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Use of High-Frequency and Muscle Vibration in the Treatment of Tinnitus

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Abstract: Although tinnitus is defined as an internal auditory sensation, external auditory stimuli can mask tinnitus under some circumstances. High-frequency vibration delivered as bone conduction stimulation is effective in masking high-pitched tinnitus. In this preliminary report, somatosensory stimulation in the form of low-frequency muscle vibration can also mask high-frequency tinnitus. Somatosensory stimulation provides fast, immediate relief, whereas high-frequency vibration provides longer-lasting benefit. Either modality can stand alone or can be used in conjunction for tinnitus treatment. A clinically feasible technique has been identified for more wide-scale evaluation.

Key Words: hallucinations; high-frequency vibration; somatosensory; tinnitus; tinnitus model

In a well-known experiment, von Bekesy [1] canceled the perception of an air-conducted pure tone with a second tone of the same frequency presented simultaneously to the ear by bone conduction. The trick was to alter the phase, canceling the stimulation in the cochlea. It is also well-known that reversing the phase of the masker can result in perception of the tone previously masked, even in children [2]. That masking effect is central in the brainstem [2]. Masking is a powerful auditory tool, but can an external sound mask an auditory image (i.e., tinnitus)?

The answer is "sometimes," because not all tinnitus can be masked (approximately 11%) [3,4]. When masking occurs, the mechanism is not the same as peripheral masking [5–7]. For example, perhaps one-third of people with tinnitus mask with external tones having pitch characteristics similar to those of their tinnitus; approximately another one-third achieve masking with any sound frequency; and approximately 20% achieve masking only at high intensity levels [8]. Because some patients choose maskers that contain frequencies that only partially overlap with their tinnitus pitch, apparently masking can be effective regardless of whether the masker contains the tinnitus frequencies [9].

This outcome is just the opposite in cochlear masking. The more a masker is frequency-separated from the tone to be masked, the less likely it is that masking will occur. It is important that residual inhibition appears to be less if maskers do not contain the tinnitus frequencies, which hints that tinnitus frequencies are perhaps important after all [10].

Many cases of tinnitus are characterized by mild to moderate high-frequency hearing loss with tinnitus pitch matches of 4 kHz or higher. If the extent of residual inhibition is, in fact, related to having tinnitus frequencies in the masker, high-frequency components should be critical. Goldstein et al. [10] reported successful masking and lengthy residual inhibition using high-frequency pulse patterns delivered by bone conduction. Bone conduction is an important modality in that the middle ear acts as a low-pass filter, rendering achievement of distortion-free high-frequency stimulation difficult in the presence of hearing loss.

High-frequency bone conduction may not be effective if the tinnitus is not high-pitched and hearing loss is severe. This leaves open the possibility that masking supplementation with lower-frequency vibration stimulation could be an effective alternative. Preliminary

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evidence exists that vibrotactile therapy can indeed reduce tinnitus loudness by half [11] in a small sample. Encouraged by this outcome, we will provide a rationale to include vibrotactile stimulation in the treatment of tinnitus.

Physiological support for this approach is offered by Kanold and Young [12], who studied the somatosensory input into the auditory system, at the first synapse, by stimulating the deep muscles of the pinna. Deep motor stretching and vibration resulted in inhibition of neurons in the dorsal cochlear nucleus. Could similar vibrotactile stimulation alter human tinnitus by increasing dorsal cochlear nucleus inhibition and, if so, what delivery system would be feasible for clinical use?

METHODS

We tested high-frequency bone conduction and vibrotactile muscle stimulation in a total of 15 patients. All those receiving high-frequency stimulation had moderate high-frequency hearing loss and a pitch match that ranged from 6 to 14 kHz. Those in the high-frequency stimulation group consisted of the first 10 patients who elected to participate in an 8-week trial of a commercially available tinnitus-masking device, the UltraQuiet device. Therapy is based on high-frequency pulsed patterns recorded on a compact disk (CD) and delivered to the mastoid as very-high-frequency (>6 kHz) vibration. The stimulation is perceived as bone-conducted sound and is not felt. Essentially, the procedure of Goldstein et al. [10] was replicated clinically at four different dispenser sites. In addition, four otologically normal young adults (mean age, 20 years) participated in judging the dynamic range (detection to annoying) of the muscle vibration. An additional person, selected because of his ability to modulate the loudness of tinnitus through motor action (clenching teeth and fists), acted as a juror to assess masking effectiveness and acceptability of the various low-frequency muscle stimulators.

