Research Article

Investigating the Effect of Binaural Beat Stimulation on the Annoyance of Tinnitus in Military Personnel

Mohammadsaleh Moosapour Bardsiri[1], Parsa Cheraghipour[1*], Majid Irani[1], Seyed Meead Mousavi[1], Seyed Shahab Ghazi Mirsaeed[2]

[1.] *Ear, Nose and Throat Clinic, Imam Reza Hospital, Aja University of Medical Sciences, Tehran, Iran*
[2.] *Trauma Research Center, Imam Reza Hospital, Aja University of Medical Sciences, Tehran, Iran*

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Highlights

- ABS has more effects on subscales involving tinnitus psychological consequences
- Studies showed a marked reduction in alpha power in tinnitus sufferers

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*** Corresponding Author:**
Ear, Nose and Throat Clinic, Imam Reza Hospital, Aja University of Medical Sciences, Tehran, Iran.
mostafa.cheraghipour@yahoo.com

ABSTRACT

Background and Aim: Prevalence of noise-induced tinnitus is approximately twice as high among military personnel and veterans as in the general population. So they appear to have poorer quality of life. Many forms of sound therapy have been applied to reduce the effects of subjective tinnitus. This study aimed to investigate the effect of binaural beat stimulation on the annoyance of tinnitus in military personnel with the experience of acoustic trauma-induced tinnitus.

Methods: This study was conducted on 60 men with mean(SD) age 38.30(6.12) years individuals suffering from chronic tinnitus. They were randomly assigned to either the experimental group who were exposed to an audio file with an embedded binaural beat in the alpha frequency range or the control group who were supposed to merely listen to their favorite music without any included beat stimulation. Tinnitus Handicap Inventory (THI) and Tinnitus Handicap Questionnaire (THQ) were used as outcome measures to collect the data after a period of one month.

Results: There were statistically significant differences (score decrease) between the two study groups after intervention in terms of THI ($p<0.05$) and THQ total score ($p<0.05$) and the subscales involving emotional effects of tinnitus.

Conclusion: Binaural beat stimulation in the alpha frequency range has the potential of inducing some positive effects on subjective feelings of chronic tinnitus sufferers.

Keywords: Tinnitus; binaural beat stimulation; tinnitus handicap inventory; tinnitus handicap questionnaire

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Introduction

Tinnitus is known as a frequently reported auditory problem by military personnel [1]. It is accompanied by altered auditory functions including speech perception, and auditory attention as well as disturbances such as depression, anxiety and reduced quality of life [2]. Prevalence of tinnitus has been calculated to be twice in military veterans as in the nonveteran population [3]. It is reported that in one to two percent of individuals suffering from tinnitus, the handicap imposed by tinnitus-related provoking distress reduces their quality of life [4]. Although tinnitus risk factors and consequences have been extensively studied, [5] as a result of tinnitus heterogeneity, a large variation in treatment responses leads to the lack of presenting a definite intervention program that covers most tinnitus complainers and their variations. In other words, there is still currently no gold standard treatment for tinnitus [5, 6] as we witness a percentage of sufferers who seek various clinical interventions. Among various proposed mechanisms underlying tinnitus, the outer hair cell loss and maladaptive plasticity in the central auditory pathways are known to be linked to the generation of tinnitus [2]. Furthermore, according to Jastreboff, the limbic system is among the proposed networks involved in the emotional feelings of tinnitus and even a small degree of changes in such emotional component may have significant effects on the annoyance of tinnitus perception even without any changes in psychoacoustical characteristics of tinnitus [7]. Comparing spontaneous neuronal activity between individuals with and without tinnitus showed a marked reduction in alpha (8-12 Hz) power with an enhancement in delta (1.5-4 Hz) specifically for temporal regions. Such abnormal neuronal activity is correlated with tinnitus-related distress scores assessed with a tinnitus questionnaire specifically for the temporal and frontal regions [8]. Alpha band frequency which is the most prominent rhythm of the human brain is associated with calm and peaceful states and pleasant feelings in a person [9, 10]. Furthermore, a functional inhibition role has also been proposed for alpha oscillation [11]. Reduction in such inhibitory capacity of alpha-band due to the diminished input following hearing loss [12] may lead to increased spontaneous neural firing rate in neighboring healthy neurons. Delta wave, a low-frequency band, is related to slow-wave sleep and its enhancement has also been reported in sleep deprivation [13], brain injuries and tumors [14].

