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# ALTERNATING CURRENT AT THE EARDRUM FOR TINNITUS REDUCTION

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The effectiveness of alternating current (AC) stimulus on tinnitus was investigated in 10 patients who reported constant tinnitus in at least one ear. Patients were first screened to determine their responsiveness to electrical stimulation in relation to tinnitus reduction. The responsive patients were then stimulated for a treatment period of at least 10 min, during which time the tinnitus was measured. The AC stimuli (62 Hz to 8000 Hz) were applied to the eardrum of the patients via a specially constructed electrode. Psychophysical measurements (pitch matching, loudness matching, minimum masking level, and loudness and annoyance scaling) of the patient's tinnitus were made before and after electrical stimulation. Minimal masking level was determined and tinnitus scaling was performed during the treatment period. Electrical stimulation was effective in tinnitus reduction in 5 of the 10 patients. These 5 patients reported that the loudness and the annoyance of their tinnitus decreased during the treatment period. These observations were consistent with psychophysical measures of contralateral broadband noise masking. Poststimulation reduction in tinnitus varied in duration among individuals from 40 s to about 4 hr.

The debilitating nature of tinnitus has prompted researchers to seek novel treatments. One of these approaches, electrical stimulation, can be dated as far back as 1801. Grapengiesser (cited by Vernon, 1987) established that anodal (+) current could reduce tinnitus in some patients during the course of stimulation. These findings were replicated by Hatton, Erulkar, and Rosenberg in 1960.

It was not until the 1970s that electrical stimulation again received attention. House (1976), Pialoux, Chouard, Meyer, and Fugain (1974), and House and Brackmann (1981) observed that many of their cochlear-implant patients experienced relief from tinnitus when using their implants. Studies to examine the effects of stimulus parameters and stimulation sites on tinnitus reduction were undertaken by other investigators. Stimuli included pulsed direct current (DC) (Aran & Cazals, 1981; Cazals, Negrevergne, & Aran, 1978; Portmann, Cazals, Negrevergne, & Aran, 1979); low-to-mid-frequency alternating current (AC) (Graham & Hazell, 1977; Hazell, Graham, & Rothera, 1985); and high frequency AC (Shulman, 1985). Stimulation sites included the promontory and the round window (Aran & Cazals, 1981; Cazals et al., 1978), the external ear canal (Chouard, Meyer, & Maridat, 1981), and the pre- and post auricles of the external ear (Engleberg & Bauer, 1985; Vernon & Fenwick, 1985). The criteria for success were not always defined clearly, but success rates typically ranged from 13% (Graham & Hazell, 1977) to 80% (Engleberg & Bauer, 1985).

Although these studies showed that electrical stimulation can be effective in reducing tinnitus, its use as a clinical tool is still questionable. The chief concerns are its invasive nature, the short-lived relief, dizziness, and the possible side effects of DC stimulation, such as tissue damage (Hatton et al., 1960). The failure of some investigators to report either the duration of the reduction or the criteria used to measure reduction, along with the use of patients with fluctuating tinnitus, renders it difficult to determine the usefulness of electrical stimulation for tinnitus reduction.

The effect of AC stimulation from 62 Hz to 8000 Hz using a noninvasive eardrum electrode was studied in this preliminary investigation. An eardrum electrode was used, assuming that the electrical stimulus could be transmitted more efficiently through the ossicles to the inner ear. A possible advantage of this approach over cutaneous stimulation is that less current would be needed to reduce the tinnitus magnitude. The use of lower current levels means that fewer cutaneous pain receptors would be stimulated.

The purposes of this experiment were to (a) determine the feasibility of using AC in achieving tinnitus reduction, (b) identify the stimulus conditions that yield maximum tinnitus reduction, and (c) identify patient characteristics that might predict therapeutic benefit from such a procedure.

