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Improved Selective Attention and Word Perception in Tinnitus Patients Treated with Electrical Stimulation

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Abstract: Grammatically correct but nonsense twenty 4-segment sentences mixed with multiple talk recorded on CD were delivered to ears tested in 47 tinnitus patients at a comfortable level via a headphone. The signal-to-noise ratios were 0dB, 5dB and 10dBSPL. Patients were requested to repeat what they heard before and after electrical treatment.

A sinusoidal wave of 10kHz at the intensity of about 200mA was delivered to ears for 30 minutes by using a plate electrode for ECG at the tragus or a stimulating Pt-Ir electrode on the middle ear. Alternatively, 0.5mA DC was delivered to patients using a iontophoretic instrument.

Improved word perception under noises was observed in most patients with tinnitus relief following electrical stimulation of the ear, demonstrating that electrical stimulation improved auditory selective attention. There may be a relationship between tinnitus relief and improved selective attention. It may be electrical stimulation of the ears that produced improved selective attention, inducing tinnitus relief and improved word perception according to our previous reports.

Key Words: Electrical stimulation, Word perception, Competing task test, Tinnitus relief, Selective attention

INTRODUCTION

Although we often speak of tinnitus as if it were a single entity, tinnitus consists of the sensory and affect components.[1] Affects of tinnitus consist of a lot of components, such as insomnia, annoyance, anxiety, and interference in communication capability.[2] Among those affects of tinnitus, we have focused especially on effects of tinnitus on interference in communication capability because many tinnitus patients report difficulty in hearing and understanding or the "interference" effect of tinnitus on the ability to communicate.[3] Electrical stimulation of the cochlea has been used widely to treat tinnitus of cochlear origin.[4]

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We previously reported that electrical promontory stimulation relieved tinnitus[5] and improvement of hearing was sometimes reported by patients with tinnitus relief at that time. We showed improvement of hearing on the audiogram in a tinnitus patient with implanted tinnitus suppressor which was developed by Hokkaido University.[6] However, few people showed improvement of hearing on the audiogram although patients reported hearing improvement and tinnitus relief. Therefore, we speculated that more cognitive process attributes to hearing improvement in patients with tinnitus relief.

Our preliminary report showed that word perception using a grammatically correct but non-sense Japanese 4-segment sentence perception test improved in patients with tinnitus relief following electrical stimulation of the ear.[7] This result suggested that difficulty in word perception which tinnitus patients complained of may be partly because of the existence of tinnitus. Eventually, a question, why tinnitus relief is linked with improved word perception, arises.

Language analysis consists of such mechanisms as attention, memory, and cognitive process. Tinnitus patients sometimes complain of the lack of concentration.[1] Concentration may be a kind of focused attention. Therefore, focusing on attention process in the central auditory system may get us find some relationships between tinnitus relief and improved word perception following electrical stimulation of the ear.

Patients

Forty seven tinnitus patients (24 males and 23 females) aged from 42 to 75 years old (mean age: 60.4) were assessed. All patients had some hearing loss. The etiology of hearing loss was sudden deafness (n = 1), Ménière's disease (n = 1), and chronic middle ear infection (n = 7). The causes of hearing loss in the other 38 patients were unknown.

Electrical Stimulation

We used three types of stimulation method. One is an external stimulation method. Two plate electrodes for ECG were attached to the skin at the tragus and behind the ear. This method was used for 34 patients. In eleven patients Teflon-insulated platinum-iridium (90-10) wire with a diameter of 250μm along its length and 750μm at the tip ball was placed on the promontory through a small incision made in the ear drum after local anesthesia with iontophoresis. The stimulation intensity level was fixed at approximately 200μA and the duration of stimulation was 30 minutes. Electrical stimulation was supplied by an oscillator and a current amplifier. We used a 10 kHz frequency in the form of charge-balanced sinusoidal waves. In 2 patients DC of 0.5 mA was delivered through xylocaine® in the external ear canal.

The wire was connected to a stainless steel lead wire that was attached to an electro-magnetic coupling system. A return electrode, which was a plate electrode for recording the electrocardiogram, was attached to the post-auricular skin.

