TINNITUS CLASSIFICATION AND SUPPRESSION

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Abstract: Subjective tinnitus subjects were classified into 3 tinnitus types. Cicada, Tonal (Buzzing) or Hissing. These subjects were examined with a group of acoustic suppressor stimuli including a new suppressor -- a morlet click (short guassian tonal spread) applied at about the tinnitus frequency. A preliminary comparison of suppressors is made.

Key Words: Tinnitus, Tinnitus Suppression, Masking.

Introduction: Tinnitus, in one or both ears, is a neuro-otological condition in which a sound (such as ringing, hissing, buzzing, roaring, etc) is perceived by a person without external auditory stimulation. The exact cause is yet unknown. Over 50 million Americans suffer from tinnitus and it is severe enough for 12 million to seek medical attention. Tinnitus has been classified into objective tinnitus and subjective tinnitus.

Objective pulsatile tinnitus is a condition caused by the individuals respiration, muscular contractions, heartbeat and even venous pressure. Characteristic sounds include a blowing sound, a clicking sound (uncontrolled contraction of middle ear muscles), a thumping, booming and even a clip-clop sound. Objective spontaneous otoacoustic emission (SOEA) tinnitus is a second form of objective tinnitus. It has been reported that the ear can generate SOEA’s that can be perceived as tinnitus [1].

Subjective tinnitus is more common and may arise along the auditory system from the periphery to the Auditory Cortex (AI). Studies have demonstrated that when the 8th nerve is severed in some tinnitus patients the tinnitus is still perceived [2]. Some practioners propose that there are two types of subjective tinnitus, peripheral and central tinnitus. Higher nuclei may be responsible for the generated signal, either at onset or after a period of time even if the origin was initially peripheral. Peripheral tinnitus is thought to arise from changes to the inner ear from damage or aging. There are two different kinds of peripheral tinnitus. Burst tinnitus, possibly caused by excessive firing of auditory nerves, and sounding like buzzing. The second is rate tinnitus which is possibly caused by excessive release of neurotransmitters which one way or another leads to excessive firing of auditory nerves [3]. Sufferers of rate tinnitus generally perceive a hissing sound as their tinnitus.

Current Devices Used To Alleviate Tinnitus
A cure or effective therapy for these tinnitus-afflicted individuals remains evasive. Certain combinations of auditory devices, drug and relaxation therapies have been used by clinicians, but no universal solution has been found to date. Many patients use some other sound to ‘mask’ Tinnitus; so whilst the Tinnitus is still there, the masker “drowns it out”. Music, white noise and ‘relaxation’ tapes (e.g. beach of waterfall sounds) have been used. Masking can have a residual effect, where residual inhibition (RI) lasts after the masker has been turned off. RI can be temporary diminution or possibly complete suppression of an individual’s tinnitus. RI can be either "partial" (PRI - the tinnitus is still audible but at a reduced level) or "complete" (CRI - the tinnitus appears to be totally absent). Although audible masking noise has become a widely accepted form of treatment, it is not always accepted by a tinnitus patient as it introduces yet another noise, and listening to it can be unpleasant.

Tinnitus Retraining Therapy (TRT) has been used to address what some researchers see as the involvement of the neurophysiological emotion-regulating limbic system. TRT depends upon the clinicians ability to “habituate” the subject to a tinnitus signal on a subconscious level, so that over a period of time the negative emotional autonomic response to the tinnitus can be gated [4]. TRT can take up to 18 months to achieve results and does not appear to work on all tinnitus-afflicted individuals [5]. Another recently reported technique used to alleviate tinnitus is the Tinnitus Suppression Therapy (TST) [6].

Suppression Therapy (TST)
TST uses a low-intensity or sub acoustic narrowband or pure tone acoustic stimulus at a frequency away from the tinnitus frequency to suppress the perception of tinnitus. TST is based on Öffutt’s electromodel of hearing [7], and the inhibitory effect that activation of neighbouring outer hair cells (OHC) can have on corresponding inner hair cells (IHC) along the cochlear array. TST focuses on recruiting the remaining (hopefully sufficient) OHC close to the errant IHC. The delivery of low-level acoustic stimulation at a frequency matching the centre frequencies of target OHC allows the normal inhibitory function of OHC to be recruited for the suppression of errant IHC. It is likely that the suppression frequency can be one of a number of such frequencies; where the best suppression frequency may be determined by the number of OHC available and proximity to the errant IHC. The TST signal is determined by performing a normal audiogram, location of the tinnitus frequency by tinnitus matching and then gradual changes to both frequency and intensity until suppression is optimized [6].

