Listening to Filtered Music as a Treatment Option for Tinnitus: A Review

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Tinnitus is the perception of a sound in the absence of an external acoustic stimulus and it affects roughly 10-15% of the population. This review will discuss the different types of tinnitus and the current research on the underlying neural substrates of *subjective tinnitus*. Specific focus will be paid to the plasticity of the auditory cortex, the inputs from non-auditory centers in the central nervous system and how these are affected by tinnitus. We also will discuss several therapies that utilize music as a treatment for tinnitus and highlight a novel method that filters out the tinnitus frequency from the music, leveraging the plasticity in the auditory cortex as a means of reducing the impact of tinnitus.

Received January 27, 2010, accepted February 1, 2010.

Key words: tinnitus, music therapy, plasticity, auditory cortex, retraining therapy

Tinnitus is defined as the perception of sound in the absence of any external acoustic stimulus. It affects roughly 10-15% of the population and of these cases, approximately 20% seek medical attention because the tinnitus is negatively affecting their quality of life (Heller, 2003). Multiple types of tinnitus have been reported, although a single cause of tinnitus is unknown. Most tinnitus can be categorized as *subjective*, where the individual experiences a phantom auditory percept and is typically tonal in quality (i.e., a pure tone of a distinct frequency is perceived). *Objective tinnitus* typically has a specific biological cause, such as the pulsing of an artery, and is much less common than subjective tinnitus (Henry, Dennis, & Schechter, 2005). *Somatic tinnitus* involves the somatosensory system and is usually the result of an injury to the muscles of the neck and can often be modulated by head and jaw movements (Levine, Nam, Oron, & Melcher, 2007). Often tinnitus is a byproduct of cochlear injury from an infection, exposure to ototoxic drugs (Sun et al., 2009), or exposure to high sound pressure levels (above 100 dB SPL). Although an individual does not need to have a hearing loss in order to experience tinnitus, when tinnitus is accompanied by a hearing loss, the percept of the tinnitus-tone is often in the range of the lost or degraded hearing.

This review will focus on subjective tinnitus—what is currently believed to be the underlying neural substrates and what treatments have been utilized for patients suffering from it. We also will discuss a novel treatment proposed by Okamoto, Stracke, Stoll, & Pantev (2010) that is based on music therapy, and then offer possible directions for future research in this area.

Neural Substrates Involved in Tinnitus

Given the preservation of frequency maps from the cochlea to the auditory cortex, changes in this organization (i.e., plasticity) are believed to contribute to a percept of tinnitus as a result of an imbalance between excitation and inhibition in a given frequency region (Bartels, Staal, & Albers, 2007; Eggermont, 2005). Neuroimaging studies on human subjects with tinnitus have suggested that plasticity in the brain is associated with a shift in tonotopic maps in the auditory cortex (Adjamian, Sereda, & Hall, 2009; Lanting, de Kleine, & van Dijk, 2009; Muhlnickel, Elbert, Taub, & Flor, 1998;), as well as increased activation in the auditory midbrain compared with controls (Melcher, Levine, Bergevin, & Norris, 2009).

Contributions from non-auditory systems have been implicated in the generation of tinnitus. The limbic system—the part of the brain involved in emotion and the processing of sensory stimuli with an emotional load—appears to be particularly engaged in individuals whose tinnitus negatively affects their quality of life (Adjamian et al., 2009; Cacace, 2003) and has been shown in animal models (Mahlke & Wallhausser-Franke, 2004). Other research has suggested a broad network of involvement from non-auditory areas including the

Music Perception volume 27, issue 4, pp. 327–330, issn 0730-7829, electronic issn 1533-8312 DOI:10.1525/mp.2010.27.4.327

prefrontal and parietal-occipital region (Schlee et al., 2009), while some studies suggest a crossmodal role in the generation of tinnitus, specifically audiovisual and audiotactile interactions (Cacace, 2003; Dehmel, Cui, & Shore, 2008). Behaviorally, a temporary form of tinnitus can be induced through the use of a *Zwicker Tone*, an auditory artifact of a pure tone of frequency equal to the center of the filter, which lasts several seconds after the cessation of filtered-broadband noise (Norena, Micheyl, & Chery-Croze, 2000; Zwicker, 1964). It is believed that this artifact arises because of neural adaptation and a decrease in surround inhibition at the center of the filtered noise.

