

Critical Review: What are the effects of long-term sound therapy on the perception of tinnitus loudness?

Quelch, R.W.

M.Cl.Sc. (Aud) Candidate

University of Western Ontario: School of Communication Sciences and Disorders

This critical review considers the efficacy of long-term sound therapy in reducing patient's subjective ratings of tinnitus loudness. Study designs include: one single subject repeated measures, two mixed measures nonrandomized clinical trials and one mixed measures randomized clinical trial. Overall, the available research supports the conclusion that sound therapy may be an effective tool in reducing a patient's perception of tinnitus loudness when it is custom-tailored to match the frequency characteristics of the tinnitus percept.

Introduction

It is likely that at some time the audiologist will be called upon to counsel a patient about tinnitus, the involuntary perception of sound(s) when none is present in the environment. It is known that for some patients, tinnitus can have a negative influence on emotional well-being and quality of life (Erlandsson, 2000). Recent estimates suggest that 10% to 15% of adults experience chronic tinnitus (Hoffman et al., 2004) and that for 20% of these individuals, the tinnitus is clinically significant (Davis et al., 2000).

Sound therapy is commonly used to treat tinnitus complaint. The term refers to the use of sound stimuli (e.g. white noise, environmental sounds, music or speech) delivered by stand-alone or ear-level devices to treat tinnitus. Traditionally, sound therapy using white noise was employed to provide relief from tinnitus by rendering the tinnitus percept inaudible (complete tinnitus masking). Initial results of outcome studies cast doubt over the benefits of the use of masking when employed in this manner (Erlandsson et al., 1987; Jakes et al., 1992). Most modern mainstream tinnitus treatments use sound to only partially mask the tinnitus in an effort to reduce the contrast between the tinnitus percept and sounds in the acoustic environment. Often, partial masking of tinnitus is employed in conjunction with some form of psychological counselling directed toward reducing the patient's emotional response to tinnitus. Proponents of this type of therapy argue that leaving the tinnitus percept audible beneath the masking sound can facilitate habituation to its presence (e.g. Jastreboff, 1996).

There is a growing body of research to suggest that tinnitus is a consequence of neuroplastic changes that occur within primary auditory cortex following hearing loss (for a review see Eggermont,

2004). According to this theory, reduced input to the cortical neurons associated with the frequency region of the loss results in their 'rewiring' to acquire a characteristic frequency corresponding to the kneepoint of the audiogram (Rajan et al., 1993; Eggermont et al., 2000). Within this altered region of cortex, increased spontaneous and synchronous neural discharges have been reported (Eggermont et al., 2000; Noreña et al., 2003). It is hypothesized that this abnormal neural activity supports the perception of tinnitus.

Importantly, the results of studies using animal models that have been subjected to a noise treatment known to cause tinnitus suggest that these neuroplastic changes can be prevented if additional acoustic stimulation with a spectrum corresponding to the frequency band of the tinnitus is provided following the treatment (Noreña et al., 2005; Noreña et al., 2006). In light of this evidence, there has been renewed interest in investigating how sound therapy might be used as a tool to reduce the perception of tinnitus.

Objectives

This paper seeks to critically evaluate the recent literature regarding the effects of long-term sound therapy on subjective ratings of tinnitus loudness. Recommendations for future research will follow.

Methods

Search Strategy

Computerized databases including Scopus and PubMed were searched using the following search strategy: (tinnitus) AND (sound therapy) OR (acoustic stimulation) OR (masking) OR (sound generators) AND (treatment outcome). Relevant

papers were also identified from references in the published literature using the process of snowballing.

Selection Criteria

Studies included in this review investigated the effect of long-term sound therapy on subjective ratings of tinnitus loudness. Studies employing a treatment protocol that included a counseling component beyond providing basic information about tinnitus were excluded from this review. The search was limited to articles published between 1995 and 2010.

Data Collection

The literature search identified four studies that met the above selection criteria: one single subject repeated-measures, two mixed measures nonrandomized clinical trials and one mixed measures randomized clinical trial demonstrating levels of evidence of one-plus for two articles (Goldstein et al., 2005; Okamoto et al., 2009) and two-plus for two articles (Folmer et al., 2006; Schaette et al., 2010) based on the level of evidence hierarchy as presented in Cox et al. (2005).