## METHOD

### SUBJECTS

Five male and 5 female patients seen for tinnitus and ear disease in the Department of Otolaryngology at the University of Iowa Hospitals and Clinics volunteered as subjects. All reported relatively constant, nonfluctuating



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TABLE 1. Descriptive information. The first 5 patients did not respond (nonresponders, NR) to electrical stimulation during the screening phase, and the last 5 patients reported tinnitus reduction (responders, R) to electrical stimulation during the screening phase. Entry under each category was reported by the patient on a questionnaire.

| *Patient* | *Age (yrs.)* | *Sex* | *Location* | *Ipsilateral (test) ear* | *Tinnitus No. of sounds* | *Probable cause* | *Tinnitus duration (yrs.)* | *Description* |
|---|---|---|---|---|---|---|---|---|
| NR1 | 32 | M | bilateral, worse in right | R | 2 | unknown | 32 | whistling |
| NR2 | 39 | F | bilateral, equal | L | 3 | fever/flu | .9 | steam whistle |
| NR3 | 70 | F | bilateral, equal | L | 2 | presbycusis | 5 | ringing |
| NR4 | 50 | F | bilateral, equal | R | 1 | car accident | 25 | whistling |
| NR5 | 72 | F | bilateral, equal | L | 3 | presbycusis | 15 | ringing |
| R1 | 39 | M | bilateral, worse in left | L | 4 | noise induced | 18 | ringing |
| R2 | 48 | M | unilateral, right ear | R | 3 | noise induced | 19 | rushing |
| R3 | 26 | F | bilateral, worse in left | L | 5 | car accident | 10 | ringing |
| R4 | 70 | M | bilateral, worse left of head | L | 1 | presbycusis | 15 | hissing |
| R5 | 38 | M | bilateral, worse in right ear | R | 1 | noise induced | 16 | musical note |

tinnitus in at least one ear. Table 1 summarizes the identifying information on each patient. Table 2 summarizes the prestimulation audiometric thresholds for the ear that was stimulated.

## PROCEDURE

The ear with the louder tinnitus was chosen as the test ear; this will be referred to as the "ipsilateral" ear. In patients with bilateral, equally loud tinnitus, the ipsilateral ear was chosen arbitrarily (NR2, NR3, NR4, NR5). The other ear was defined as the contralateral ear. For all conditions with electrical stimulation to the ipsilateral ear or acoustic stimulation to the ipsilateral or contralateral ear, the patients were required to base their judgments on the tinnitus in the ipsilateral ear.

There were four phases in the experiment: pretreatment, screening, treatment, and posttreatment. The psychophysical characteristics of the tinnitus in the ipsilateral ear were determined during the pretreatment phase. In the screening phase, the ipsilateral ear was stimulated with various stimulus waveforms at frequencies from 62 Hz to 8000 Hz to determine if electrical stimulation could change the patient's tinnitus in that ear. Patients who responded to electrical stimulation were further stimulated with selected optimal stimuli for 10 min in the treatment phase. During this time, psychophysical measurements were made of the patients' tinnitus. Characteristics of the tinnitus for all the patients were again determined during the posttreatment phase. All measurements were completed on the same day.

### *Pretreatment Tinnitus Measurements*

Patients' tinnitus was characterized using a Norwest Acoustic Tinnitus Synthesizer (model SG-1) and Koss HV/XLC earphones with a flat frequency response (± 3 dB to 15,000 Hz, and ± 6 dB to 20,000 Hz). Stimuli were calibrated on a mannequin (KEMAR) with a Zwislocki ear simulator. Patients completed pitch matching, loudness matching, and masking level tasks. Each measurement was performed at least three times. Results of these measurements are shown in Table 3.

