The Effects of Listening to Notched Music on Reducing Tinnitus Symptoms

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1 Introduction

Tinnitus is a complex disorder that has various causes and can occur with different severity depending on its source. In general, tinnitus is defined as the perceptions of sound that has no external source. Objective tinnitus is caused by sounds generated in body reaching to the ear through conduction in body tissues. This form of tinnitus is called objective tinnitus, and is less common among tinnitus sufferers. In contrast, subjective tinnitus is more common among sufferers. Subjective tinnitus is caused by abnormalities in receptors and neural pathways and in the auditory system. Both objective and subjective tinnitus are known to be symptoms of physiological problems in the auditory system. However, these symptoms may lead to further psychological problems that may exaggerate a pre-existing symptom such as tinnitus.

Researchers have tried different approaches in addressing this issue. Roberts et al. claim that traditional noise-masking devices that produce a broadband noise in tinnitus frequency are successful in eliminating tinnitus symptoms [2]. On the other hand, some researchers claim that such devices exacerbate this problem by making tinnitus sufferers more aware of the intrusive sound in their heads. Okamotoa et al. claim that using notched tailor-made music, they have been able to reduce tinnitus symptoms in sufferers [1]. Comparing the results of these different methods, I found that using notched music is known to have more long-term effects in reducing tinnitus symptoms. Hence, I decided to test this method on a group of 6 tinnitus sufferers, and measure the effects of listening to notched music on tinnitus symptom relief. Using the results of this test, I determined that listening to notched music can help to reduce tinnitus intensity. Analyzing these results, I decided to develop an application for Windows and Mac OS which applies a real-time band-stop octave-space filter centered at the tinnitus frequency. This application, when used by tinnitus sufferers for listening to music on a daily basis, would reduce the tinnitus intensity.

2 Related Work

In this section I introduce two methods that researchers have been used in reducing the intensity of tinnitus symptoms.

2.1 Masking and Residual Inhibition

The study by Roberts et al. focuses on the overlap of tinnitus frequency range and hearing loss region among tinnitus sufferers [2]. Their research is based on the hypothesis that dysfunctional neurons express the tuning behavior of their neighbors, and hence increase the neural activity in their corresponding frequency range. Accordingly, tinnitus is caused by spontaneous synchronous activity of neurons in the regions of hearing impairment, and hence its center frequency is closely associated with the region of hearing loss. Based on this hypothesis, Roberts et al. claims that presentation of sounds above the hearing threshold in the hearing impairment frequency region reinforces intracortical inhibition, and hence segregates synchronous neural activity which leads to dampening the tinnitus tone.

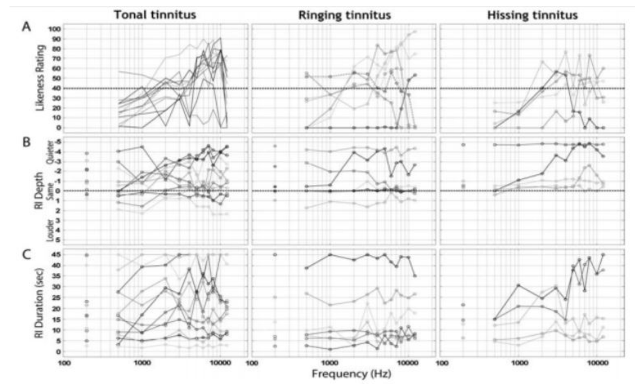

Figure 1: Tinnitus spectra (A), RI functions depth (B), and RI duration (C) are overlaid for each subject in the three tinnitus groups. The broken horizontal line in panel A denotes a likeness rating of 40, where subjects reported that the tinnitus sensation began to resemble their tinnitus. The broken horizontal line in panel B denotes no change in the tinnitus sensation (-5, tinnitus gone). The data points to the left in panels B and C are for the white noise masker.

In order to test this hypothesis, Roberts et al. tested 24 tinnitus sufferers with more than 25 dB hearing loss reporting bilateral tinnitus. They asked participants to listen to 12 different stimuli with center frequencies at 0.5, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 10.0, and 12.0 kHz, with intensity above the hearing threshold, for 30 seconds. Following with 30 seconds of silence, they asked the participants to rate their tinnitus intensity in a scale of -5 (lower intensity) to +5 (higher intensity), with 0 being the initial tinnitus intensity.Figure 1 shows the depth (reported intensity rate) and duration of this effect, called Residual Inhibition, measured by Roberts et al. in their study.

