

Differential intensity sensitivity of the ear for underwater pure tones

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(Received 9 July 2001, Accepted for publication 18 July 2001)

Keywords: Underwater audibility, Listening experiment, Discrimination, Difference-limen, Distinguishable steps
PACS number: 43.66.Fe

1. Introduction

The ability of discrimination to the sound intensity is one of the fundamental auditory senses in man. It is reported that the differential intensity sensitivity in air is highest near 1,300 [Hz] and that the amount of steps which we can discriminate in sound intensity at 1,300 [Hz] becomes about 370 (that is to say in every 10 dB, the maximum is about 40 [step/10 dB] around 100 [dB re 20 μ Pa] of SPL) [1,2].

On the other hand, the research of differential sensitivity in water has been seldom found until now except the study of the ability of localization [3], since the realistic necessity was little. Recently, the necessity of ensuring the safety of divers occurs with the popularization of marine leisure and it is noted that the direct transmission to divers using an audible acoustic signal is the most effective way in the water [4-8]. When such underwater transmission is considered, differential intensity sensitivity becomes an important problem in relation to the type and quantity of information.

In this study, we examined the differential sensitivity of the ear to sound intensity through listening experiments with a water tank and obtained the resolution of auditory intensity sense (i.e. number of distinguishable steps to sound intensity) in the underwater audible range.

2. Experiments in the water tank

In order to obtain the difference-limen (DL) to sound intensity, listening experiment with a water tank was carried out by beet method [1]. As shown in Fig. 1, a beet sound was made in the water tank by synthesizing the two pure tones in which the frequencies are slight different (ω , $\omega + \Delta\omega$). Next, the subject who put one's whole head into the water listened to the beet sound and compared the fluctuation of amplitude between the maximum value (amplitude A) and the minimum value (amplitude B). Then, the value of relative DL ($\Delta I_{th}/I$) was determined from Eq. (1) when he judged that the beet has arisen or vanished.

$$\frac{\Delta I}{I} = \frac{(A+B)^2 - (A-B)^2}{(A-B)^2} = \frac{4 \cdot AB}{(A-B)^2} \quad (1)$$

The frequency of the beet is made to be 3 Hz and the carrier frequencies are 1 kHz, 2 kHz, 4 kHz and 6 kHz. The subjects are two men in which the auditory sense in the air is normal. Here, as the present experiment is concerned with the

differential sensitivity of auditory sense, a standard of sound intensity should be shown by sensation level $SL = 10 \log(I/I_0)$ with reference value of minimum audible field (I_0). Then, the MAF was measured in advance at every experiment of DL as the value of minimum audible field (MAF) usually depends on the experimental conditions and subjects.

3. Results and discussion

3.1. Minimum audible field

The MAF in the water obtained in the present work shapes roughly a straight line leaned to the left for $\log f$ (see MAF in Fig. 3 or Ref. [5,7]). This means that the sound in the high frequency region is hard to listen. This is similar to our previous result and is essentially different from the case in the air.

3.2. Relative difference-limen to the sound intensity

Figure 2 shows the relationship between the relative DL ($\Delta I_{th}/I$) and the value of $SL = 10 \log(I/I_0)$ at 4 kHz. Above $SL = 30$ dB, $\Delta I_{th}/I$ shows a constant value in which the Weber's law is almost established. In the meantime, near $SL = 0$ dB, when the sound pressure level approaches the MAF, $\Delta I_{th}/I$ rapidly increases. The solid line in Fig. 2 was described from the Eq. (2) proposed by Riesz [1] as below,

$$\frac{\Delta I}{I} = S_{\infty} + (S_0 - S_{\infty}) \cdot \left(\frac{I_0}{I} \right)^{\gamma} \quad (2)$$

where S_{∞} , S_0 and γ are the parameters depending on the frequency. It is known that this equation shows well the experimental results in the air.

In the range of measurement error, it can be said that the present results in the water (●) is in agreement with the value in the air (solid line). In short, the differential sensitivity to sound intensity upon the sensation level in the water seems to be almost the same as in the air though the value of MAF is greatly different each other.