TABLE 2. Hearing thresholds in dB HL (ANSI, 1969) in ipsilateral (test) ear.

| *Patient* | *Ear* | *Frequency (Hz) 250* | *500* | *1000* | *2000* | *4000* | *8000 Hz* |
|---|---|---|---|---|---|---|---|
| NR1 | R | 20 | 15 | 20 | 15 | 50 | 75 |
| NR2 | L | 20 | 20 | 15 | 25 | 65 | 50 |
| NR3 | L | 10 | 10 | 5 | 20 | 30 | 75 |
| NR4 | R | 15 | 15 | 10 | 10 | 85 | >95 |
| NR5 | L | 15 | 10 | 15 | 45 | 55 | 70 |
| R1 | L | 10 | 10 | 25 | 50 | 45 | 40 |
| R2 | R | 0 | 5 | 0 | 0 | 15 | 15 |
| R3 | L | 5 | 15 | 20 | 65 | 100 | >95 |
| R4 | L | 25 | 15 | 20 | 25 | 45 | 75 |
| R5 | R | 45 | 55 | 35 | 20 | 30 | 70 |

TABLE 3. Measurements made during the pretreatment phase. The category "Masking Recovery Pattern" is from the classification of Tyler et al. (1984). "CNM" means that the tinnitus could not be masked by the masker. Standard deviations for the pitch and loudness matches are given in parentheses.

| *Patient* | *Masking recovery pattern* | *Mean ipsilateral pitch match frequency (Hz) and standard deviation* | *Mean ipsilateral loudness match at 500 Hz (dBSL) and standard deviation* |
|---|---|---|---|
| NR1 | CNM | 7084<br>(1380) | 66<br>(1) |
| NR2 | CNM | 8660<br>(53) | >85<br>NA |
| NR3 | C | 5834<br>(400) | 38<br>(3) |
| NR4 | A | 3773<br>(222) | 11<br>(0.6) |
| NR5 | C | 4970<br>(949) | 19<br>(1) |
| R1 | C | 9430<br>(1157) | 28<br>(0.6) |
| R2 | C | 10858<br>(2591) | 4<br>(0.6) |
| R3 | D | >20000<br>NA | 14<br>(1.7) |
| R4 | C | 2260<br>(222) | 4<br>(2.9) |
| R5 | C | 10140<br>(1926) | 21<br>(0.6) |

In the pitch-matching task, patients adjusted the frequency of a 1-s, 50% duty-cycle sinusoid until its pitch matched the dominant pitch of the tinnitus. The comparison sinusoid was adjusted to a comfortable listening level. The frequency of the comparison tone was adjusted in ascending and descending fashions to avoid octave confusion. The measure was repeated five to seven times. The mean of those estimates was recorded as the tinnitus pitch match.

Patients adjusted the intensity of a 500-Hz pulsed sinusoid to match the loudness of the tinnitus. The frequency at the tinnitus pitch match was not used for loudness matching because the pitch of the tinnitus may be altered by electrical stimulation (Engleberg & Bauer, 1985). Consequently, the patient may be matching the loudness of a tinnitus pitch-matched frequency to the pitch of the "altered" tinnitus. A standard frequency should be used for tinnitus loudness matching for ease of comparison. The 500-Hz tone was chosen because most patients (except R5) had relatively normal thresholds at that frequency.

Patients also scaled the loudness and the annoyance of the tinnitus by marking on two separate lines that were labelled "No tinnitus" at one end and "The worst tinnitus I can imagine" at the other end. The distance between "no tinnitus" and the patients' mark indicated their tinnitus perception.

Minimum Masking Level (MML), the level of a pulsed broadband noise (100–20,000 Hz) necessary to mask the tinnitus, was determined in the test ear, using the method of adjustment when stimuli were presented both ipsilaterally and contralaterally. In addition, post-masking residual inhibition produced by a one-minute, continuous broadband noise at 15 dB above the MML was measured in the ipsilateral ear. This level, instead of the conventional 10 dB above the MML, was used to produce more residual inhibition. Post-masking recovery functions were classified using the system of Tyler, Conrad-Armes and Smith (1984).

An otolaryngologist placed an electrode on the eardrum of the patient's ipsilateral ear. The electrode consisted of a flame-balled platinum-iridium wire encased in 1-mm diameter Dow-Corning Silastic® Medical grade tubing with the flame ball embedded in a piece of sponge soaked in 3M Red Dot® 2248 solid conductive electrode gel. The tip of the sponge touched the eardrum (Stypulkowski & Staller, 1987). A 3M Tenzcare™ 6225 self-adhering electrode was applied on the forehead to be used as the reference. All patients tolerated the procedure well. Only mild discomfort was reported when the electrode was first placed.

