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Measurement of masked threshold of low-frequency tones in outdoor and indoor environmental background noise

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ABSTRACT

Recently in Japan, noises from wind turbines and domestic use heat source sometimes cause increase of noise annoyance due to low-frequency tonal components. To cope with the noise problem, it is necessary to grasp the audibility of the tones under environmental noise. The authors conducted auditory tests to measure masked threshold of low frequency tones under several conditions of broadband background noise. The tonal frequency was 40, 50, 80, 100, 160, 200, and 400 Hz, and the maskers were assumed as pink noise and modeled noises of environmental noise outdoor and indoor. Measured masked thresholds were analyzed by Tonal Audibility (TA) provided in IEC 61400-11:2012. TA at the masked thresholds of tones higher than 80 Hz were about -2 dB and that of 40 and 50 Hz tone were about 2 dB, and their standard deviations were 2 - 3 dB. Similar trends were observed in all three noises.

Keywords: Masked Threshold, Environmental Noise, Tonal Noise
I-INCE Classification of Subject Number: 79 Psychoacoustical evaluations and testing

1. INTRODUCTION

Noises from wind turbines and domestic use heat source sometimes contain low-frequency tonal components. These tonal noises cause increase of annoyance and lead to arise noise problems such as sleep disturbances. In order to evaluate the prominence of the tonal components of such noises, tonal audibility (TA) which is specified in IEC 61400-11:2012[1] is used. TA is based on masking effect under the situation which the pure tones are masked by broad band noises. As for the masking effects, Hawkins and Stevens measured masked thresholds of pure tones in the frequency range between 100

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Hz and 10 kHz under white noise at the level from -10 to 70 dB/cps [2]. Masked threshold was also measured to grasp auditory characteristics of human such as Critical Band [3] and Equivalent Rectangular Bandwidth [4]. In those experiments, white noise was used as the masking noise. In addition, the levels of the masking noises were enough loud in most of the experimental conditions, in order to avoid the effect of absolute thresholds of hearing. However, frequency characteristics of environmental noises in living spaces are different from those test stimuli and varies according to situations such as outdoor and indoor.

In order to evaluate environmental noises containing tonal components, the masked thresholds of pure tones are fundamental. The authors conducted auditory tests to measure the masked threshold of low-frequency pure tones under modeled environmental noises; outdoor and indoor noise. In addition, a pink noise was used for a masking noise as a reference case. We have studied the influence of the difference in frequency characteristics of background noise on the masked thresholds of pure tones.

2. HEARING EXPERIMENT

2.1 Experimental settings

Auditory test was conducted in an anechoic room with 210 m^3 air volume in the Institute of Industrial Science, The University of Tokyo (Figure1 and 2). The stimuli were presented through 16 woofers (FOSTEX, FW405N) and a squawker (AURATONE, SUPER-SOUND-CUBE) on the wall. 8 woofers and a squawker were used to play masking noise and remaining 8 woofers were used to play pure tone. The distance between a subject and the speakers was 3.5 m. The sound pressure level was calibrated at a midpoint between the subject's ears in the condition without a subject. Subjects responded by pushing the button when they could hear the pure tone buried in the masking noise.

