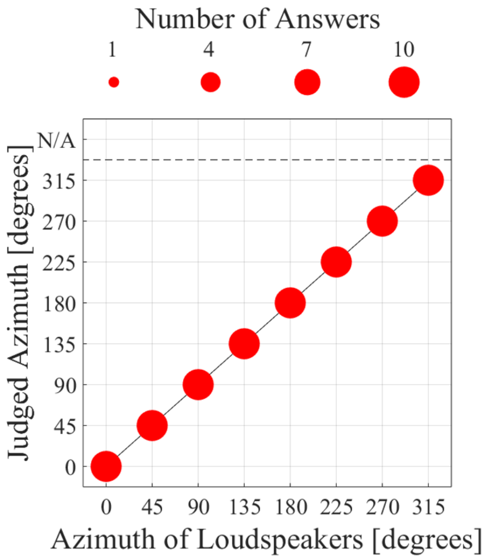

Figure 2. Result of sound direction recognition with hearing person.

diagonal line rising to the right indicates the case where the presentation angle matches the judged angle.

From figure 2, you can see that all red circles are on the diagonal. That is, this result shows that the hearing person judged the direction of the sound correctly, and the validity of this experiment environment can be confirmed[13].

3 RESULTS OF PERSON WITH UHL

3.1 results and UHL feature

Figure 3 show the results of a direction recognition experiment for three people with UHL. The signal used at this experiment was white noise, and the sound pressure level was randomly selected in five steps within 45 to 55 [dB].

The results in figure 3 indicate that the accuracy rate is high on the forward and hearing sides (0, 45, 90 degrees) and low on the posterior and hearing loss sides (180, 225, 270 degrees). This suggests that there is the feature in the direction recognition of the sound for the person with UHL; it is easy to recognize the direction of the sound coming from the front and the hearing side, while it is difficult to recognize the direction of the sound coming from the back and the hearing loss side.

This feature is unique to the person the UHL. It was found that the direction of the sound could be recognized by monaural hearing (the person the UHL) depending on the direction. In the next section, we examine what kind of clues are used to recognize the direction of the sound of person with UHL[13].

3.2 Cue of direction recognition in one ear

As mentioned above, persons with UHL can not use the difference between both ears. This is similar to the situation of the direction recognition of the sound in the median plane for a hearing person. There is in principle no difference between ILD and ITD for the sound coming from the median plane. Therefore, it is generally considered that spectral cues are used to distinguish between front, back, up and down directions[1]. Spectral cues is the change of peak and notch against the frequency axis caused by the angle of incidence

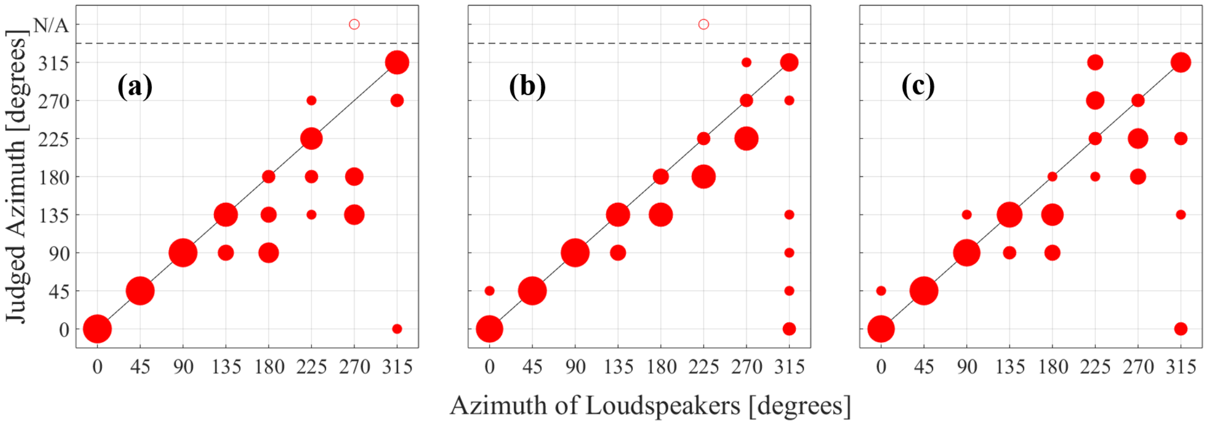

Figure 3. Results of sound direction recognition experiment with person with UHL . : (a) subjectA, (b) subjectB, (c) subjectC

to the ear, and it is said that the direction of the median plane is judged by distinguishing this information. The cause of the change of peak and notch is considered to be the physical acoustic effect by the hollow of the pinna, and there are also reports that the influence by concha is rather large[9]. Moreover, [10] conducted direction recognition experiments in median plane under the condition where rubber was used to block concha of a hearing person. They reported that the change in spectral cue caused a drop in the rate of correctness in directional recognition in the median plane.

