Increasing the Effective Use of High-Frequency Spectrum Tinnitus Therapy

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Abstract: A new device and method described here will allow real-time processing of any audio signal (e.g., from a television set) into a high-frequency tinnitus sound therapy stimulus. By simultaneously listening to the unprocessed and processed speech, a patient can enjoy the entertainment while obtaining therapy that appears to be a viable alternative in the treatment of severe disabling tinnitus.

Key Words: neuroplasticity; sound therapy; tinnitus; UltraQuiet

One of the oldest treatments of tinnitus has been broadband sound therapy as a masker [1]. This approach is based on the observation that tinnitus will occur in many individuals at night when the ambient background is lower. In fact, after briefly entering echo-free (anechoic) or sound-attenuated space, self-generated physiological sounds become audible, one of which is usually tinnitus [2]. A logical consideration was to elevate masking as a tinnitus treatment. Hearing aids do this and have proven to be effective in masking tinnitus.

Not all therapy necessarily employs high-frequency spectra sound. In one form, an attempt is made to phase-cancel tinnitus by applying at the tinnitus pitch sounds that are phase-shifted. Though clearly no tinnitus-induced basilar membrane movement can be canceled at 180 degrees out of phase, changing the phase (though not usually 180 degrees) is reported to alter neural tinnitus [3].

High-frequency therapy has proven to reduce tinnitus and alter metabolic activity in brain regions thought to contribute to tinnitus [4]. For tinnitus relief, this approach requires listening to high-frequency modulated sound over a period of weeks. The stimulation has a high-frequency musical quality, but effectiveness is not only based on the spectra but is related to disciplined usage.

We report herein a means to modulate any audio signal in such a fashion to provide high-frequency stimulation. Such an adaptation should increase therapy use and effectiveness.

DEVICE DESIGN GOALS

We aimed to produce a convenient method of high-frequency sound therapy featuring ease of use. It would produce a therapeutic mode that would result in increased compliance. The method is adaptable to any audio-producing electronic source, is reliable, and works in real time. Additionally, it is wireless-compatible.

METHODS

Subjects

Two 21-year-old engineering students served both as experimenters and subjects. Each exhibited normal hearing in the range of 250–20,000 Hz as measured in a sound-attenuated booth. Speech discrimination was obtained over earphones mounted in custom audiocup cranials. *Cranials* are sound-isolating covers for earphones that were modified to accept the earphones used in this study. Intelligibility was found to be 100% at 65 dB HL in quiet.

Stimulus

The tinnitus treatment stimulus was produced using Kyma Version 6 software with a Capybara 320 Sound Computation Engine. The stimulus consisted of speech digitally processed and used to modulate one or two signals in the 10- to 22-kHz range. The processed speech

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was played through a custom-made amplifier into a piezoelectric bone conduction transducer. The transducer was held in place on the subject's mastoid bone by a headband. The bone conduction transducer was placed on the right mastoid but was heard binaurally [5]. Unprocessed speech was presented simultaneously through earphones.

The effects of high- and low-pass filtering on speech intelligibility were determined. The mean performance is presented in Figure 1. With increasing low-pass filtering, intelligibility dropped in an expected fashion. The reverse was true of high-pass filtering. The point of equal intelligibility was determined to be about 1200 Hz.

To prepare the speech for tinnitus therapy, the low-pass filter was set with a cutoff frequency of 6 kHz and the high-pass filter with a cutoff frequency of 2 kHz. Thus, the resulting passband was 2–6 kHz. This passband was chosen to minimize intelligibility but also to capture the envelope fluctuations that are characteristics of high-frequency consonant sounds. This is considered the speech analogy to the filter and processed music used with the UltraQuiet system for tinnitus relief. One or two carrier frequencies can be used, but the data presented here were obtained with the carrier set at 20 kHz (Fig. 2A).

The carrier is phase-suppressed in the modulator. The output of the modulator is the speech passband plus the carrier and the speech passband minus the carrier. This signal is amplified and presented to the mastoid. The general scheme is presented in Figure 1B. A parallel unprocessed speech line is sent to earphones.

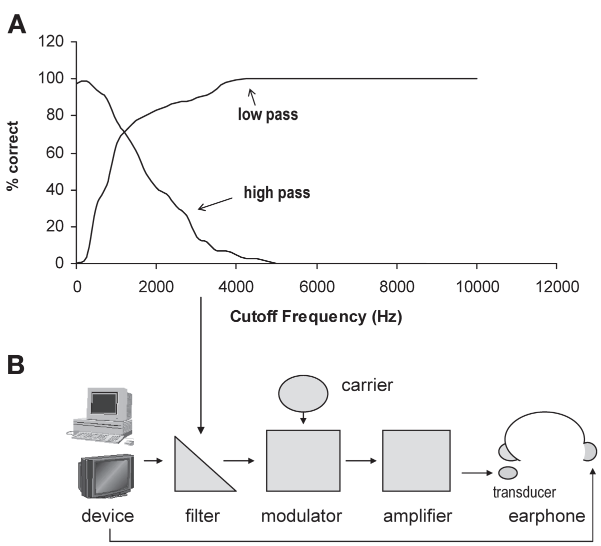

Figure 1. (A) Speech intelligibility is determined for various degrees of low- and high-pass filtering. The objective was to determine a passband that carried the fluctuations in the speech spectrum that could be modulated with a low level of intelligibility in and of itself. (B) The speech passband that is selected is further filtered (as would be the audio output of a device such as a television) and then modulated on a high-frequency carrier (e.g., 20 kHz) prior to amplification and delivery to a bone conduction transducer. A parallel unprocessed line is fed from the device to air-conduction earphones.