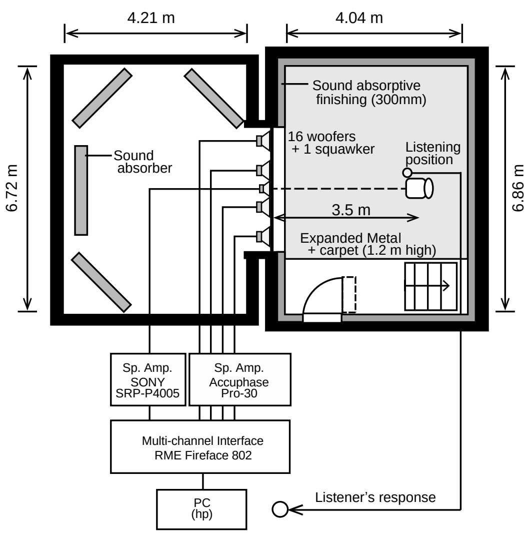


Figure 1. Experimental system

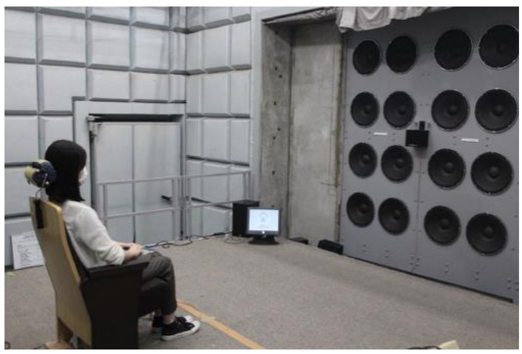


Figure2. Speaker system in the anechoic room

2.2 Test stimuli

Three types of noises were used as masking noises (Table 1). The frequency characteristics are shown in Fig. 3. A pink noise was used as the reference noise. To simulate an outdoor environmental noise, an artificially synthesized noise modeling the frequency characteristics of general wind turbine noises observed outdoor (-4 dB/octave in band spectrum [5]) was used. In order to simulate an indoor situation, the outdoor noise was attenuated according to the house filter for the single-pane window proposed by Tachibana et al. [6]. The 1/3 octave hand spectrum of the house filter model is shown in Fig.4. The A-weighted sound pressure levels of the masking noises were 55 dB for the pink noise, 45 dB for the outdoor noise, 35 dB for the indoor noise. The frequency of a pure tone added to the masking noise was 40, 50, 80, 100, 160, 200, and 400 Hz.

Table 1. Test stimuli

Masking noise		Pure tone
Type	A-weighted S.P.L [dB]	Frequency [Hz]
Pink noise	55 dB	40, 50, 80, 100, 160, 200, 400
Outdoor noise	45 dB	
Indoor noise	35 dB	

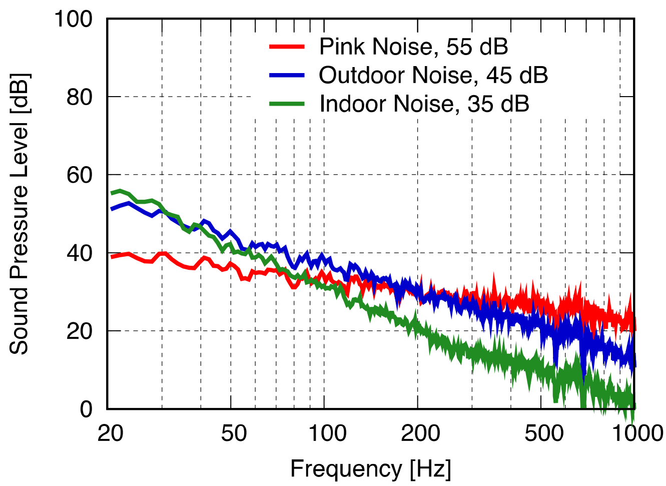


Figure 3. Frequency characteristics of masking noises

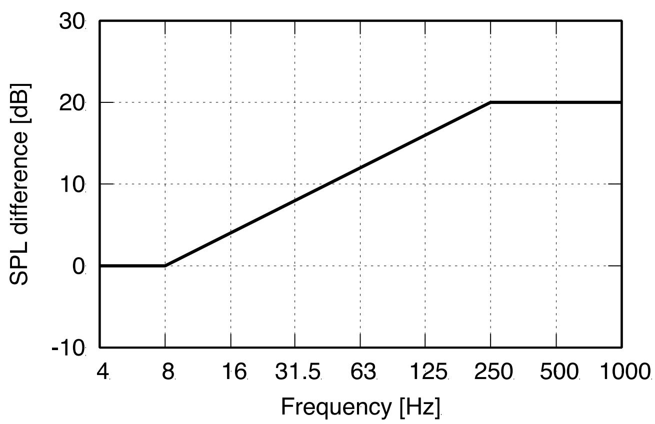


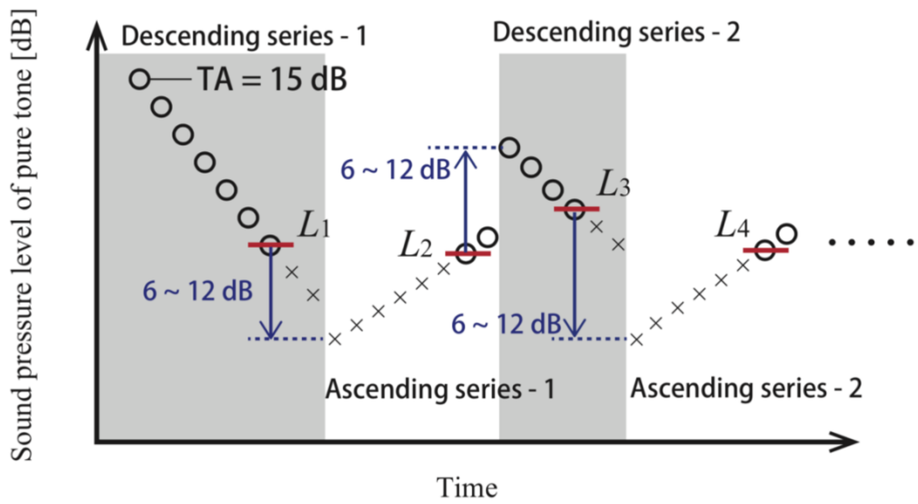
Figure 4. House filter for the single-pane window [6]

