Annoyance of low frequency pure tones and effect of one additional tone

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1. Introduction

The Ministry of Environment of Japan defines low frequency noise (LFN) as a sound wave of frequencies below 80 Hz. In the recent years, there has been an increase in the complaints arising from the LFN. Civil engineering structures, such as viaducts and railway tunnels, are some of the known sources of LFN. In the recent years, the nature of complaint from LFN has been shifting from physical ones, such as rattling of windows and other house fittings, to psychological ones, such as depression and sleep disturbance [1]. It is difficult to assess these psychological effects in controlled short-term experimental designs. However, measurement of other direct responses, such as annoyance, can give better understanding of the nature of these long-term psychological effects.

Measurements of annoyance in the past for low frequency pure tones have indicated that rate of increase of annoyance with respect to sound pressure level (SPL) is higher for lower frequencies [2]. However, the exact nature of increase in the annoyance for SPL near hearing threshold is not clear because of the starting SPL 20 dB above the hearing threshold in the study. On the other hand, measurements of annoyance for complex sounds indicated that the slope of the noise spectra of the LFN rather than their absolute levels might be important in determining the annoyance [3]. Although no such behavior was observed in another study [4], it was concluded that the hypothesis couldn't be ruled out [5]. Simplification of the complex sounds to only two tones can give better understanding of the real behavior. The objectives of this present study, therefore, are to investigate: 1) rate of increase of annoyance of LFN for SPLs near hearing threshold, and 2) the effect on annoyance for different levels of combination of two tones.

2. Definition of annoyance

Annoyance is a complex phenomenon, and many factors, such as personal and social, besides physical attributes of the sounds, such as frequency and sound pressure level, affect annoyance. Furthermore, level of annoyance for a person for the same sound is different depending upon the circumstances e.g., sleeping, reading or working inside a factory. However, for this study annoyance is defined as the general term of unpleasantness for the subjects sitting in the experimental room condition. In Japanese, the term was translated as *Fukaisa*.

3. Experimental method

The experiments were carried out in two stages. In the first stage, low frequency pure tones of 31.5 Hz, 50 Hz and 80 Hz at 4 different levels (Fig. 1) were selected as test signals. In the second stage, the pure tones of the first stage were considered main tones and additional tone of 40 Hz at SPL 5 dB above hearing threshold of individual subjects was added with the main tones. Annoyance was measured by making comparison with equally annoying level of 63 Hz comparison tone.

Sixteen students, 14 males and 2 females, volunteered as subjects for the experiment. Nine subjects were Japanese students and seven subjects were foreign students. The subjects' age range was 22-31 yrs. All of the subjects participated in both stages of the measurements. A soundproof cabin (1.8 x 1.2 x 2.3 m) constructed for the purpose of experiments on LFN was used for the measurement purpose. Four speakers (YAMAHA, YST 800) were used to present the test signals to the subjects sitting inside the chamber. PC was used as source of the test signals, and function oscillator was used as source of the comparison tone. Another speaker (YAMAHA, YST 350) placed inside the chamber was used to generate the comparison tone. Specially designed switches and indicator lights were used to communicate between the subjects and the experimenter.

The test signals were presented to the subjects for one minute. After one minute, the test signals were turned off. The subjects were then asked to adjust SPL of the comparison tone so that it was equally annoying as the test signals. The subjects used function oscillator to adjust level of the comparison tone. To compensate the carry over effects, the test signals were presented in random order for each subject. Care was taken not to make order of two test signals same for any two subjects. The measured SPL of 63 Hz tone adjusted by the subject after listening to test signal for one minute is inferred in this study as annoyance level for that signal.

Measurements of the first stage were completed in 3 days, and the measurements of the second stage were also completed in 3 days starting 12 days after the first stage. Measurement of annoyance for pure tone test signal of 50 Hz at 72 dB was repeated in the second stage also. Average perception thresholds of the subjects measured during the experiment and the hearing threshold specified in ISO [6] are also shown in figure 1.

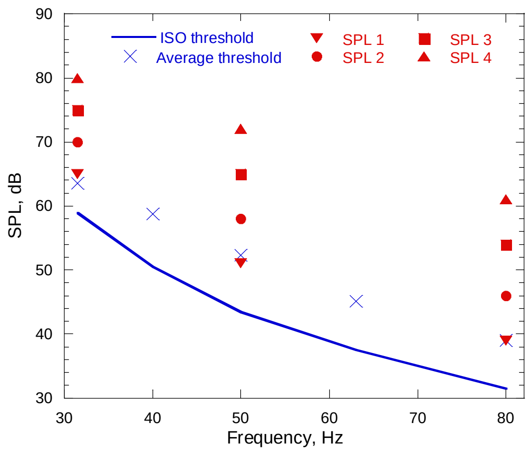

Figure 1. Average threshold of the subjects and designed sound pressure level of pure tones used in the experiment. Average hearing threshold of ISO 389-7 [6] is also shown.

4. Results and Discussions

4.1 Effect of measurements in two stages

One assumption in the measurement process is that no systematic changes occur in the measurement of annoyance at two different stages. In

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order to investigate reliability of this assumption, measurement of 50 Hz test signal at SPL of 72 dB was repeated in both stages. Wilcoxon matched-pair signed rank test showed that the differences in the two measurements are statistically not significant (p>0.05, two-tailed). Further discussions are made with the assumption that there are no systematic differences in the annoyance levels measured in the two stages.