TST also possibly exploits the inhibitory properties of auditory neurons to suppress Tinnitus by generating this ‘narrowband’ tone.
Figure 1: Response Field Classification. The sound level on the vertical axis increases in dB level from the bottom. Adapted and reconstructed from Altschuler, R et al. [8]

Referring to Figure 1 above, the response map is a characteristic of auditory nerve fibers (ANF). It shows inhibitory sidebands around the excitatory tip of the response map. By stimulating these inhibitory regions we should be able to stimulate the inhibitory neurons, which will aim to inhibit the firing of excitatory neurons that are postulated to cause the generation and thus perception of tinnitus.

Objective: This study aimed to provide a preliminary comparison of a group of suppressor stimuli including a new TST suppressor -- a morlet click (short gaussian tonal spread) applied about the tinnitus frequency.

Methods: The first part of the study was to select from 170 subjects a small group that fit into the subjective tinnitus class and meet the following criteria: (a) Subject’s tinnitus has been shown to be suppressible (b) Subject’s tinnitus is always present (c) Subject describes tinnitus as ‘buzzing’ or ‘ringing’ (d) The Subject does not have more that moderate hearing loss (e) Subject does not have cochlear implant / hearing aid and (f) The perceived loudness of tinnitus must be at least 5dB above hearing threshold at that frequency. According to these criteria 22 subjects were selected for the initial trial with TST. 11 Subjects were tested in detail.

Tinnitus Matching Tinnitus matching involves both frequency and intensity level matching between the Subject’s perception of tinnitus and a pure tone artificially generated and presented to the ear via a headphone inside an audio booth. The best type of TST suppressor tone was chosen based on testing with tones and noise stimuli. Where the Subject matched their tinnitus closer to a pure tone, a pure tone TST signal was used; otherwise narrowband noise was used.

Procedure: Expose Subject to complete silence for a few minutes (sitting in anechoic chamber wearing headphones with no sound input). During this time hearing adjusts and the perception of tinnitus resolves. If the Subject can ‘hear’ a tinnitus sound, continue to next step. During frequency matching, first input a 1000Hz pure tone and adjust the intensity to a comfortable level where the patient perceives their tinnitus as being LOUDER than the input signal. Ask them if the frequency of the input signal sounds higher or lower frequency than their tinnitus. Once the frequency is matched, attempt to match the perceived loudness of the patient’s tinnitus, by adjusting the volume of the input signal until it just drowns out (reach the same loudness level as) the tinnitus. During step 3 and 4, subject will be asked to signal to indicate an increment or decrement in terms of frequency and loudness level respectively. Tinnitus identification is able to provide a starting point to locate the suppression tone, which hopefully is below the threshold level.

Stimuli:

Continuous pure tones
Continuous pure tones were initially introduced into the Subjects as suppression tones. Pure tones were generally used to suppress ringing pitch-like tinnitus patients. Pure tones are considered One issue that might also arise is tone (threshold) adaptation by the Subject. This refers to the progressive decline in the loudness of an unchanging, continuous sound as a function of exposure time [9].

Gated burst tones
These are pure tones that have specific silent interval in between, sometimes known as pulsed tones. Based on signal theory, the optimal duration of each tone is from 200-500msec [10]. Pulsed tones are used to suppress ringing pitch-like tinnitus patients. Each pulsed tone has a period of 1 second made up of 0.1sec rise time, 0.4sec steady state, 0.1sec of falling time and 0.4sec of quiescent. In terms of tinnitus suppression, previous studies have shown that pulsed or intermittent pure tones are preferred to continuous tones as they may avoid the phenomenon of “threshold adaptation” and may assist the afflicted individual to differentiate between the input tones and their tinnitus. One issue that may arise is the broadening of bandwidth of suppression.