2.3 Experimental procedure

In the experiment, randomized maximum likelihood sequential procedure (RMLSP) [7] was used for evaluations. The subject was asked to push the response button while he/she could hear a pure tone and release it when he/she could not hear it. The duration of each stimulus was 2.0 s including rise- and decay-time of 50 ms.

The masking noise was presented constantly during the test. The experiment was started with the descending series. In the first descending series, the level of test pure tone sound was decreased stepwise every 2 dB from the level which was considered sufficiently loud to hear (TA = 15 dB). The series continued until the level at which the subject could not hear the pure tone sound 2 times in rows. Then the presentation level was further decreased by 6 to 12 dB and the ascending series started. In the process, the presentation level was increased stepwise every 1 dB until the subject could hear the pure tone 2 times in rows. After that, the presentation level was further increased by 6 to 12 dB and the second descending series started. 4 descending- and 3 ascending-series were conducted. The smallest hearing level in 2nd to 7th series were averaged, and it was determined as his/her masked threshold for each pure tone (Fig. 5).

The auditory test was divided into 3 sessions according to the types of masking noises. In this experiment, 19 subjects ranging in age from 24 to 40 years of age (9 males and 10 females) with normal hearing abilities participated. Before starting the auditory tests, hearing levels (HL) of all subjects are measured. Hearing threshold level of all subjects were less than 10 dB HL at frequency below 4 kHz.



$$\text{Masked Threshold} \quad L = \frac{L_2 + L_3 + L_4 + L_5 + L_6 + L_7}{6}$$

Figure 5. Diagram of randomized maximum likelihood sequential procedure

3. RESULTS

3.1 Masked thresholds

Measured masked thresholds are shown in Fig.6 (a) - (c). Red closed circles show the average of the thresholds and the error bars show the standard deviation. Black line shows the frequency characteristics of masking noise in [dB/Hz]. As a reference, 50 percentile value of normal hearing threshold, which is described in ISO 389-7:2005 is shown by blue broken line [8].

In 80 Hz or higher, the levels of masked thresholds were higher by 10 to 13 dB than spectral levels of masking noise for all three conditions. However, for 40 and 50 Hz tone, the masked thresholds were relatively higher. This may be because the levels of absolute thresholds of hearing are higher than that of masking noise in lower frequency range than 80 Hz. In Hawkins' research, the masked thresholds in lower presentation level were relatively higher in the vicinity of the threshold of hearing. Our results in 40 and 50 Hz tones seem to be the same trend of the research.