Evaluation

In order to know relationships between selective attention and tinnitus, a competing task test using grammatically correct but non-sense Japanese 4 segment sentences mixed with noise was used. Twenty grammatically correct but non-sense Japanese 4 segment sentences recorded on CD (compact disk), which was used for hearing aids fitting, were applied to tinnitus patients and patients were asked to repeat what they heard before and after electrical treatment. Time interval between two word perception tests was approximately 35 minutes. An example of sentences is as follows: *Red, dog, cow, barks*. This is the Japanese word order in the sentence. In English, it means "*A red dog barks cow.*" Thirty seven ears tested in 47 patients were contralateral to ears treated because hearing levels at treated ears were severely impaired or nearly normal.

Noise used for this experiment was multiple talk recorded on the same compact disk as grammatically correct but nonsense twenty 4-segment sentences were recorded. The signal-to-noise ratios were 0dB, 5dB and 10dBSPL. The ratio used for experiments depended on patients' ability. The S/N ratio, 0dBSPL, was defined as follows. The signal intensity at the sampling frequency of every 30 msec was averaged at each sentence. Noise picked up from multiple talk recorded on the compact disk was also averaged in the same way as the signal averaged. The S/N ratio, 0dB SPL, was defined as no difference in dBSPL between the averaged signal and noise intensity.

The signal and noise mixed up at the same channel of the same DAT tape was delivered to tested ears in 47 tinnitus patients at a comfortable level via a headphone.

APPARENT IMPROVEMENT DUE TO PRACTICE

Taking the possibility of adaptation to the test into consideration, the value of mean and one standard (Std.) deviation (Dev.) was calculated from the difference in the number of incorrect words at each segment of the sentences between the first and the second test in eighteen patients (mean age: 64.3) without treatment. The interval between two trials was approximately 5 minutes. The summated values of mean and two Std. Devs. are shown as squares at each segment in Figure 1.

Statistically there are only three percent of patients who exceed the summated values of mean and 2 Std. Devs. among tested patients. Therefore, when the improved number of incorrect words at each segment exceeded 2, 3, 4, and 4, respectively, the word perception was defined to be improved following electrical stimulation.

RESULTS

Briefly, results were the followings: Totally 30 patients reported tinnitus relief and 31 patients, improved word perception. 4 out of 30 patients did not show any improvement of word perception according to our control study. However, 3 out of seventeen patients without tinnitus relief showed improvement of word perception. Totally, 29 patients showed improvement of word perception according to our control study. In 37 of forty seven patients, tested ears were contralateral to ears treated. In those 37 patients, 25 patients showed improvement. In other 10 patients whose treated ears were the same as ears tested, 4 patients showed improved word perception according to our control study. These results are summarized in Figure 2.

