A Fundamental Study on Acoustic Stimulus for Tinnitus Retraining Therapy

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ABSTRACT

Tinnitus retraining therapy (TRT), which seeks to improve brain plasticity and adaptation to tinnitus, has received a lot of attention in recent years as a treatment based on a neurophysiological model of tinnitus. The goal of TRT is to decrease the discomfort associated with tinnitus by retraining the brain to habituate to tinnitus. Sound therapy in TRT uses broad-band noise such as white noise, pink noise, and speech noise to remove tinnitus from conscious perception. However, the relationships between the effects of the therapy and the acoustical characteristics of the noise, such as the frequency spectrum, sound pressure level, and time-varying properties, have not yet been examined. Thus, this study was designed to investigate the effectiveness of different types of sounds for TRT. Although there are many types of tinnitus, pure tones for simulating tinnitus were first prepared. Next, psychological listening experiments were conducted in which both pure tones and band-limited pink noise passing through eight bands of critical band filters were transmitted to participants with normal hearing. The results allow the relationships of the signal-to-noise ratios between pure tones and band-limited noise, and the psychological impressions with respect to the pure tones and noise, to be determined.

INTRODUCTION

In recent years, tinnitus retraining therapy (TRT) [1], which seeks to improve brain plasticity and adaptation to tinnitus, has received a lot of attention as a treatment based on a neurophysiological model of tinnitus. TRT is a sound therapy that aims to remove tinnitus from conscious perception. The goal of TRT is to decrease the discomfort associated with tinnitus by using constant low sound pressure levels of broad-band noise (white noise, pink noise, speech noise) to reduce the detectability of tinnitus at the subconscious level. Although the systemization of the therapeutic techniques in TRT is progressing [2], the relationships between the effects of TRT and the acoustical characteristics of the noise, such as the frequency spectrum, sound pressure level, and time-varying properties, have not yet been examined. Thus, this study was designed to investigate the effectiveness of different kinds of sounds for TRT. Although there are many types of tinnitus, pure tones for simulating tinnitus were first prepared. Next, psychological listening experiments were conducted in which both pure tones and band-limited pink noise passing through eight bands of critical band filters were transmitted to participants with normal hearing. The results allow the relationships of the signal-to-noise ratios between pure tones and band-limited noise, and the psychological impressions with respect to the pure tones and noise, to be determined. We found that a signal-to-noise ratio between the tinnitus-simulating sound and the noise of around 3 dB was the most efficient.

OUTLINE OF PSYCHOLOGICAL LISTENING EXPERIMENT

A psychological listening experiment was conducted to establish the relationships between the signal-to-noise ratios of the sounds used for simulating tinnitus and the band-limited noise, and the psychological impressions with respect to the tinnitus simulation sound and the band-limited noise.

Participants

A total of eight students (seven were male and one was female) with normal hearing participated in the psychological listening experiment.

Acoustic stimuli

(A) Sound for simulating tinnitus

Although there are many types of tinnitus, pure tones were used to simulate tinnitus in this study. The pure tone frequencies were 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz. The sensation levels of pure tone for each participant were set at 5, 10, and 15 dBSL based on a case report on the loudness balance test [3].

(B) Band-limited noise

Band-limited pink noise with [12, 113], [75, 175], [200, 300], [450, 500], [920, 1080], [1850, 2150], [3660, 4340], and [7150, 8850] Hz frequency bandwidth equal to the critical bandwidth of pure tones with frequencies at 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz were used. The signal-to-noise ratios between the pure tones and the band-limited noise were set at −3, 0, 3, 6, 9, and 12 dB.

