Possible Role of Sound Therapy in Treatment of Tinnitus

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Abstract

It is difficult to obtain a precise definition of tinnitus. Generally, tinnitus is defined as perception of noise in the absence of an external sound source. However, in some patients, there is an actual source causing the sound perception such as vascular lesions &tempero-mandibular joint (TMJ) disorders. It may be perceived in one or both ears, centered in the head or localized outside the head.Tinnitus can be classified into objective and subjective. Objective tinnitus is a rare condition that can be defined as the perception of a sound which has been generated physically in or near the ear as in case of muscle spasms or vascular disorders. It can be perceived by the individual and the external observer. On the other hand, subjective tinnitus is more common and perceived only by the patient with the symptom as it doesn`t involve an identifiable sound source. It is a highly complex condition that has a multifactorial origin, different patient profiles and caused by disturbed activity in the auditory system. Sound therapy is the oldest and most natural approach aimed at improving tinnitus as tinnitus patients can experience every day that an external acoustic source can mask their tinnitus. Sound therapy is not aimed at treating the causes of tinnitus but helping to manage the consequences of tinnitus as it assume that tinnitus results from central changes after hearing loss that can be reversed by appropriate acoustic stimulation. Acoustic stimulation may be very beneficial for some patients while completely ineffective for others.

Keywords: Notched Sound Therapy, Tinnitus

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Introduction:

Tinnitus can be classified into objective and subjective. Objective tinnitus is a rare condition that can be defined as the perception of a sound which has been generated physically in or near the ear as in case of muscle spasms or vascular disorders. It can be perceived by the individual and the external observer. On the other hand, subjective tinnitus is more common and perceived only by the patient with the symptom as it doesn`t involve an identifiable sound source. It is a highly complex condition that has a multifactorial origin, different patient profiles and caused by disturbed activity in the auditory system**(1)**.

Tinnitus can be also classified according to the underlying cause into primary, secondary, pulsatile and somatosensory **American-Speech-Language-Hearing Association** [ASHA], **(2)**. defined primary tinnitus as idiopathic with or without associated sensorineural hearing loss (SNHL). Secondary tinnitus involves underlying specific causes. Moreover, pulsatile tinnitus is a rhythmic type that resembles the heartbeat either synchronous with the heartbeat or not and in general not associated with pathology in the auditory pathway. Pulsatile tinnitus synchronous with heart beats seems to be related to arterial causes and most likely transmitted to the cochlea via cerebrospinal fluid. If it is synchronous with respiration, it seems to be venous in origin. Almost all causes of pulsatile tinnitus can be diagnosed by magnetic resonance imaging (MRI) and magnetic resonance angiography (MRA) expect for benign intracranial hypertension **(3)**.

Another type of tinnitus that mimics pulsatile one is known as Pseudopulsatile tinnitus and caused by patulous Eustachian tube, Palatal myoclonus, tensor tympani or stapedial muscle myoclonus. It's neither arterial pulse synchronous nor respiratory rate synchronous. It tends to fluctuate in intensity and perceives as clicks **(4)**.

Somatosensory tinnitus is caused by an alteration in somatosensory afference from the cervical spine or temporomandibular area. It can be evoked or modulated by inputs from somatosensory, somatomotor and visual-motor systems. This means that psychoacoustic characters of tinnitus might be temporarily changed by different stimuli such as forceful muscle contraction of head or neck, eye movement in horizontal or vertical axis, pressure applied to TMJ and orofascial movements **(5)**.

Another classification system takes into account the functional and psychological impacts of tinnitus. The impact of tinnitus on one's quality of life can differ from non-bothersome to bothersome tinnitus. Bothersome tinnitus can be frequently associated with psychological, psychosomatic and psychiatric co-morbidities that can be either pre-existing or induced by tinnitus. Anxiety, depression and insomnia are commonly existed in this type of tinnitus. The higher the levels of distress, the more likely co-morbid disorders are present **(6)**.

The characteristics of tinnitus can vary from ringing, buzzing and hissing to tonal sounds. It can be presented as multiple sounds. In some patients, the sound is persistent in quality whereas the quality changes in others. The course of tinnitus can be continuous or intermittent, heard in one or both ears or inside the head. Tinnitus is considered acute if it has been experienced by the patient for less than three months. After three months, tinnitus is defined as subacute whereas it is termed chronic when persisting for six months or greater **(1)**.

