A Design of Comfortable Dental Treatment Sound Based on Auditory Masking

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ABSTRACT

In a dental treatment, patients and doctors often feel strong discomfort feeling by hearing the dental treatment sound. It is caused by peak frequency components on a high frequency-band. For reducing discomfort feeling of a single peak frequency component, we have previously proposed the discomfort reduction method that can mask a single peak frequency component based on auditory masking. Auditory masking is a phenomenon to increase an audible level by a composite sound. Here, we focus on discomfort feeling of the dental treatment sound. The previous method has difficulty applying it to the discomfort reduction of the dental treatment sound because it has multiple-peak-frequency components. In this paper, we therefore propose a new method for designing the masking sound that can mask them. The proposed method employs the comfortable nature sound including a running water sound as the sound source of the masking sound to achieve a comfortable masking sound design. As a result of subjective experiments, we confirmed that the proposed method can make the dental treatment sound more comfortable.

Keywords: Dental treatment sound, Auditory masking, Peak-frequency, Comfortable sound
I-INCE Classification of Subjects Number(s): 01.4

1. INTRODUCTION

Unpleasant noise which often interferes with our lives is a huge problem. Therefore, various methods have been studied to overcome it. In generally, methods for noise suppression are used to achieve this goal (1). They are much essential to reduce loud noises which have high power on lower frequency-band such as those caused by traffic, construction sites, and so on. However, there is the tendency that humans often feel discomfort in quiet surroundings even if the noises are small. In particular, in the case of wind noise and air-conditioning noise including a peak-frequency component on higher frequency-band, the tendency is remarkable (2). It is difficult to solve this problem by only reducing the sound pressure level of noise. Thus, we previously proposed the discomfort reduction method based on auditory masking to reduce discomfort of higher frequency noise (3). Auditory masking is the phenomenon that listener can't perceive the unique frequency by a band-limited noise including the unique frequency. We have already confirmed that the previous method can reduce discomfort feeling of the noise including a single peak-frequency component. Meanwhile, the previous method insufficiently reduces discomfort of the noise including multiple peak-frequency components. Accordingly, we focuses on the dental treatment sound including them. In dental treatment, many patients feel a strong discomfort by the treatment sounds which arise by a tooth grinding (4). In this paper, we therefore propose the method to generate the masking sound which can mask multiple-peak-frequency components in the dental treatment sound. The proposed method detects the peak-frequencies of the dental treatment sound, and designs the masking sounds based on auditory masking to mask them. Here, the proposed method may insufficiently improve the feeling in dental treatment by applying only auditory masking because the designed masking sound has power in only higher frequency-band. Therefore, in this paper, we also try to design the comfortable masking

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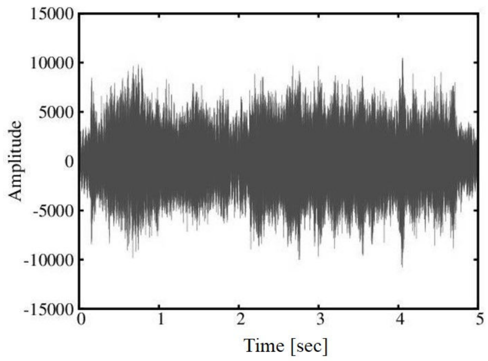
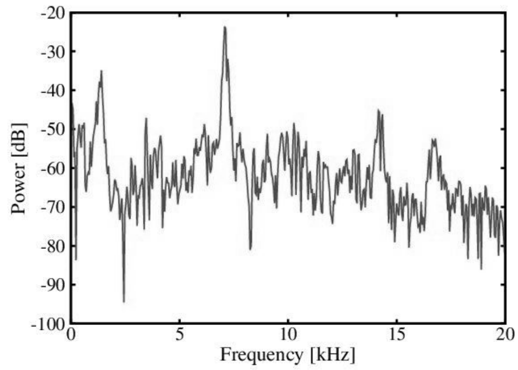


(a) Time waveform



(b) Power spectrum

Figure 1 – Time waveform and power spectrum of the dental treatment sound

sound by combining lower frequency components of comfortable sound source to the masking sound. The proposed method improves the feeling on the dental treartment by emitting the comfortable masking sound in that space. For confirming the effectiveness of the proposed method, we carried out a subjective evaluation experiment.