2.2 Tailor-made Notched Music

Based on a similar hypothesis regarding the effects of dysfunctional neurons on unusual cortical activity that causes tinnitus, another study by Okamoto et al. claims that notched music can reduce cortical activity at the notch center frequency through lateral inhibition [1]. In their study, they test a group of 25 tinnitus sufferers. During the test, the target group was asked to listen to filtered music for average of 12.4 ± 3.5 hours per week. The filter used in order to process music for each individual participant was a stop-band octave-space filter, centered at that the center frequency of the individuals tinnitus sound. After 12 months of notched music treatment, tinnitus loudness was significantly reduced for the target group with $p - value = 0.001$. Figure 2 shows tinnitus loudness change for participants in different groups after 6 months and 12 months of this experiment.

Comparing the results of the two studies discussed above, I believe that the second study which deploys notched music treatment has resulted in more steady and long-term improvements in reducing tinnitus intensity. Hence, I decided to take the approached ex-

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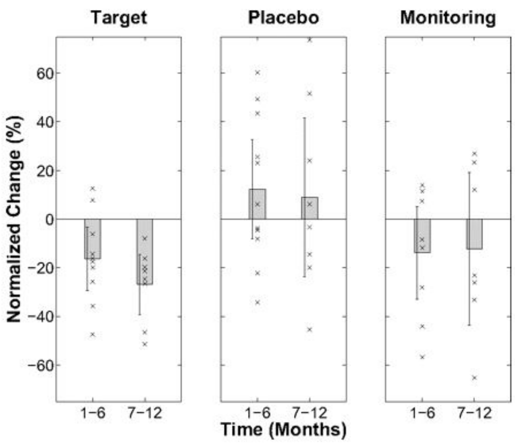

Figure 2: Normalized tinnitus loudness change after 6 and 12 months of treatment (or monitoring) relative to baseline (0) for the three patient groups (target, placebo, and monitoring). Positive change values reflect impairment, negative change values reflect improvement. The bars indicate group averages, each x indicates an individual data point. The error bars denote confidence intervals. The data were normalized as following: [(tinnitus loudness average months 1-6, or 7-12 / tinnitus loudness baseline) - 1]×100. As indicated by the confidence interval bars, only the changes in the target group were statistically significant.

plained in this study, and test notched music treatment on 6 tinnitus sufferers. Furthermore, I developed a music player application which allows tinnitus sufferers to apply such band-stop filters on the music they choose to listen to.

3 Methods

In order to observe the effects of listening to notched music on reducing tinnitus symptom, I decided to test this method on tinnitus sufferers and measure any changes in the intensity of their symptom after treatment. Because tinnitus symptoms are only perceived by individual tinnitus sufferers, it is impossible for others to objectively measure the intensity of these symptoms. The most commonly used method for measuring the intensity of tinnitus symptom is tinnitus matching. During the tinnitus matching process, I asked tinnitus sufferers to listen to a tonal stimulus and match the center frequency, bandwidth, and balance of the stimulus with the tinnitus sound they perceive. The same process was used after the therapy sessions to measure any changes in the characteristics of their perceived tinnitus sound.

Six adults, two females and four males, having ages between 28 and 64 years, who have reported steady tinnitus in both ears for at least one year were chosen for this research. The participants had no more than 35 dB hearing loss in both ears.

In this project, I asked participants to complete an initial tinnitus matching session. The participants were asked to use a smartphone application (Whist: Tinnitus Relief) to match the intensity, frequency, balance, and minimum masking level of a tinnitus stimulus sound to their tinnitus sound. Using a smart-phone, participants listened to a tonal stimuli through headphones and manipulated the frequency, intensity, and balance of the stimuli using sliders on the screen, to match the stimuli with their tinnitus sound. After going through this first session of tinnitus matching, the participants were given a playlist consisting of 8 music tracks, processed based on the individual's specific tinnitus sound, and they were asked to listen to the playlist for 30 minutes per day for 7 consecutive days. Participants were asked to rate their tinnitus intensity every day, in a scale of -5 (lower intensity) to +5 (higher intensity), with 0 being the initial tinnitus intensity. Finally, during a final tinnitus matching session, participants were asked to match a tinnitus stimulus sound with their tinnitus sound.