Based on these facts, in this study, we investigate whether the spectral cues affect the direction perception in one ear. Here, as a hypothesis, we suggest that if a person with UHL uses spectral cues as a clue for direction recognition, changing the spectral cue should change the direction recognition.

Therefore, a similar experiment was conducted for subject A, with the concha of the normal hearing ear blocked with clay. The results are shown in the figure 4. Comparing figure 3 and figure 4, the unrecognized direction is significantly increased in figure 4 and incorrect answer can be seen in the hearing side (0 to 90). From this experimental result, it can be said that spectral cues are used as a clue for the direction recognition of the horizontal plane for persons with UHL.

In the next section, we measure the subject's HRTF and compare it with the spectral cue and the UHL feature.

4 THE REASON OF UHL FEATURE

4.1 Comparison with HRTF

Figure 5 shows the HRTF of subject A. The vertical axis is relative amplitude, and the horizontal axis is frequency. In general, the hearing person is supposed to distinguish between the front, back, top and bottom of the median plane based on the difference between peak and notch contained in HRTF. Here, the figure 3 and 5 are compared. Figure 3 shows that the correctness rate of the hearing side (0 to 90) of the subject A is high. Figure 5 shows that clear peaks and notches can be seen on the hearing side (0 to 90). In other words, it is inferred that the direction is determined by using these spectral cues as a clue.

On the other hand, the figure 3 shows that the accuracy rate on the hearing loss side (180 to 270) of the subject A is rather low. However, figure 5 shows that the characteristics of HRTF (180 to 270) on the hearing loss side is not clear compared to the hearing side (0 to 90), although there are peaks and notches.

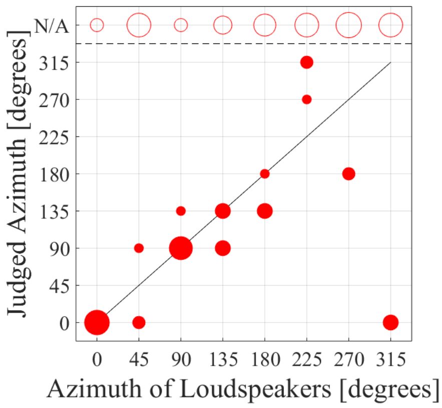

Figure 4. Result of sound direction recognition experiment with subjectA, with the concha of the normal hearing ear blocked with clay

According to the discussion up to this point, a person with UHL seems to be able to distinguish the spectral cue and recognize the direction on the hearing side, whereas the characteristics of the spectral cue on the hearing loss side can not be recognized.

We needs consider the reason why person with UHL can not sufficiently recognize peak and notch in HRTF on the hearing loss side as spectral cue. The major difference between HRTF on the hearing side and the hearing loss side is the difference of sound pressure. The difference is that the sound coming from the hearing loss side is attenuated by the head (head shadow effect). This suggests the following finding for the characteristics of persons with UHL; it is possible for them that the HRTF on the hearing loss side has peaks and notches, they can't sufficiently perceived peaks and notches as spectral cues, considering sensation level.

In the next section, based on this idea, we examine the relationship between the sound pressure of the signal and the direction recognition.

4.2 Loudness and direction recognition

In the previous section, it was suggested that the perceived spectral cue could change depending on the sensation level, which may affect the sound direction recognition. Hence, the following can be implied.

(1) For the sound from the hearing loss side whose direction is difficult to recognize, persons with UHL can distinguish the spectral cue and recognize the direction if the loudness is sufficient.

(2) On the other hand, for the sound from the hearing side whose direction is relatively easy to recognize, persons with UHL can't distinguish the spectral cue and recognize the direction if the loudness is insufficient.

In order to confirm the above two assertions, in this study, we performed direction recognition experiments by changing the subject's loudness. At this experiment, the sound pressure level was randomly selected in 10 steps of 30 to 75 [dB], and the direction recognition accuracy in each direction was examined. Each trial was performed 10 times. The experimental results are shown in figure 6. Here, the vertical axis and horizontal axis of the figure present the sound pressure of the signal and the presentation angle, respectively. The color indicates the accuracy rate in each case. The red circle in the figure 6 points out the case of the highest accuracy rate in each direction.

First, form this figure, on the hearing loss side, the correct answer rate is about less than 50 % when the sound pressure of the signal is about 30 to 45 dB, whereas it is about 80 % when the sound pressure is 60 to 70 dB.

