Patterned sound therapy for the treatment of tinnitus

By Kelly M. Reavis, Janice E. Chang, and Fan-Gang Zeng

USING SOUND TO CURE TINNITUS

Sound therapy, via either acoustic or electric stimulation, uses external sounds to provide short- and long-term relief from tinnitus. The interactions between external sounds and tinnitus are well established, as the external sounds can not only induce tinnitus, but can alter its perception as well.

Excessive exposure to loud sounds is the single greatest risk associated with tinnitus onset, and for those with tinnitus, sound overexposure may exacerbate it. However, sounds used at safe levels can be highly beneficial to an individual with tinnitus. Sounds can not only distract a person's attention away from tinnitus, but also affect the overall quality of the tinnitus. In some cases, people report noticeable changes in tinnitus pitch or quality following exposure to certain external sound sources.

For example, a variety of sounds, ranging from constant, low-level background sounds mimicking running water to intermittent sounds mimicking fire crackling have been used to mask the overall perception of tinnitus.[1] Additionally, many tinnitus sufferers who use hearing aids or cochlear implants to treat a concomitant hearing loss have reported a reduction in their overall tinnitus percept, with some even reporting complete elimination of their tinnitus.[2,3] It is not surprising, then, that sound therapy has become a vital component in most tinnitus treatment plans.

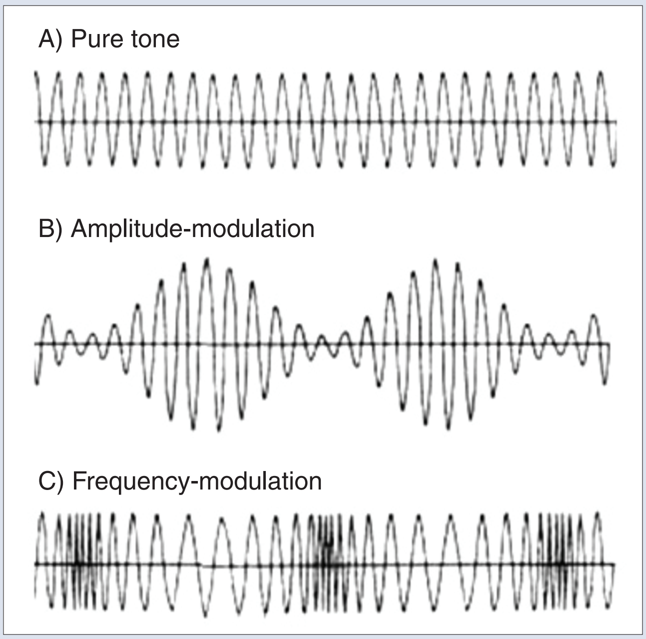

Figure 1. *The time waveform of a pure tone (1A) is shown, along with two dynamic sounds, amplitude and frequency modulation (1B and 1C, respectively).*

Over the years we have gone from perceiving tinnitus as a disease of the ear to understanding it as a disorder of the brain. A clear example is that some tinnitus sufferers who have had their auditory nerve severed still have significant tinnitus. While it is still generally believed that insult to the peripheral auditory system is a necessary factor in triggering tinnitus, recent evidence suggests that tinnitus is caused by abnormal activities resulting from cortical re-organization.[4]

Our approach is to introduce cortically interesting sounds to positively alter these abnormal neural activities for the purpose of tinnitus suppression. Different from steady-state sounds such as pure tones and noises, which produce mostly onset and offset responses in the cortex, the temporally patterned sounds we use, such as amplitude- and frequency-modulated signals, produce highly synchronized and robust cortical responses.[5,6] Therefore, we hypothesize that temporally patterned sounds may be more effective than steady-state sounds in tinnitus suppression.

Figure 1 shows the time waveform of a pure tone (1A) and two dynamic sounds, namely, amplitude and frequency modulation (1B and 1C, respectively). Figure 1A is a plot of a pure tone in which both the frequency and amplitude remain constant. Figure 1B is the same pure tone with amplitude modulation: The amplitude is varied over time while frequency remains constant. The degree of the amplitude changes can be described in terms of a modulation rate, or how fast the change in amplitude occurs, and modulation depth, or how much the amplitude increases and decreases. Figure 1C is the pure tone with frequency modulation: The frequency is varied over time while amplitude remains constant. Similarly, how fast the frequency varies over time can be described in terms of modulation rate and how much the frequency varies can be described in terms of modulation depth. These time-varying signals are interesting to the brain and evoke strong cortical responses.

