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Description	

Relationship between discomfort sound and its physical corre-lates

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Abstract

In serious disasters as earthquake and typhoon, emergency evacuation calls are important. To listen the calls clearer, it is necessary to improve salience of those calls. Since discomfort sounds seem to be salient, it is effective to increase discomfort of the sound to make the calls salient. If these characteristics of calls are clearly known, salient sound could be designed. We clarify what kind of physical quantity is related to sound discomfort. In order to clarify the physical characteristics of discomfort sound, correlations between evaluation values of discomfort obtained by listening experiment and the value of the calculated physical properties are investigated. As a result, discomfort of the sound has a positive correlation with spectral centroids. Therefore, it can be said that the higher the frequency of the spectral centroid, the more discomfort it feels. It means that it feels discomfort as sharpness sound.

1. Introduction

In past few years, there have been serious disasters as earthquake and typhoon. Serious damages occur by these disasters. In such cases, emergency evacuation calls are important to protect everyone's safety. This is because about 80% of the people who heard the evacuation calls felt the need to evacuate [1]. However, the emergency evacuation calls often do not arrive because of presence of much information such as occurrence time of a disaster. In fact, there are reports that only 56% of the people can catch the evacuation warnings clearly from emergency broadcast system [1]. It is necessary to improve salience of those calls to be able to hear them more clearly. Since discomfort sounds seem to be salient [2, 3], it is effective to increase discomfort of the sound to make the calls salient. Thus, studying discomfort sounds is challenging. If characteristics of the discomfort sounds are clearly known, salient sounds could be designed. In previous studies, Aures proposed a scale for 'comfort' focusing on sound quality indices [4]. Watanabe et al. introduced that discomfort in tactile sense is closely related to phrases representing sharpness and roughness [5]. The terms, roughness and sharpness, are also used as sound quality evaluation index. However, 'comfort' is on the opposite direction of discomfort. Additionally, there are differences between touch and hearing. Discussing these reports, relationships between discomfort sounds and acoustic features in sense of hearing are still not clear. Therefore, it is necessary to discuss physical correlates of discomfort sounds. Moreover, it is required to clarify what kind of physical quantity is related to sound discomfort.

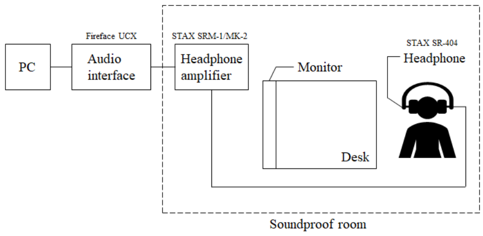

Figure 1: Experimental system

2. Experiment

2.1 Purpose

To answer the above question, we investigate correlations between degrees of discomfort sounds and acoustic features. Therefore, it is necessary to know what type of sounds discomfort are and how much discomfort those sounds are. A listening test is carried out to collect scores for discomfort from sounds.

2.2 Setup

Figure 1 shows the experimental setup. The system is constructed with a Windows-based PC, audio interface (Fireface UCX), headphone amplifier (STAX SRM-1/MK-2), and headphone (STAX SR-404). The experiment is conducted in a soundproof room.

2.3 Stimuli

Table 1: Characteristics of stimuli

No.01	alarm
No.02	train bell (high frequency)
No.03	peep sound
No.04	flicker sound
No.05	siren sound
No.06	buzzer sound (continuous)
No.07	fern sound
No.08	fern sound
No.09	pew-pue sound
No.10	emergency bell
No.11	bells sound (long cycle)
No.12	chime (long cycle)
No.13	buzzer sound (intermittent)
No.14	train bell (low frequency)
No.15	chime (short cycle)
No.16	horn
No.17	invaders sound
No.18	pirara sound
No.19	alarm bells sound
No.20	ping-pong-pan-pong sound
No.21	bang sound
No.22	tankatata sound
No.23	cuckoo sound
No.24	nightingale sound
No.25	bells sound (short cycle)

25 types of sounds are used as stimuli. Duration time of all stimuli was 5 seconds. Sampling frequency was 44.1 kHz. The average sound pressure level was 60 dB. The stimuli used for these experiments were actual warning sounds produced by Schneider Electric Japan Holdings Ltd. Names of the stimulus sounds are shown in Table 1. In order to study correlations between degrees of discomfort and features, we extract centroid, skewness and kurtosis of the modulation spectra and long-term amplitude spectra. We considered that since there are relevance to the shape and discomfort of spectrum, we focused on these physical features.