3.3. Number of distinguishable steps to sound intensity

We can obtain the resolution of auditory intensity sense (i.e. number of distinguishable steps to sound intensity) from the results of differential sensitivity obtained above. Figure 3 shows the number of distinguishable steps in every 10 dB in the frequency range from 1 kHz to 8 kHz and in the sound pressure level above the MAF. Each number of steps was

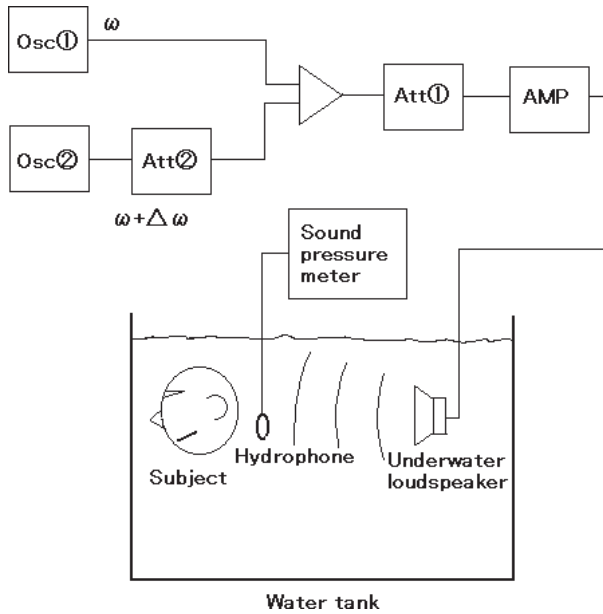


Fig. 1 Measurement of differential-limen (DL) to sound intensity in the water tank.

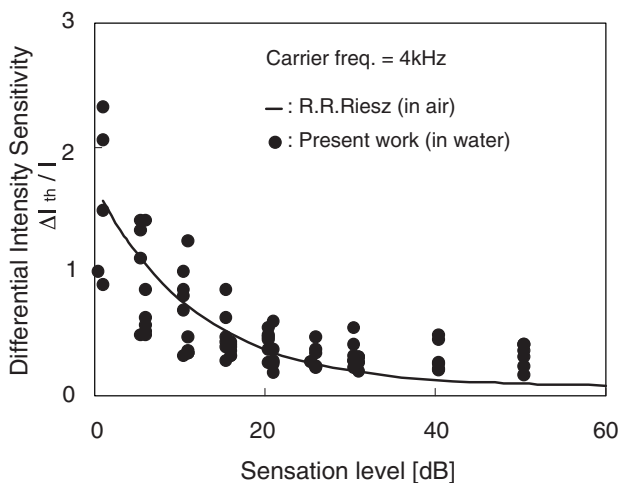


Fig. 2 Dependence of the relative difference-limen to sound intensity ($\Delta I_{th}/I$) upon the sensation level $SL = 10 \log(I/I_0)$.

derived from the relative DL calculated by Eq. (2) assuming that the differential intensity sensitivity in the water is equal to that in the air. It seems that the ability of discriminating the change of sound intensity are more excellent as the frequency lowers and as the sound pressure level increases. The maximum number of steps is about 40 [step/10 dB] around 1 kHz of 160 [dB re 1 μ Pa]. Therefore, it is considered that these sounds are more suitable for information transmission to the divers in the water.

4. Conclusion

As a part of the research for constructing the underwater transmission system to divers, differential intensity sensitivity

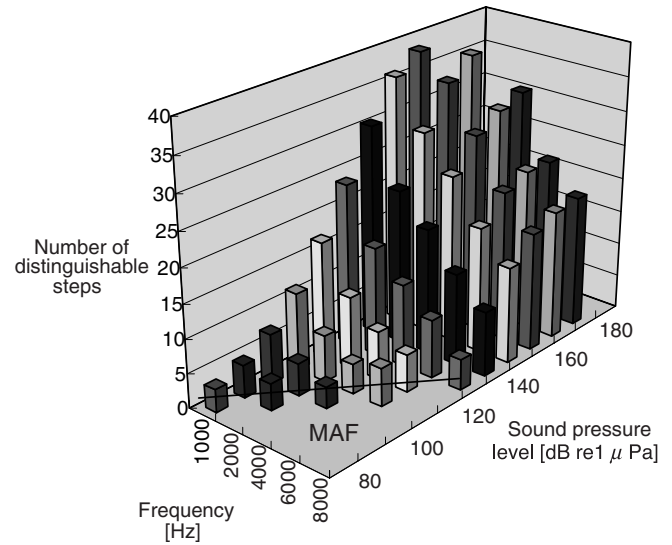


Fig. 3 The number of distinguishable steps to sound intensity in the underwater auditory area.

of the ear was examined through listening experiments with a water tank. Although the value of MAF in the water was greatly different from that in the air for the reasons that the acoustic impedance of each medium and propagation path of the sound to the internal ear are different respectively, it is found that differential sensitivity to sound intensity upon the sensation level is almost same between in water and in air. This implies that the discrimination of the sound intensity is a phenomenon mainly related to the internal ear in man whether in the water or in the air. Furthermore, it suggests that the experimental methods and results in the air already existing can be utilized for considering the differential sensitivity in the water.

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