Epidemiology of Tinnitus

The prevalence of tinnitus shows widespread variability, with most studies reporting prevalence estimates between 10 and 15% worldwide. **Biswas et al. (7)** studied the prevalence on tinnitus in Europe and founded that it significantly increases with aging and deterioration of health. Cross- sectional European tinnitus survey conducted in 12 European Union nations in 2017-2018 (11427 adults aged > 18 years) and found that the prevalence of tinnitus was 14.7%.

An Egyptian study was conducted by **Khedr et al. (8)** to study the prevalence of tinnitus involved 8,484 subjects from rural and urban communities. They reported tinnitus prevalence of 5.17%. Of these subjects, 15.2% had severe to catastrophic tinnitus. **Eladawy et al. (9)** studied the prevalence of tinnitus on 550 adult patients and reported that it was 70% among adult's attendees to the audio vestibular unit Al-Azhar University. The tinnitus was associated with hearing loss in 76.1% of these patients while the rest had normal hearing threshold. The type of hearing loss was variable, where 31.6% had SNHL, 27.2% had mixed hearing loss and the rest their hearing impairment was of conductive type.

Tinnitus and hearing loss were found to be associated in 49% of subjects **Xiong et al., (10)** suggested the possibility of hidden hearing loss in tinnitus patients with normal hearing. **Vielsmeier et al. (11)** reported that 83% of tinnitus patients with normal hearing had elevated hearing thresholds more than 15dB HL at one or more of these frequencies (10, 11.2, 12.5, 14 and 16kHz). Similarly, **Kim et al. (12)** reported that 74% of the patients with tinnitus who had normal hearing at 8kHz exhibited thresholds more than 25dB HL at 12kHz and/or 16kHz.

Background of sound therapy

Sound therapy is the oldest and most natural approach aimed at improving tinnitus as tinnitus patients can experience every day that an external acoustic source can mask their tinnitus. Sound therapy is not aimed at treating the causes of tinnitus but helping to manage the consequences of tinnitus as it assumes that tinnitus results from central changes after hearing loss that can be reversed by appropriate acoustic stimulation. Acoustic stimulation may be very beneficial for some patients while completely ineffective for others **(13).**

There are numerous mechanisms by which sounds could interfere with tinnitus **(13).**Tinnitus may be masked by sound usually white noise that reduces the contrast between the tinnitus signal and background activity in the auditory system. Sounds may desynchronize neural ensembles suspected in tinnitus generation **(14)**.

Long-term alleviation of tinnitus may occur through habituation. Attention, cognition and context of perception also appear to be important factors that manipulate long term adaptation to tinnitus. Another mechanism suggested by **Jastreboff, (15)**based on low level of white noise treatment could be used to achieve down regulation and habituation of the disordered auditory perception.

The benefit from using sound therapy based on the concept of sound enrichment, in which the white noise also acts as a source of stimulation to the central auditory system to compensate for the loss of auditory stimulation arising from the cochlea in patients with hearing loss. This would prevent sensory deprivation, which is one of the theories of tinnitus generation **(16).**

Sound therapy devices tend to be worn as in the ear or behind the ear devices. They can output a broad spectrum of white noise or they may be focused to the frequency band of the patient's tinnitus. They may be combined with a hearing aid to augment a patient's hearing. Sound therapy devices can also take the form of CDs and music cassettes that play a similar white noise or music but through conventional stereophonic equipment **(13).**

Definition of sound therapy

Sound therapy is the oldest and most natural approach for treatments of tinnitus. The original idea was to partially or completely mask tinnitus with broadband noise delivered by sound generators or hearing aids, for a few hours each day **(17).**

Types of sound therapy

Sound therapy is used in different ways as neuromonics approach, tinnitus masking therapy, customized music stimulation and notched sound therapy **(18).** These approaches aim at improving tinnitus, not by treating the causes of tinnitus but simply by helping to manage the consequences of tinnitus **(1).**

1. Neuromonics tinnitus treatment (NTT)

NTT is a noninvasive approach which consists of an acoustic stimulation combining music and broadband noise as shown in. The spectrum of this combination is customized to provide an equalized stimulation over the audible frequency range. In addition to providing stimulation within the deprived sensory region, the acoustic stimulation is also designed to promote relaxation and relief. These effects are reinforced and complemented by counseling **(19).**