Muscle stimulation was achieved using low-frequency vibration with magnetostriction, or vibration provided by one of two commercially available transducers. The frequency response of each transducer was determined by feeding in white noise and recording the response on a film accelerometer input (Model EPA-102; Piezo Systems Inc., Cambridge, MA) to an HP 35670A Dynamic Signal Analyzer (Hewlett-Packard, Palo Alto, CA). The amplitude was recorded in relative decibels of volts. Tactile stimulation of the pinna consisted of light cutaneous brushing. Low-frequency muscle vibration consisted of swept tones from 50 to 110 Hz recorded on a CD and delivered to the postauricular muscle using either a magnetostriction transducer, Model MFR OTY77 (Etrema Products Inc., Ames, IA) or audiological vibrators (Model B-71, Radioear, New Eagle PA; Model VBD 32, Tactaid Audiological Engineering Corp., Somerville, MA). Figure 1 depicts the Radioear and Tactaid vibrators and a standard CD player. No additional amplification other than the internal amplifier was required to modulate tinnitus; however, an external amplifier can be used for more output if needed. The frequency spectra of the two vibrators are portrayed in Figure 2. The Tactaid has a lower resonance. Muscle vibration was applied by the patient using one of the three hand-held transducers at 5 dB sensation level.

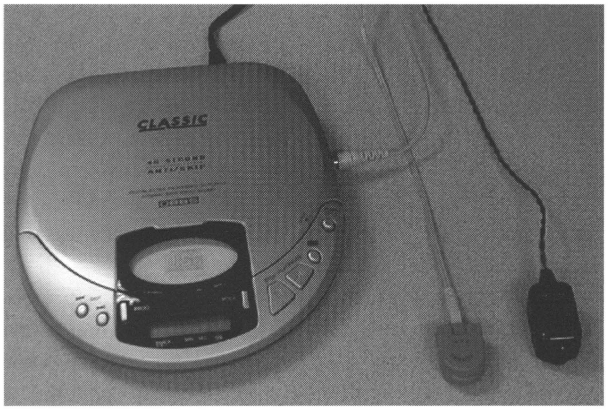

Figure 1. The Radioear and Tactaid transducers are shown with the compact disk player. For stimuli in the 50- to 110-Hz range, this is a plug-and-play arrangement; no additional signal enhancement was required.

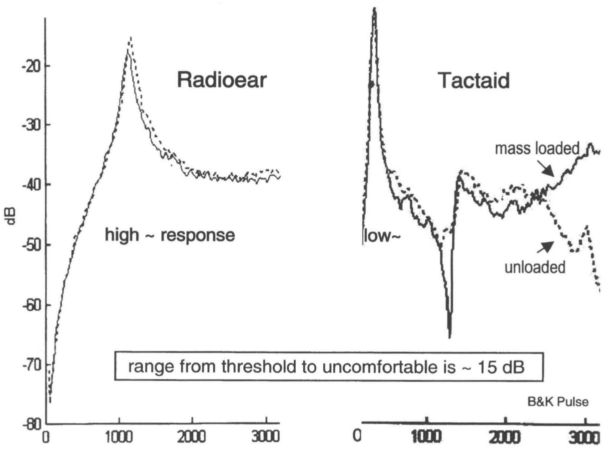

Figure 2. Frequency response of the two commercially available transducers—the Radioear and Tactaid—used for muscle vibration. The Tactaid had a lower fundamental resonance, but both were acceptable. For the frequency range of interest (50–110 Hz), mass loading of the head did not influence the results.