4.2 Annoyance due to pure tones

The average increase in the annoyance level with average increase in the SPL of different frequencies is shown in Fig. 2. The results show that rate of increase of annoyance is higher for lower frequencies. Although the effects do not appear for SPL near hearing threshold, the tendency is clear 10 dB above the threshold. The higher increase rate at lower frequencies suggests that even small increase in sound pressure levels results in significant change in the annoyance compared to higher frequencies.

One possible reason for no clear trend in the slopes below 10 dB is that the subjects had different hearing threshold levels, and the threshold of some subjects at 63 Hz was below the average threshold. Hence, the level of comparison tone above the subject's threshold can become lower than the average threshold. This effect results in negative value of comparison tone above average threshold, although the value is positive for that particular subject. Therefore, the results for SPL near the threshold must be dealt carefully.

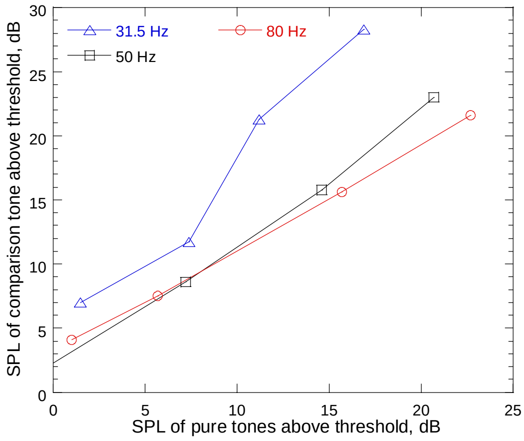

Figure 2. Increase in annoyance level for pure tones with increase in SPL. Increase in annoyance level is the SPL of 63 Hz comparison tone above average threshold at 63 Hz.

4.3 Annoyance due to combined tones

The annoyance levels for pure tone and combined tones for individual subjects at 31.5 Hz along with their median values are shown in Fig. 3. For the combined tones, tone at 31.5 Hz is the main tone and 40 Hz tone at SPL of 5 Hz above threshold for individual subject is the additional tone. In the figure, level of additional tone is not shown. The results show that at the lowest level of main tone, the additional tone has the effect to increase annoyance level. However, with the increase in the level of main tone, the annoyance for combined tones becomes similar to the annoyance of 31.5 Hz pure tone. The contribution to annoyance from additional tone is insignificant for higher levels of main tones.

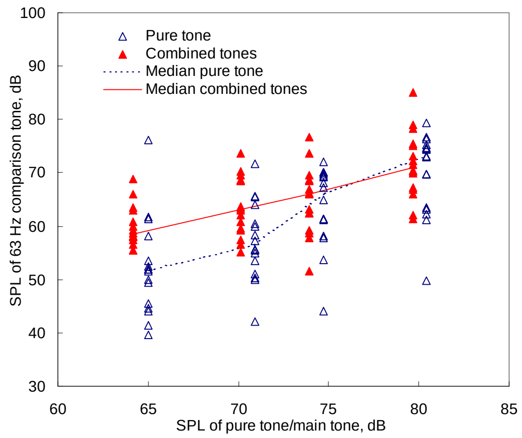

Figure 3. Annoyance level for individual subjects and median results for pure and combined tones at 31.5 Hz.

Median values of the annoyance ratings of all the subjects for pure tones and combined tones of the 3 frequencies are shown in figure 4. For combined tones at 50 and 80 Hz, main tones are tones at 50 and 80 Hz respectively. The results show that at 50 and 80 Hz also, the effect of additional tone decreases with increase in the level of main tones. The results point to the fact that annoyance of complex sounds is very much dependent upon the relative SPL of individual components rather than absolute SPL of the components.

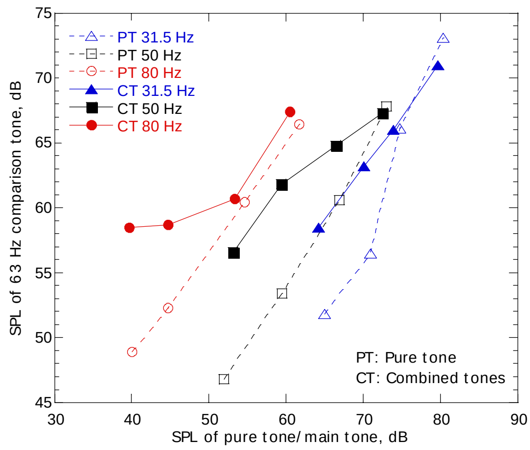

Figure 4. Comparison of annoyance level for pure tones and combined tones. SPL of additional tone at 40 Hz is not shown in the figure.

5. Conclusions

The findings from this study can be summarized as follows:

1. Rate of increase of annoyance for pure tones is higher for sounds of low frequencies compared to sounds of high frequencies even at lower sound pressure levels. However, this phenomenon could not be observed near the threshold.
2. Annoyance for combination of two tones is dependent upon the relative difference in the sound pressure level of the two tones rather than the absolute level of the individual tones.

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