Narrowband noise
Tinnitus suppression was also attempted with narrowband noise, i.e. band limited white noise. This Narrowband noise is not periodic and hence ‘threshold adaptation’ as it applies to regular or pure tone sounds may not apply. Narrowband noise is often used as a masker or TRT sound. This narrowband noise was shown to be a good masker in some cases, and it was used in attempt to suppress cicadas-like tinnitus. Its spectrum shown below:

Figure 2: Energy spectrum of narrow band noise at 2kHz and 60dB.
Morlet tones (click)
The use of Morlet tones was used to suppress tinnitus in individuals afflicted with tinnitus that sounds like cicadas. These tones were generated in Matlab (Figure 3).

Figure 3: Morlet ‘click’ generated from Matlab 6.5, at 2kHz and 40dB.

Morlet spectrum is shown in Figure 4. This wave is enveloped in a Gaussian curve, which behaves like narrow band noise, only narrower.

Figure 4: Energy spectrum of Narrowband Matlab Morlet Click generated at 2kHz and 40dB.

TST Suppression: Start at the matched tinnitus point. Reduce the intensity of the suppressor signal until it reaches a level where suppression fails (tinnitus can be heard again). Increase the frequency until suppression occurs (tinnitus cannot be heard) once again. Keep on performing steps 2 and 3 until the suppression point ‘iterates’ to a point (of certain intensity and frequency) at which there is no further improvement. The intention is for this point to be at a sound level that is softer than the patient’s hearing threshold at that frequency – so they can’t ‘hear’ the suppressor tone as well as their tinnitus. This step is deemed to be successful if Suppression occurs and the suppression point is softer than the hearing threshold. Perform the above steps with different tones mentioned before (flat pure tones, pulsed tones, narrowband noise and Morlet click tones).

Results: Among the 11 tinnitus subjects tested in detail 2 (cicada type) were completely suppressed, 3 (pure tone and ringing type) were partially suppressed and the remaining six (mainly hissing type) were unsuccessfully suppressed. From these results it was generally found that pure tones were a better tinnitus suppressor although pulsed pure tones were more effective than continuous pure turns. Narrowband noise was found to be a better tinnitus masker, however it did not suppress the tinnitus very well. The newly implemented morlet click did not yield positive outcomes as a tinnitus suppressor.

Example data:
Subject D had bilateral multi-tone plus humming tinnitus. Narrowband noise and the morlet had no suppressive effect. Partial tonal suppression was achieved. Subject A had bilateral cicada tinnitus. Tonal suppression was successful. A Morlet stimulus centred on 2kHz did successfully suppress the patients tinnitus but required constant manual adjusting of the mixer level. The suppression effects were confounded and his tinnitus came back worse than ever.

Discussion: Among the 11 tested subjects, it seemed that individuals with cicada-like tinnitus achieved better suppression than those with ringing and pure tone tinnitus. The subjects with hissing-type tinnitus did not respond to TST suppression. Pure tones were considered a better tinnitus masker and better for tinnitus matching purposes, whereas pulsed pure tones were a much better suppressor. OHC that were present and had centre frequencies matching the stimulus frequency regulate the level of nearby IHC activity and can thereby suppress tinnitus. Narrowband noise was also used but worked better as a masker rather than suppressor. The location of the tinnitus perception also varies from subject to subject. In some cases tinnitus was perceived in the head (i.e. between both ears) whilst in other subjects the perception was located in one ear or the other. During TST suppression some subjects reported a change of perception location (from ear to head or vice-versa). When the location perception changed, perhaps there was an increased level of neural activity in the auditory pathway or higher brain centres; leading to the perception of head noises (also known as tinnitus).

Whilst the observations derived from the 11 tinnitus subjects are useful in gaining a further understanding of tinnitus factors, the sample size for each type or categorization of tinnitus are too small in this study to permit rigorous conclusions to be drawn from this research or to draw conclusions that would apply to all those affected by tinnitus.
Conclusions: Different types of tinnitus are more likely to be alleviated with different types of sounds. Although TST does not work on all subjects it does provide a useful tool for the exploration of the topic and can provide relief for some people. The use of an inaudible acoustic suppressor signal to alleviate tinnitus has been shown to be effective in some and may be preferable over existing treatments like masking with white noise.

References: