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Basic Investigation of Sound Field Around Head Under Pulse Ultrasound Irradiation

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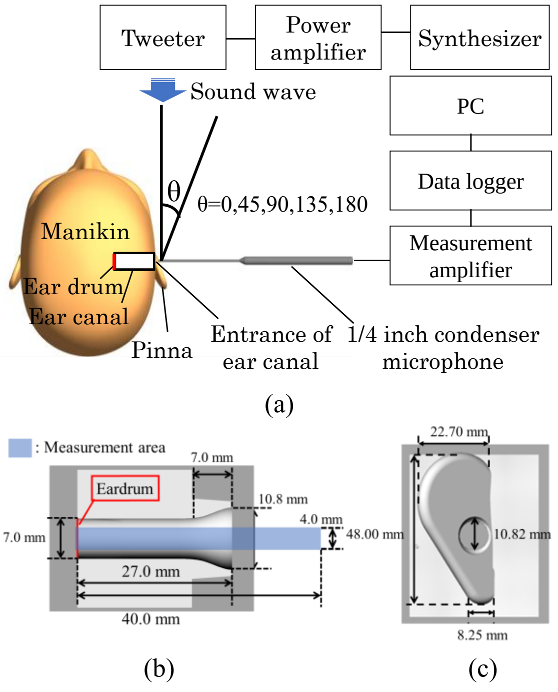
1. Introduction

Many technologies that use high-intensity airborne ultrasounds have been studied, and devices have been developed that can radiate such ultrasounds, including super-directional parametric speakers, airborne ultrasound phased arrays that can perform high-speed electronic scanning, and devices that can emit extremely high-intensity airborne ultrasounds. However, exposure to the high-intensity airborne ultrasound used in these techniques is problematic, and so various safety standards for ultrasound exposure have been studied.1-4) One way to evaluate ultrasound exposure is to evaluate the sound pressure at the eardrum. We have proposed evaluating the sound pressure inside and outside the ear canal when manikin heads are irradiated with airborne ultrasound. In previous work, we showed that the sound pressure at the eardrum can be estimated from the distribution of standing waves formed in the ear canal when exposed to airborne ultrasound with a frequency of 20 – 40 kHz. We also found that the sound pressure at the eardrum depends on the shape of the auricle (pinna) and the ear canal. In this report, the sound fields formed inside and outside the ear canal when a manikin head is exposed to ultrasounds (20 kHz) arriving from various directions are assessed based on measurement results and analysis results.

2.Overview of experiment

The experiment involved a manikin head (KEMAR type 45BA; GRAS Sound & Vibration) that is fitted with a pseudo auricle and a pseudo ear canal made of chemical wood, and the end of the pseudo ear canal is covered with a 0.1-mm-thick polyethylene membrane to mimic an eardrum. **Figure 1** shows **(a)** a schematic of the apparatus used for the measurements, **(b)** the measurement area inside and outside the ear canal, and **(c)** the dimensions of the pseudo ear canal and auricle. The experiment was conducted as follows. First, a tweeter irradiated the manikin head with planar ultrasound waves from the directions of 0°, 45°, 90°, 135°, and 180° as shown in Fig. 1. Next, the sound fields inside and outside the ear canal of the manikin head were measured a 1/4-inch microphone (type 7017; ACO Co., Ltd.) with a 2-mm-diameter probe tube. The measured sound-pressure waveform data were recorded by a data logger (USB-6353; NI) together with the coordinate information of the measurement position. The instantaneous sound pressure distribution at each moment in the measurement domain was reproduced, and these distributions were run continuously to obtain a movie of the pulsed ultrasound propagation inside and outside the ear canal. By observing this movie, we assessed the behavior of the sound waves inside and outside the ear canal and near the eardrum. The measurement area inside and outside the ear canal was a 4 mm × 40 mm, measurements were made at 1-mm spacing. The tweeter was driven with a frequency of 20 kHz, an applied voltage of 1.5 V, and a sinusoidal input of eight cycles the sound waves were acquired with a sampling frequency of 1 MHz and a sampling time of 1 ms.



(a)

(b) (c)

Fig. 1 Experimental system.