Measurements of the muscle vibration dynamic range (threshold to uncomfortable) were recorded in the four otologically normal young adults. Thresholds were determined by the method of limits. Movement and replacement of the transducers could alter threshold; thus, extreme care was used in testing. Subjects were instructed over three trials to increase the vibration from threshold (just detectable) until the sensation was uncomfortable but not intolerable.

One additional participant, who could reliably modulate his tinnitus intensity by the muscular maneuvers of clenched teeth or fists, evaluated the effectiveness and acceptability of the muscle vibration systems to modulate tinnitus loudness.

RESULTS

Six of the ten patients given the high-frequency bone conduction stimulation experienced relief after one session and continue to report relief after 2 months of usage. Complete tinnitus masking was reported in 40% and partial masking in 10%, whereas 40% did not continue owing to lack of relief. One patient reported no masking but did experience tinnitus relief. All patients had no or marginal benefit with air conduction maskers and were not currently on any pharmacological therapy for tinnitus. Two found their participation in habituation programs ineffective.

Vibration to the postauricular muscle was easily detected using each of the three vibrators. To reach discomfort, the intensity was raised approximately 15 dB for each of the three vibrators. The person who could perform two motor maneuvers to modulate tinnitus served as the juror for pinna brushing and three vibrotactile delivery systems. Tinnitus modulation (pitch or loudness) from light brushing of the pinna was not observed; therefore, light cutaneous stimulation was completely ineffective in tinnitus management. Motor maneuvers (clenching teeth and fists) did modulate the loudness of tinnitus but only during the maneuver; thereafter, the tinnitus returned to its previous loudness. Muscle vibration induced by the magnetostrictive device was effective in tinnitus masking, but the transducer became uncomfortably warm rapidly in the session (after approximately 10 minutes). For that reason and because of the inherent high voltage used, the device was not favored. In contrast, the two standard vibrators were found effective in delivering muscle vibration. These data are presented in Table 1. Further, the subjective impression of tinnitus loudness was modulated and masked by both transducers. The preference for the Tactaid over the Radioear was based on the former's lower-frequency response, thus producing less radiated sound in the air.

DISCUSSION

Is it possible that tinnitus masking is not just masking after all? For example, if a tone is paired with a light for a sufficient number of times, the presentation of the light alone will evoke the sensation of the tone. The sensation of the tonal image is identical to one produced by a physical stimulus [13]. In that case, can a physical tone mask an imagery one? If the answer is yes, maskers would be popular in the treatment of auditory hallucinations associated with schizophrenia. Clear evidence suggests that external sound does, however, produce relief from auditory voice imagery. Listening to personal stereos can result in hallucinatory inhibition, but the effect is attributed to refocusing attention on the outside world and not to masking [14–17]. Presumably, the frequency content of a stereo would have the frequency and intensity requirements for masking but, even if stereo frequencies only partially overlapped, spectral content would be irrelevant if attention and not masking were important.

Alternatively, external sound in some way may interfere with previous auditory conditioning [13]. Shulman's final common pathway in severe tinnitus involving the medial temporal lobe system includes reference to "paradoxical memory" of an aberrant auditory signal, possibly produced by conditioning [18]. Is what is termed *auditory conditioning* in hearing actually the establishment of a memory? The parallel between hearing

Table 1. Masking by High-Frequency Stimuli and Vibration in 11 Subjects

Treatment	Number	Masking	Modulation	No Masking	Residual Relief
High frequency	10	5	—	5	6
Magnetostriction	1	1	—	0	0
Radioear	1	1	—	0	0
Tactaid	1	1	—	0	0
Radioear/Tactaid BC	1	0	—	0	0
Light brushing	1	0	—	0	0
Motor maneuvers	1	0	1	0	1