Figure (1): Neuromonics tinnitus treatment. Quoted from **Davis et al. (19)**

Patients undergoing NTT are permitted to completely mask their tinnitus in the early stages of the treatment to maximize relief and relaxation. This initial stage (2 months) is also intended to maximize the amount of stimulation of the deprived sensory region. In a second stage (4 months), the patients are discouraged from masking their tinnitus to facilitate desensitization **(19).**

Theoretical basis for counseling and sound treatment based on the abnormal neural activity in the brain that is perceived as a sound is a result of neuroplastic processes. There is a general agreement that the limbic system and autonomic nervous system are involved in generating the awareness and annoyance from tinnitus. This can explain why an individual's reaction to tinnitus seems to be linked to the person's emotional state **(19).**

Sheppard et al. (20) suggests the use of music to provide distraction from tinnitus and notes that it has otherwise been highly underutilized. The use of music in NTT enables tinnitus sufferers to have a pleasant and relaxing sound to listen to while being treated. This approach facilitates patient`s compliance to treatment and provides gradual desensitization to the tinnitus signal.

Trochidis et al. (21) compared the cost effectiveness and cost utility of Neuromonics versus ear level sound generators at about one third of the cost. Both interventions resulted in reduced tinnitus handicap score with no difference in improvement between groups.

2. **Tinnitus masking therapy (TMT)**

The main objective of TMT is using wideband noise to provide a sense of immediate relief from the tinnitus. The relief is usually accomplished through the use of wearable, ear level devices that include noise generators (maskers), hearing aids and combination instruments (masker plus hearing aid). Ear level devices are recommended for patients with more severe tinnitus **(22).**

Use of devices with TMT is very different from their use with tinnitus retraining therapy (TRT). In TMT the patients are instructed to adjust the level of their ear level maskers to the point that provides the greatest degree of relief from their tinnitus either complete or partial masking. With TRT, patients adjust the level of their ear level sound generators to the mixing point. TRT patients must always adjust their sound generators at or just below the mixing point, which is thought to be necessary to optimize the process of habituation to the tinnitus. Most of the improvement induced by TMT was achieved during the first 3–6 months of treatment, while TRT induced a steady improvement over the course of the treatment (18 months) **(15).**

Tyler et al. (13) compared the efficacy of TMT and TRT and finding that both methods led to self-reported improvements in tinnitus, but that TRT was superior to TMT in reducing tinnitus related distress.

3. **Customized music stimulation**

Mahboubiet al. (23) developed web-based customized harmonic sound therapy as a method of tinnitus treatment available at www.beyondtinnitus.com. Harmonic sound therapy is a customized masking strategy specifically designed to deliver non-noxious acoustic energy with significant portions of the hearing spectrum to remain unmasked. This design makes it possible to have dramatically increased exposure to the therapeutic sound because the ambient acoustic space is left open.

The first step was to determine the participant`s tinnitus type, then they were given a series of choices of different sound frequencies to select the closest sound to their tinnitus (pure tones for tonal/ringing tinnitus, narrow band noise for hissing/buzzing tinnitus). In the second step, the participants were asked to rematch their tinnitus with a choice of the tinnitus frequency and one octave above and below the tinnitus frequency. This allowed the elimination of octave confusion, which can occur when selecting the tinnitus frequency **(23).**

In the third step, participants selected if the tinnitus was unilateral or bilateral. In bilateral cases, they were instructed to adjust the balance on a scroll bar to hear the pitch matched sound equally in both ears, to allow for asymmetry in tinnitus and hearing loss. The website implements participant`s selections of frequency, loudness and inter-aural characteristics to construct a customized harmonic sound therapy file which composed of a series of narrow-band noise peaks centered on the tinnitus frequency and the first and fifth sub-harmonics. The width of these bands is one-half octave of the center frequency as shown in**.** The last step was to download the therapy file into the MP3 player and listened to it for an hour at a level equal to tinnitus loudness (mixing point) by headphones **(23).**

