

Exploring the Parametric Space of Tinnitus Suppression in a Patient with a Cochlear Implant

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ABSTRACT:

Educational Objective: The participants should be able to understand the potential role of individualized electrical stimulation of the auditory system in the suppression of tinnitus in patients with cochlear implants.

Objectives: Tinnitus is a debilitating condition in which one perceives sound in the absence of external stimuli. Most treatments consist of masking the tinnitus with an external sound that is louder than the tinnitus. We hypothesize that there exists a characteristic tinnitus signal individual that, when found, can be utilized to suppress their tinnitus at a level that is significantly softer than the tinnitus itself.

Study Design: Prospective randomized single blinded study in a unique individual with a unilateral cochlear implant in an ear with persistent tinnitus and normal hearing in the non-implemented ear.

Methods: Monopolar electrical stimulation at rates from 40 Hz to 10 kHz stimulation levels from threshold to the tinnitus mixing point, and stimulation placement from apex to base were administered over a time period of 3 to 10 minutes. Successful suppression was defined as the complete elimination of the subject’s tinnitus.

Results: Seven of eighty-three (8.4%) conditions tested led to complete suppression of the subject’s tinnitus while delivering a stimulus that was perceived to be softer than the initial level of the tinnitus. Two main characteristics of the signal were found to be effective. Mapping of the parametric space demonstrated that success in suppressing the subject’s tinnitus was achieved with very low rates of stimulation at the most apical electrodes and in stimulation with high rates at basal electrodes that closely matched the subject’s tinnitus.

Conclusions: Tinnitus suppression is a mechanism specific to the individual. Exploring the parametric space of tinnitus suppression with respect to stimulation rate, sound level, and placement gives insight into the potential treatment of an individual’s tinnitus. The development of a clinical algorithm to create individualized maps of tinnitus suppression may lead to the successful treatment of tinnitus.

INTRODUCTION:

Tinnitus is the perception of sound in the absence of external stimuli. It occurs in Hearing and Deaf individuals, and may present itself as a mere annoyance to complete devastation. The possible mechanisms that have been proposed to ameliorate tinnitus in patients with unilateral cochlear implants include the utilization of electrical stimulation to restore spontaneous activity, the introduction of electric masking, and the reorganization of the auditory cortex.

Recent studies have shown that high-rate electric stimulation can suppress tinnitus in some cochlear implant users. In many cases, the electric stimulation over time adapts to be inaudible. Other studies demonstrate that low pulse rates are the most efficacious in suppressing tinnitus, with the least amount of current required to obtain the desired effect.

With the administration of both high and low-rate stimuli to various electrodes, this study creates a map of the parametric space of the response of an individual’s tinnitus to electrical stimuli in a systematic fashion. We propose that every individual, both Hearing and Deaf, has a similar map that can be developed and employed to suppress their tinnitus in the most effective manner. Furthermore, we suggest that the creation of such a map may give us insight into the mechanisms behind tinnitus

MATERIALS AND METHODS:

A prospective, randomized single-blinded study was performed with a musician who had been implanted with a Clarion HiRes60K cochlear implant to control debilitating tinnitus in his right ear despite having normal hearing in his contralateral ear.

After obtaining approval from the University of California Irvine institutional review board, informed consent and HIPAA consent, the patient was familiarized with a loudness ranking 0 to 10 scale and instructed on how to discern between loudness and annoyance. Prior to testing, he was asked to report the baseline loudness of his tinnitus from 0 to 10, where 0 is equal to silence, 6 is conversation level and 10 is the upper limit of loudness. His tinnitus was matched to an acoustic stimulus of 4000-8000 Hz and at 70-90 dB SPL, and remained consistent throughout the study time period reported here.

Monopolar electrical stimulation rates from 40 Hz to 10 kHz were administered at various locations from apex to base at a phase duration of 107.8 µs for a total of 83 trials with the aim of covering a broad parametric space. A single stimulus was administered for 3 minutes, and the subject reported his tinnitus level every 20 seconds. The subject continued to report the level of his tinnitus after the cessation of the stimulus until his tinnitus returned to baseline in order to record any residual inhibition or rebound effects. The stimulus was placed at a current (loudness level) that resulted in an initial perception that was at or below the level of the perceived tinnitus. This level was chosen to help differentiate between a masking phenomenon and that of suppression. Successful suppression was defined as the complete elimination of the subject’s tinnitus.

