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ATTEMPT TO HRTF MEASUREMENT IN VERY HIGH FREQUENCY REGION

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ABSTRACT

We investigated the azimuth angle characteristics of head related transfer function (HRTF) at very high frequency region using two kinds of head and torso simulators (HATS). In the measurement of hearing thresholds, there are two ways using a headphone or a loudspeaker. In general, it will be carried out using a loudspeaker because sound pressure calibration and measurement are simple. However, the hearing threshold which measured using a loudspeaker at very high frequency region may contain some errors because sound pressure level (SPL) reaching the ear are seriously affected by a small movement of the head. Also, the SPL near the pinna seriously depends on both shapes of a pinna and a head because excess attenuation by diffraction of VHF sound is very large. To provide assurance for the accuracy measurement of hearing threshold, it is important to make clear the relationship between the SPL and shape of head and/or ear. In this paper, we reported the HRTFs calculated from the SPLs measured at three different positions of left ear – a tragus, an auricle and an eardrum and discussed the influence of head and/or ear of HATS from the azimuth angle characteristics of these HRTFs.

Keywords: Very high frequency sounds, HRTF, HATS

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1. INTRODUCTION

The very high frequency (VHF) sounds are defined as those have frequency components of 16 kHz to 32 kHz in this paper. The ordinal people hearing threshold is around 20 to 20 kHz, but some children can hear sounds as high as 28 kHz [1]. In order to grasp hearing thresholds above 20 kHz, we have continued to measure hearing thresholds of VHF sounds for people including children. However, there are several issues in the measurement of hearing thresholds for VHF sounds. In audible threshold measurements of VHF sound using a loudspeaker, It can cause changes in the audible sound pressure even with slight fluctuations in the position or direction of the listener's head because the VHF sound makes it difficult for the sound to diffract [2] To accurate hearing threshold measurements in the VHF region, we need understand the fluctuations in sound pressure caused by small head movements. In this paper, we measured and evaluated the sound pressure fluctuation of pure tones depending on the sound hearing position and angle of the sound receiving point using two type Head and torso simulator (HATS).

2. MEASUREMENT METHOD

2.1 Measurement equipment

We conducted the experiment in a hemi anechoic room in the sound studio at Kanagawa Institute of Technology. The background noise level (LAeq,10s) in the room was 23.5 dB. Table 1 shows the equipment configuration for the sound receiving system of the two types of HATS[3]. Figure 1 shows a block diagram. HBK's HATS is modeled after typical figure of Danish people, while ACO's SAMURAI HATS is modeled after that of Japanese people.

Table 1. Equipment for receiving system in two types of HATS.

HATS	A	B	C
HBK	1/4 inch. mic	A/D converter	Note PC
	MEMS mic.	oscilloscope	USB memory stick
ACO	Built-in mic.	A/D converter	Note PC

Because the build-in microphone of HBK's HAT was appropriate for measuring the sounds in the VHF region, we used a 1/4 inch. microphone or a MEMS microphone.
Figure 2 shows the arrangement of each microphone. We used a built-in microphone of 1/4 inch size of ACO's HAT (TYPE8328AH) which was shown in Figure 3.