### *Screening*

A custom signal generator with an isolated constant current source was used for stimulation. Stimulus generation and delivery were controlled by a DEC 11/23 computer system. Waveforms included sine, triangular, and square waves at octave frequencies from 62 Hz to 8,000 Hz. The maximum current output was 2 mA.

Patients were instructed to report when they could just detect the presence of the electrical stimulus (i.e., threshold), the associated sensation at suprathreshold level, and whether the tinnitus in the ipsilateral ear changed in loudness, pitch, or quality during the stimulation. Stimulus frequencies were presented from low to high (i.e., 62 Hz first), and stimulus intensity at each frequency was presented in an ascending order. Trials with a specific

frequency were terminated when the patient reported discomfort, when a stable change in the tinnitus was reported, or when the output limit of the system was reached. Trials at another frequency were started only when the patient reported that the tinnitus had returned to its normal level.

All three waveforms were used to determine if stimulus waveform could affect the outcome. In half the patients, a sinusoid was used first, followed by triangular and square waveforms. The other half of the patients were tested with square wave first, followed by triangular and sine waves. This procedure took approximately 1 to 2 hours. The electrodes were removed from the nonresponding patients after the screening phase.

Placebo trials were carried out on the first 2 patients (R5, NR3), who were asked several times during the session if a change in the tinnitus was perceived when electrical stimulus was withheld. However, the patients were typically aware when the stimulus was present (because there was usually an auditory or nonauditory sensation). Therefore, an adequate control was not possible. Consequently, placebo trials were omitted for later patients to allow time to examine the effectiveness of different frequencies and waveforms.

### *Treatment*

Patients who reported tinnitus reduction in the screening phase proceeded to the treatment phase. During this phase, patients were stimulated with different stimulus waveforms and were instructed to indicate the current level that provided maximum tinnitus reduction. The frequencies and waveforms that yielded the maximum tinnitus reduction with the lowest current were chosen as the optimal stimuli. Patients were stimulated with selected optimal stimuli (frequency, waveform, and current level) for 10 min each. The stimuli used can be found in Table 5.

Tinnitus loudness and tinnitus annoyance scaling, and the MML for a broadband noise presented in the contralateral ear to mask the tinnitus in the ipsilateral ear, were determined during stimulation. The duration of tinnitus reduction was recorded for each stimulus.

### *Posttreatment Tinnitus Measurement*

The electrodes were removed from the responsive patients after the treatment phase. Poststimulation tinnitus measurements were made either after the patients reported that the tinnitus had returned to "normal," or one half-hour posttreatment, whichever occurred first. The same psychophysical measures employed during prestimulation were used.

## RESULTS

The effectiveness of electrical stimulation was evaluated from psychophysical measurements made during the screening and treatment phases.

### *Screening*

Table 4 summarizes patients' subjective responses to electrical stimulation during screening. Five patients (nonresponders, NR) reported no change in their tinnitus perception during stimulation, and 5 patients (responders, R) reported change.

All nonresponders reported a nonauditory sensation in response to the applied current. However, 3 responders also reported nonauditory sensations. These sensations included feelings of "pressure," "blockage," and "tingles."

Most patients reported that their tinnitus had low- and high-pitch components. In general, patients (R1–R4) who experienced tinnitus reduction reported a reduction in the low-pitch component of their tinnitus; this occurred for all stimulus frequencies that were effective in tinnitus reduction, and at a current level lower than that required to reduce the high-pitch tinnitus components. Descriptors used by the responders during stimulation included "softer" (all responders), "muffled" (R2), "disorganized" (R3), and "wavering high-pitch sound" (R2).

Stimulus frequencies that were effective in tinnitus reduction varied across individuals and did not appear to be related to the patients' audiograms or dominant tinnitus pitch match frequency. The optimal stimulus current to reduce tinnitus also differed among individuals.