Measurements

Both the sounds used for simulating tinnitus and the band-limited noise were presented using headphones (Sennheiser HDA 200) to each participant's left or right ear. After listening to the acoustic stimuli for 60 s, a subjective evaluation on how distracted the participant was from the tinnitus-simulating sound was made using the following evaluation scale:

A1: Not at all distracted from tinnitus-simulating sound

A2: Slightly distracted from tinnitus-simulating sound

A3: Moderately distracted from tinnitus-simulating sound

A4: Very distracted from tinnitus-simulating sound

A5: Extremely distracted from tinnitus-simulating sound

Additionally, subjective evaluation on how much the participant's attention was attracted towards the band-limited noise was investigated using the following evaluation scale:

B1: Not at all attracted to the band-limited noise

B2: Slightly attracted to the band-limited noise

B3: Moderately attracted to the band-limited noise

B4: Very attracted to the band-limited noise

B5: Extremely attracted to the band-limited noise

Furthermore, participants were required to answer 'Yes' or 'No' based on whether or not they thought that they would be able to listen to the band-limited noise for a long period of time. The above procedure was performed once in each ear.

RESULTS AND DISCUSSION

Means and standard deviations of the subjective evaluation as to how distracted participants were from the tinnitus-simulating sound were calculated for each signal-to-noise ratio between the tinnitus-simulating sound and the band-limited noise. Figure 1 shows the results for each sensation level of pure tone. The difference in subjective evaluation of the tinnitus-simulating sound due to the signal-to-noise ratio, sensation level of the pure tone, and frequency of the pure tone was examined using a three-factor repeated-measures analysis of variance (ANOVA) with the signal-to-noise ratio between pure tone and band-limited pink noise of −3, 0, 6, 9, or 12 dB, the sensation level of the pure tone between 5, 10, and 15 dBSL, and the frequency of pure tone as 63, 125, …, and 8000 Hz. The ANOVA revealed two significant main effects: the signal-to-noise ratio between the pure tone and the band-limited pink noise, and the sensation level of the pure tone ($p < 0.001$). In Figure 1, the mean of the subjective evaluation of the tinnitus-simulating sound when the signal-to-noise ratio was less than or equal to 3 dB was larger than approximately 2.5 (on the category scale) for all frequencies of pure tone. These results demonstrate that band-limited noise with a signal-to-noise ratio less than or equal to 3 dB may take attention away from the tinnitus-simulating sound.

Means and standard deviations of the subjective evaluation on how much participants' attention was attracted to the band-limited pink noise were calculated for each condition. Figure 2 shows the results for each frequency of pure tone. A three-factor repeated-measures ANOVA on the signal-to-noise ratio between the pure tone and the band-limited pink noise, the sensation level of the pure tone, and the frequency of the pure tone revealed two significant main effects: the signal-to-noise ratio between the pure tone and the band-limited pink noise, and the sensation level of the pure tone ($p < 0.001$). In Figure 2, the mean of the subjective evaluation of the band-limited noise when the signal-to-noise ratio was greater than or equal to 3 dB was smaller than approximately 2.5 (on the category scale) for all frequencies of pure tone. These data indicate that the band-limited pink noise may have attracted attention to itself when the signal-to-noise ratio was greater than or equal to 3 dB.

The percentages of 'Yes' responses to whether or not participants thought that they would be able to listen to the band-limited pink noise for a long time were calculated for each condition. Figure 3 shows the results for each frequency of pure tone. These results demonstrated that the percentages of 'Yes' responses when the signal-to-noise ratio was greater than or equal to 3 dB were larger than approximately 90% for all frequencies of pure tone.

Ultimately, the most useful signal-to-noise ratio between a tinnitus-simulating sound and band-limited noise is approximately 3 dB.