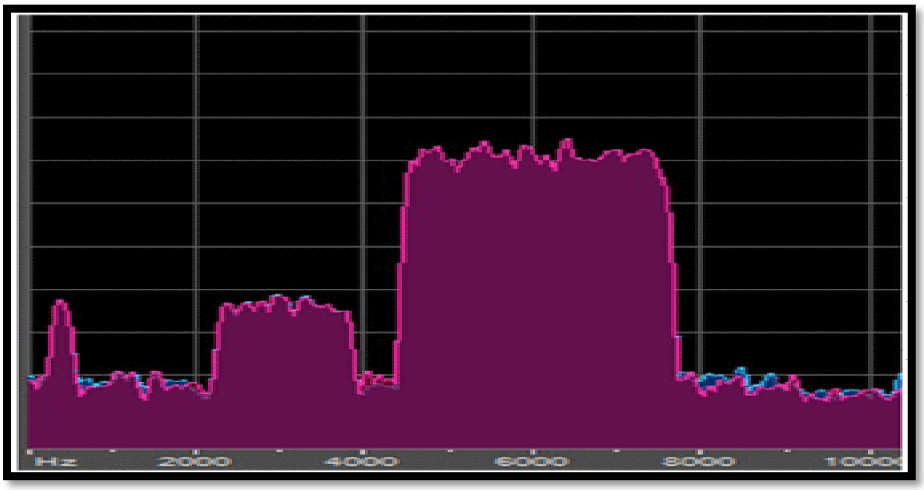

Figure (2): Spectrum analysis of a sample customized sound therapy for a patient with tinnitus pitch matched at 6 kHz and high-frequency sensorineural hearing loss. More sound is targeted around 6 kHz and a narrowband sound at 3 kHz and 375 Hz **(23).**

Mahboubi et al. (23) compare customized versus non customized sound therapy for treatment of tinnitus and concluded that customized sound therapy can decrease the loudness and tinnitus handicapped inventory questionnaire scores and that results superior to broadband noise.

4. **Notched sound therapy (NST)**

Pantev et al. (24) developed novel treatment strategy for tonal tinnitus which deprives the specific neuronal population that codes the tinnitus frequency, induces a circumscribed auditory functional deafferentation and transient sensory input deprivation. The notch (1 octave width) being chosen to correspond to the tinnitus pitch as shown in**.** The NST was intended to reduce tinnitus related cortical activity within the notch, possibly through increasing lateral inhibition. After 12 months of regular listening, this approach was reported to reduce tinnitus loudness.

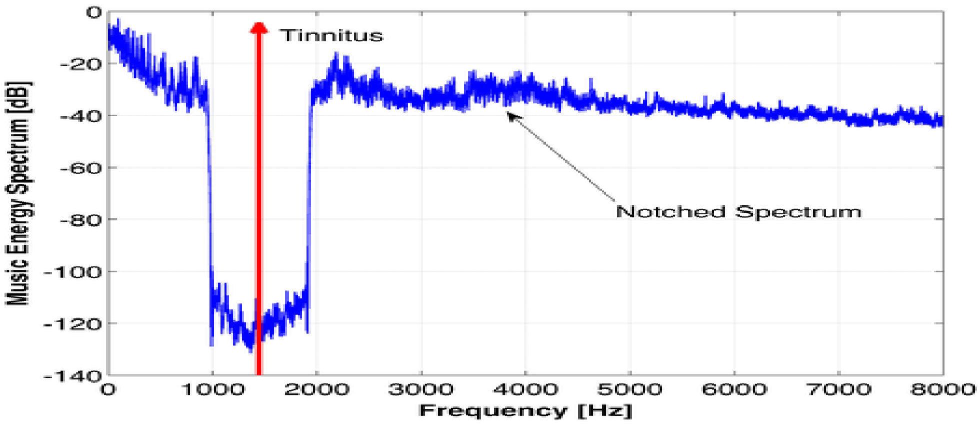

Figure (3): the notch is centered at 1500 Hz. Quoted from **Pantev et al. (24).**

<u>**Lateral inhibition and habituation of the human auditory cortex**</u>

Lateral inhibition plays an important role in the functioning of our sensory modalities. The afferent auditory pathway is formed not only from excitatory neural connections; inhibitory networks also play an important role. **Schneider et al. (25)** proposed that inhibition in the human auditory cortex, as mediated by lateral connections, is an active mechanism that innervates inhibitory neurons and causes the attenuation of the auditory evoked response. Lateral inhibition in the auditory system seems to contribute to improving the perceptual contrast by enhancing the spectral edge of the sound stimuli.

