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Quantitative Electroencephalography: Preliminary Report—Tinnitus

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Abstract: This preliminary report is an account of 21 consecutive patients who had tinnitus of the severe disabling type and were examined with quantitative electroencephalography (QEEG). A multimetric analysis of the raw data was highlighted by an abnormal incidence of significant central nervous system electrical dysfunction identified in each patient (21 of 21). Relative power was increased or decreased in the temporal region in 10 of 21 patients. Relative power was reported to be increased or decreased in temporal frontal regions in 20 of 21 patients. Coherence irregularity was identified in all 21 patients. QEEG preliminary data support the hypothesis of a final common pathway for tinnitus and the significant role of the temporal and temporofrontal regions of interest in patients with tinnitus of the severe disabling type. QEEG with multimetric analysis is considered a significant addition to the medical audiological tinnitus patient protocol as one of a battery of electrophysiological tests for the clinical identification of a predominantly central type of tinnitus.

Key Words: absolute power; montage; neurotherapy; phase; quantitative electroencephalography; relative power amplitude asymmetry; spectral frequency analysis; tinnitological electroencephalography

Quantitative electroencephalography (QEEG) has been introduced into the medical audiological tinnitus patient protocol (MATPP) [1]. This development has several goals: to improve the accuracy of tinnitus diagnosis by the identification of an electrophysiological correlate, to attempt tinnitus control with a biofeedback treatment method influencing brain rhythms (neurotherapy), and to monitor the efficacy of therapeutic modalities directed at tinnitus relief.

It has been hypothesized on the basis of single-photon emission computed tomography (SPECT) of brain in patients with idiopathic tinnitus of the severe disabling type (SIT) that a final common pathway exists in brain for all clinical types of tinnitus [2]. Significant perfusion asymmetries in multiple brain regions of interest, highlighted by the medial temporal lobe system (MTLS), have been identified. The introduction of QEEG into the MATPP will attempt in the future to identify what, if any, correlations can be established between the perfusion asymmetries identified with SPECT of brain and QEEG. Such correlations may provide objective electrophysiological and metabolic correlates for all clinical types and subtypes of tinnitus and may establish or explain its psychophysiological implications.

Sensory physiology teaches that all sensations, normal or abnormal, involve different components, among them sensory, affect, and psychomotor. Electrophysiological and metabolic correlates can, when identified, provide objectivity to subjective sensory perceptions. Clinical types and subtypes of tinnitus have been reported [3]. In an attempt to objectify the symptom of tinnitus, parameters of tinnitus identification were reported of short-latency responses to broad-band click stimulation (i.e., auditory evoked potential brainstem responses) [4]. Evoked potentials are electrical responses of the nervous system to motor or sensory stimulation [5]. Electrical activity unrelated to the stimulus is averaged out of the recording. The term *evoked potentials* is defined as the average of multiple responses. It is the electrical recording following a single stimulus. It has been clinically applied via inclusion in the MATPP for the identification of a predominantly central type tinnitus [1,4].

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QEEG is a power spectrum quantitative analysis of brain functions as reflected in electrophysiological measures (i.e. metrics, which are demonstrated as the electroencephalograph [EEG]). Normative databases have been established for normative brain function [6–8] and can be used in charting function after head injury [9]. EEG is not a structure-oriented test but is a reflection of function and dysfunction recorded at the brain cortex. Patterns of EEG have empirically been correlated with central nervous system (CNS) function and dysfunction and diseases [10].

QEEG has been applied clinically for the diagnosis and treatment of tinnitus by Weiler et al. [11], who reported differences between normal control subjects and tinnitus patients. Additionally, it has been used to identify beta foci in T3 and C4 in patients with tinnitus, which foci resolve with spontaneous remission of the tinnitus [12], and QEEG has been employed for determining the influence of noise generators on inducing changes in EEG activity in healthy control subjects and in subjects suffering from tinnitus [13].