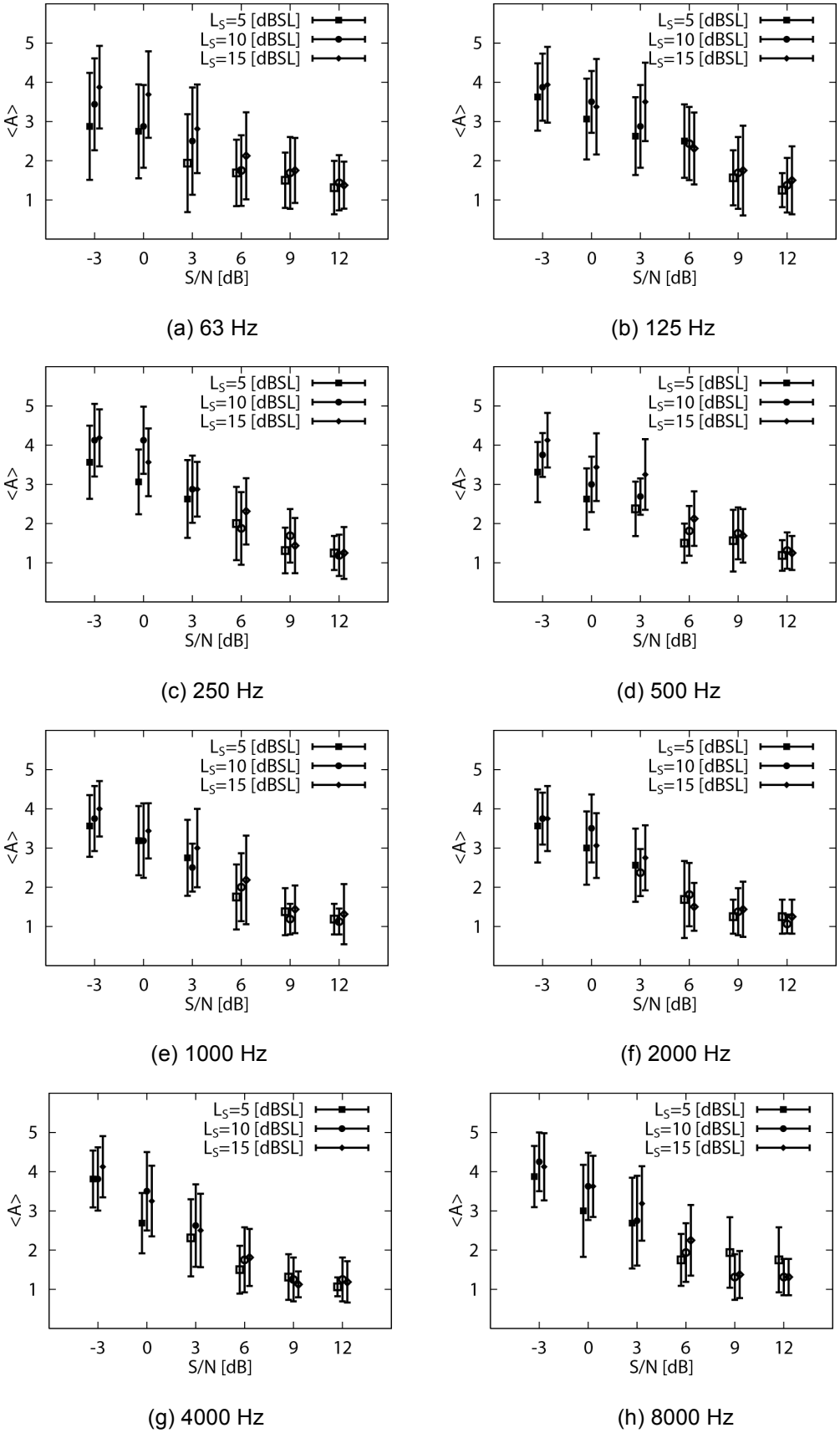

Figure 1: Means and standard deviations of the subjective evaluation of how distracted participants were from the tinnitus-simulating sound