"voices" and tinnitus suggests some overlap in auditory processing [18–22]. The masking or interference mechanism for both may also include the cerebellum [23]. Brain-imaging perfusion asymmetries in the cerebellum have been demonstrated in 60–70% of patients with tinnitus of the central type [23]. The central function of the cerebellum was initially perceived as a "breaking action" and has been modified to include both GABAergic (braking) and glutaminergic (acceleration) functions [24]. The external nucleus of the inferior colliculus (in the cat) has afferent connection to the cerebellum and the somatosensory system [25]. Sensory convergence in the cerebellum and in the medial temporal lobe system and some areas of the thalamus and cortex can account for central interaction of vibration and tinnitus. Support for the hypothesis of an interneural tinnitus network [26] is found in the preliminary magnoencephalographic recordings in waking tinnitus patients that reveal a dynamic thalamic primary auditory cortical interaction resulting in increased low-frequency theta activity [27].

The preferred treatment of external auditory stimulation in hallucinations is redirecting the patient's attention outward; thus, the long-term habituation of sensory conditioning is not masking, but both use external sound as a perceptual interference. The initial goal in tinnitus is masking and, subsequently, long-term residual inhibition. Shifting attention is not masking, and habituation is not exactly inhibition. In the case of high-frequency bone-conducted stimulation, not all patients with a similar profile experienced immediate masking. In fact, the present data and that of Goldstein et al. [10] would suggest that immediate masking is a positive predictor of long-term relief, although not in every case. The overall percentage of tinnitus relief was 60%. One patient did not experience masking but indicated reduction in tinnitus awareness. This patient experienced tinnitus relief for 3 months, possibly suggesting that this is not a placebo effect; however, he remained in counseling, so a placebo effect cannot be excluded. The other four patients exhibited no masking and no long-term relief.

Broadband bone conduction masking appears effective in masking, particularly in the presence of some conductive hearing loss [28]. Even if the masker contains the tinnitus frequencies, residual inhibition does not necessarily occur. Some other central factor, as also true in hallucinations, must be involved in tinnitus persistence in the presence of external auditory interference stimulation [18].

Muscle vibration consistently masked or interfered with the perception of high-frequency tinnitus in the one patient chosen because of his ability to modulate tinnitus with a motor maneuver. This outcome can be viewed as somatic masking, and Levine [29] estimates that this ability is present in approximately one-third of tinnitus patients. Postauricular muscle vibration masked tinnitus loudness. The effect was not likely due to bone-conducted hearing, because the effect disappeared when the transducer was placed on the mastoid. Light touch or cutaneous stimulation was ineffective, suggesting that touch or refocusing attention was not the responsible mechanism. Tinnitus masking was likely due to multisensory interference or, specifically in this case, somatosensory (C2) inhibitory input to the cochlear nucleus (CN) [8]. Cochlear hearing loss results in less neural tonotopic input to the CN. As a result, the CN increases neural spontaneous firing, and the output of the inferior colliculus and the cortex is enhanced [18,21–23]. Adding inhibition via the somatosensory system could conceivably alter higher neural processing that contributes to the physiological basis of tinnitus. It is also possible that activation of multisensory neurons higher in the colliculus, parietal cortex, or cerebellum play a role in somatosensory masking [18,23,26]. Tinnitus can be modulated in intensity by the motor maneuvers of clenching the teeth and fists [11,29]. In the now classic study, Brick and Kinsbourne [30] reported that opening of the mouth wide (80%) and clenching of the fists (8%) abolished (masked or interfered with) auditory hallucinations in 39 patients. Seemingly, schizophrenia and tinnitus also share a somatosensory modulation.

The use of somatosensory stimulation for fast, immediate tinnitus relief, when possible, would likely afford some patients control over tinnitus, which may over time reduce their tinnitus affect. Muscle vibration could also be used in conjunction with high-frequency bone conduction stimulation to promote short-term and longer-term effects. Since neither high- nor low-frequency vibration (especially with the Tactaid transducer) interferes with the speech spectrum (no upward spread of masking), treatment time is not limited by periods of limited communication demands. Given the shared neurobehavioral substrate of hallucinations and tinnitus, psychiatric applications of high- and low-frequency vibration seem promising.

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