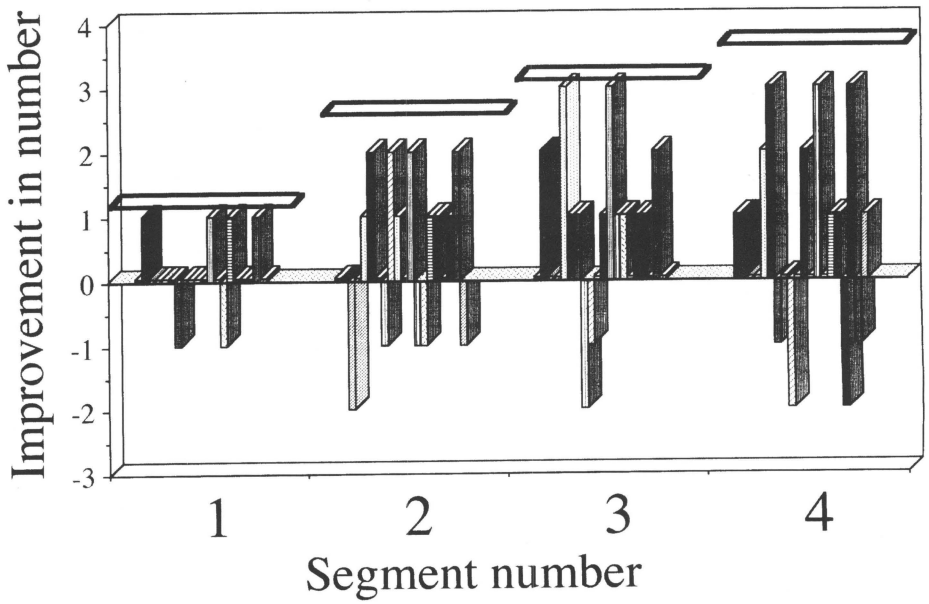

Fig. 1. Apparent improvement due to practice. The summation values of mean and two standard deviations are shown as squares at each segment. When the improved number of incorrect words at each segment exceeded the minimum digit 2, 3, 4, and 4, respectively, the word perception was defined to be improved following the electrical stimulation.

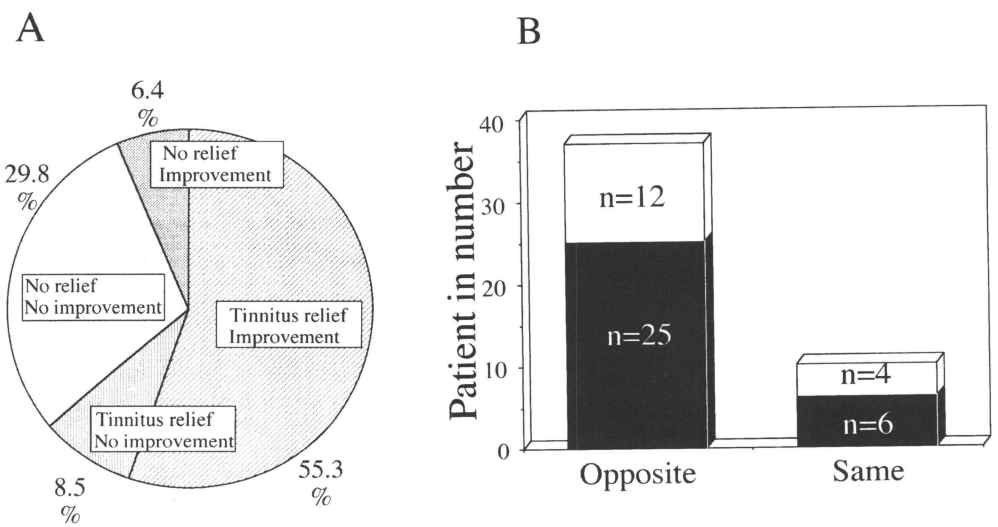

Fig. 2. Results according to tinnitus relief and improvement of word perception (A) as well as relation to side of treated versus tested ears (B). A total of 47 patients were divided into four groups according to tinnitus relief and improvement of word perception (Fig. A). In 37 patients ears tested were the same as ears treated and in ten patients ears tested were opposite to ears treated (Fig. B). In Fig. B, closed bars show patients with improvement of word perception and open bars show patients without improvement. Legend in Fig. A: Improvement: Improvement of word perception. Legend in Fig. B: Same: Ears tested were the same as ears treated. Opposite: Ears tested were opposite to ears treated.

There was no significant difference (p = 0.292; Mann-Whitney U-test) in averaged hearing level between patients with (mean: 40.8 dB SL, SD: 15.9) and without (mean: 45.7dBSL, SD: 15.3) improved word perception. The averaged hearing level was calculated from the following equation: Averaged hearing level = threshold of (500Hz + 1000Hz + 1000Hz + 2000Hz)/4. No significant correlation between averaged hearing level at each S/N ratio and total errors before treatment was observed. The correlation coefficients, r^2, are 0.006, 0.204, and 0.076 at the S/N ratio of 0, 5, 10 dB SPL, respectively. Figure 3 is a representative example obtained at the S/N ratio of 0dB SPL.