Neural activity is capable of changes by Binaural Beat (BB) frequencies, that's why binaural beats are often used to induce certain psychological states [15]. the effects of such stimulation have been demonstrated on functional brain connectivity, intracranial power, and phase synchronization [16]. Auditory Beat Stimulation (ABS) is also known to have an impact on cognitive processing and mood states and the potential ability to reduce the level of stress and anxiety. When two sine waves which are below 1000 Hz with less than 40 Hz frequency differences are presented dichotically, binaural beats are perceived subjectively inside the head. Even though the neural mechanism of BB perception is not clear [16] it is suggested that the perception of this auditory illusion is arising from binaurally sensitive neurons including neurons in the brainstem inferior colliculi and superior olivary complex where the two concurrently presented stimuli are integrated and then travel in forms of neural impulses through the reticular formation to the thalamus, auditory and non-auditory cortical regions [17-20]. When the perceived auditory beat is in certain brain wave ranges such as alpha, the brain wave changes toward the beat frequency. Resulting neuronal changes in the brain have been associated with some health benefits including stress reduction and anxiety [17, 21, 22]. However, despite utilizing this regulation potential of spontaneous brain waves activities through techniques such as neurofeedback, lacking a general guideline has led to its variable reported efficacy among patients with tinnitus [6, 23]. ABS can be used with music or other sounds in which certain frequency differences are embedded. David et al. have put forward the application of a home-based program which is based on binaural stimulation in people who suffer from tinnitus. Their study results confirmed the probable effectiveness of designing customized programs to manage tinnitus [21]. Other studies have also confirmed the promising effect of such auditory stimulation in the alpha wave frequency range [17, 24]. It is worth noting that apart from the reported utility of such stimulation in the enhancement of brain wave oscillatory activity, Lopez-Caballero and Escera are among the researchers whose findings did not support the potential usefulness of BB to induce specific neural activity and emotional changes [20]. In addition to inconsistency in reported positive effects of BB stimulation, it is noteworthy that research on tinnitus treatment with binaural sounds appears to be scarce [25]. Therefore, due to the high prevalence of tinnitus in veterans who struggle with chronic tinnitus and given the challenging characteristics of tinnitus and resultant variations in treatment outcomes, this study aimed to investigate the effectiveness of ABS application in military personnel who are a large group of chronic tinnitus sufferers. Self-reported handicap questionnaires are considered a standard means of

evaluation of the severity of tinnitus-related distress and are used to assess the adverse effect of tinnitus on quality of life [26-28]; therefore, we used the two Tinnitus Handicap Inventory (THI) and Tinnitus Handicap Questionnaire (THQ) questionnaires as outcome measures to objectify the effects of intervention in the evaluation of tinnitus severity and its effects on quality of life.

Methods

Participants

This study was conducted from September 2021 to February 2022 in the department of Ear, Nose and Throat Imam Reza hospital in Iran. 60 men with mean(SD) age 38.30(6.12) years old with chronic tinnitus)from about six months to five years(and with mild to moderate symmetrical high-frequency hearing loss were selected using convenience sampling method. They all reported having unilateral tinnitus [including cases with tinnitus only in the right or merely in the left ear] with the experience of acoustic trauma due to their presence in military services. The tinnitus perception described by the participants included a constant feeling of ringing, whistling, buzzing, hissing and other combinations of these sounds. Although most of them had a history of using dietary supplements as one of the remedy options during the past few years, none of them received specific remediation for at least six months before the initiation of our intervention program. Other inclusion criteria considered for all participants included normal otoscopy (Riester, Germany(and tympanometry)R26M Resonance, Italy(results and no record of severe neurologic or psychiatric disorders. In most participants reported pitch matching was close to audiometry hearing loss)3500 to 6800 Hz(, in loudness matching the loudness were in the range of 1 to 4 dB SL. Prior to the experiment they all gave written informed consent and were informed of the possibility to quit the study whenever they felt uncomfortable.