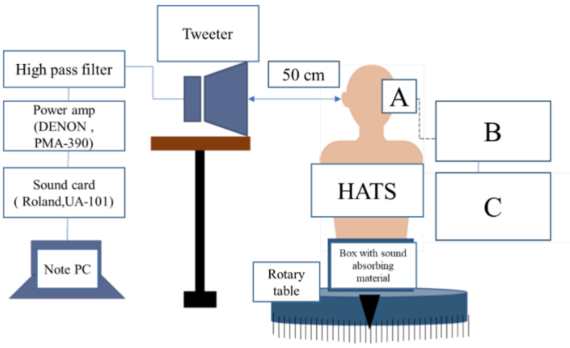
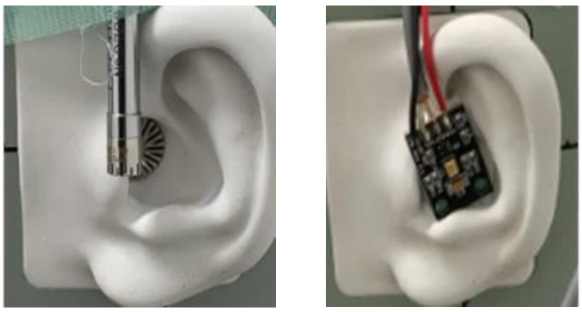
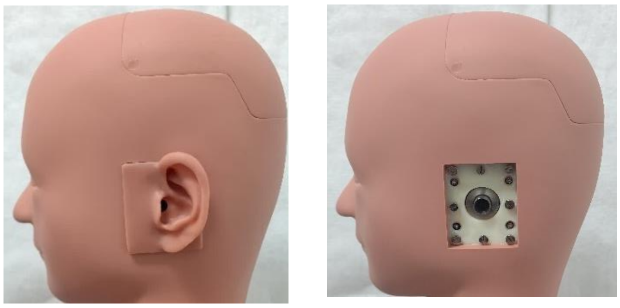


Figure 1. Block diagram of sound source and receiver systems.



(a) 1/4 inch. mic. (b) MEMS mic.

Figure 2. Arrangements of two microphones at left ear of HAT (HBK product).



(a) In pinna of left ear (b) A built-in mic.

Figure 3. Appearance of left pinna and built-in microphone of HAT (ACO product).

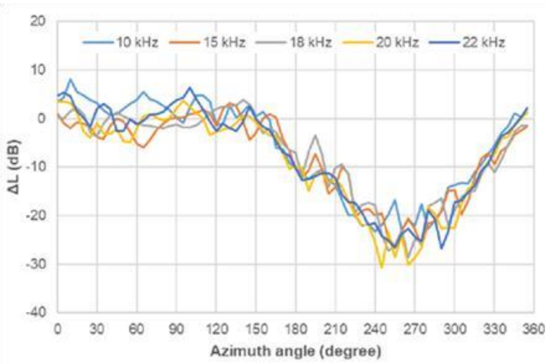
2.2 Measurement and analysis procedures

For experiments, we used pure tones (30 sec.) at 10 kHz, 15 kHz, 18 kHz, 20 kHz and 22 kHz as test signals. We set a tweeter at distance of 50 cm away from the HAT which was placed on a turntable. In our measurements, we defined an angle measured clockwise from the direction of a tweeter as the azimuth angle. We measured the sound pressure levels of test signals for the azimuth angle between 0 and 355 degrees at an interval of 5 degree. Moreover, we measured the test signals at a middle position between right and left ears in the absence of HATS.
The test signal was stored with sampling frequency of fs=192 kHz by the AD converter, and we used DAQ-200 SPECTRA for FFT analysis of the measured test signals. In the case of the oscilloscope, we stored the data at fs=5 MHz or 10 MHz. We performed FFT analysis of the digital waveforms via oscilloscope after applying a 5 kHz high-pass filter. We calculated Head-Related Transfer Function (HRTF) ΔL from the difference of sound pressure levels between with and without HAT. However, the sound pressure level with HAT generally means that measured at ear canal entrance or eardrum, in this paper, we recognize the sound pressure level measured around ear pinna as same as those positions.