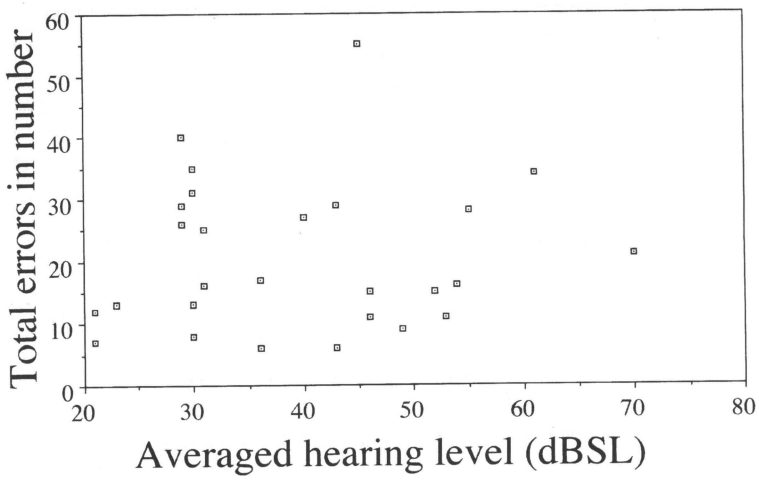

Fig. 3. Correlation between averaged hearing level and total errors at the S/N ratio of 0 dBSPL. No significant correlation between averaged hearing level and total errors. This figure is an example at the S/N ratio of 0 dBSPL. Averaged hearing level = threshold of 500 Hz + 1000 Hz + 1000 Hz + 2000 Hz divided by four.

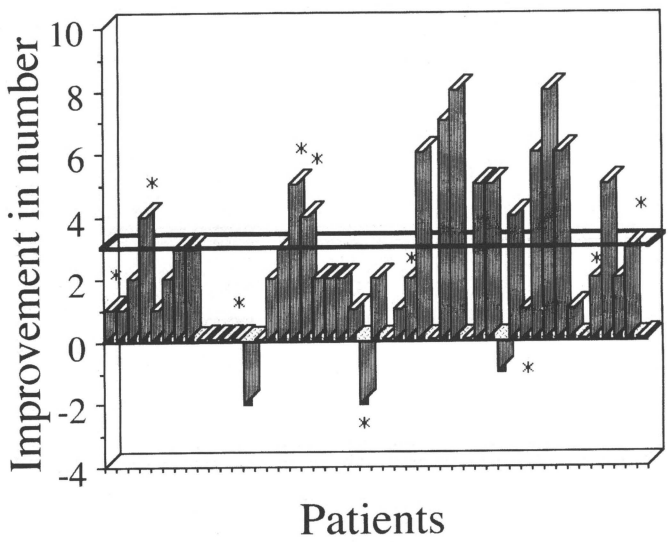

Fig. 4. Improvement obtained from the second segment as representative data. The abscissa shows patient number and the ordinate improved word in number in each patient. A square shows the minimum digit which exceeds the mean and two standard deviations from apparent improvement. The symbol * means that ears tested were the same as ears treated.

Figure 4 shows an improvement obtained from the second segment. The abscissa shows patient number and the ordinate improved word in number in each patient. A square shows the minimum digit which exceeds the mean and 2 standard deviations from apparent improvement. The symbol * means that ears tested were the same as ears treated. At the second segment 17 patients were defined to be improved in word perception according to the prior criteria. A significant improvement was observed in 16 patients at the first segment, 13 at the third segment, and 17 at the fourth segment, as shown in Figure 5.