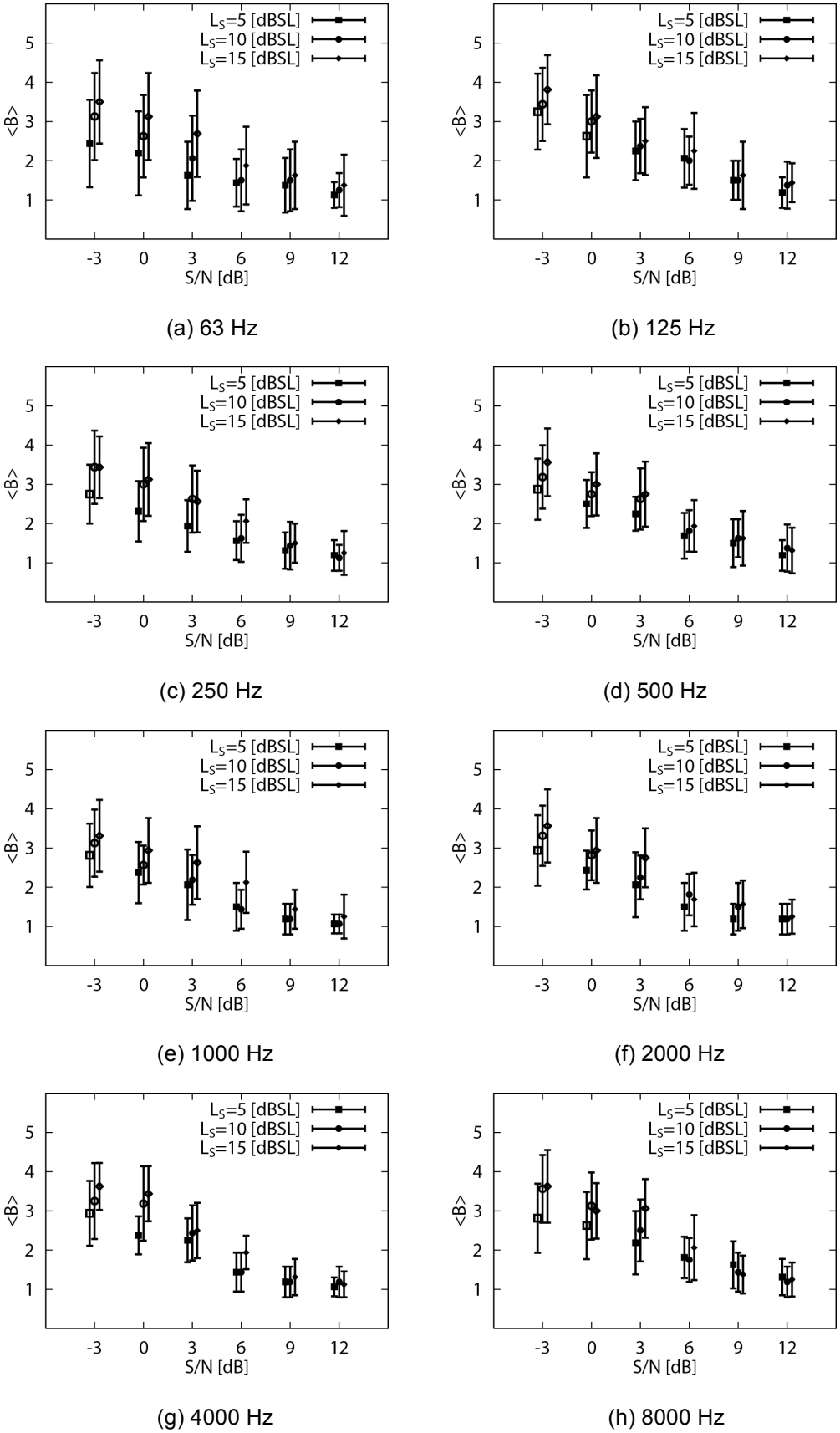

Figure 2: Means and standard deviations of the subjective evaluation of how much participants' attention was attracted to the band-limited noise