2. AUDITORY MASKING

Auditory masking is the phenomenon that one sound is drowned out by another sound. This phenomenon is defined as the threshold of hearing one sound being increased by another sound. The specific band that can influence the threshold of hearing one sound is called the "critical band" (5). Bandwidth of the critical band is uniquely determined based on the frequency of the masked sound and given by the following Eq. (1), approximately.

$$CB = 25 + 75\left(1 + 1.4\left(\frac{f}{1000}\right)^2\right)^{0.69}, \tag{1}$$

where CB stands for the bandwidth of the critical band, and f is the frequency of the target masked sound. For example, the threshold of hearing a sound with a frequency of 1000 Hz can be increased by the only noise with a bandwidth of about 162 Hz that centers on 1000 Hz. Even if the sound pressure of the band except the critical bandwidth increases, the threshold of hearing the sound with a frequency of 1000 Hz remains constant. This phenomenon is referred to as the auditory filter. In this study, we utilize the critical band to the proposed method for masking the peak-frequency component of the dental treatment sound.

3. DENTAL TREATMENT SOUND

The former researches have already investigated that the noise including a peak-freqiency causes a strong discomfort (2). In particular, it has also been reported that uncomfortable sound such as noise caused by grinding a tooth and scratching a blackboard has peak-frequency components in 2000 Hz or more on the frequency-band. Figure 1 shows the time waveform and the power spectrum of the dental treatment sound. As shown in Fig. 1, the dental treatment sound also has multiple-peak-frequency components. We presumed that these components around them cause uncomfortable of the dental treatment sound. For reducing discomfort by them, the proposed method should mask them on higher frequency-band in 2000 Hz or more.

4. DESIGN OF MASKING SOUND FOR COMFOTABLE DENTAL TREATMENT

We propose the method for designing the masking sound to reduce the unpleasantness of the dental treatment sound. Figure 2 shows the overview of the proposed method. In the proposed method, first, it analyzes the dental treatment sound, and detects peak-frequencies on the power spectrum of the

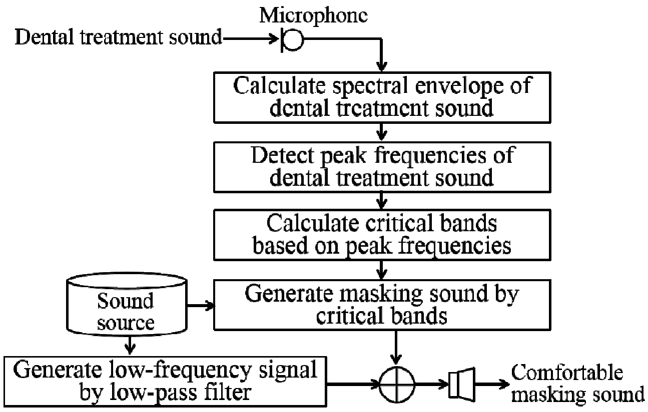


Figure 2 – Overview of the proposed method

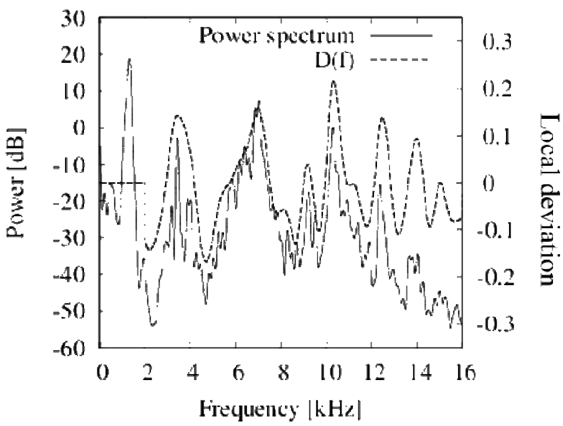


Figure 3 – Power spectrum and local deviation of the dental treatment sound

dental treatment sound. Second, it calculates each critical band that can mask each detected peak-frequency. Finally, it designs the masking sound by each calculated critical band and comfortable sound source.