TINNITUS SUPPRESSION

We systematically investigated to see if temporally patterned sounds would suppress tinnitus. These patterned sounds can be delivered acoustically via headphones or electrically via cochlear implants. The subjects were adults with chronic tinnitus lasting longer than 6 months. For acoustic stimulation, subjects were asked to listen to 17 different sounds. The sounds varied by frequency and included pure tones, amplitude-modulated pure tones, frequency-modulated pure tones, and narrow-band-noise. White noise was also included as a control condition.

Each acoustic condition was played randomly and at a level lower in volume (based on loudness ranking) than the subject's perceived tinnitus. For electric stimulation, subjects were asked to listen to 18 different pulse trains. The stimuli varied by stimulation pulse rate, place of stimulation, and loudness level. Again, each electrical condition was presented in a random order.

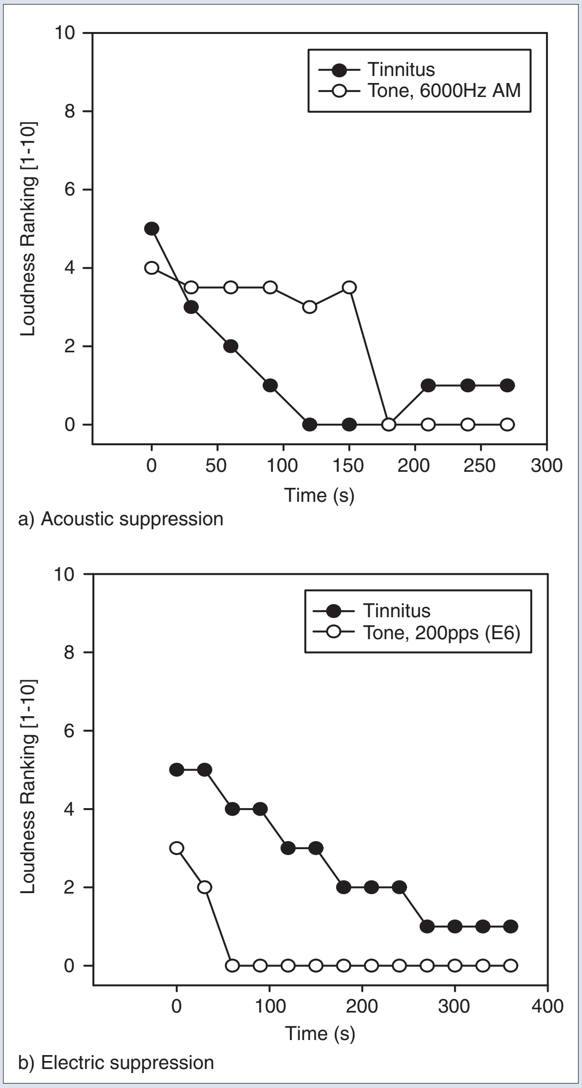

Figure 2. *How one subject receiving acoustic stimulation (top graph) and one subject receiving electrical stimulation (bottom graph) responded to an experimental condition. The graphs plot loudness ranking (y-axis) of the tinnitus percept (filled circles) and loudness ranking of the external stimuli (open circles) over time (seconds, x-axis). In both cases, the loudness of the perceived tinnitus decreased significantly.*

Subjects were asked to listen to the external stimuli and report on the loudness of their tinnitus and the loudness of the external stimuli. Loudness was ranked on a visual analog scale (VAS) from 1 to 10. We defined suppression as a percent reduction in tinnitus rankings over baseline levels, and considered a sound "successful" if it decreased the tinnitus loudness percept by 30% or more.

In the acoustic stimulation condition (top graph in Figure 2), the subject was listening to a 6000-Hz carrier frequency with 40-Hz amplitude-modulation. At baseline, the subject ranked his tinnitus loudness as 5 (medium) on the 1 to 10 VAS. Within 30 seconds, the subject started to experience some tinnitus suppression and by 120 seconds reported being unable to hear his tinnitus. This is an example of 100% suppression [((5 – 0) / 5) * 100 = 100%]. The subject was left listening to the external patterned-sound for the duration of the 3-minute experiment.

In the electrical suppression condition (bottom graph), the subject's cochlear implant was being stimulated in the middle region (electrode 6), with a slow stimulation pulse rate (200 pps), and at a soft level (loudness rating: 3). At baseline, she ranked her tinnitus as 5 (medium) on the 1 to 10 VAS. Within the first minute, the subject began to notice a decline in her overall tinnitus percept. By 270 seconds, she reported her tinnitus was reduced to a 1 (barely audible) on the VAS.

This is an example of 80% suppression [((5 – 1) / 5)* 100 = 80%]. In this example, the subject also experienced loudness adaption of the external stimulus. Toward the end of the experimental condition, the subject was left listening to only her tinnitus, which she reported as barely audible. This is a best-case scenario: Total tinnitus suppression with loudness adaptation to the external sound.