Procedure

Individuals who met the inclusion criteria were recruited as study participants. They were all asked to fill out the two THQ and THI questionnaires before the start of the intervention program. THI questionnaire is a 25-item questionnaire that is developed in order to objectify the functional and psychosocial consequences of tinnitus and its effect on life quality. And tinnitus impact is categorized into three subscales of functional, emotional, and catastrophic [27]. THQ, another self-reported questionnaire comprising 27 items that are divided into three subscales:1) behavior, social, and emotional effects, 2) hearing abilities of the patient, and 3) the patient's perspective on tinnitus [26]. The two questionnaires have also a high reported correlation coefficient [26]. In the next phase of the study, participants were randomly allocated to either the control or the experimental group groups. The intervention program for the experimental group consisted of presenting the alpha BB stimulation embedded in a favorite classical music [29]. So that the inconvenience of raw BB presentation would reduce, and the individuals were encouraged to continue the intervention program. Two sinusoidal tones, one at 396 Hz and the other at 406 Hz were created using MATLAB software to produce a 10 Hz binaural beat. ABS was provided to the participants in the experimental group in form of an audio file which was supposed to be listened to daily for 30 minutes, for 4 weeks [30]. Meanwhile, the control group was supposed to listen to the same music without any embedded binaural beat stimulation. Moreover, to ensure that individuals did not have any problems using audio files at home, they all were supported with follow-up calls. Both study groups were asked to listen to the audio files at a comfortable level and with earphones. Furthermore, they were asked not to listen to the files when they feel drowsiness or during sleeping time. At the end of one month, right after the completion of the last session of the intervention program, each participant was reevaluated with the same questionnaires that were completed before the administration of the intervention program. Moreover, the pitch matching and loudness matching tests were re-tested after the intervention period.

Statistical analysis

Statistical analyses were performed using SPSS Software (v. 17) at a significance level of 0.05. To examine the mean difference between the study groups before and after the training program and to measure the effectiveness of the intervention, Wilcoxon test and Mann-Whitney test were performed respectively.

Results

In the present study, the mean(SD) age of participants was 38.30(6.12) years (ranged 27–51 years) who had chronic tinnitus (more than six months). Tables 1 and 2 demonstrate the two questionnaires pre and post-training. Based on the Mann-Whitney test there was a statistically significant difference between total scores of both THI and THQ after intervention ($p<0.001$). THI total score decreased from 61.75 to 49.25 and from 36.83 to 34.62 for THQ total score for the group exposed to

Table 1. Comparison of the tinnitus handicap questionnaire scores between experimental and control groups

Subscale	Mean(SD)		p	Mean(SD)		p
	Pre-intervention	Post-intervention		Pre-intervention	Post-intervention	
Subscale 1	32.64(1.85)	26.03(1.53)	0.001	33.07(2.17)	33.33(1.46)	0.560
Behavioral effect	31.86(4.30)	22.40(2.44)	0.001	32.30(3.66)	32.76(2.64)	0.620
Social effect	33.70(3.48)	32.91(3.43)	0.160	34.04(4.26)	33.70(3.72)	0.910
Emotional effect	32.36(2.42)	22.77(2.37)	0.001	32.88(3.06)	33.52(2.72)	0.500
Hearing abilities of the patient	33.47(2.08)	33.25(2.01)	0.720	33.77(2.49)	32.91(2.14)	0.110
The patient's perspective on tinnitus	44.37(3.75)	44.58(3.84)	0.850	43.87(4.32)	45.20(4.06)	0.150
Total score	36.83(1.49)	34.62(1.47)	0.001	36.90(1.84)	37.15(1.78)	0.570