Modulation spectrum was calculated as follows. The original signal $s(t)$ Next, the power envelope $e^2(t)$ of each band component is obtained from (1). Then, obtain the modulation spectrum defined by (2).

$$e^2(t) = LPF(|x(t) + j * Hilbert(x(t))|^2) \tag{1}$$

$$E(f_m) = |DFT(e^2(t))| \tag{2}$$

where Hilbert is Hilbert transform, LPF is a low pass filter with a cutoff frequency of 64 Hz, DFT is a discrete Fourier transform, f_m is the modulation frequency.

2.4 Participant

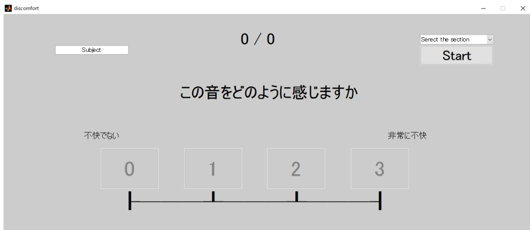

Figure 2: Experimental GUI

Participants were seven male and seven female Japanese listeners in their twenties with normal hearing ability.

2.5 Procedure

In the experiment, participants were asked to listen to stimuli to score degrees of discomfort (not dis-comfort (0) - very discomfort (3)). One session includes 25 stimuli and 5 sections were presented to the participants. Figure 2 shows the GUI used for the experiment. The evaluated values were averaged, and the extent of discomfort of the stimulation sound was calculated.

2.6 Result

The results for discomfort scores of the stimuli are shown in Figure 3. The minimum value of the value is 0.543, and the maximum value is 2.314.

3. Correlations between degree of discomfort and features

3.1 Analysis of sounds

Using Equation (3), correlation coefficient between the discomfort of the sound and the physical quantity was calculated.

$$\rho(A,B) = \frac{\frac{1}{N}\sum_{i=1}^{N}(A_i - \mu_A)(B_i - \mu_B)}{(\sqrt{\frac{1}{N}\sum_{i=1}^{N}(A_i - \mu_A)^2}) * (\sqrt{\frac{1}{N}\sum_{i=1}^{N}(B_i - \mu_B)^2})} \tag{3}$$

N is number of scalar observations, A (Degree of discomfort) and B (Physical features) are random variables with positive variance, μ is the mean and σ is the standard deviation.

3.2 Evaluations of features

The scatter plot with centroid of the long-term spectra vs degrees of discomfort is shown in Figure 4. The correlation coefficient is 0.55. Therefore, it can be said that there is a positive correlation. The scatter plot with skewness of the long-term spectra vs degrees of discomfort is shown in Figure 5. The correlation coefficient is -0.41. Therefore, it can be

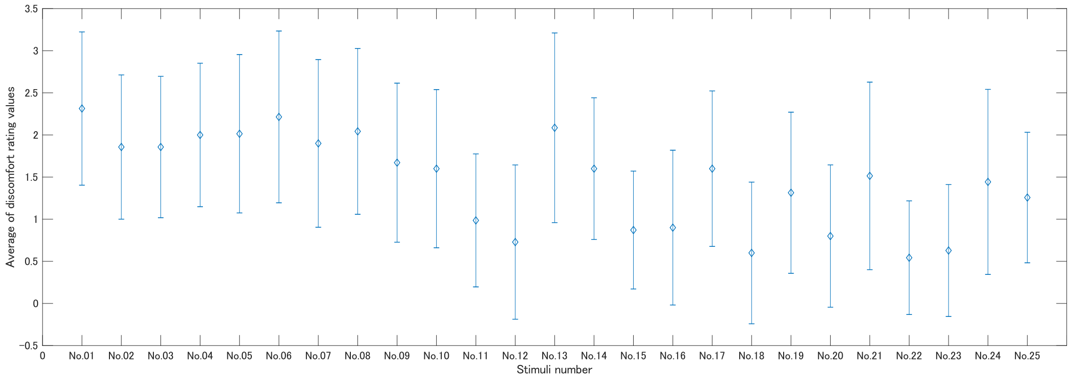

Figure 3: Evaluated results of stimuli for discomfort

said that there is a low negative correlation. The scatter plot with kurtosis of the long-term spectra vs degrees of discomfort is shown in Figure 6. The correlation coefficient is -0.35. Therefore, it can be said that there is a low negative correlation. The scatter plot with centroid of the modulation spectra vs degrees of discomfort is shown in Figure 7. The correlation coefficient is -0.02. Therefore, it cannot be said that there is a correlation. The scatter plot with skewness of the modulation spectra vs degrees of discomfort is shown in Figure 8. The correlation coefficient is 0.06. Therefore, it cannot be said that there is a correlation. The scatter plot with kurtosis of the modulation spectra vs degrees of discomfort is shown in Figure 9. The correlation coefficient is 0.03. Therefore, it cannot be said that there is a correlation. The summary is shown in the table 2.