4.1 Detection of peak frequency

In our study, we propose the method for masking multiple-peak-frequency components of the dental treatment sound in order to provide comfortable feeling on the dental treatment. Each peak-frequency is detected by local deviation $D(f)$. It is derived from Eq. (1).

$$D(f) = \frac{P(f) - \mu(f)}{\sigma(f)}, \tag{1}$$

$$\mu(f) = \frac{1}{F}\int_{f-F/2}^{f+F/2} P(f')df', \tag{2}$$

$$\sigma(f) = \frac{1}{F}\int_{f-F/2}^{f+F/2} (P(f') - \mu(f))df', \tag{3}$$

where f is the frequency, $P(f)$ indicates the spectral envelope of the dental treatment sound, and $\mu(f)$ and $\sigma(f)$ indicate the median and the variance of the power in F that centers on f. Thus, $D(f)$ represents how the power of f has exerted value in the frequency-band around f. Figure 3 shows the power spectrum of the dental trearment sound and $D(f)$ calculated for the case in which F is experimentally 2000 Hz. In this paper, the proposed method estimates f as peak-frequencies in 2000 Hz or more if the value of $D(f)$ gets over 0.1.

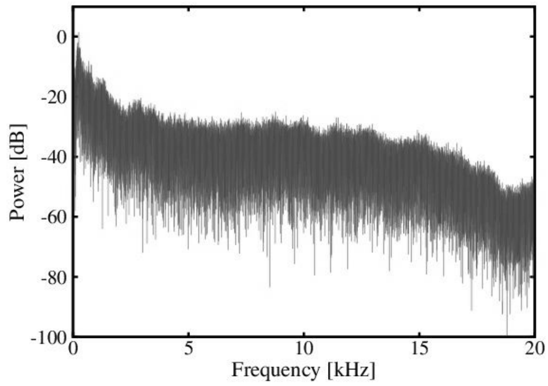
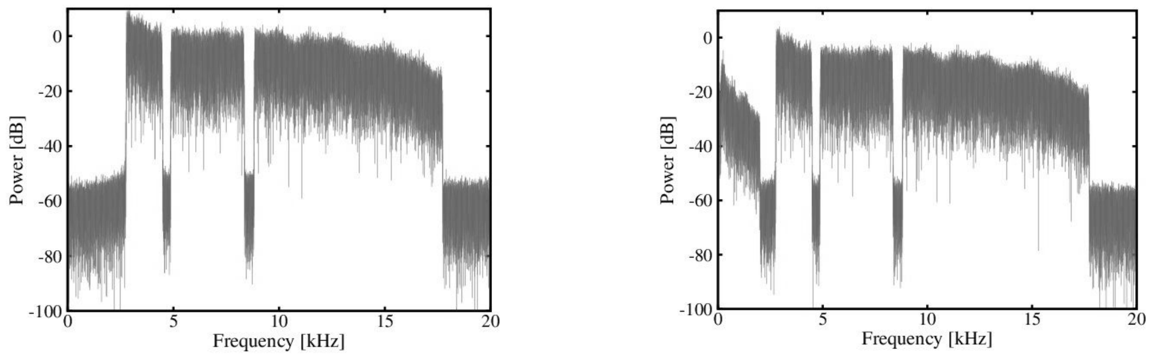


Figure 4 – Power spectrum of the comfortable sound (Running water sound)



(a) Before designing comfortable

(b) After designing comfortable

Figure 5 – Power spectra of the each masking sound by the proposed method

4.2 Making sound design

The proposed method calculates each critical band which can mask each detected peak-frequency in Eq. (1). The detected peak-frequencies are assigned to Eq. (1) as f . In accordance with the calculated critical band, the masking sound is generated by band-pass filter that passes the critical band. In this study, the masking sound $y(t)$ is derived from Eq. (4).

$$y(t) = h(t) * x(t), \tag{4}$$

where t is time index, $x(t)$ indicates the sound source, and $h(t)$ indicates the band-pass filter based on the calculated critical band. The symbol $*$ indicates the convolution. In addition, the proposed method should design the comfortable masking sound to much improve the sound field in the dental treatment. The comfortable sounds often have dominant power in lower frequency-band as typified by a running water sound. Therefore, the proposed method designs the comfortable masking sound by adding the lower frequency component of the comfortable sound source to the masking sound. The lower frequency component is extracted by low-pass filtering. Figure 4 shows the power spectrum of the comfortable sound source. Figure 5 (a) shows the power spectrum of the masking sound based on the comfortable sound source and critical bands. Figure 5 (b) shows the comfortable masking sound by adding the lower frequency component of the comfortable sound source to the masking sound.

