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Quantitative Electroencephalography Patterns in Patients Suffering from Tinnitus

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Abstract: We conducted this study in an attempt to determine whether the electroencephalographic activity in patients suffering from tinnitus exhibits tinnitus-typical electroencephalography features. Our results indicated a significant increase in the average total power in female tinnitus patients and a significant decrease in average total power in male tinnitus patients. Furthermore, we noted a suppression of the alpha peaks or a split alpha band (or both). The reactivity of the alpha frequency was employed to evaluate the efficacy of noise generators, a critical component of tinnitus-retraining therapy. In conclusion, tinnitus-typical electroencephalography features can be extracted from the electroencephalogram.

Key Words: brain map; power spectrum; quantitative electroencephalography

Approximately 8.7 million people in Germany experience tinnitus, and 1.5 million of these people consider their tinnitus to be a significant problem [1]. Tinnitus affects their daily lives profoundly, often leading to depression, anxiety, concentration problems, social isolation, insomnia, and suicide [2]. The yearly incidence rate for chronic tinnitus amounts to 250,000 people per year [3].

Power-spectrum analysis of electroencephalography (EEG) has often been applied to the study of various forms of brain dysfunctions [4]. Different research groups employed this technology to elucidate the pathological mechanisms involved in tinnitus [5–8]. In this context, Weiler et al. [7,8], Shulman and Goldstein [6], and Bertora and Bergmann [9] were able to demonstrate that tinnitus patients exhibit significant changes in cortical activities as compared to outcomes in normal controls. Significantly changed vestibular evoked potentials in patients suffering from tinnitus were described by Schneider et al. [10]. A normalization of these potentials was reported by Weiler et al. [11] after EEG-guided feedback. Furthermore, Brill and Weiler [12] and Dehler et al. [13] noted that muscular dysfunctions lead to a significant decrease of the alpha activity, thus possibly indicating sustained stress. Therefore, correcting these dysfunctions before any tinnitus therapy is of utmost importance. The aim of our study was to confirm tinnitus-specific EEG changes within a larger group of patients.

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SUBJECTS AND METHODS

Subjects

Patients with diagnosed tinnitus were referred to us by their physician. The control group consisted of subjects without any medical and neurological disease. All patients signed an informed consent form before participating in the study. A total of 155 normal controls and 304 tinnitus patients were subjected to a computer-assisted EEG analysis. The average age of the control-group men was 43 ± 14 years, and that of the control-group women was 41 ± 12 years, whereas the average age of the male tinnitus group was 49 ± 12 years and of the female tinnitus group was 46 ± 14 years. No significant difference between the different groups was noted in respect to age. The average period of duration of the tinnitus suffered was 46 ± 8 months for female patients and 63 ± 10 months for male patients. The patients were classified according the Goebel Hiller questionnaire. The control group consisted of healthy, normal subjects without any neurological disease.

Quantitative EEG

The brain waves (EEG signals) were acquired employing a Neurosearch 24 instrument (Lexicor Medical Technology, Inc., Boulder, CO, USA) by placing 19 electrodes on the scalp in a standard international (10/20) pattern. The EEG signals from each electrode were independently amplified by matched differential amplifiers with less than 2 mV peak-to-peak noise; input impedance of > 70 MΩ differential; common mode rejection of > 90 dB at 60 Hz; high-pass filter of 2 Hz; and low-pass filter of 32 Hz. Analog-to-digital conversion of the signal was achieved with a 12-bit A/D converter with sampling interval governed by a 50-kHz crystal oscillator.

Before the records were subjected to quantitative analysis and interpretation, all EEG data were visually inspected for artifacts due to movements and muscular activity. Statistical calculations were performed using only artifact-screened data. The EEG signal was divided into four different frequency bands: delta (0–4 Hz), theta (4–7 Hz), alpha (8–13 Hz), and beta (14–21 Hz).