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3. Result and discussion

Figure 2 shows examples of the sound fields inside and outside the ear canal formed by pulsed ultrasound when the positive peak value of the fourth wave of the pulsed ultrasound reached the eardrum. The left column shows the measurement results, and the right column shows the analysis results obtained using the finite-element method (FEM). In the plot, the horizontal axis represents the distance from the eardrum in the ear canal, the vertical axis represents the distance across the measurement area, and the colors represent either the normalized microphone voltage (experiment) or the normalized sound pressure (FEM). For each angle, the two sets of results show approximately the same trend. Next, Fig. 3 summarizes Fig. 2 in terms of instantaneous values along the central axis of the ear canal. **Figure 3(a)** shows the measurement results, and **Fig. 3(b)** shows the FEM results. Each result has been normalized with its maximum value. Figure 2 and 3 show that the sound pressure in the ear canal differs depending on the angle of arrival of the sound waves, and both sets of results show very similar trends. Comparing the sound pressure at the eardrum, both sets of results show the highest sound pressure at θ = 90° and lower values at θ = 0° and 180°.

4. Conclusion

In this report, the sound fields formed inside and outside the ear canal when a manikin head is exposed to ultrasound (20 kHz) arriving from various directions are investigated by experiment and FEM analysis. The distributions of (i) the sound fields inside and outside the ear canal and (ii) the sound pressure when the ultrasound arrival direction is changed, are clarified by measurement results and analysis, and the results for both are highly similar. This suggests that acoustic analysis using pulsed ultrasound may be useful for estimating the sound pressure at the eardrum under ultrasound exposure when the ultrasound arrival direction is changed.

Acknowledgment

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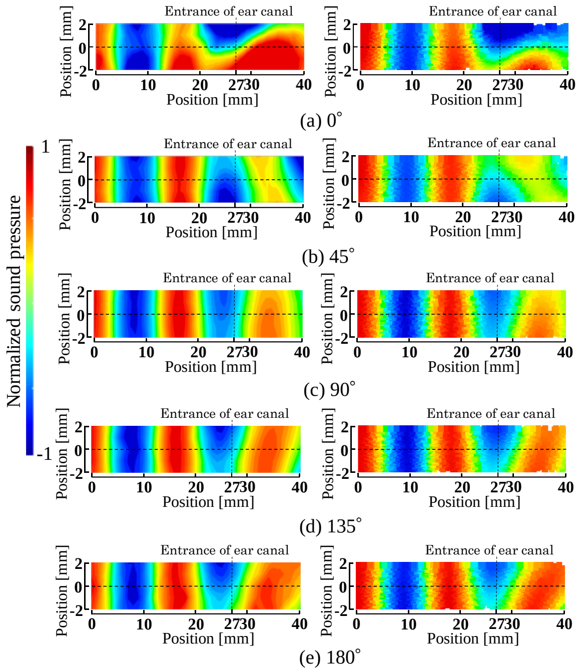


(a) 0°

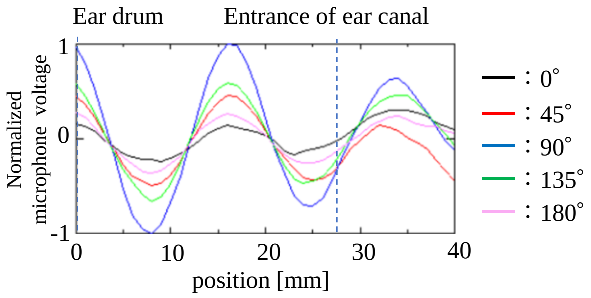
(b) 45°

(c) 90°

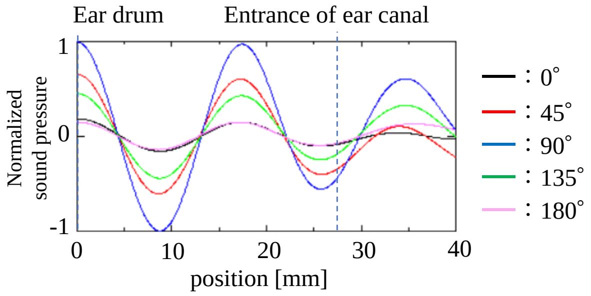
(d) 135°

(e) 180°

Fig. 2 Sound pressure distribution in ear canal.



(a) Measurement results



(b) FEM results

Fig.3 Sound pressure distribution on central axis of ear canal.

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