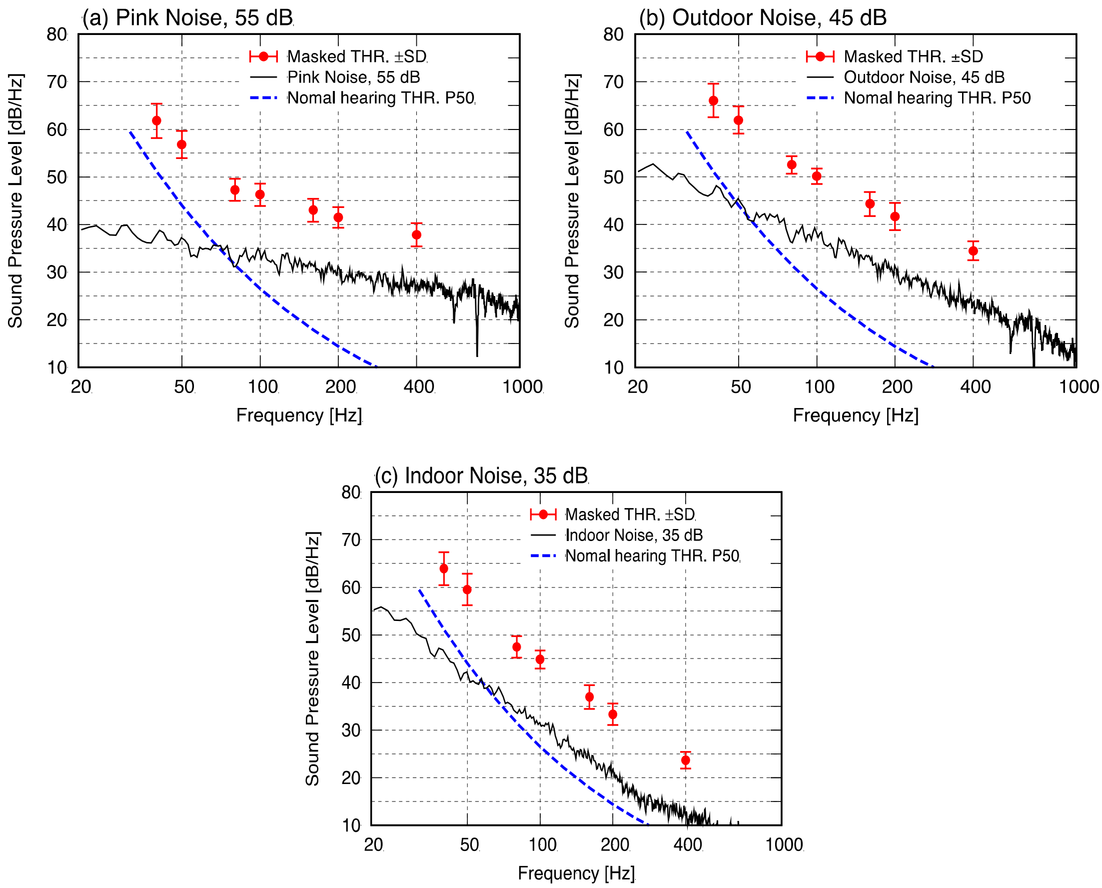


Figure 6. (a)-(c) Masked thresholds of pure tones under (a) pink noise, (b) outdoor noise, and (c) indoor noise

3.2 Evaluation in Tonal Audibility

The tonal audibility (TA) of the test stimuli at the masked threshold obtained in the RLMSP experiments were analysed according to IEC 61400-11:2012. The relations between the TA at the masked threshold and the frequency of the test pure tones are shown in Fig. 7.

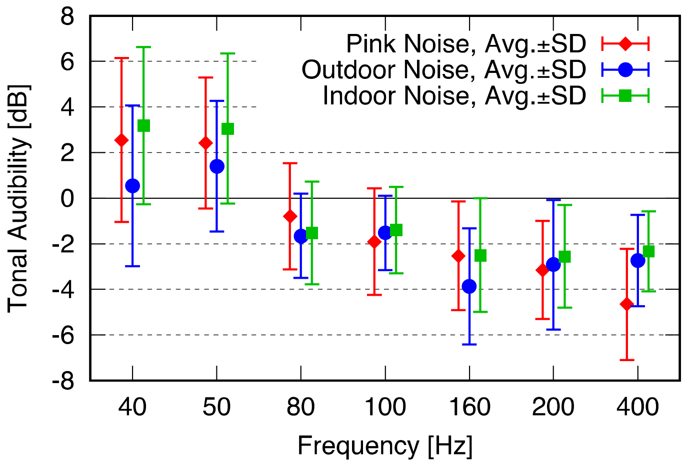


Figure 7. Tonal Audibility at the measured masked threshold

In the 80Hz or higher, the TA was about -2 dB for all three masking noise conditions. However, for 40 Hz and 50 Hz pure tone, the TA at the masked threshold ranges between 0 and 3 dB, which is higher than that of higher frequency tones.

In IEC 61400-11:2012, it is described that a tone is audible if the tonal audibility is above 0 dB. However, the measured masked thresholds were about -2 dB in this study. The reason of the difference in levels are not clear, but it may be because of the following two reasons. 1. difference of evaluation procedure; Békésy tracking method and RLMSP, 2. difference of stimulus presentation method; presentation via headphones and free field presentation.

4. CONCLUSIONS

Masked thresholds of low-frequency pure tones under pink noise, modelized outdoor- and indoor-noise were measured. In higher frequency range in which the spectral levels of masking noise were above the threshold of hearing, the TA at the masked threshold was about -2 dB for all three masking noise conditions. On the other hand, for 40 and 50 Hz pure tone, the masked thresholds were relatively high because of the influence of absolute thresholds of hearing. The result implies that both of absolute threshold of hearing and level difference between pure tone and masking noise affect the masked threshold of the pure tone.

5. ACKNOWLEDGEMENTS

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