All EEG data were collected under controlled conditions with the patient reclining comfortably in an armchair with eyes closed in a sound-attenuated, electrically shielded room. Unless stated otherwise, the data used for topographical color maps have been manually screened for eye-blink movements, and only eye-blink-free epochs were used in the preparation of quantitative results, including spectral averages and topographical maps.

RESULTS

Average Total Power

The average total power for a patient was calculated by averaging the total power from each of the 19 electrode leads. The average total power for the male tinnitus patients (N = 195; 21.9 ± 0.3 μV^2) was significantly lower than the average total power of the male control subjects (N = 94; 25.9 ± 0.5 μV^2; $p < .0001$; Fig. 1). However, for the female patients, the average total power for the tinnitus patients (N = 109; 29.4 ± 0.5 μV^2) was significantly higher than the average total power for the respective control subjects (N = 61; 25.6 ± 0.6 μV^2; $p < .0001$; Fig. 2). We noted no significant difference between the average total power for the control male subjects (N = 94; 25.9 ± 0.5 μV^2) and the female control subjects (N = 61; 25.6 ± 0.6 μV^2; p = not significant).

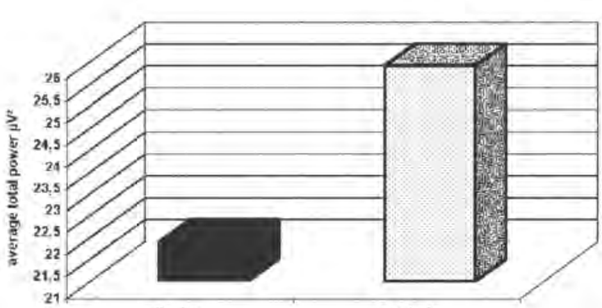

Figure 1. Comparison of the average total power of male tinnitus patients and male control subjects.

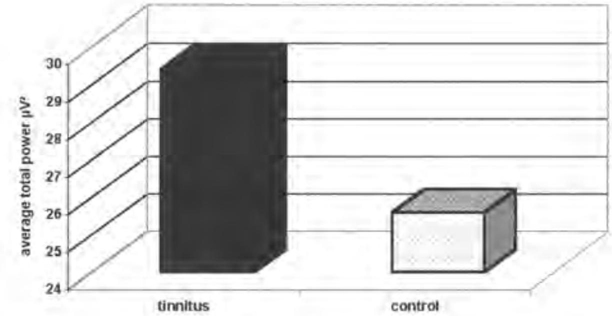

Figure 2. Comparison of the average total power of female tinnitus patients and female control subjects.

Average Power with Respect to Frequency Bands

Average power was calculated for delta (2–4 Hz), theta (4–7 Hz), alpha (8–13 Hz), and beta (14–21 Hz) frequency bands. For the male tinnitus group, a significantly reduced average power was noted for all frequency bands except for beta. For the beta frequency band, we noted only a weakly significant difference as compared to the normal control value (Table 1). The female tinnitus group exhibited no significant change in average power for the delta frequency band. We noted a weak increase in average power for the theta and beta bands. However, a highly significant increase in average power was noted for the alpha band only (Table 2).

Table 1. Average Power (μV^2) of Delta, Theta, Alpha, and Beta Frequency Bands in Male Tinnitus Patients and Normal Controls

Group	Delta (μV^2)	Theta (μV^2)	Alpha (μV^2)	Beta (μV^2)
Tinnitus	11.3 ± 0.2**	11.2 ± 0.2**	52.8 ± 1.4**	11.7 ± 0.2*
Normal control	13.1 ± 0.3	14.3 ± 0.4	66.0 ± 2.9	12.5 ± 0.3

*$p < .03$; **$p < .0001$.

Table 2. Average Power (μV^2) of Delta, Theta, Alpha, and Beta Frequency Bands in Female Tinnitus Patients and Normal Controls

Group	Delta (μV^2)	Theta (μV^2)	Alpha (μV^2)	Beta (μV^2)
Tinnitus	14.5 ± 0.2	15.2 ± 0.3***	74.5 ± 2.5*	16.4 ± 0.4**
Normal control	15.3 ± 0.5	14.0 ± 0.4	55.4 ± 3.1	14.6 ± 0.5

*$p < .0001$; **$p < .005$; ***$p < .02$.