Previous Tinnitus Treatment

Tinnitus has been treated in a number of different ways. Most striking is the finding that classical auditory masking paradigms are not effective in masking the tinnitus percept compared with a treatment plan (Jastreboff, Hazell, & Graham, 1994). Clinical treatments often include a psychological counseling component that is geared towards training the patient to associate positive or neutral feelings towards the tinnitus—i.e., moving the patient away from negative associations with a final goal of ignoring the tinnitus. The Tinnitus Retraining Therapy (TRT) proposed by Jastreboff and colleagues (Jastreboff, 1990, 2007; Jastreboff, Hazell, & Graham, 1994) is an approach to the treatment of tinnitus through two main stages: 1) psychological counseling, and 2) sound therapy aimed at decreasing the strength of the abnormal neural activity involved in tinnitus. This is often accomplished by fitting patients with a hearing prosthesis and transmitting (typically) broadband noise at levels selected by the patients to cover/mask their tinnitus. After monitoring patients for 3-12 months with behavioral self-reports, the authors showed a significant reduction in tinnitus loudness and/or annoyance. This model has shown to be fairly effective in reducing the impact of tinnitus on patients' everyday life, although the authors state that they were unconcerned with the etiology of tinnitus itself and did not weed out patients on any basis (i.e., they took patients with and without hearing loss).

The music therapy approach discussed by Nickel, Hillecke, Argstatter, and Bolay (2005) and Argstatter, Krick, and Bolay (2008) is a modification of the TRT in which music is applied to the patient's therapy routine. This therapy includes counseling (to decrease negative feelings toward one's own tinnitus), singing (especially in frequencies near or at that of the tinnitus), listening to music (as a means of distraction from the tinnitus and to create and encourage a positive emotional response to sounds), and an awareness of one's own body is encouraged through music (in some cases by playing instruments). Therapy includes twelve 50-minute sessions and progress is measured through a subject self-report of tinnitus loudness. This model has been applied to various diseases such as chronic pain, migraine, and tinnitus and the authors have suggested that it has had a positive outcome in reducing the symptoms of the patient's disease.

New Treatment Approach

In a recent paper by Okamoto et al. (2010), a novel treatment for tonal tinnitus is proposed in which filtered music is utilized as a basis for therapy. The authors hypothesize that tinnitus is a result of over-excitation at the tinnitus frequency in the auditory system and that removal of those frequency components from an auditory stimulus will cause the brain to reorganize around that frequency, thereby decreasing the percept of tinnitus. Unlike other treatments, this study combined both subjective and objective measures of the tinnitus loudness. A behavioral self-report was performed in addition to two neurophysiological measures of activity of the auditory cortex: the Auditory Steady State Response (ASSR) measuring primary auditory cortex responses, and the N1m, measuring responses in secondary auditory cortical areas. The auditory stimulus was music chosen by the individual participants and was filtered to exclude a one-octave range around the individual's tinnitus frequency in cases of tonal tinnitus (as measured at the beginning of the study). As a comparison, two other groups were monitored: one group received music that was also altered, but the filters were moving windows that excluded frequencies outside of the tinnitus range while preserving frequencies near the tinnitus tone. The second group received no music stimulus. After 6 and 12 months of exposure (with an average of 12.4 hours per week of listening), those subjects whose tailor-made music excluded their tinnitus frequency showed a significant decrease in both the behavioral and physiological responses compared to controls. Subjects in the other two groups did not show any systematic difference in their behavioral or neurophysiological results compared to their baseline measurements.

The authors suggest that their stimuli utilized the plasticity of the auditory cortex in order to increase lateral inhibition of the frequencies surrounding the tinnitus frequency, thereby reducing the impact of the excitation at the tinnitus frequency. Given that a strong emotional

response to music has been shown previously (Blood & Zatorre, 2001; Koelsch, Fritz, & Schlaug, 2008), the authors suggest further that inputs from the limbic to the auditory system as a result of the positive feelings associated with the music could have contributed to the decrease in tinnitus measured in these subjects.

Future Directions

The use of filtered music presented by Okamoto et al. (2010) is a promising methodology for the treatment of tonal type tinnitus and offers many possible directions for further study. While the authors measured changes in behavior and neurophysiology at discrete time intervals (6 and 12 months), correlating the length of stimulus exposure and sound pressure level could further our knowledge of plasticity in the auditory system. Additionally, exploring the use of different types of stimuli, such as filtered music that might have different emotional loads, broadband noise, or speech could be a means of measuring the involvement of limbic or language areas in the remediation of tinnitus.

Author Note

Dr. Schlaug and Dr. Wilson acknowledge salary support from the National Institute of Health (DC008796, DC009823).

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