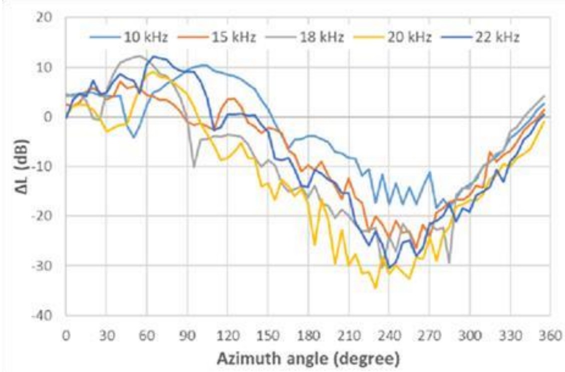
3. MEASUEMENT RESULT

3.1 Measurement results of HBK's HATS

Figure 4 shows two types of HRTFs ((a) 1/4 inch. microphone, (b) MEMS microphone) measured with HBK's HATS. The horizontal axis shows the angle of rotation and the vertical one shows the level difference ΔL.
In Figure 4 (a), in so far as range from 0° to 90° and from 90° to 150°, ΔL fluctuates around 0 dB.
The fluctuation of ΔL depend on frequency is also small. ΔL gradually decreases in the range from 150° to 270°. ΔL is smallest around 270°. ΔL increases monotonically toward 0 dB from 270° to 355°. It is likely that the small fluctuation of ΔL due to the interference of the reflected sound from the nose and auricle.
Figure 4 (b) shows the HRTF for the MEMS microphone, MEMS mics ΔL was generally 0 dB in the angle range from 0° to 30°. However, it fluctuated significantly in the range from 30° to 270°. The angles at which ΔL is maximum and minimum are significantly different from the 1/4-inch microphone depending on the frequency. The range of ΔL fluctuation was 29 to 33 dB for the 1/4-inch microphone and 29 to 43 dB for the MEMS microphone. MEMS microphone's HRTF having a larger fluctuation range and it increases in proportion to frequency.



(a) 1/4 inch. microphone

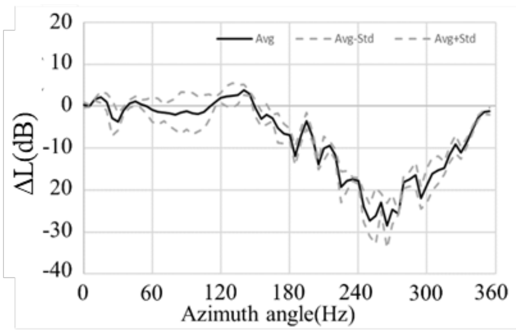


(b) MEMS microphone

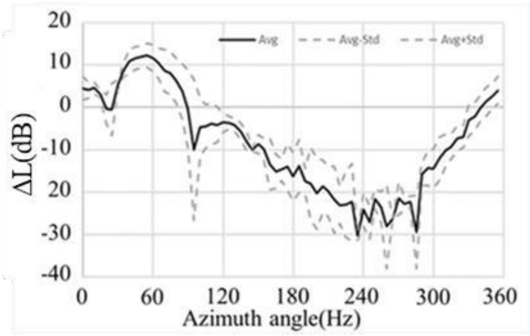
Figure 4. HRTF of HBK HATS.

In the measurement result of the MEMS microphone placed in the auricle, the ΔL fluctuations were significantly different with frequency compared to the results of the 1/4 inch. microphone 's HRTF. It was found from the result, different ΔL fluctuation patterns even in the angular range (40° ~ 100°) with good line of sight from the sound source.

It is likely that differences cause by differences in microphone position. It is likely that due to the effect of the auricular shape, not the head shape and the auricular shape has a significant effect on the listening level of VHF sounds. Figure 5 to Figure 7 shows the ΔL which is the average value and standard deviation's sum difference of it for the pure tones at 18 kHz, 20 kHz, and 22 kHz. At 18 kHz, there was a large difference around 270° for both microphones. It is likely that the difference depend on the influence of the head and body. At 20 kHz, the variation tended to be smaller than other frequencies. However, the MEMS microphones showed significantly fluctuation from 240° to 270°and 1/4-inch microphones showed from 0° to around 90°. At 22 kHz, the fluctuation is larger than at other frequencies, and the MEMS microphones show larger fluctuation than the 1/4 inch. microphones. This difference is mainly due to the difference in microphone position, but it is likely that the shape of the auricle have an effect.
The variation of the 1/4 inch microphone tends to increase as the frequency.