Power Spectrum of Patients Suffering from Tinnitus

For tinnitus patients, we recognized a suppression of alpha power in particular in the temporocentral regions of the brain (Fig. 3A). Additionally, we noted a "split" alpha band in patients suffering from tinnitus (see Fig. 3B).

Brain Maps

Furthermore, specific brain maps could be calculated for patients suffering from a bilateral or unilateral tinnitus. In most cases, beta foci could be located within the central regions of the brain. In case of a unilateral tinnitus, we noted only a single beta focus in the central strip (Fig. 4).

Additionally, we calculated a distribution pattern for delta, theta, and beta foci in male and female tinnitus patients. In the male tinnitus group, we noted theta foci in F3 and CZ; however, beta foci were demonstrable in C3 and P3. In the female tinnitus group, delta foci was noted in CZ, and theta foci were noted in FZ, C3, CZ, and O2. Beta foci were demonstrable in T3,C3, CZ, and O2.

Determination of Positive and Negative Effects of Noise Generators

We employed power spectra to evaluate the efficacy of noise generators in the treatment of patients suffering from tinnitus. A *positive effect* of the noise generators always correlates with an increase of the alpha power or a rightward shift of the alpha frequency (Fig. 5). Figure 6 shows *negative effects* of this device with a leftward shift of the alpha frequency (e.g., a slowing of the EEG).

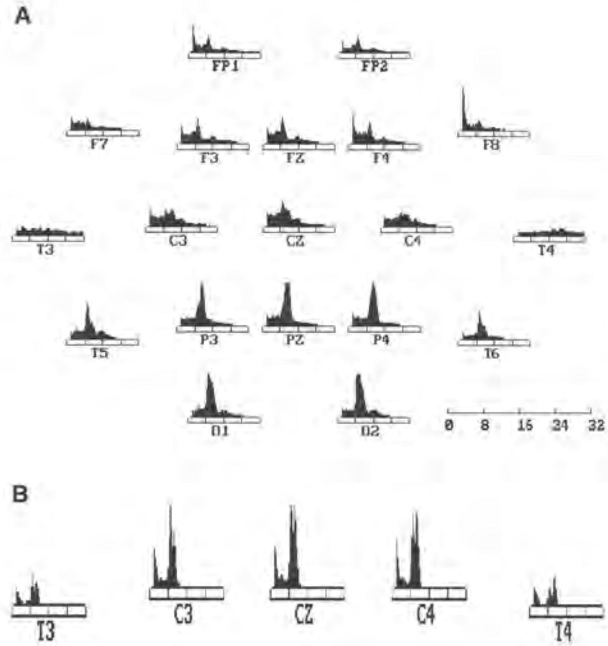

Figure 3. (A) Illustration of alpha suppression at the temporocentral region in a patient suffering from tinnitus. (B) Illustration of a "split" alpha band in a patient suffering from tinnitus.

DISCUSSION

The presented data indicated that with the aid of computer-assisted EEG analysis, tinnitus-typical EEG features can be extracted from the electroencephalographic activity. In male tinnitus patients, we observed a significant decline of average power as compared to that in normal controls. Female tinnitus patients, however, exhibited

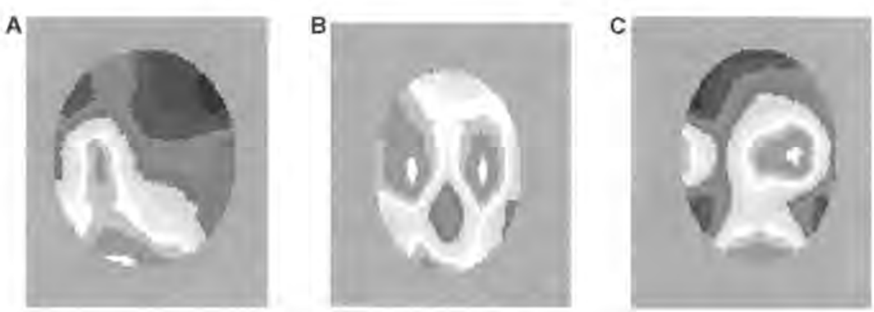

Figure 4. Topographic distribution pattern of the beta frequency range (14–21 Hz) in patients suffering from (A) left-sided, (B) bilateral, and (C) right-sided tinnitus. White indicates region with maximal activity.