BUT DOES IT WORK?

Does the patterned sound work for all tinnitus sufferers? More than half the subjects in both our experiments achieved tinnitus suppression. In the acoustic experiment, subjects achieving suppression did so with a dynamic sound more often than a steady-state sound. While electric stimulation was successful for many subjects, effective paradigms (the combination of rate/place/level) varied greatly among individuals. When the external sound did not reduce the tinnitus, the subjects reported clearly hearing both the external sound and their tinnitus, typically at constant levels over the duration of the experimental condition.

While we explored only short-term transient effects using patterned stimuli, some patients reported longer-lasting effects. One patient reported "relaxing" and calming effects the afternoon following electrical stimulation from the time she got home until she woke up the next morning. Her tinnitus in the implanted ear had decreased from a "roar" to "a slight whistle" and was barely noticeable. She experienced an unexpected and unusual relief from tinnitus. The patient wondered if "excess stimulation of brain had led her tinnitus to quiet down."

HOW TINNITUS SUPPRESSION IS DIFFERENT

Many different sound therapy approaches have been marketed over the last couple of decades, with varying success. Some of the most widely used therapy approaches for which benefits have been reported include tinnitus masking (wearing an ear-level masking device), Tinnitus Retraining Therapy (which includes counseling and a masking component), and Neuromonics (a music-based approach combined with counseling). For more on these treatments, see Sweetow and Henderson Sabes in this issue.[7] However, no single treatment is 100% effective across all tinnitus sufferers, which may be because tinnitus is multifactorial.

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These therapies use sounds in various ways. Most commonly used, as mentioned earlier, is masking, which typically involves the use of white noise played at a volume equal to or louder than the perceived tinnitus. The goal is to enhance background sounds to make the tinnitus less noticeable. Other approaches, such as Neuromonics and Tinnitus Retraining Therapy,[8,9] use sounds as a tool to desensitize a tinnitus sufferer to the disturbing aspects of their tinnitus rather than to eliminate tinnitus itself.

It is important to draw distinctions between masking and suppression, as the two are often used interchangeably in the literature. Masking can be divided into two types, total and partial, both of which use a broad-band noise as the external stimulus. With total masking, the external sound is played loudly enough that the tinnitus can no longer be heard. However, some patients are unable to mask their tinnitus totally or can do so only at intolerable sound levels. In such cases, partial masking is employed.

With partial masking, the external stimulus is played at nearly equal levels to the perceived tinnitus or at a tolerable level softer than the tinnitus. Some approaches, such as Tinnitus Retraining Therapy, combine partial masking with intensive counseling. Both total and partial masking are psychophysical methods focused on diverting the patient's attention away from their tinnitus, and they are distinct from what we have found in the present suppression study.

In suppression, a sound is presented that is softer than the level of the tinnitus, which may completely eliminate the perception of the tinnitus. The overall level of the sound environment is less than the tinnitus alone. We have also noted that some subjects experience partial suppression in which the lower-level external stimuli only partially reduce the tinnitus percept.

Another important distinction between masking and suppression is the time course of their effect on tinnitus. Masking of tinnitus is typically instantaneous, while suppression of tinnitus takes time to develop and decay (from several seconds to several minutes; see Figure 2 for an example). This suggests different neural mechanisms for the two methods.

The third distinction is that the most effective masker has spectral and temporal properties similar to the perceived tinnitus, whereas the most effective suppressor often has different spectral and temporal properties from the perceived tinnitus.

Our patterned stimuli sound therapy approach is similar to other approaches in that it can provide tinnitus sufferers control over their tinnitus. However, we focus specifically on decreasing, or even eliminating, the tinnitus percept. For acoustic suppression, this treatment may be implemented using a low-cost sound generator such as an MP3 player. For cochlear implant users, this treatment may be implemented with a separate tinnitus-reduction processing strategy incorporated into their cochlear implant processor. Using a patient's own device for electrical suppression or a low-cost device for acoustic suppression makes this tinnitus treatment method more accessible to patients.

TAKE-HOME MESSAGE

Sound therapy has a long history, but it continues to evolve along with our understanding of the neural substrates of tinnitus. While excessive sound can be harmful to the auditory system and can induce tinnitus, sound that is used appropriately can suppress tinnitus.

The mechanisms underlying tinnitus suppression are different from those in tinnitus masking. Masking attempts to divert a patient's attention away from the tinnitus. Suppression is a physiologic process where sounds—in this case, patterned sounds—may likely be modulating the activity of the auditory cortex and interrupting tinnitus generation.

As tinnitus treatments continue to be investigated, patterned-sound therapy holds great promise because it is non-invasive and can provide relief and restore control to those who suffer from tinnitus.

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