Results

Goldstein, Lenhardt and Shulman (2005) investigated the long-term efficacy of high-frequency bone-conducted (HFBC) music on levels of tinnitus severity, annoyance, loudness and minimum masking levels. Fifteen individuals with severe disabling high-frequency tinnitus (>3 kHz) were randomly assigned to one of three treatment groups each differing in the number of treatment sessions. Participants were exposed to music that was digitally processed to play back in the 10-20 kHz range via bone conduction for 10, 12, or 14 sessions each lasting 1 hour long with the exception of the first session which lasted 30 minutes. A visual analog scale (VAS) was used to assess tinnitus loudness. While 11 of the participants reported a reduction on some of the different tinnitus outcome measures the results of this study failed to demonstrate any effect of high-frequency bone conduction therapy on tinnitus loudness ratings in any of the three treatment groups.

The methodology of this study has several strengths including the use well-researched tinnitus assessment tools. Baseline measures were established at the beginning of the experiment and outcome measures were recorded both before and after each treatment session, and at 8 weeks following the final exposure allowing the researchers to gather information about the potential time course of the treatment. T-tests were employed to assess differences in mean ratings of tinnitus loudness.

It should be noted that no control group was included in this study and blinding was not employed. Further, the authors mention that some of the participants dropped out of the experiment before the treatment was completed. They do not, however, provide an explanation for the dropout rate.

Folmer and Carroll (2006) examined changes in tinnitus severity and perceived tinnitus loudness in participants who purchased hearing aids ($n=50$) or sound generators that played broadband noise encompassing frequencies from 0.1-8 kHz ($n=50$) and a control group who did not receive any sound therapy ($n=50$). All participants underwent a medical and audiological assessment prior to treatment. Tinnitus severity was assessed using the Tinnitus Severity Index and the Beck Depression Inventory and tinnitus loudness was measured using a VAS. Two-tailed t-tests and analyses of variance were used to compare the mean values derived from the patient audiometric, and tinnitus data. The results of follow-up questionnaires completed between six and 48 months after the start of the treatment showed that those participants who wore ear-level devices experienced a significant reduction in tinnitus loudness and tinnitus severity.

Convenience sampling was used to select the participants for this study. Assignment to one of the two treatment groups depended on results of the audiometric testing performed during the initial assessment. Individuals with tinnitus and hearing loss for whom a recommendation of hearing instruments was made (and were subsequently purchased) were assigned to the hearing aid group. Individuals with tinnitus and no hearing loss for whom a recommendation of sound generators was made (and were subsequently purchased) were assigned to the sound generator group. It is, however, unclear what criteria were used when assigning participants to the control group. Overall, these participants did not differ on the measures of tinnitus severity from those who purchased sound generators, although they did have tinnitus for significantly longer. If it were the case that participants in the control group did not receive sound therapy because they were unable to afford sound generators, then it is likely that a confounding variable was introduced into the study.

In Schaette, Konig, Hornig, Gross and Kempter (2010) the authors investigated the hypothesis that sound therapy will have a greater effect on perceived tinnitus loudness and distress if the tinnitus pitch falls within the frequency range of the device used to deliver the sound therapy. All of the participants in this study ($n=15$) reported having chronic pure-tone tinnitus resulting from noise-induced hearing loss. In each case, the tinnitus had persisted for longer than 3 months. Tinnitus distress

was assessed using the Tinnitus Questionnaire and tinnitus loudness using a VAS. Participants with hearing loss were provided with hearing aids and those without hearing loss were provided with ear-level noise generators. Both devices had a frequency range encompassing 0.25 to 6 kHz.

Given the small number of participants recruited for this study, the authors used nonparametric statistics to assess differences between and within groups. Cohen's d was calculated to quantify effect sizes. When analysed as a single group after six months of treatment, ratings of tinnitus loudness did not differ significantly from the baseline measures. When the participants were grouped according to the pitch of their tinnitus, those whose tinnitus pitch fell outside the range of the sound devices reported no reduction in tinnitus loudness following treatment. However, a significant reduction in tinnitus loudness was reported in the group whose tinnitus pitch fell within the frequency range of the sound devices. The effect size reported for this result was large ($d=0.83$).