### *Treatment*

Table 5 summarizes the results obtained during the treatment phase. The percent reductions in tinnitus loudness and tinnitus annoyance ratings during stimulation were determined by dividing the difference between the before and during treatment ratings by the ratings obtained before the treatment and multiplying by 100. Electrical stimulation was effective in lowering the tinnitus annoyance or its loudness by at least 33%. In 2 patients, (R2 and R4), electrical stimulation totally eliminated the tinnitus. Reduction in the contralateral minimal masking level was observed in all patients.

Square and triangular waves were more effective than sine waves in reducing tinnitus. The duration of tinnitus reduction following the 10-min stimulation varied from 40 s to about 4 hr.

Figure 1 shows the sensation level of contralateral broadband noise that just masked the tinnitus pre-, during, and posttreatment. The magnitude of the tinnitus as revealed by this measure was reduced during the 10-min stimulation period. In four cases poststimulation tinnitus reduction was also verified. One patient (R4) required greater contralateral MML poststimulation.

Patients' subjective reactions to tinnitus reduction were mixed. All 4 patients with bilateral tinnitus noted that, while the tinnitus was reduced in the ipsilateral ear, they were still aware of the tinnitus in the contralateral ear. Four patients were asked what they thought of the reduced tinnitus. Two (R1 and R3) welcomed the change, 1 felt "different" (R5) and 1 (R2) reported that the absence

TABLE 4. Subjective report during the screening phase of electrical stimulation. Responses under each category were solicited from the patient during the stimulation. The "optimal current level" (μA) for each "stimulus frequency showing effects" is defined as the lowest current level that produced the maximum amount of tinnitus reduction. The "maximum current level used" is the current level at which stimulation was terminated. Only the range of current level across frequencies is reported for the nonresponders.

| *Patient* | *Sensation during stimulation* | *Description of changes in tinnitus during stimulation* | *Stimulus frequencies (Hz) showing effects* | *Optimal current level (μA)* | *Maximum current level used (μA)* |
|---|---|---|---|---|---|
| NR1 | nonauditory, tingling, imbalance | no change | none | | 80–335 |
| NR2 | nonauditory tactile sensation | no change | none | | 43–2000 |
| NR3 | nonauditory, pressure, blocked | no change | none | | 146–2000 |
| NR4 | both auditory & nonauditory pressure, cricket | no change | none | | 81–520 |
| NR5 | nonauditory, pressure | no change | none | | 22–1200 |
| R1 | auditory | Low-pitch tinnitus components decreased in both ears. Heard high-pitch component in right ear more clearly. | 125 | 137 | 1962 |
| | | | 250 | 50 | 1962 |
| | | | 500 | 39 | 2000 |
| | | | No reduction above 1000 | | 2000 |
| R2 | auditory | Low-pitch tinnitus component disappeared at 250-4000 Hz. As level increased, some mid-pitch tinnitus was reduced. At 8 kHz, tinnitus appeared "muffled" and totally disappeared (both high and low components). High-pitch component was first to return as "wavering" high pitch sound. | 250 | 20 | 45 |
| | | | 500 | 15 | 31 |
| | | | 1000 | 14 | 65 |
| | | | 2000 | 90 | 795 |
| | | | 4000 | 144 | 195 |
| | | | 8000 | 304 | 500 |
| R3 | nonauditory tingling | No change in tinnitus when stimulus was below 2000 Hz. At 2000 Hz, low pitch component disappeared at moderate level. Tinnitus appeared "disorganized, like falling bowling pins." At 8000 Hz, low- and high-pitch components were gone, middle-pitch component remained. Tinnitus worsened as stimulus level was raised above optimum level | 2000 | 73 | 93 |
| | | | 4000 | 119 | 158 |
| | | | 8000 | 49 | 140 |
| R4 | nonauditory, warmth, pressure | Felt warmth and pressure at eardrum. Low-pitch tinnitus component disappeared at low frequency of stimuluation (62.5 Hz). At 2 kHz and 4 kHz *all* components of tinnitus disappeared starting with the disappearance of low pitch component. At 8 kHz high pitch component of tinnitus "spread" and then disappeared. | 62 | 58 | 58 |
| | | | 125 | 18 | 18 |
| | | | 250 | 18 | 18 |
| | | | 500 | 16 | 16 |
| | | | 1000 | 5 | 6 |
| | | | 2000 | 6 | 12 |
| | | | 4000 | 4 | 4 |
| | | | 8000 | 7 | 7 |
| R5 | nonauditory tingling around face | Whole tinnitus disappeared (high- and low-pitch components) even at 62.5 Hz. Effective at all tested frequencies. Hears high pitch sound when 2 kHz and 4 kHz tones were used. | 62 | 41 | 77 |
| | | | 125 | 73 | 104 |
| | | | 250 | 110 | 160 |
| | | | 500 | 126 | 237 |
| | | | 1000 | 177 | 226 |
| | | | 2000 | 126 | 1312 |
| | | | 4000 | 900 | 2000 |