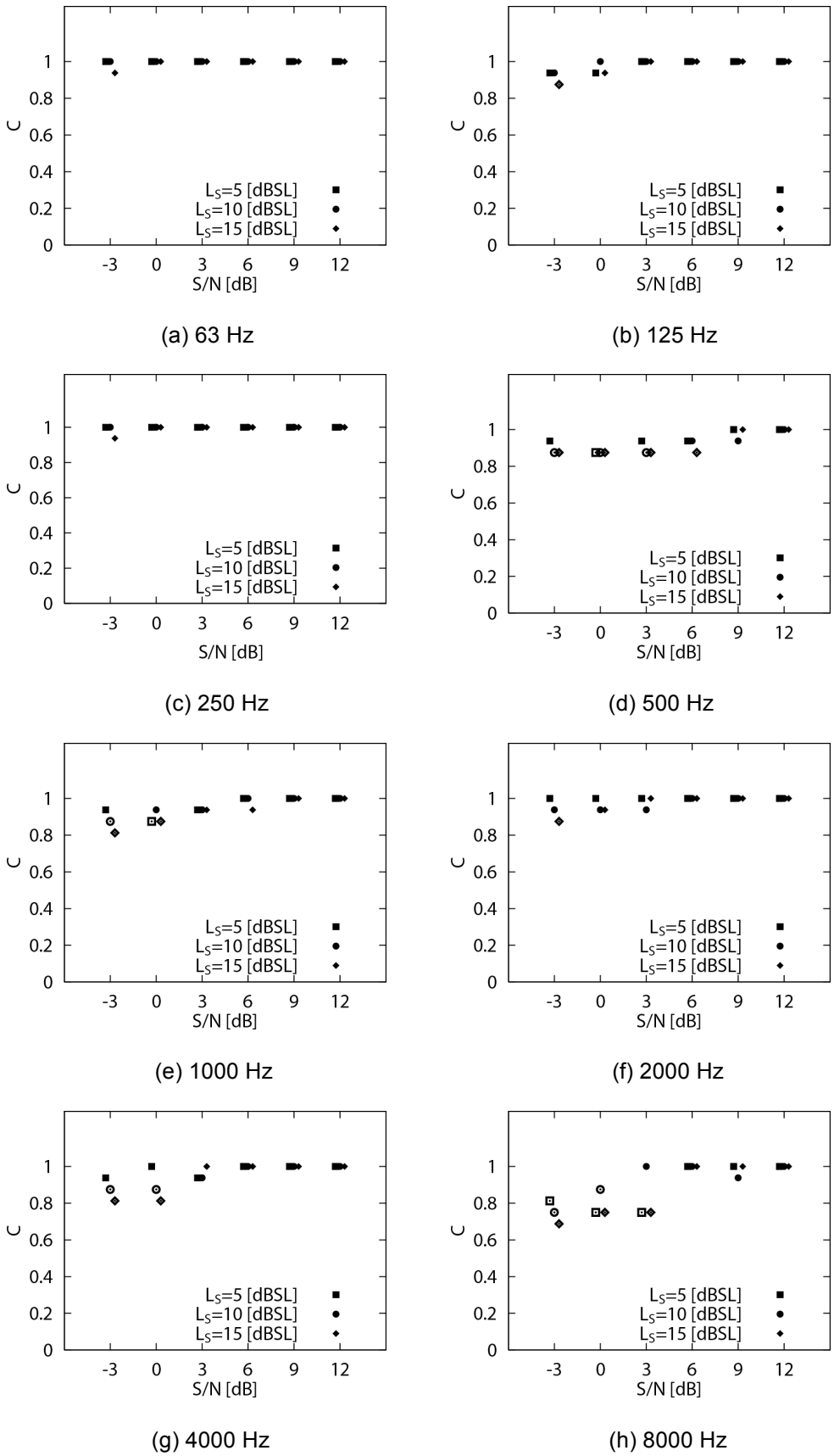

Figure 3: The percentages of 'Yes' answers to whether or not participants thought that they would be able to listen to the band-limited noise for a long time

CONCLUSION

This study investigated an effective sound pressure level of band-limited noise for a tinnitus-simulating sound. Psychological listening experiments were conducted in which both pure tones and band-limited pink noise passing through eight bands of critical band filters were transmitted to participants with normal hearing. The results of an inquiry into the subjective evaluation of how distracted participants were from the tinnitus-simulating sound, how attracted their attention was to the band-limited noise, and whether or not they thought that they would be able to listen to the band-limited noise for a long time gave a useful signal-to-noise ratio between the tinnitus-simulating sound and band-limited noise as approximately 3 dB.

Future studies should examine the following aspects of this research.

(1) Because the current study was limited to participants with normal hearing using simulated tinnitus, the applicability of the same method to situations where the participants actually have tinnitus should be confirmed. However, our study provides fundamental data to aid in determining whether the results of such psychological listening experiments conducted using participants normal hearing who experience simulated tinnitus are as valid as those conducted on participants who actually have tinnitus.

(2) Although there are many types of tinnitus, only pure tones were used to simulate tinnitus in this study. However, it is still necessary to consider other sounds that simulate tinnitus.

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