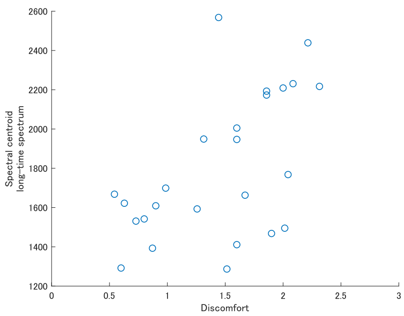

Figure 4: The center of gravity and discomfort in the long-term spectrum

4. Discussion

It was found that there was a positive correlation between degrees of discomfort of the sounds and the center of gravity of the long-term spectra. The spectral centroid has the property that it increases as the sound height increases. Centroid

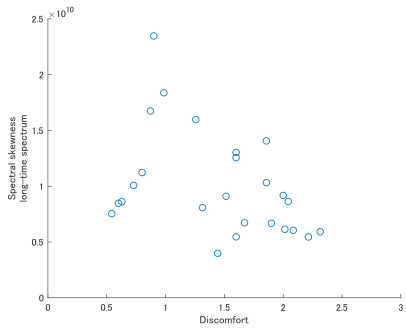

Figure 5: The skewness and discomfort in the long-term spectrum

and skewness of long-term spectra are highly correlated with discomfort. In other words, discomfort is related to the fact that the spectrum is biased toward the higher frequency side.

5. Conclusion

In order to clarify the physical characteristics of discomfort sounds, correlations between the evaluation values of discomfort obtained by the listening experiment and the estimated physical features were investigated. As a result, it was found that discomfort of the sounds has a positive correlation with the spectral centroid. Deviation of the spectra considered to be uncomfortable if the higher. The result of this research is considered to help research that considers the remarkable sound from physical properties.

Acknowledgment

Stimulus sounds used in this study were provided by Schneider Electric Japan Holdings Ltd.

Table 2: Correlations between degree of discomfort and features

		correlation coefficient
long-time spectrum	entroid	0.55
	kewness	-0.41
	kurtosis	-0.35
modulation spectrum	centroid	-0.02
	skewness	0.06
	kurtosis	0.03

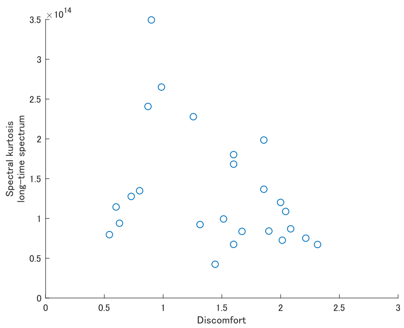

Figure 6: The kurtosis and discomfort in the long-term spectrum

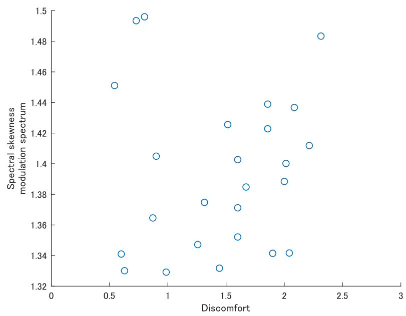

Figure 8: The skewness and discomfort in the modulation spectrum

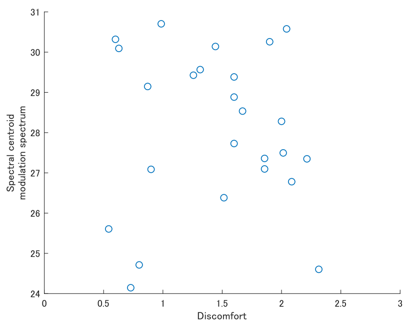

Figure 7: The centroid and discomfort in the modulation spectrum

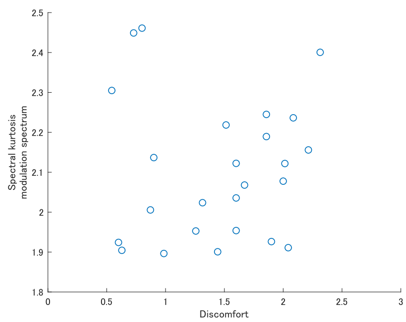

Figure 9: The kurtosis and discomfort in the modulation spectrum

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