the music with an embedded BB. While for the control group the total score of THI changed from 61.50 to 62.25 and for THQ total score changed from 36.90 to 37.15. The results showed a significant decrease in behavioral, social, and emotional effects of tinnitus score of THQ after the ABS (p=0.001) which is an indication of less discomfort caused by tinnitus. Concerning each subscale, no significant changes were observed for the scores of social effects of behavioral, social, and emotional effects of tinnitus, hearing abilities of the patient and the patient's perspective on tinnitus of THQ in comparison with the pre-intervention scores (p>0.05). The emotional subscale of THI indicated a similar marked score reduction with the emotional effect of THQ, however, neither the experimental nor the control group showed a statistically significant difference between pre and post-intervention scores for functional and catastrophic scores (p>0.05). For ease of comparison, we converted the THI scores into percentages so that the two questionnaires can be compared with the same scoring unit. Evaluation of pitch matching and loudness matching also showed no significant score differences after completion of the intervention (p>0.05).

Discussion

In this study, the effect of 10 Hz binaural beat stimulation on the annoyance of tinnitus was investigated in the individuals with chronic tinnitus and the results of THI and THQ questionnaires were compared between the experimental and the control group who were suffering from tinnitus caused by acoustic trauma. Two stimuli including a tone with the frequency of 396 Hz and 406 Hz were presented dichotically to the right and left ear respectively. Based on the between-group comparisons, the experimental group who received ABS showed significantly decreased total THI and THQ scores which indicates the perceived annoyance and disturbance of tinnitus reduced following the completion of one-month beat stimulation. In addition to the total score, assessment of individual subscales for each questionnaire yielded statistically significant differences only for behavioral, social, and emotional effects of tinnitus in THQ and the emotional subscale for the THI questionnaire that represents beat stimulation positive effects in alleviating psychological states of the patients. This is consistent with the finding of David et.al, who suggested that the application of BB stimulation has the potential

Table 2. Comparison of the tinnitus handicap inventory scores between experimental and control groups

Subscale	Mean(SD)		p	Mean(SD)		p
	Pre-intervention	Post-intervention		Pre-intervention	Post-intervention	
Emotional	60.00(12.5)	26.25(9.75)	0.001	57.75(9.00)	61.00(9.75)	0.220
Functional	58.00(8.00)	58.00(8.25)	0.980	62.00(9.75)	61.50(10.00)	0.890
Catastrophic	67.25(10.75)	63.00(11.25)	0.180	64.50(11.25)	64.25(12.00)	0.940
Total score	61.75(5.25)	49.25(5.50)	0.001	61.50(7.75)	62.25(6.50)	0.510

effect of lowering the level of tinnitus severity over a short time period [21]. Since no score changes were observed for the social effect subscale of THQ and both functional and catastrophic subscales of THI, it seems that the effect of the intervention on the reduction of tinnitus disturbance is more prominent for the subscales that involve emotional and psychological consequences of tinnitus. Neither the hearing abilities of the patient nor the patient's perspective on tinnitus subscales of THQ showed any significant score changes after the intervention for any of the experimental and the control group participants.

A higher level of anxiety, more negative mood states and higher occurrence of depressive tendencies has been reported in tinnitus sufferers compared to a normal control group [31]. Furthermore, the perceived severity of chronic tinnitus has shown to be correlated with the severity of such psychological symptoms [28] therefore, it can be concluded that exploiting management options with the potential capacity of improving mood states and diminishing anxiety may have a beneficial effect on the annoyance experienced by tinnitus complainers. In fact, the essential qualities evaluated by the behavioral and emotional subscales of THQ and the emotional subscale of THI are a general feeling of tension, depression, nervousness and worries which were targeted by the ABS in the alpha frequency range.