of tinnitus in the ipsilateral ear was more annoying than its presence. However, R5 and R2 added that they could adjust to that change.

## DISCUSSION

The results of this experiment suggest that AC electrical stimulation presented via an eardrum electrode is potentially a useful treatment for some tinnitus sufferers. The following discussion will focus on patient characteristics, stimulus parameters, the adequacy of controls, and clinical applications.

### *Patient Characteristics*

Table 6 lists the differences between responsive and nonresponsive patients to electrical stimulation. All 5 patients in the responsive group showed type "C" or type

TABLE 5. Description of changes during 10 min of electrical stimulation. The "optimal waveform" was the one (among 3 waveforms—since, square, and triangular) that produced the most tinnitus reduction at the lowest current level. The decrease in "loudness" and in "annoyance" ratings were calculated as the percentage difference between the pre- and during-stimulation ratings divided by the prestimulation ratings, multiplied by 100. Entry in the "Decrease in broadband noise masking" was calculated relative to the minimum masking level (MML) obtained in the prestimulation measurements. The "duration of effect" was measured from the termination of stimulus current to the time the tinnitus returned to its normal level.

| *Patient* | *Stimulating frequency (Hz)* | *Optimal waveform* | *Decrease in reported annoyance (%)* | *Decrease in reported loudness (%)* | *Decrease in contralateral broadband noise masking level (MML, in dB)* | *Duration of effect* |
|---|---|---|---|---|---|---|
| R1 | 1000 | square | 67 | 57 | 17 | 5 min |
| R2 | 8000 | square | 100 | 100 | no tinnitus | 4 hrs |
| R3 | 4000 | sine/triangular | 58 | 36 | 32 | 10 min |
| | 8000 | triangular | 33 | 40 | 28 | 30 min |
| R4 | 1000 | square | 100 | 100 | no tinnitus | 50 s |
| | 4000 | triangular | 100 | 90 | no tinnitus | 40 s |
| R5 | 500 | triangular | 57 | 48 | 23 | 2.5 min |
| | 4000 | triangular | 93 | 95 | no tinnitus | 4 hrs |

"D" (Tyler, Conrad-Armes, & Smith, 1984) postacoustic masking recovery patterns. Type C represents tinnitus reduction to an acoustic masker followed by a gradual return of tinnitus to its premask level. Type D represents tinnitus reduction followed by an abrupt return. Only 2 of the 5 patients in the nonresponsive group exhibited the type C pattern. Patients who experienced tinnitus reduction to electrical stimulation identified one ear/side of the head as having louder tinnitus, whereas patients in the nonresponsive group (except NR1) had bilateral tinnitus of equal severity in both ears. The pitch match frequencies to the tinnitus ranged from 2,600 to 8,700 Hz in the nonresponsive group. The responsive group matched their tinnitus to frequencies above 9,000 Hz (except R4). Finally, the tinnitus in the responsive group could be masked at a lower masker sensation level than in the nonresponsive group.