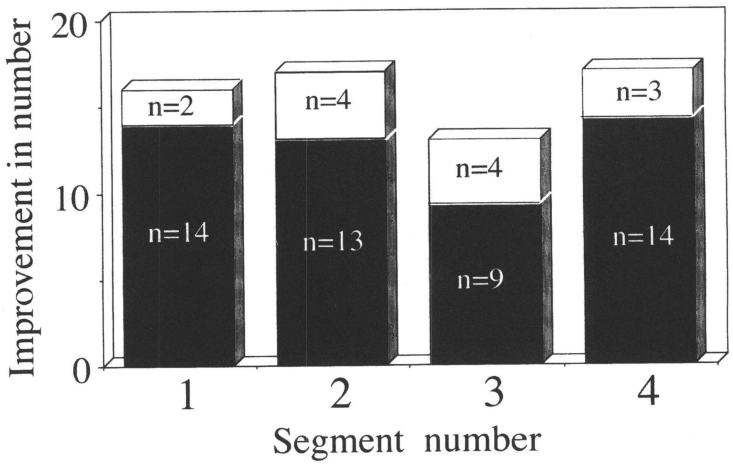

Fig. 5. Improvement in number at each segment. A significant improvement was observed in 16 patients at the first segment, 17 at the second segment, 13 at the third segment, and 17 at the fourth segment. The smallest number was observed at the third segment. Closed bars show that improved word perception was observed at ears opposite to ears treated. Open bars show that ears tested were the same as ears treated.

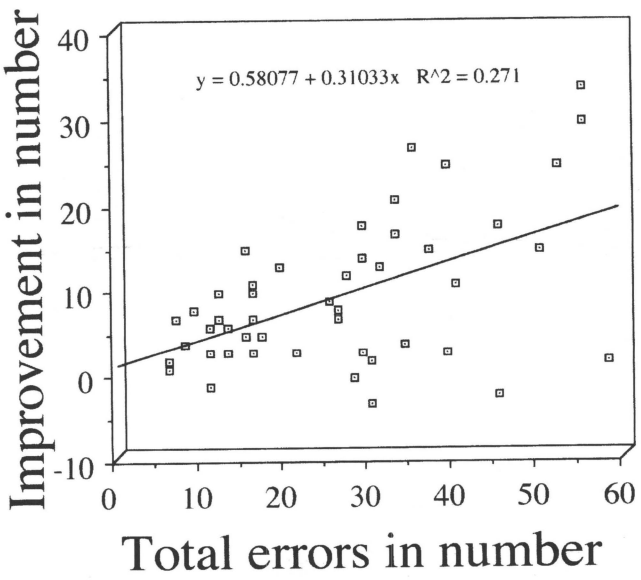

Fig. 6. Improvement following treatment versus total errors before treatment. No significant correlation between improvement following treatment and total errors before treatment was observed.

Open bars show that improved word perception was observed at ears opposite to ears treated. Closed bars show that ears tested were the same as ears treated. We easily found that improvement occurred at both treated and untreated ears.

The smallest number was observed at the third segment. Comparing the number of improvement in all with total errors before treatment, we found no correlation between them (Figure 6).

Figure 7 shows how many segments each patient improved.

Improved word perception was observed in totally 29 patients according to the prior criteria. Improved word perception was observed in 13 patients at one segment, 2 patients at two segments, 9 patients at three segments and 5 patients at four segments. Open bars show that improved word perception was observed in ears opposite to ears treated. Closed bars show that ears tested were the same as ears treated. We easily found that improvement occurred at both treated and untreated ears.

DISCUSSION

There are few papers which focus on the effects of tinnitus on word perception. Word perception is one of the affects of tinnitus. Many psychological assessments for the affect component have been performed in patients.[1] Goldstein and Shulman[3] identified that tinnitus affects specific components of the auditory pathway using central speech tests such as the monaural low pass filtered test and the competing sentence test. Although they could not suggest how tinnitus disturbed language analysis, their paper addressed disturbed central speech testing in tinnitus patients. They also suggested that the central auditory tests have provided a basis for the selection of treatment and control methods of tinnitus with an increased efficacy. Our finding of close relationships between tinnitus relief and improvement of word perception support their conclusion.