Figure 5. (A) Baseline electroencephalographic power spectrum of subject suffering from tinnitus. (B) Positive changes of the electroencephalographic power spectrum profile of a patient suffering from tinnitus during use of a noise generator.

an increase of average power as compared to female controls. This increase of average power was mainly associated with a significant increase of power of the alpha activity. These data suggested that tinnitus affects brain electrical activity in a manner dependent on gender.

Various publications have described changes of the beta and alpha frequency bands in tinnitus patients [6,8,9,14]. Beta rhythms occur in individuals who are alert and attentive to external stimuli or who exert specific mental effort. It may also be associated with "remembering" or retrieving memories. The presence of beta foci has been observed in the temporocentral region of the brain. An interesting note is that increased values of blood flow and metabolism at rest correlated with increased beta-2 (17–23 Hz) power values [14–16].

Patients suffering from a unilateral tinnitus exhibited increased beta power in the central region of the brain, whereas a reduced beta power was detected in the anterior frontal and posterior temporal regions of the brain, areas that are involved in attention and related to cognitive processes [17]. The alpha rhythm is thought to be associated with cognitive idling and inward-turned attention [18]. Because alpha activity is more pronounced under enhanced relaxation, the first field of application of alpha feedback was a reduction of stress and anxiety [19,20]. Interestingly, in this context, Weiler et al. [11], Schenk et al. [14], and Rozelle and Budzynski [21] successfully employed the neurofeedback-based alpha training in treating tinnitus patients.

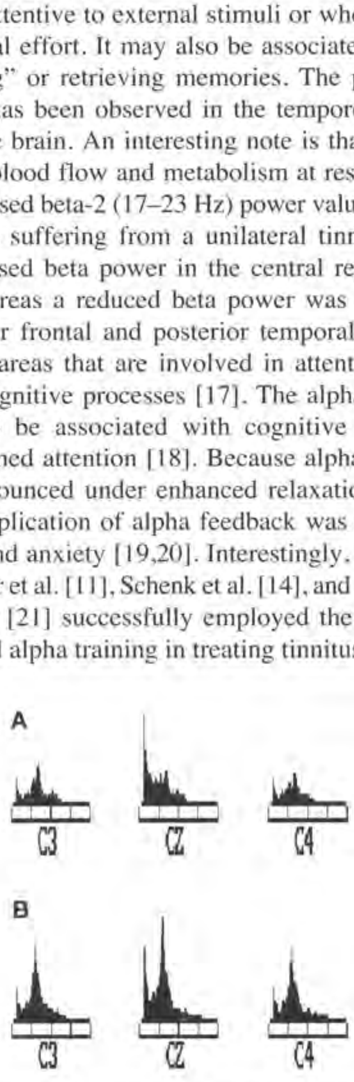

Figure 6. (A) Baseline electroencephalographic power spectrum of a subject suffering from tinnitus. (B) Negative changes of the electroencephalographic power spectrum profile of a patient suffering from tinnitus during use of a noise generator.

The reactivity of the alpha frequency band represents a reliable parameter in evaluating the efficacy of the noise generator, a device crucial in tinnitus-retraining therapy. Suppression of the alpha power or a slowing of the alpha frequency (or both) indicated a negative effect of this device. However, an increase of alpha power or an acceleration of the alpha frequency (or both) indicated that the device is appropriate for treating such patients. These data clearly indicate that tinnitus induced significant changes of the EEG patterns.

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