Electroencephalography Correlates in Tinnitus

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Abstract: This study was conducted in an attempt to determine whether the quantitative electroencephalograph activity differs between normal control subjects and subjects suffering from tinnitus. Results indicated that male tinnitus patients as a group had a significantly reduced average total power as compared to control subjects. This finding contrasted with female tinnitus patients, who as a group had a higher average total power as compared to normal female control subjects. Topographical maps (control value–tinnitus value) indicate that with male patients, the frontocentral regions of the brain show the greatest difference. For the female tinnitus patients, the brain regions most affected are the central, parietal, temporal, and occipital regions.

Keywords: gender; QEEG; tinnitus

Twelve million US citizens suffer from tinnitus (ringing in the ear), a common and distressing condition. An additional 40 million people have a milder form of this disease. Tinnitus is characterized by the perception of auditory signals, usually lacking any internal or external source of sound [1]. Many tinnitus patients make a successful adaptation to the presence of these phantom sounds. However, for those who fail to adapt, tinnitus can affect their daily lives profoundly, often leading to depression, anxiety, concentration problems, social isolation, insomnia, and suicide [2]. The goal of our study was to determine whether the quantitative electroencephalographic (QEEG) activity of tinnitus patients differs from that of normal subjects.

The neural loci and mechanisms that cause tinnitus and its attendant disabilities remain poorly understood. Single-photon emission computed tomography and positron emission tomography provide evidence for an altered cerebral perfusion, receptor density, and altered metabolic activity in tinnitus patients [3]. Studies employing acoustic evoked potentials, visual evoked potentials [4], and vestibular evoked potentials [4,5] indicated a cortical information dysfunction in tinnitus patients.

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METHODS

Demographics

Patients were referred to us by their physicians with a diagnosis of tinnitus. The control group consisted of patients without any medical and neurological diseases. All patients signed an informed consent form before participating in the study. A total of 55 normal controls and 151 tinnitus patients were subjected to a computer-assisted EEG analysis. The composition of both groups is given in Table 1.

The average age of the control group male was 45.1 ± 16.3 years; that of the female control group was 43.0 ± 11.1 years. The average age of the male tinnitus group was 49.5 ± 11.5 years, and that of the female tinnitus group was 44.4 ± 14.1 years. No significant age difference existed between the different groups. The average period of tinnitus duration suffered by the female patients was 33.7 ± 4.0 months and was 44.7 ± 2.7 months for the male patients. On the basis of the Goebel questionnaire, both patient groups were categorized as having decompensated tinnitus.

Quantitative Electroencephalography

The brain waves (electroencephalography [EEG] signals) were obtained employing a Neurosearch 24 instrument (Lexicor Medical Technology, Inc., Boulder, CO) by placing 19 electrodes on the scalp in a standard international (10–20) pattern. The EEG signals from each electrode were amplified independently by matched

Table 1. Composition of the Normal Control Group and the Tinnitus Group

		Tinnitus Location in Subjects		
	Controls	Left-sided	Both-sided	Right-sided
Female	20	13	30	15
Male	35	29	45	19
Total	55	42	75	34

differential amplifiers with less than 2 μv peak-to-peak noise; input impedance of more than 70 MΩ differential; common mode rejection of more than 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.

All EEG data were inspected visually for artifacts due to movements and to muscular activity before the records were subjected to quantitative analysis and interpretation. Statistical calculations were performed using only artifact-screened data. All EEG data were collected under controlled conditions, with patients 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 screened manually 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 is calculated by averaging the total power from each of the 19 electrode leads. The average total power for the male tinnitus patients (n = 93; 23.7 ± 0.5 μV^2) was significantly lower than the average total power of the male control patients (n = 35; 31.0 ± 1.1 μV^2; $p < .0001$). However, for the female patients, the average total power for those in the tinnitus group (n = 58; 29.8 ± 0.6 μV^2) was significantly higher than the average total power for the respective control patients (n = 20; 25.1 ± 0.8 μV^2; $p < .0001$). An interesting note is that the average total power for the control males patients (n = 35; 31.0 ± 1.1 μV^2) was higher than that for the female control patients (n = 20; 25.1 ± 0.8 μV^2; $p < .0002$).

Average Total Power with Respect to Tinnitus Location

Separating patients on the basis of gender and location of the tinnitus, a significantly decreased average total power was found for all those in three male tinnitus groups (Table 2). Patients in the three female tinnitus groups, however, had a significantly increased average total power (see Table 2).