RESULTS:

In our study, the subject experienced successful suppression in seven of eighty-three (8.4%) conditions (Table 1). The two main characteristics of the signal that were found to be effective were stimuli at a low rate at the most apical electrodes and stimuli that closely resembled the subject’s tinnitus in character and pitch. All stimuli were sampled at a rate of 44100 Hz. The first condition that produced a successful response was that of monopolar stimulation at the most apical electrodes (2 and 3) with a low rate (60 pps) and short phase duration (PD = 107.8 µs / phase) (Figure 1A). The other condition that produced a successful response was monopolar stimulation at mid- and basal electrodes (8, 11 and 13) at mid- to high rates that the subject described as being close to his tinnitus in character. The high rate stimulus also created an environment in which the subject’s tinnitus mixed with the signal, thereby making it indistinguishable (Figure 1B). During some stimuli for which the subject reported as being similar in quality to his tinnitus, beats were created from the interaction between the subject’s tinnitus and the external stimulus.

Unlike masking, the patient did not experience the mitigation of his tinnitus as soon as the stimulation began. Instead, his tinnitus gradually dissipated over a time period of 20 to 200 seconds. The subject noted residual inhibition lasting anywhere from 20 to 40 seconds and only in the high frequency conditions. For every condition, the subject perceived a rebound phenomenon when the stimulus was removed (Figure 2).

DISCUSSION:

In our study, we have found that there is a unique map of pulse rate and monopolar electrode stimulation that creates successful stimuli for tinnitus suppression. Past studies have tested a limited number of electrode – frequency combinations in various subjects, but these have been limited in scope and breadth1-3. Some found that low frequency stimuli of 20 Hz to 125 Hz are the most effective suppressors2. Others have noted that high rate pulses trains suppress tinnitus2. However, no studies that we have found to date have examined such a broad range of stimuli in a single individual. While the high pulse rates that closely matched the patient’s tinnitus may guide us toward a more efficient masking phenomenon for tinnitus reduction, the success of low pulse rates in tinnitus suppression may lead us to new mechanism behind tinnitus and its treatment.

As in prior studies, our subject noted a delay between onset of the stimulus and tinnitus suppression4. However, unlike other studies, our subject did not experience a prolonged period of residual inhibition. This could be due to the cause of the individual’s tinnitus, the amount of current that was employed or that despite the large parametric space that was tested, the ideal suppressing stimulus for this subject may not have been discovered.

In nearly every successful condition, the subject adapted to the stimulus that was presented to him. This occurred most often during high rate stimuli, creating an overall sound environment that was quieter than his tinnitus alone. The phenomenon of adaption of signal with increasing frequency and decreasing loudness level despite rate, place and mode of stimulation has previously been described5. The subject also defined each successful stimulus as more pleasant in quality than his tinnitus that was being replaced, regardless of whether the stimulus

The subject did experience a mild amount of rebound when the stimulus was removed. This may be indicative of a masking mechanism of tinnitus reduction. However, because the rebound did not occur instantaneously once the stimulus was removed, the phenomenon could be due to the interaction of the stimulus and the tinnitus by a yet undefined neural mechanism. Mechanisms that have been proposed recently include the disruption of the balance between the spontaneous activity or the stochastic noise of the auditory system and a synchronous signal6. The further definition of this mechanism may lead to the creation of successful treatments of tinnitus in all individuals.

Future studies will include bipolar electrode stimulation, creating results that are reproducible out of a research laboratory environment and creating additional unique suppression maps in both Hearing and Deaf individuals with tinnitus.

REFERENCES:


Table 1: All frequencies and electrodes tested (x). Successful stimuli (those that suppressed tinnitus) are highlighted in blue.

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Figure 1: A. Monopolar biphasic pulse at 60 pulses per second (pps), phase duration (PD) of 107.8 µs and amplitude (current) of 120 microamperes (µA). B. Monopolar biphasic pulse at 4038 pps, phase duration of 107.8 µs and current of 37 µA.

Figure 2: Suppression time course of a 60 pps stimulus. Stimulus started at time 0 with a duration of 360 seconds. The subject’s tinnitus is not suppressed until the 140 second time point and he experiences a rebound of longer than 2 minutes once the stimulus is removed.

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