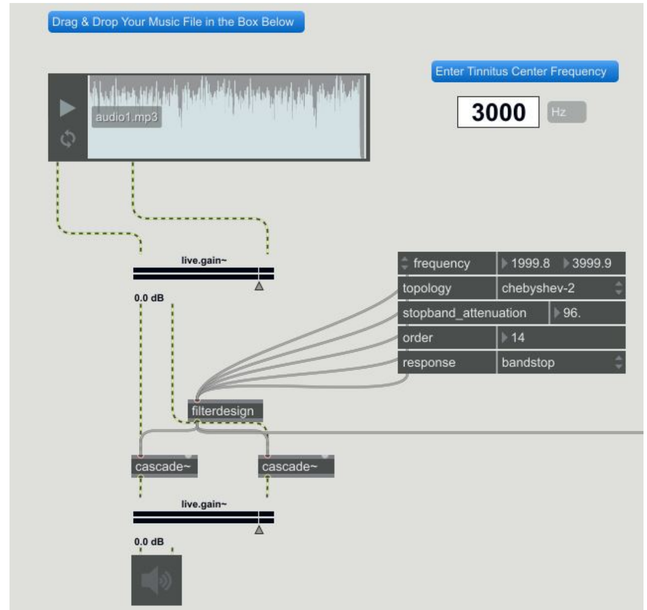

Figure 3: MAX/MSP system overview.

4 System Design

This application is a real-time audio processing system, which receives the audio signals from internal audio channels of the system, and processes those signals based on the tinnitus center frequency which is inputted to the system. After applying a real-time stop-band octave-space filter centered at the indicated frequency, the system outputs the sound through the system audio channels to the speakers. This application is designed by MAx/MSP for Windows and Mac OS.

As shown in figure 3, the path to the input audio file should be provided to the system (or using drag and drop). The tinnitus center frequency has to be entered by the user to the system. Next, the system measures the stop-band frequencies of an octave band around the center frequency. For a frequency centered at f_0, we have:

$$f_{c1} + f_{c2}/2 = f_0$$
$$2 \times f_{c1} = f_{c2}$$

Hence,

$$f_{c1} = f_0 \times 2/3$$
$$f_{c2} = f_0 \times 2/3 \times 2$$

As shown in figure 3, this application implements a Chebyshev type 2 filter of order 14 with cut off frequencies calculated using the equations above, and stop-band attenuation of 95 dB. The filter attenuates frequency content 1 octave space around the tinnitus center frequency to -95 dB, and hence frequencies in that range will not be audible anymore.

The magnitude response of a filter with characteristics described above and tinnitus center frequency of 3000 Hz is shown in figure 4.

5 Results

In order to achieve accurate results, ideally I aimed to divide participants into target and placebo groups, with 8 participants in each group. However, because a total of 6 participants signed up for the

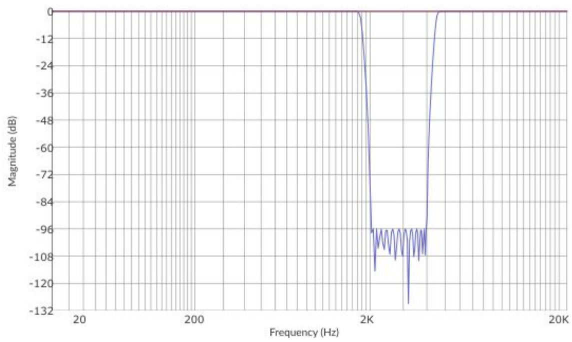

Figure 4: Filter magnitude response for tinnitus center frequency of 3kHz.

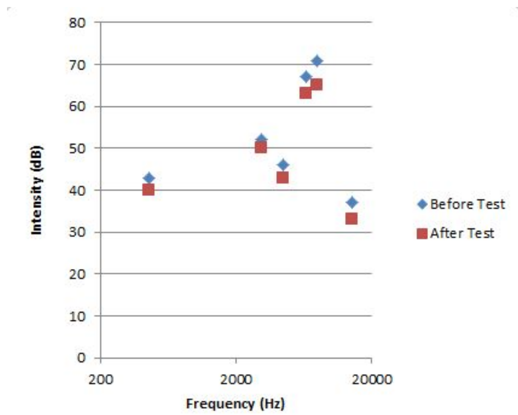

Figure 5: Frequency and intensity of tinnitus recorded during tinnitus matching sessions before and after the test.

study, I decided to perform the actual test on all participants and record changes in their tinnitus intensity, assuming that not going through the test procedure would result in stable tinnitus intensity on average. So, the null hypothesis was that on average, tinnitus intensity would not change during 7 days for our 6 participants if they did not listen to notched music for at least 30 minutes per day. Figure 5 below indicates the tinnitus intensity for all participants before and after the test. All 6 participants claimed that their tinnitus intensity has decreased by at least 2 dB. Using the T-test, the results rejected the null hypothesis with p-value ¡ 0.05, which means that listening to notched music 30 minutes per day for a week can reduce tinnitus intensity with a probability greater than 0.95.

These findings match the results of the study by Okamotoa et al. [1] . However, Okamotoa's study tests a population of 24 participants for 6 12 months, and hence their conclusion is more statistically significant than what we found in this study. According to these findings, I decided to implement a program that make this treatment process easier for tinnitus sufferers. This application would apply customized stop-band filter on audio signals while playing them. The center frequency of the stop-band filter could be modified based on the participants tinnitus frequency.

6 Discussion

We observed at least 2 dB of tinnitus intensity reduction for all participants. Considering the fact that there has been no evidence of a tinnitus symptom reduction trend over time observed by epidemiologists so far, our findings support the results obtained by Okamotoa et al. in their study of notched music treatment for tinnitus sufferers with $p - value < 0.05$ [1]. Our results indicate that lower tinnitus intensity in the target group is caused by a specific treatment effect of stop-band filter centered at tinnitus frequency.

Based on Okamotoa et al., tinnitus is caused when damaged auditory cortex neurons become sensitive to excitatory inputs from neighboring neurons, and after a while, they become tuned to neighboring frequencies [1]. Thus, if tinnitus sufferers avoid listening to neighboring frequencies for a while, the sensitivity of damaged neurons would decrease in these frequency ranges. Accordingly, if tinnitus sufferers use the program developed in this project when listening to music in a daily basis, they would be expected to perceive a less intense tinnitus sound after a while with $p - value < 0.05$.

7 Conclusion

Although there has been no known cure to tinnitus found, I believe that listening to notched music can help to lower the perceived burden of tinnitus. My results match the findings in the study by Okamotoa et al., indicating that listening to notched music will help reduce tinnitus intensity in tinnitus sufferers [1]. The stop-band filter that I used for the this test was an octave-space, Chebyshev type 2, stop-band filter of order 14, centered at the participant's tinnitus frequency.

After analyzing the results of these studies, I found out that most music player programs do not provide such filtering options for their users. In those rare cases that music players provide this option, using this option and interacting with the filter design characteristics is not very easy for people who do not have some knowledge about audio processing and filters. Thus, I implemented a music player program that enables users to apply an octave-space, Chebyshev type 2, stop-band filter of order 14 on the playing music, centered at any given frequency. Using this program, tinnitus sufferers can filter frequencies in one octave around tinnitus frequency, so that those frequencies would not be audible by their auditory neurons. Reducing neural activity in that frequency range results in lower excitation of damaged neurons which cause tinnitus, and hence reduces the tinnitus intensity.

References

[1] H. Okamotoa, H. Strackea, W. Stollb, and C. Pantev. Listening to tailor-made notched music reduces tinnitus loudness and tinnitus-related auditory cortex activity. *Proceedings of the National Academy of Sciences*, 2009. 1, 2.2, 5, 6, 7

[2] G. Roberts, L. E.and Moffat and B. D. J. Residual inhibition functions in relation to tinnitus spectra and auditory threshold shift. *Acta Oto-Laryngologica (Supplement)*, 2006. 1, 2.1