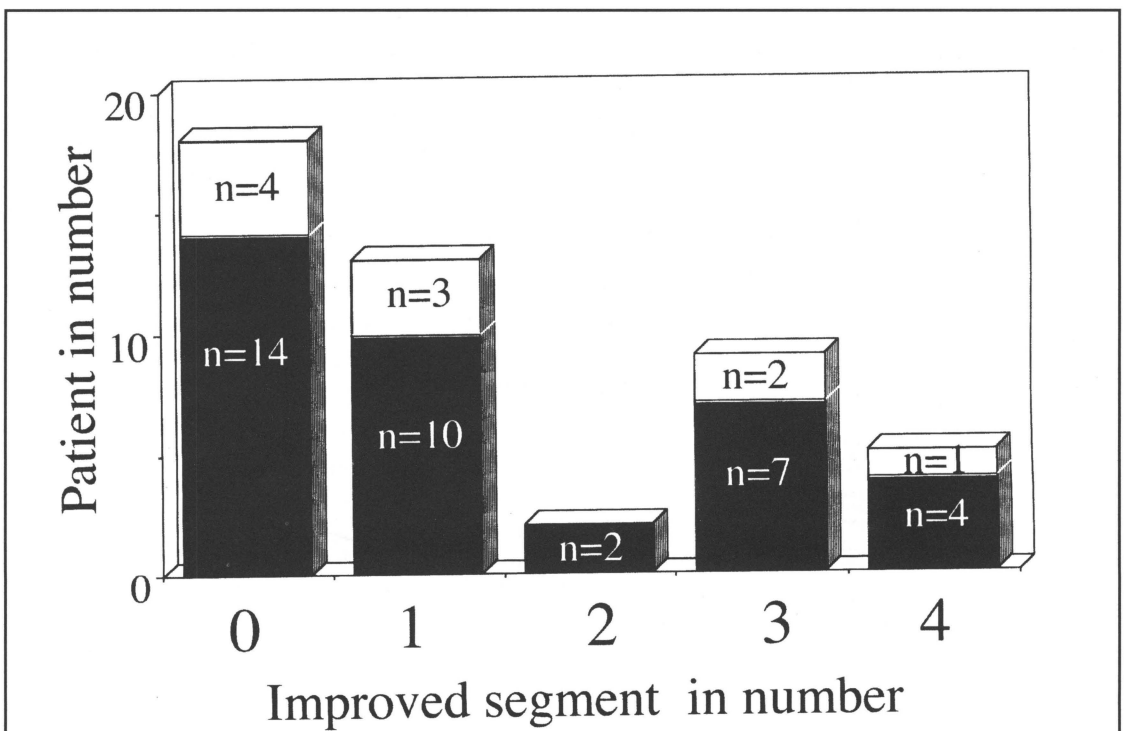

Fig. 7. Improved segment in number of each patient. Improved word perception was observed in 29 patients according to the prior criteria. Improved word perception was observed in 13 patients at one segment, two patients at two segments, nine patients at three segments and five patients at four segments. Open bars show that improved word perception was observed in ears opposite to ears treated. Closed bars show that ears tested were the same as ears treated. We easily found that improvement occurred at both treated and untreated ears.

Sensorineural hearing loss is not believed to be improved except for the acute stage of hearing loss because damaged hair cells regenerate in mammals. We should, however, focus more on the central auditory processing to identify the mechanisms of improved word perception following electrical stimulation of the ear. We should recall that language is analyzed with regard to such mechanisms as attention, cognitive processing and memory.[8]

Of these mechanisms, this study was designed to focus on selective attention. Selective attention may include *divided attention*, as in dichotic listening tasks when more than one input may provide relevant information; and *focused attention*, as in message tasks where the subject is able to ignore irrelevant information. Individuals can communicate with each other in the presence of circumferential noises at a party, i.e. "the cocktail party effect". This occurs partly because selective focused attention can make a person pick up what they want to listen to even in the presence of noises.

This study has demonstrated that auditory selective attention in tinnitus patients was disturbed according to the competing task test and improved selective attention following electrical stimulation of the ear may be related with improved word perception. Unlike this study, Jacobson showed that auditory selective attention in subjects with bothersome tinnitus may be stronger than in normal subjects.[9] However, as mentioned in the introduction of this paper, the clinical findings that tinnitus patients sometimes complain of a so-called "interference effect" of tinnitus on communication could not be demonstrated in the results of Jacobson's electrophysiological study.[9] When bothersome tinnitus chronically annoyes patients, it may induce a lack of concentration.[1] Concentration may be a type of focused attention, i.e. bothersome tinnitus may induce disturbed selective attention.