The poststimulation tinnitus measures for most patients were similar to those obtained prior to the electrical stimulation. The only exceptions were patients R4 and NR5. Patient R4 experienced tinnitus reduction during electrical stimulation but showed elevated tinnitus pitch and increased minimal masking levels in the poststimulation period. Patient NR5 did not experience any reduction during the screening phase but reported tinnitus reduction after the electrode was removed. One possibility is that the sensation caused by the electrode could have obscured any tinnitus reduction during electrical stimulation. This is unlikely because the patient reported no discomfort in the ear during stimulation.

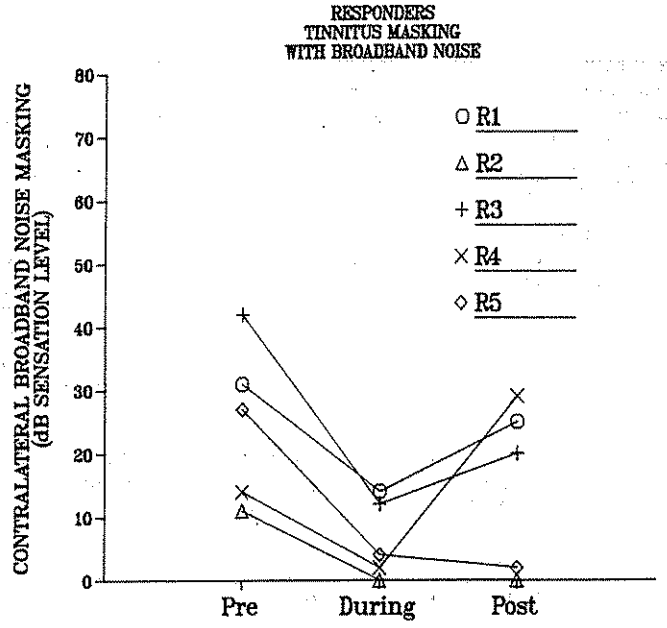


FIGURE 1. Contralateral broadband noise levels required to mask the tinnitus pre-, during, and posttreatment (10 min of electrical stimulation).

## *Stimulus Characteristics*

For patients who reported tinnitus reduction, triangular (R3, R4, R5) and square (R1, R2, R4) wave stimuli were most effective. These stimuli have energies at odd harmonics of the fundamental. Although square waves have more energy at odd harmonics than do triangular waves, square waves were not more effective in tinnitus reduction than were triangular waves.

Patients differed in their responsiveness to different frequencies of stimulation. For patients R5 and R4, a change was reported for all stimulus frequencies. However, for the other 3 patients (R1, R2, and R3), only certain frequencies were effective. There was no simple relation between the effective stimulus frequencies and the tinnitus pitch-match frequency.

## *Control for Placebo Effect*

The design of this experiment did not allow for the measurement of potential placebo effects because the AC stimuli could be either heard or felt at a suprathreshold level. Although patients reported no sensation (auditory

TABLE 6. Comparison of patient characteristics between responsive and nonresponsive groups (to electrical stimulation) based on subjective report during screening.

| *Nonresponsive patients* | *Responsive patients* |
|---|---|
| 1. Two patients (NR2, NR1) could not be masked with broadband noise masker, but showed no postmasking effect. Two patients could be masked and showed type "C" postmasking effect. One had a type "A" postmasking effect. | 1. All 5 patients showed postmasking effect and exhibited either type "C" (R1, RD, R4, R5) or "D" (R3) patterns. |
| 2. Pitch of tinnitus ranged from 3000 to 8700 Hz.<br>NR1 = 7084 Hz<br>NR2 = 8660 Hz<br>NR3 = 5834 Hz<br>NR4 = 3773 Hz<br>NR5 = 4970 Hz | 2. Tinnitus pitch was usually above 9 kHz, except R4.<br>R1 = 9430<br>R2 = 10850 Hz<br>R3 = >20000 Hz<br>R4 = 2260 Hz<br>R5 = 10140 Hz |
| 3. All reported bilateral tinnitus, 4 of them reported equal severity in both ears. Only NR1 reported worse in right. | 3. All reported more difficulty on one side than the other. Subjects R1, R3, R4 identified left ear as worse ear; R2 & R5 identified right ear as worse. |
| 4. All required greater than 40 dB SL contralateral broadband noise to mask their tinnitus.<br>NR1 = >70<br>NR2 = >70<br>NR3 = 51<br>NR4 = 51<br>NR5 = 42 | 4. Most required lower than 40 dB SL contralateral broadband noise to mask their tinnitus.<br>R1 = 31<br>R2 = 11<br>R3 = 42<br>R4 = 14<br>R5 = 27 |