A comparison of patients in the male tinnitus groups revealed that the average total power of the right-sided tinnitus patients was significantly higher than that of the left-sided ($p < .05$) and the both-sided tinnitus groups ($p < .0001$). Furthermore, the average total power of patients in the left-sided tinnitus group was significantly higher than that of those in the both-sided tinnitus group ($p < .03$).

Comparing those in the female tinnitus groups, differences between the right-sided and both-sided tinnitus patients were not significant. The average total power of the left-sided tinnitus patients was increased significantly as compared to the right-sided tinnitus patients ($p < .005$) and were increased significantly as compared to the both-sided tinnitus patients ($p < .0001$).

Average Power with Respect to Tinnitus Location and Frequency Bands

Average power was calculated for four frequency bands: delta (2–4 Hz), theta (4–7 Hz), alpha (8–13 Hz), and beta (14–21 Hz). The patients in the male tinnitus groups demonstrated a significantly reduced average power between the left-sided and both-sided tinnitus patients for these frequency bands as compared to those for normal male control subjects. For the delta and theta bands, patients in all three male tinnitus groups had a significantly reduced average power as compared to that of the normal male control patients (Table 3).

For the delta band, there was a significant difference between the average power of the right-sided tinnitus group and the both-sided tinnitus group ($p < .02$). For the beta and the theta bands, the average power for the right-sided tinnitus group were significantly higher than that for the left-sided and the both-sided tinnitus groups.

Table 2. Comparison of the Average Total Power of Normal Control, Female, and Male Tinnitus Patients Suffering from Right-Sided, Left-Sided, or Both-Sided Tinnitus

	Average Total Power (μV^2)			
		Tinnitus Location in Subjects		
Gender	Control	Left-sided	Both-sided	Right-sided
Female	25.1 ± 0.8	34.3 ± 1.4[a]	28.1 ± 0.8[b]	29.6 ± 1.6[a]
Male	31.0 ± 1.1	24.4 ± 0.8[a]	21.5 ± 0.6[a]	27.6 ± 1.7[b]

[a] $p < .003$.
[b] $p < .02$.

Table 3. Average Power (μV^2) of Delta, Theta, Alpha, and Beta Frequency Bands in Male Tinnitus Patients and Normal Controls

Tinnitus Location	Delta (μV^2)	Theta (μV^2)	Alpha (μV^2)	Beta (μV^2)
Left-sided	11.81 ± 0.26^a	13.18 ± 0.46^b	58.64 ± 3.34^a	12.80 ± 0.48^a
Right-sided	12.52 ± 0.48^a	15.13 ± 0.86^b	69.74 ± 8.06	14.42 ± 0.64
Both-sided	11.25 ± 0.25^a	11.19 ± 0.28^b	52.99 ± 2.55^a	11.05 ± 0.28^a
Normal control	14.81 ± 0.46	17.43 ± 0.63	80.37 ± 4.73	14.26 ± 0.52

$^a p < .0001$.
$^b p < .005$.

For the alpha band, the right-sided tinnitus group had a significant higher average power than the both-sided tinnitus group.

Patients in the female group with left-sided tinnitus had a *significantly reduced* average power, and the female patients with right-sided tinnitus had a *significantly increased* average power for the beta band as compared to the normal female control patients. No significant difference was seen between the control female patients and the both-sided tinnitus patients. For the delta and theta bands, only those in the group with left-sided tinnitus had a significantly increased power value as compared to that of patients in the control group. For the alpha band, all three groups had significantly increased power values (Table 4).

For the delta and theta bands, the left-sided tinnitus patients had a significantly increased average power as compared to the average power of the both-sided tinnitus patients ($p < .0001$), and the right-sided tinnitus patients ($p < .0001$). For the beta band, the average power was significantly higher for the right-sided tinnitus patients than for the both-sided tinnitus patients ($p < .0001$) and the left-sided tinnitus patients ($p < .0001$). For the alpha band, those in the left-sided tinnitus group had an average power significantly higher than that of the both-sided tinnitus patients ($p < .04$).

Subdividing the alpha band into $alpha_1$, $alpha_2$, and $alpha_3$ revealed significant differences for all three bands (Table 5). The average power of the $alpha_1$ band was reduced significantly in the male tinnitus groups but was increased significantly in the female tinnitus groups with left-sided and both-sided tinnitus as compared to the respective normal control patients.