Brainwaves entrainment with auditory stimuli such as binaural beats is known as a safe and effective training approach which can assist with inducing certain mood states such as better relaxation [9]. It is proposed that a BB may encourage a meditation-like state and reduce chronic anxiety [32]. A decrease in the aforementioned scores indicates that participants were in a relaxed mood after the completion of the intervention. Although there is no consensus on the mechanism underlying binaural beats, neuronal excitability entrainment which in turn causes neural oscillation to be synchronized with the external auditory stimuli and also improvement in interhemispheric connectivity have been proposed [33, 34]. The auditory system exhibits alpha-like resting oscillatory activity. It is hypothesized that auditory alpha activity reflects excitation and inhibition balance in the sensory system and the disturbance in this balance is associated with tinnitus perception at behavioral level [35]. Based on the relation between tinnitus-related distress and inhibitory activities in auditory areas it is probable that alteration of inhibitory activities that are represented in the alpha band and resulting excitatory/inhibitory balance functions contributes to the reduction of the distressing component in tinnitus [12]. Decreased GABAergic inhibition in the central nucleus of the inferior colliculus and thereby elevated spontaneous activity following noise exposure is one suggestive potential mechanism of imbalance between excitatory and inhibitory imbalance functions [36]. The limbic system is involved in negative emotions such as depression and anxiety in tinnitus [7]. Alteration of neural bands at the limbic system and the resulting reduction in activation of the sympathetic system followed by stress decrement have been found with BB stimulation [25]. Gao et al, reported the increase in the relative power of the alpha band after the application of binaural beats at alpha band frequency for five minutes [37]. Increased alpha-wave activity in frontal lobes is known to be associated with relaxation states and increased cognitive functions [38]. Enhancing alpha brainwave using audio signal has been applied in an attempt to improve the mood of the subjects. Phneah and Nisar's findings on the comparison between the effect of exposure to merely a favorite music or the music with embedded alpha waves showed more prominent and prolonged psychological and physiological effects for the latter one; because the second type of music caused the brain to produce more alpha wave and thereby higher alpha power [29]. Significant anxiety scores reduction was also reported in a group of patients who were asked to listen to a 20 min recording with an embedded binaural beat frequency of 10 Hz than the group who only listened to the audio file of natural sounds [17]. On the other hand, although music therapy is considered a common practice in alleviating tinnitus, it is recommended that care must be taken in utilizing the mere music in tinnitus management as it could even worsen the tinnitus sufferers' conditions such as increased anxiety and stress [25]. Another explanation for the lack of improvement in the control group may be that the only music therapy for 30 minutes a day for 4 weeks was not long enough to obtain any significant improvement. Studies also pointed out that after 6 weeks only a 10% improvement was reported [39, 40].

One of the limitations of our study was the coronavirus pandemic which made access to the study participants more difficult and increased the likelihood of emotional stress. It is also suggested that the long-term effect of such intervention should be considered for future studies.

Conclusion

We studied the potential benefit of applying binaural beat stimulation to tinnitus distress. Concerning the correlation between tinnitus severity and distress symptoms and positive effects of binaural beat stimulation protocol, as well as our study results, it seems that administra-

tion of this kind of intervention can be helpful for those whose quality of life is adversely affected by tinnitus.

Ethical Considerations

Compliance with ethical guidelines

This study was conducted under the supervision of Iranian Military Medical Hospital and Aja University with Ethics Code of IR.AJAUMS.REC.1400.161.

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Authors' contributions

MMB: Study design, acquisition of data, statistical analysis, interpretation of the results, and drafting the manuscript; PC: Study design, drafting the manuscript; revised then manuscript; MI: Study design, drafting the manuscript; SMM: Study design, interpretation of the results; SSGM: interpretation of the results, statistical analysis.

Conflict of interest

There are no competing financial interests.

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