or nonauditory) when the stimuli were presented below threshold, the trials consisted of increasing the level until some form of sensation was produced. Without control for placebo effects on all patients, it may be overly optimistic to conclude that AC stimulation can effectively reduce tinnitus. A recent report by Dobie, Hoberg and Rees (1986) showed that 4 out of 6 patients who reported a positive tinnitus change to the use of Theraband were actually using a placebo device. However, in that trial patients could not perceive the presence of the stimulus.

Several observations on the patients' response patterns (see Table 4) suggest the unlikelihood that the reported results were influenced by placebo effects. First, Table 4 showed that the responsive patients reported maximum tinnitus reduction at a certain stimulus intensity level; higher or lower levels reduced the effectiveness. Second, some stimulus frequency regions were more effective than others in tinnitus reduction (e.g., for R1 and R3). Third, the patients' subjective reports to different frequencies of stimulation varied (e.g., those of R2, R3, R4). Last, triangular and square waves were more effective than sine waves in tinnitus reduction in all of the responsive patients. In addition, other investigators (Chouard et al., 1981; Vernon & Fenwick, 1985) reported that less than 4% of their success cases with electrical stimulation were influenced by placebo effects.

### *Clinical Application*

The results of the present experiment show that stimulating the eardrum with AC can be effective in reducing the tinnitus in that ear for some patients. Its advantage over DC stimulation is that it eliminates potential tissue damage (Hatton et al., 1960). Furthermore, tinnitus reduction can occur without the electrical stimuli being audible. This occurred in 3 out of 5 patients in the present investigation. Another advantage of electrical stimulation is the long poststimulation reduction period. In 2 of our patients this poststimulation reduction lasted more than 4 hr, after only 10 min of stimulation.

Hatton et al. (1960) suggested that electrical stimulation was effective in reducing tinnitus only in profoundly deaf individuals. This is seen in subject R3, whose tinnitus was reduced by stimuli in her severe-to-profound hearing loss region (2,000 Hz to 8,000 Hz). However, our success with the other 4 responsive patients suggests that AC stimulation can be effective in tinnitus reduction with various degrees of hearing loss.

It appears that the stimulus characteristics have to be selected carefully for the individual, and that spectrally complex stimuli may have advantages over pure-tone stimulation.

The number of patients for whom this would be appropriate is difficult to predict. It may be appropriate mainly for patients whose tinnitus can be masked with low-level acoustic stimuli. Our success rate of 50% is certainly encouraging.

## SUMMARY

The findings from this preliminary investigation can be summarized in two categories.

1. Effectiveness of electrical stimulation:

a. AC stimulation at the eardrum was effective in reducing tinnitus in some patients.

b. The effectiveness of stimulation was not restricted to the period of stimulation. It extended as many as 4 hr posttreatment.

c. Electrical stimulation was effective in patients with varying degrees of hearing loss.

d. Square and triangular waves were more effective in tinnitus reduction than were sine waves.

e. The optimal frequency for stimulation was different for different individuals.

2. Patient characteristics:

a. Four of 5 responsive patients matched their tinnitus pitch to frequencies above 9,000 Hz.

b. The tinnitus in all 5 responsive patients could be masked by broadband noise at low sensation levels, and 4 of 5 patients showed a type "C" postmasking recovery function.

c. All 5 responsive patients could identify one ear as the worse ear—that is, the one with the louder tinnitus.

d. Three of the 5 responsive patients reported that their tinnitus probably originated from noise exposure.

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