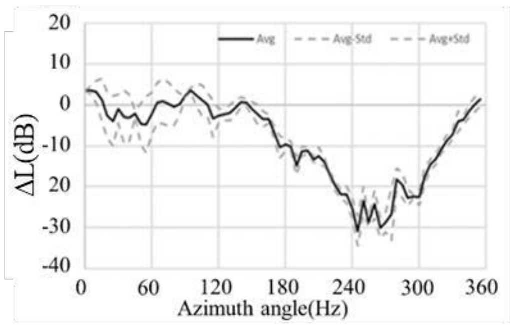


(a) HRTF of 1/4 inch. Mic. near

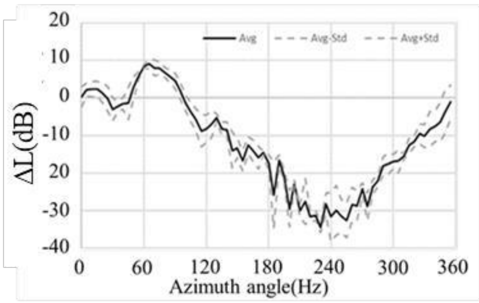


(b) HRTF of MEMS Mic. in the pinna of left ear. by the tragus of left ear

Figure 5. A comparison between two kinds of HRTF for HBK HATS at 18 kHz.

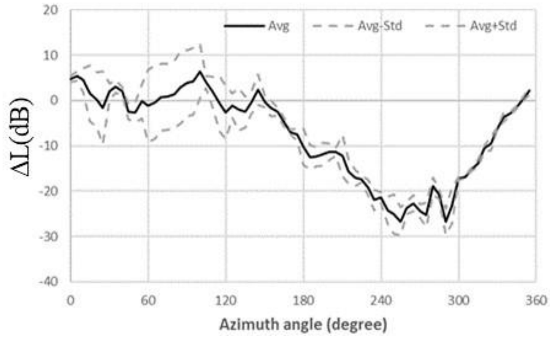


(a) HRTF of 1/4 inch. Mic. near

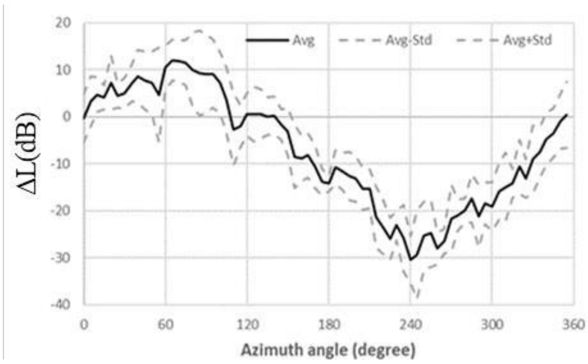


(b) HRTF of MEMS Mic. in the pinna of left ear. by the tragus of left ear

Figure 6. A comparison between two kinds of HRTF for HBK HATS at 20 kHz.



(a) HRTF of 1/4 inch. Mic. near



(b) HRTF of MEMS Mic. in the pinna of left ear. by the tragus of left ear

Figure 7. A comparison between two kinds of HRTF for HBK HATS at 22 kHz.

3.2 Measurement results of ACO's HATS

Figure 8 shows the HRTF of SAMURAI. Comparing Figure 8 and Figure(a), the HRTF of SAMURAI has a large variation depend on frequencies. It is large from 0° to around 150°.
In the angle range from 150° to 360°, the trend from monotonically decreasing to increasing is similar to HRTF of HBK's HATS. However, the position of peak dip at each frequency is different. However, the position of peak dip at each frequency is different. Also 1/4 inch. microphone is located outside the auricle, so there is little reflection and interference within the auricle.
Therefore, the variation between frequencies from the front (0°) to an angle of 150° is small so it is likely that the HRTF differs significantly from the SAMURAI HRTF.