5. SUBJECTIVE EVALUATION EXPERIMENT

We carried out a subjective evaluation experiment to confirm the effectiveness of the proposed method.

5.1 Subjective experimental conditions

The proposed method was evaluated in a soundproof room with background noise of less than L_A = 20 dB. Table 1 shows the experimental conditions. In this experiment, we employed various dental treatment sound and various comfortable sound source as shown in Table 2. Subjects evaluated the comfort feeling of the evaluation sound on the basis of five grades by comparing the uncomfort

Table 1 – Subjective experimental conditions

Headphone	SONY, MDR-CD900ST
Sampling rate	96000 Hz
Quantization	16 bits
Environment	Soundproof room
Subjects	8
Evaluation sounds	16 (4 dental treatment sounds ×4 sound sources)

Table 2 – Sound sources for the evaluation sound

Dental treatment sounds	Sharp turbin soud
	Blunt turbin sound
	Polishing sound
	Scaling sound
Comfortable sound sources	Streaming down brook
	Flushing the toilet
	Flowing river lock
	Running water

feeling of only dental treatment sound. In this experiment, we defined grade 5 as very comfortable, grade 1 as not at all comfortable. We also defined only dental treatment sound as grade 3. Each evaluation sound consisted of the dental treatment sound and the designed masking sound. Signal-to-noise-ratio (SNR) equals 5 dB (S: Comfortable masking sound, N: Dental treatment sound). Sound pressure level was about L_A = 75 dB as with in real environment of the dental treatment.

5.2 Subjective experimental results

Figure 6 shows the results of the subjective evaluation experiment. In Fig. 6, the horizontal axis represents the kind of dental treatment sound, the vertical axis represents the score that is average of answer of each subject. The higher value means a higher comfort. From Fig. 6, in employing the running water and the flushing the toilet as the comfortable sound sources, the proposed method achieved higher comfort. On the other hand, we could not confirmed the effectiveness of the proposed method in employing the streaming down brook and flowing river lock. It may be a cause that they were the non-stationary sound. Therefore, perfomance of the proposed method increases by stationary comfortable sound.

6. CONCLUSIONS

We newly proposed the design method of the comfortable masking sound for reducing discomfort of the dental treatment sound. The proposed method could design the comfortable masking sound by adding lower frequency component of the comfortable sound to the masking sound. We carried out the subjective evaluation experiment to confirm the effectiveness of the proposed method. As a result, we confirmed that the comfort in dental treatment was improved by the proposed method when it used the stationary comfortable sound as the sound source. In future work, we intend to achieve more comfortable masking sound for much improving the sound field in noise environment. In addition, we also challenge to design the masking sound that can mask the non-stationary noise.

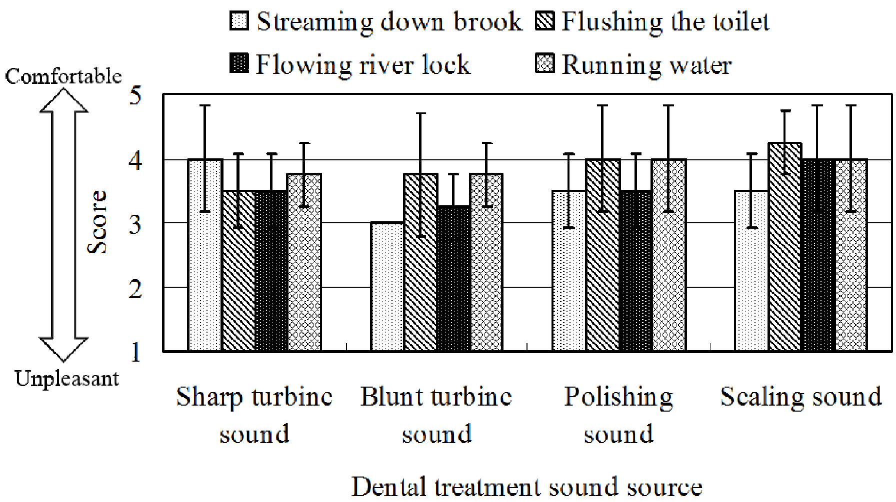


Figure 6 – Results of the subjective evaluation experiment

ACKNOWLEDGEMENTS

This work was partly supported by Grand-in-Aid for Scientific Research, funded by MEXT, Japan.

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