Prior to treatment, no differences were found between the two groups on the tinnitus loudness or severity measures. However, the authors reported that some of the participants had previously participated in different tinnitus related drug therapies. Which individuals participated and the drugs prescribed were not reported. If the purpose of the medications was to alter functioning within the auditory system then a confounding variable may have been introduced in the study. That is, the use of these medications may have altered the response properties of auditory neurons in ways that noise induced hearing loss would not. Blinding procedures and the addition of a control group would have improved the quality of this study.

Okamoto, Stracke, Stoll and Pantev (2009) investigated the effects of listening to custom-tailored frequency notched music on tinnitus loudness ratings. Three groups were established for the purpose of this study: a treatment group ($n=13$), in which the participants were exposed to music that was filtered to exclude a one-octave range around the individual's tinnitus frequency; a placebo group ($n=13$), that also received filtered music but the filters were moving windows that excluded frequencies outside the tinnitus tone and stimulated frequencies overlapping the tinnitus tone; and a monitoring group ($n=13$), that received no music exposure. Unlike the other experiments reviewed above, the authors used both subjective and objective measures of tinnitus loudness to assess the efficacy of the treatment. Subjective tinnitus loudness was assessed using a VAS. Two different measures of cortical activity, the auditory steady state response (ASSR) and the N1m,

were used to objectively assess changes in neural activity.

Following 6 months of exposure (participants listened to the music an average of 12.4 hours per week), those participants who listened to music that had been modified to contain no energy in the frequency range surrounding the individual tinnitus frequency showed a significant decrease on the subjective measure of tinnitus loudness and both objective measures of neurophysiological responding. Data obtained for the placebo and monitoring groups did not differ from baseline on any of the outcome measures.

The stimuli, tests and procedures employed in this well controlled, double-blinded study are reported in detail. It should, however, be noted that the participants were free to choose their own music for this study. This may be of particular importance because while the reversion of the tinnitus related cortical reorganization was likely initiated by 'bottom-up' neural processing of the music stimuli, 'top-down' processing may have also played a critical role in stimulating plastic events within the auditory system. That is to say, listening to enjoyable music appears to activate the reward system in the brain leading to the release of dopamine (Blood et al., 2001) and dopamine has been shown to play an important role in cortical reorganization (Bao et al., 2001). Thus, it may be that the most effective stimulus to treat the perception of tinnitus loudness is one that the patient finds enjoyable to listen to.

Discussion

Three of the four studies reviewed above reported a significant reduction in tinnitus loudness ratings following long-term sound therapy. Two of these research groups (Schaette et al., 2010 and Okamoto et al., 2008), set out with the purpose of investigating if sound therapy is most effective when the patient's tinnitus pitch falls within the stimulated frequency range. In both experiments, the author's findings confirmed this hypothesis. Although Folmer et al. (2006) and Goldstein (2005) did not explicitly set out to test this hypothesis, their results do go some way to support it. For example, in Folmer et al. (2006) the authors found a significant effect of sound therapy on tinnitus loudness. Interestingly, the average tinnitus pitch for the participants in both the hearing aid and the sound generator groups did fall within the available bandwidth of both ear level devices. In Goldstein et al. (2005), despite recruiting participants with high frequency tinnitus and employing a device capable of reproducing high frequency acoustic energy, loudness ratings remained unchanged from baseline levels following treatment.

However, only two of the participants tested in this study identified the pitch of their tinnitus within the limits of the device's frequency range. As such, the results of this study agree with the above hypothesis in that one would not expect these participants to have experienced a reduction in tinnitus loudness. Thus, when considered collectively, the results of all four studies provide support for the conclusion that sound therapy can reduce tinnitus loudness when the stimulus is custom-tailored to include energy in the frequency region of the tinnitus pitch.

Recommendations

Future research employing different types of stimuli (e.g. filtered white noise, emotionally charged music, or speech) and correlating the presentation level of the stimulus with the length of exposure (e.g. does increasing the level of the stimulus result in faster or greater results?) may improve the efficacy of sound therapy in treating tinnitus loudness and further our understanding of plasticity in the auditory system.

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