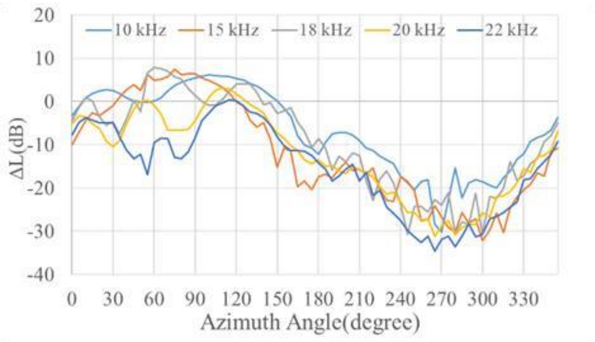
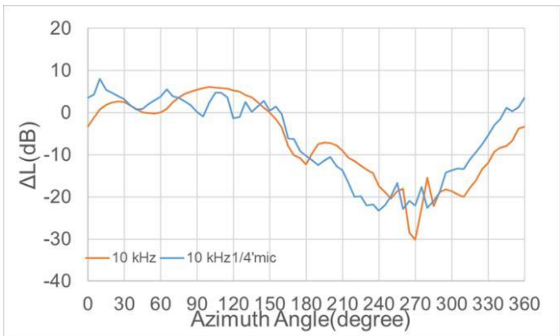


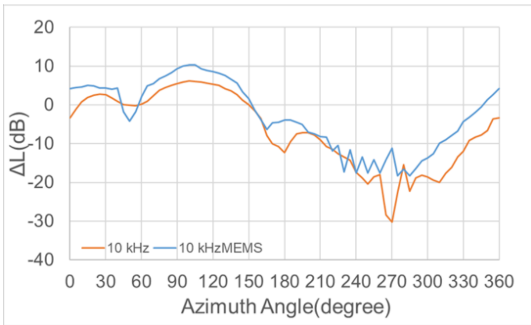
Figure 8. HRTF of ACO HATS (SAMURAI).

On the other hand, Figure 4(b) (MEMS microphone) has a larger variation due to the difference frequencies than Fig. 4(a) (1/4 inch. microphone), which is similar to the HRTF of SAMURAI. Figure 9 shows a graph comparing the measured HRTF at 10 kHz and 22 kHz. At 10 kHz, the tendency of both HRTFs to fluctuate is similar. However, at frequencies above 15 kHz, the angle position difference of peak of ΔL of the maximum and minimum becomes larger at higher frequencies. For example, at the 22 kHz, the maximum of ΔL shifts by about 50° and the minimum of ΔL by about 30°. As a result, there is a difference of about 20 dB between the two HRTFs at an angle of about 70°. MEMS microphone is placed inside the auricle, unlike the 1/4-inch microphone so it likely that due to the effects of reflection and interference from the auricle.

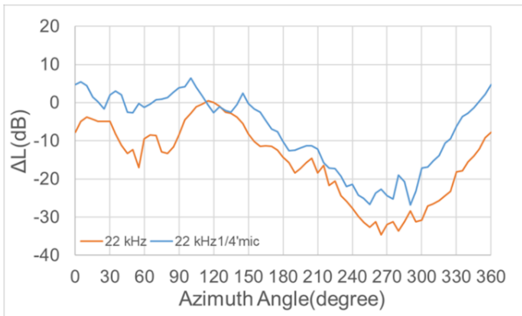


(a) HRTF of 1/4 inch. Mic. and SAMURAI at 10 kHz

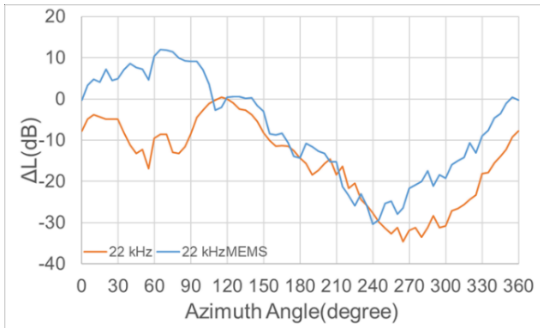
In the comparison at 10 kHz, both the 1/4 inch. microphone and the MEMS microphone have a small variation and similar HRTF overall. Figure 9(c) and (d) shows the results of the comparison at 22 kHz. There is about 10 dB difference between HRTF of SAMURAI and HRTF of MEMS microphone. Also there is about 20 dB difference