Comparison of the auditory evoked magnetic field response in tinnitus patients before and just after electrical treatment revealed an increase in the amplitudes of P2/N1, especially P2, in patients suffering from unilateral tinnitus.[10] Consideration of results of the present study and our magnetic field response study, suggest that the improvement in auditory selective attention was related to the patient reports of tinnitus relief and improved word perception. It is to be mentioned that the task for evoking the magnetic field response was much easier in our study than in the Jacobson study. However, electrophysiology studies are necessary to establish the relationship between tinnitus relief and auditory selective attention in the same way as was performed by Jacobson et al.

Hoke et al. are the first to measure the auditory evoked magnetic field response in tinnitus patients.[11] They reported in a longer follow-up study of tinnitus patients that the P2 response was augmented when tinnitus disappeared. Our findings are similar to Hoke's finding. Jacobson et al,[12] however, could not reproduce Hoke's finding. One of the differences between the Hoke study and our own is the time when the auditory evoked magnetic field response was measured. We compared the auditory evoked magnetic field response before and just after electrical treatment. In Hoke's study factors other than tinnitus relief could not be excluded, because the intervals of the two measurements were quite longer than ours.

Tinnitus relief by electrical stimulation may be related to Shulman's comment[13] that tinnitus may be masked secondary to improvement of hearing. The present study supports a close relationship between tinnitus relief and improved word perception. The masking effect of tinnitus would disturb word perception. Our previous study, however, showed that improved word perception following electrical stimulation was observed in the hearing-impaired even without tinnitus.[7]

This finding is considered to support the observation that electrical stimulation of the ear may produce improved word perception. Therefore, improved word perception may be related not only to tinnitus relief but also improved auditory selective attention.

Nowadays a new hypothesis for generation of tinnitus has been proposed by Shulman.[2] There may exist a final common pathway for the transition of the sensory to the affect component of the symptom of tinnitus, meaning that there are close relationships between the sensory and affect components of tinnitus. It is known that electrical stimulation of the auditory nerve relieves tinnitus (sensory component).[14]

In addition to the direct effect of electrical stimulation on tinnitus (sensory component), we have demonstrated that electrical stimulation of the ear induced an increase in the parasympathetic tone (affect component) with accompanying tinnitus relief,[15] of a degree significant to eventually induce temporary sleep.[6] The effect of our method on the autonomic nervous system and sleep suggests that electrical stimulation of the ear is a kind of relaxation therapy. After relaxation, the patient's attention improved. Hearing-impaireds experienced improved word perception. Emotions and moods, i.e. affects of tinnitus, actually may be important for the development of attention to incoming stimuli.[16] Therefore, improvement in emotions and moods, i.e. affect components, following electrical stimulation of the ear, could produce better auditory selective attention in patients, inducing improved word perception (affect component) and tinnitus relief (sensory component). In other words direct effects of electrical stimulation of the auditory system may produce tinnitus relief and improved word

perception by other unknown mechanisms and/or improvement in the affect components.
We still have to perform many studies on selective attention in tinnitus patients. Such studies will lead us further to understand the mechanisms of tinnitus production and the functions of the central auditory system.

CONCLUSIONS

1. Close relationships have been demonstrated between tinnitus relief and improvement in word perception with electrical stimulation.
2. Electrical stimulation of the ear resulted in improved selective attention in the tinnitus patient.
3. Improved word perception may be related to both tinnitus relief and improved auditory selective attention.
4. Improved word perception in both treated and untreated ears in most patients reporting tinnitus relief, could support the speculation that improvement occurred within the central auditory system.
5. Comparing the number of improvement with total errors before treatment, we found no correlation between them. There was no significant difference in averaged hearing level between patients with and without improved word perception.
6. Improved word perception may be related to both tinnitus releaf and improved auditory selective attention.
7. Electrical stimulation of the ear in tinnitus patients resulted in improvement in sleep and can be considered a form of relaxation therapy.

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