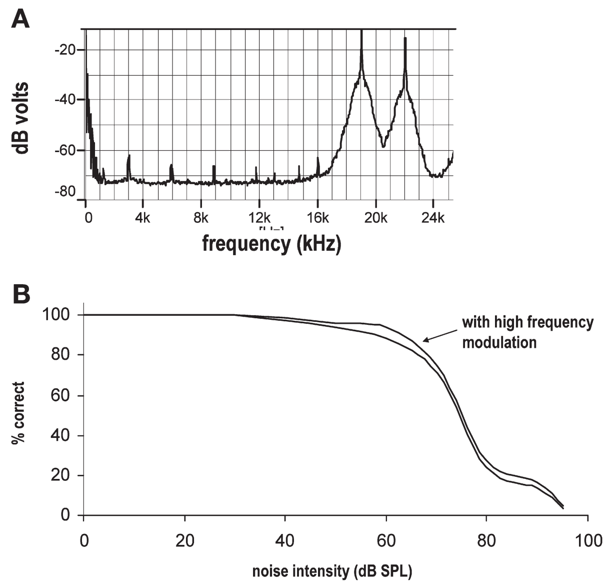

Figure 2. (A) The spectrum of the processed speech stimulus used in this study, which is comparable to that of the UltraQuiet system. Speech from any audio device can be converted in real time to provide tinnitus high-frequency therapy. (B) The intelligibility of unprocessed speech and unprocessed plus processed speech as a function of noise level revealing the high-frequency stimulation does not negatively alter speech intelligibility, which is important in using a TV as the therapeutic sound device.

Procedure

The subjects were seated in a sound-attenuated chamber wearing earphones (receiving unprocessed speech) and a bone conduction transducer on the right mastoid (receiving processed speech). Two speakers generated broad-spectrum noise from 20 to 96 dB sound pressure level (SPL). The subjects listened to either unprocessed speech with varying degrees of masking (up to 96 dB) or the combination of unprocessed speech by air conduction and the processed speech segment by bone conduction (BC), again in various levels of noise. All speech stimuli were presented at a listening level (65 dB) comfortable for each subject. Each subject repeated the word heard.

RESULTS

Perception of unprocessed (natural) speech and unprocessed speech plus processed speech (by BC) was at 100% correct until the noise exceeded 50 dB SPL. The intelligibility of the unprocessed speech and the unprocessed speech plus the processed speech gradually declined as the noise exceeded the intensity of the speech (>70 dB SPL). The addition of the modulated high-frequency components of speech (i.e., the processed speech) allowed for better understanding in high noise. At 96 dB SPL of noise, performance for both was less than 10%, with the unprocessed plus the processed speech remaining superior (see Fig. 2B). The presence of the processed speech does not lower intelligibility; in fact, it improves it.

The Capybara 320 Sound Computation Engine was replaced by wideband multiplication and a summing analog modulator circuit with easy dial-in carrier frequencies (Biosecurity Technologies Inc., Richmond, VA). This module accepts inputs from any audio device and outputs to a BC amplifier and transducer (UltraQuiet design or compatible system). All the processing is pre-engineered in the module. Wireless connection to any audio device is also possible.

DISCUSSION

Any speech source, live or recorded, when modulated on a high-frequency carrier, will result in a spectrum similar to that of the UltraQuiet system developed to provide tinnitus relief [4,6,7]. This system will convert any audio listening experience into high-frequency sound therapy for tinnitus, thus removing the drudgery of specific recorded therapy. The key is to split the output from the audio device into two channels. One runs to a loudspeaker or earphone while the other is sent to the modulator and on to the BC transducer. The subject wears the transducer and listens to the nonprocessed air conduction sound directly from a loudspeaker or earphones. The audio device volume control should be sufficient to control intensity.

High-frequency sound therapy is effective in tinnitus control [4,6,7]. Studies of high-frequency stimulation for tinnitus prevention are very encouraging in that, in the cat model, such therapy maintains normal spontaneous auditory neuron firing rates and maintains the cortical frequency map [8–11]. Clinically, this means that the map can be treated, as it were, by external sound that has already been found to be a viable treatment modality for humans with severe disabling tinnitus [4,6,7].

In the strictest sense, the real-time modulator will provide high-frequency masking of tinnitus. More important, it will provide the stimulation needed for neuroplastic adjustment by the brain. Neuroplasticity is emerging as a central factor in severe disabling tinnitus [4]; it is the process by which the brain changes its neural processing in the presence of tinnitus, changes that include the balance of inhibition-excitation and establishing new connections in the brain [12–14]. One such change is reorganization of the auditory cortical map, resulting in an increase of the tinnitus frequency area in some subjects [15]. This expansion, of course, increases activity in the limbic system and other sites in the tinnitus final common pathway [16].

CONCLUSION

A custom module can convert any audio signal, including speech, into high-frequency sound therapy for tinnitus relief. The value of a real-time device is that it can be used when listening to recreational sources, thereby reducing the need for dedicated therapy scheduling. The end result should be more efficient use of time and, presumably, more effective tinnitus therapy.

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