(b) HRTF of MEMS Mic. and SAMURAI at 10 kHz



(c) HRTF of 1/4 inch. Mic. and SAMURAI at 22 kHz

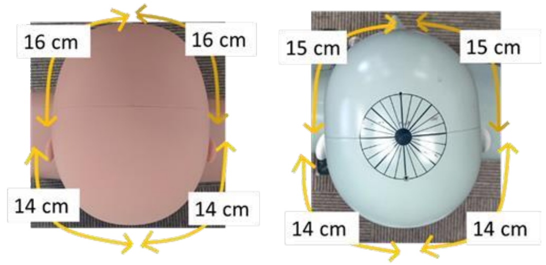


(d) HRTF of MEMS Mic. and SAMURAI at 22 kHz

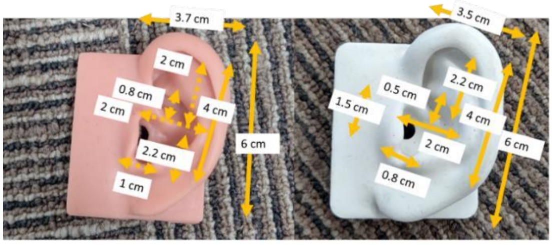
Figure 9. Comparisons of HRTF between SAMURAI and HBK HATS.

between HRTF of SAMURAI and HRTF of 1/4 inch. microphone. At frequencies above 15 kHz, the larger the difference of position of the maximum and minimum of ΔL. Figure 10(a) and Figure 10(b) shows the dimensions of SAMURAI and HBK HATS. The size of shoulder circumference of both types of HATS was 38 cm.

Therefore, it is likely that the difference in HRTF between the two HATS is largely due to the shape of the head and auricle, and not so much to the size of shoulder circumference in addition to the difference in the sound receiving position.



(a) Frontal and back head



(b) The shape of ears

Figure 10. Comparison of two HATS dimensions.

4. CONCLUSIONS

In this paper, we investigated the azimuthal characteristic of HRTF using two types of HATS for the VHF sounds, in order to grasp sound pressure fluctuation depends on hearing position and sound receiving point in such VHF region.

In the result, the ΔL was different in the left tragus HRTF and in the auricle HRTF at any frequency. They differed by more than 10 dB depending on the sound receiving position. Therefore, it is likely that the sound pressure level in the VHF region was fluctuation by the receiving position near the auricle. The HRTF at the eardrum position was similar to the HRTF measured in the auricle. The HRTF measured at the left tragus showed less ΔL fluctuation depend on frequencies than the HRTF at the eardrum position. From this, it likely that sound pressure fluctuation in the VHF region is affected by the auricle. However, the HRTFs measured in the auricle and at the eardrum shifted as became higher in the high-frequency range the angle of maximum and minimum in the same frequency. Their difference is about 20 dB. It is likely that the difference depending on sound receiving position on this difference. From this result, it likely that the shape of the auricle and head shape affect to the sound pressure fluctuation in the VHF region. However, we measured the data for only five frequencies between 10 kHz and 22 kHz in this paper. For the reason, we don't have enough experimental data available to fully cover the VHF region. In the future, we will obtain wider experiment data in a VHF region by conducting impulse response measurements using TSP signals and we will measure the HRTF of two type of HATS under the same sound received position.

By comparing them, we want to elucidation the effects of individual differences such as auricle and head shape on the hearing of VHF sounds.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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