Habituation, in contrast, is a neural mechanism that suppresses the activity of neurons, which are repeatedly activated. Habituation seems to play an important role both in suppressing irrelevant neural activity and in enhancing the neural activity elicited by irregular sensory inputs **(25).**

Pantev et al. (24)hypothesized that lateral inhibition in the central auditory pathway might also be asymmetric in order to compensate for the frequency tuning curve asymmetry originating in the cochlea.

<u>**Effects of attention on lateral inhibition**</u>

Another very important issue is the relationship between lateral inhibition and attention. We are exposed to many different types of sound signals simultaneously, yet we can easily perceive selected sounds simply by paying attention to them. This process can be tuned by the enhancement of neural responses corresponding to task relevant stimuli, by suppression of task irrelevant neural activities via lateral inhibition or by both **(26).**

Lateral inhibition in the auditory system can sharpen frequency tuning in the auditory cortex. The inhibitory system intensified by focused auditory attention leading to the sharpening of population level frequency tuning in the human auditory cortex. These results suggest that constant stimulus sequencing under focused auditory attention may cause larger neural activity at the attended frequency and smaller neural responses at the other frequencies **(27).**

The bridge between cortical plasticity, lateral inhibition and the treatment of tonal tinnitus

Training induced alterations in the cortical map correspond to perceptual correlates, which indicate superior performance. The process of plasticity itself can be utilized in order to reverse or reduce these maladaptive changes. Such rehabilitative plasticity functions by reestablishing normal cortical functional organization to a certain degree **(24)**

It was suggested that an imbalance of excitatory and inhibitory neural interactions within the auditory cortex could lead to the perception of tinnitus and treatment focused mainly on habituation mechanisms. **Pantev et al. (24)** suggest that making use of lateral inhibition within the auditory cortex could be a valuable alternative strategy for suppressing tinnitus perception

On the basis **Pantev et al. (24)** developed NST which deprives the specific neuronal population that codes the tinnitus frequency, induces a circumscribed auditory functional deafferentation and transient sensory input deprivation. This deprivation would lead to a reduction in the level of excitation of auditory cortical neurons coding the notched frequencies, among them the tinnitus frequency. The consequence for sufferers of chronic tinnitus should be reduction in tinnitus loudness.

Long term and short term NST for tonal tinnitus

Okamoto et al. (28)compared NST and broad band for treatment chronic unilateral tonal tinnitus with tinnitus frequencies ≤ 8000 Hz. Before beginning training, the patients were assigned to one of three groups: target, placebo or monitoring. The target group received the notched music with frequency band of one octave width surrounding the individual tinnitus frequency was removed. The placebo group received placebo notched music therapy: the frequency band of one octave width around the tinnitus frequency remained unfiltered and, instead, the frequency range above and below this band was notched with a slowly moving filter of one octave width. The patients of the monitoring group were just listening to their usual music. The patients listened to their notched music for 1–2 h every day, using closed headphones for 12 months. The patients were instructed to listen to their notched music in a quiet environment, selecting their own moderate loudness.

The results of this study demonstrated the specific efficacy of NST. After completing their training, the perceived tinnitus loudness as well as tinnitus related auditory cortical evoked activity was significantly reduced for patients in the target group, compared to their pre-training baseline. In contrast, in both the placebo and monitoring groups, no significant changes from the baseline were found.

Teismann et al. (29)develop and evaluate short and intensive NST and removal of the frequency band of one octave width centered at the individual tinnitus frequency as shown in. The patients listened to 24 h of NST over the course of 5 consecutive days. The results of this study demonstrated that the short and intense NST had been effective, though only for the patient group characterized by tinnitus frequencies ≤ 8000 Hz. NST efficacy was reflected by reduction in perceived tinnitus loudness and tinnitus-related distress, as well as by a reduction in tinnitus related auditory cortical evoked neuronal activity that persisted for no longer than 2 weeks.