Compared to normal control values, the power of the $alpha_2$ band was reduced significantly in the three male tinnitus groups but was increased in the three

Table 4. Average Power (μV^2) of Delta, Theta, Alpha, and Beta Frequency Bands in Female Tinnitus Patients and Normal Controls

Tinnitus Location	Delta (μV^2)	Theta (μV^2)	Alpha (μV^2)	Beta (μV^2)
Left-sided	18.0 ± 0.8^a	22.2 ± 1.5^a	78.4 ± 5.1^a	14.3 ± 0.6^a
Right-sided	13.5 ± 0.4	15.3 ± 0.6	72.1 ± 5.9^b	19.5 ± 0.9^a
Both-sided	14.8 ± 0.4	15.6 ± 0.5	66.3 ± 3.2^c	15.9 ± 0.5
Normal control	14.0 ± 0.5	14.3 ± 0.5	54.8 ± 3.2	16.3 ± 0.7

$^a p < .0001$.
$^b p < .005$.
$^c p < .03$.

Table 5. Average Power for $Alpha_1$, $Alpha_2$, and $Alpha_3$ Bands in Female and Male Tinnitus Patients

		Total Average Power (μV^2)			
			Tinnitus Location		
Frequency	Gender	Control	Left-sided	Both-sided	Right-sided
$Alpha_1$, 7–9 Hz	Female	18.4 ± 1.1	48.1 ± 3.8^a	26.1 ± 1.7^a	23.2 ± 2.2
	Male	35.9 ± 1.6	24.1 ± 1.7^a	20.5 ± 1.1^a	37.6 ± 4.9
$Alpha_2$, 9–11 Hz	Female	23.9 ± 1.5	54.6 ± 3.6^a	39.4 ± 2.6^a	38.8 ± 7.1^a
	Male	59.7 ± 3.1	41.2 ± 3.4^a	34.1 ± 1.6^a	44.2 ± 8.1^a
$Alpha_3$, 11–13 Hz	Female	15.6 ± 1.4	14.7 ± 0.9	16.0 ± 1.0	12.3 ± 1.2
	Male	15.5 ± 0.9	10.8 ± 0.7^a	14.3 ± 1.0	8.5 ± 0.4^a

$^a p < .001$.

female tinnitus groups. The average power of the $alpha_3$ band was reduced significantly in the male tinnitus groups with left-sided and right-sided tinnitus as compared to that of control values. No significant differences were found for the $alpha_3$ band for the female tinnitus patients.

Power Brain Maps for Female and Male Tinnitus Groups

Brain maps (control value–tinnitus value) for patients in all three *female* tinnitus groups indicate most changes in the central, parietal, temporal, and occipital regions, whereas in brain maps (control value–tinnitus value) for patients in all three *male* tinnitus groups, the frontocentral regions exhibited most changes.

DISCUSSION

Tinnitus is associated with a wide variety of disorders in the auditory system. Whether generated peripherally or centrally, tinnitus is believed to be associated with activity in specific cortical regions.

This study represents an initial demonstration of a significant correlation between tinnitus and QEEG. Computer-assisted EEG analysis clearly demonstrates prominent differences with regard to the average power for the delta, theta, alpha, and beta bands between patients in female and male tinnitus groups relative to differences in their appropriate normal control subjects. It also shows differences among tinnitus patients with left-sided, right-sided, or both-sided tinnitus. An interesting note is that Rozelle and Budzynski [6] found increased theta power in a male head-injured person suffering from tinnitus.

Topographical illustrations of the EEG data indicated that different brain areas are concerned with the cerebral representation of tinnitus in male patients as compared to female patients. For male tinnitus groups, the largest differences are seen in the fronto-centro-regions, whereas in female tinnitus subjects, the largest differences are seen in the centro-parieto-occipital regions.

Giraud et al. [7] reported an increased regional cerebral blood flow in the temporo-parietal association auditory areas but not in the primary auditory cortex. They assumed that the activation in these regions is compatible with cortical processing of ascending messages generated at subcortical levels. Arnold et al. [8] reported in all but one tinnitus patient an increased metabolic activity in the left primary auditory cortex. Hurst and Lee [9] found in a female tinnitus patient electrographic seizures originating from the contralateral midtemporal area. Computed tomography demonstrated a lesion involving the superior temporal gyrus and inferior portion of the supramarginal gyrus. Subtracting positron emission tomography images of regional cerebral blood flow distribution during the habitual tinnitus sensation caused increased neuronal activity predominantly in the right hemisphere with significant foci in the middle frontal and middle temporal gyri, in addition to lateral and mesial posterior sites [10]. A possible cerebellar origin was discussed by Lobo et al. [11], who described a patient suffering from dysplastic gangliocytoma, ahamartomatous malformation of the cerebellar hemisphere.

Our study indicates that EEG patterns and the regions of the brain involved are fairly different in female and male patients suffering from tinnitus. Our study is the first with a large number of tinnitus patients in whom QEEG was correlated with tinnitus. These data indicate that QEEG data may serve as a tool to aid in the diagnosis of tinnitus.

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