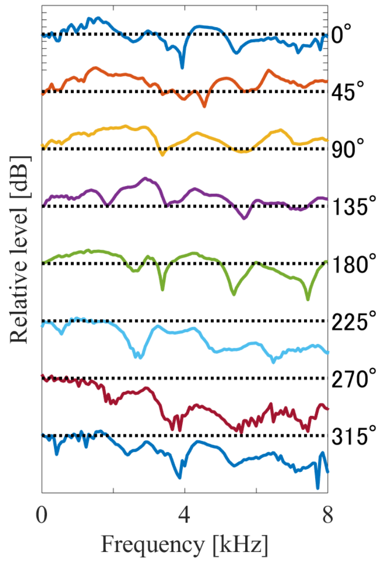

Figure 5. Measured HRTFs of subject A

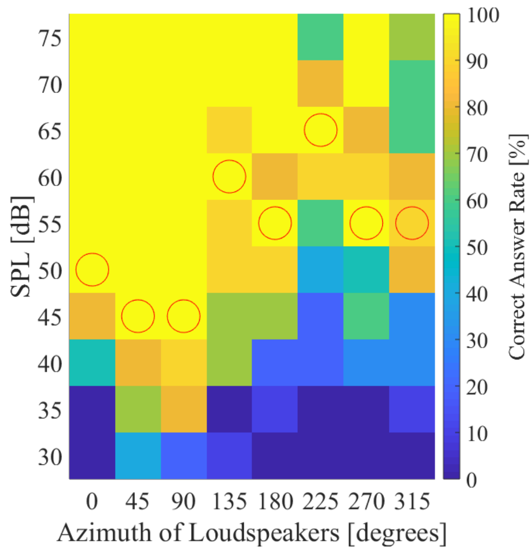

Figure 6. Result of sound direction recognition experiments by changing the subject's loudness

Additionally, on the hearing side, the correct answer rate is about 80 % or more when the sound pressure of the signal is about 40 to 75 dB, whereas it is significantly lower when the sound pressure is less than 35 dB.

From this result, it was found that loudness significantly affects the perception of the direction of sound for a person with UHL. This suggests that the sensation levels is so important for persons with UHL to perceive HRTF peaks and notches, that the apposite sensation level seems to make them perceive spectral cues and recognize their direction.

Furthermore, the experiment was performed by setting the apposite sound pressure, which is obtained by the

Table 2. SPL of Experiments (a) and (b) : Figure 7

Azimuth of Loudspeaker	SPL of Experiment (a) [dB]	SPL of Experiment (b) [dB]
0	45-55 (random)	50 (apposite)
45	45-55 (random)	45 (apposite)
90	45-55 (random)	45 (apposite)
135	45-55 (random)	60 (apposite)
180	45-55 (random)	55 (apposite)
225	45-55 (random)	65 (apposite)
270	45-55 (random)	55 (apposite)
315	45-55 (random)	55 (apposite)

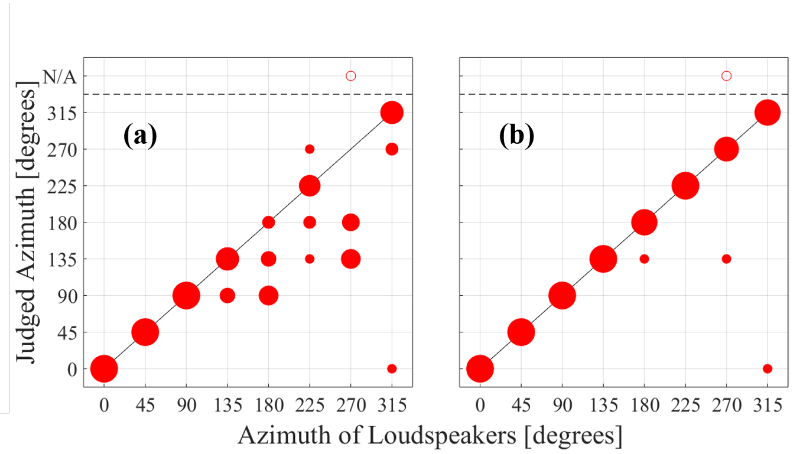

Figure 7. Results of sound direction recognition experiment with subjectA : See Table2

result of figure 6. That is, stimulation sounds are presented from each loudspeaker at the sound pressure level shown in Table 2. Here, the sound pressure level shown in Table 2 are corresponding to the case of the highest accuracy rate in each direction (a red circle of figure 6). The results under this condition are shown in figure 7 (b), while figure 7 (a) is the result where the sound pressure level was randomly selected in five steps within 45 to 55 [dB] (See figure 3). We can see that the accuracy rate is improved by setting the appropriate sound pressure from each direction.

5 CONCLUSIONS

In this paper, we examined the mechanism of the direction recognition of the sound for persons with UHL. Although it has been considered difficult for them to recognize the direction of the sound the persons with UHL because ILD and ITD is not available to the persons with UHL, the present research has revealed the following: There is possibility that persons with hearing loss in one ear should be able to recognize the direction of the sound in the horizontal plane with only one ear. There is a high possibility that spectral cue is used as a clue for direction recognition. The loudness which can recognize the sound arrival direction of sound appropriately differs from direction to direction.

In the future, we will examine in detail whether these findings are generally applicable. Furthermore, we are planning to make a directional hearing aid that adjust the sound pressure for the sound coming from the affected side due to the head shadow effect.

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