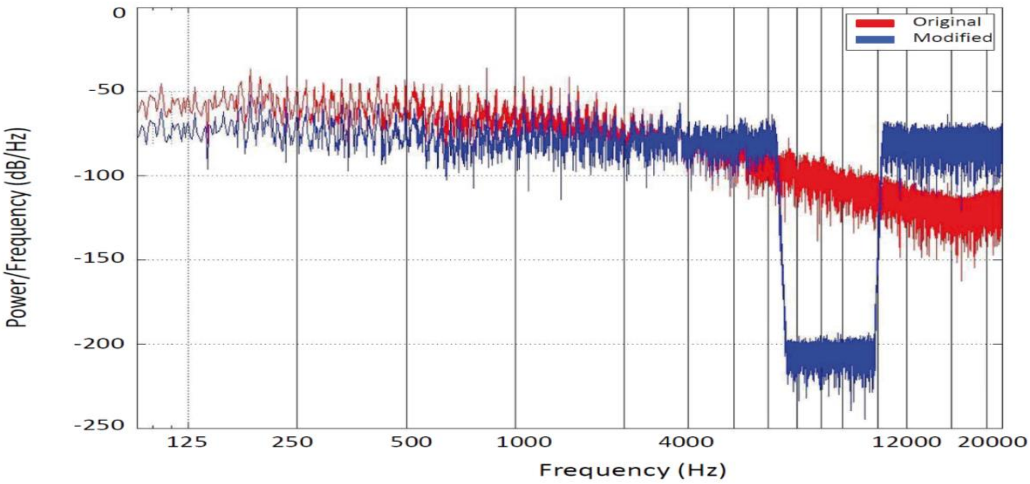

Figure (4): NST spectra: original (red) and modified (blue). The notch is centered at 7100 Hz **(29).**

Atipas et al., (18) ;Pantev et al. (24) ;Teismann et al. (29) concluded that NST is effective in reducing reported tinnitus loudness by an average of about 20% specifically for patients who suffer from chronic tonal tinnitus and who do not exhibit a greater than moderate hearing loss.

Impact of spectral notch width

Stein et al. (30) used half octave width with an equalized energy spectrum and an amplified edge of the notched frequency band while, **Wunderlich et al. (31)** investigated the notch width to find the most effective for NST. They compared 1 octave notch width with ½ octave and ¼ octave. The outcome was measured by means of standardized questionnaires and magnetoencephalography and found a general reduction of tinnitus distress in all administered tinnitus questionnaires after the training. Additionally, tinnitus-related neural activity was reduced after the training. Nevertheless, notch width did not have an influence on the behavioral or neural effects of NST. This could be due to a non-linear resolution of lateral inhibition in high frequencies.

Wunderlich et al. (31) studied the notch width that would provide the best training effect. They expected the ½ octave condition to be superior to the 1 octave condition and even the best outcome for the ¼ octave condition. Although the results of the standard questionnaire and the other distress measures did not reveal a clear effect of notch width, in the ½-octave group the most participants reported that the training had improved their tinnitus.

Effect of NST

These approaches aim at improving tinnitus, not by treating the causes of tinnitus but simply by helping to manage the consequences of tinnitus (1). Listening to NST can introduce a functional deafferentation of auditory neurons corresponding to the eliminated frequency band. This could be explained on the basis that deprivation of auditory input in the tinnitus-matched frequency range resulted in long-term depression of auditory neurons matching to the tinnitus frequency. Consequently, the notched sound no longer stimulated the cortical area corresponding to the tinnitus frequency and can effectively reduce tinnitus loudness and tinnitus-related auditory cortex activity (28) , providing amelioration on thoughts, emotions, concentration, sleep, and tinnitus annoyance (13).

Advantages of NST

1. NST considered as one optional treatment which is enjoyable and a low-cost therapy for tinnitus patients. The lateral inhibitory effect and central auditory neural plasticity of NST are the main mechanisms which explain why the therapy effectively reduces tinnitus loudness and the cortical activity related to tinnitus (18).
2. NST reduces loudness of tinnitus with subsequent improvement in tinnitus severity and quality of life (12).

Disadvantages of NST

1. Sound therapy (including masking, notched and customized) may be useful for acute relief purposes but is not considered an effective intervention with long-term results (1).
2. Not indicated in patients with severe depressive illness, severe hearing loss and hyperacusis(32).
3. There was marked heterogeneity in the intervention with sound therapy. The lack of an established universal tool for pre- and post- management assessment of tinnitus outcome measures has been a long-recognized problem in tinnitus research (32).
4. No long- term data were presented by any study and so it is impossible to state whether the effect of sound therapy is maintained after its use (33).
5. Most tinnitus rehabilitation protocols use combined approaches, which most of the time include an element of counseling combined with masking, notched sound therapy or customized music stimulation with subsequent further complicates the process of extracting evidence for or against the effectiveness and value of each individual method in the overall result of the management process (34).

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