The neuroscience of brain function has identified various rhythms of different frequencies in brain. Different rhythms (frequencies) have been correlated with certain behavioral and mental functions. Rhythmicity implies organization and function. Historically, the original 14 reports on human EEG by Hans Berger [14] identified EEG as a phenomenon having significant psychophysiological implications and established its significance in clinical investigation for understanding human behavior as reflected in mental functions. Boundaries of normality for EEG in humans have been identified. The quantitative analysis of brain function as reflected in such electrophysiological measures as EEG and sensory evoked responses was reported in the mid-1960s [15].

The use of interpolation algorithms that operated on quantitative values assigned to electrode positions on a spatial grid allowed the construction of topographical maps [16]. This practice, called *neurometrics,* provided a basis for the development of a numerical taxonomy that identified different profiles of brain functions within groups of behaviorally similar people [17]. Neurometrics is a statistical technique that quantitatively evaluates the electrical activity of the brain by extracting from different electrophysiological phenomena a common matrix of relative probability [17–20]. It is a sophisticated method of evaluating EEG. The more improbable a feature of value, the more likely it is to reflect abnormality. The more probable the value, the less likely it is to be a signal of dysfunction. The method identifies from the electrical responses "those numbers reflecting clinically meaningful signals embedded in the sea of numerical noise." It provides a comparison of subclinical and clinical neurological dysfunction with controlled data from normal individuals.

Electroencephalographers speak of EEG as "the continuous roar or noise of the brain" [21]. For epilepsy, one speaks of "epileptological EEG." Recording in tinnitus patients of the rhythmicity in brain may reflect an interruption in brain rhythm organization. Cellular substrates of brain rhythms have been reported [22].The application of EEG for tinnitus (i.e., tinnitological EEG) and its analysis with QEEG may thus provide an insight and contribution to understanding the underlying electrophysiology of all clinical types and subtypes of tinnitus. An underlying mechanism for tinnitus was originally proposed to be one of dyssynchrony (i.e., a lack of synchrony or interference in timing of the discharge rate and phase locking of the auditory signal) [4].

The early teaching of interpretation of EEG stressed that the impression of a rhythmicity and organization is "not a yardstick for the normality of an EEG"; also, an "anarchic appearance does not necessarily imply abnormality" [21]. This view is considered to be significant for the evolving experience in the clinical interpretation of QEEG in patients with severe disabling tinnitus. The clinically relevant frequency range of EEG—between 0.1 and 14–30 per second—has been identified to be important from the psychophysiological viewpoint. In the normal adult, the slow range (0.3–7.0 per second) and the very fast range (beyond 30 per second) are "sparsely" represented; the medium (8–13 per second) and fast (14–30 per second) ranges predominate. These frequencies are broken down into bands or ranges.

The frequencies of the raw EEG data, called *bands*, as discussed in Niedermeyer and da Silva [21], are as follows: delta—fewer than 3.5 per second, usually 0.1–3.5 per second; theta—4.0–7.5 per second; alpha—8–13 per second; and beta—beyond 13 per second, usually 14–40 per second. The term *gamma* [23] was used to designate frequencies beyond 30 or 35 per second; this rhythm was essentially 35–45 per second superimposed on the occipital alpha rhythm [24]. However, this term later was abandoned, and gamma frequencies are now simply a part of the beta range.

The term *delta* was introduced by Walter [25] and designates frequencies below the alpha range. The term *theta* also was introduced by Walter [25] and Knott [26] to designate the 4.0- to 7.5-per second range. The designation *theta* was chosen for thalamus because a thalamic origin was presumed to relate to these waves [25,26].

The metrics for analysis with QEEG include absolute power, relative power in terms of percentage of power; asymmetry; coherence reported as elevated or reduced; and phase reported as phase-delay positive-

negative and as both intra- and interhemispheric homologous pairs. All of these metrics can also be expressed in terms of the deviation of standardized scored based on some set of norms (i.e., *Z*-scores).

This preliminary report discusses what are considered to be the highlights of the electrophysiological analysis of the raw EEG data of 21 consecutive patients who had severe disabling tinnitus and who completed a QEEG analysis. A case report will demonstrate the highlights of the multimetric analysis of QEEG.

METHOD

Patients having tinnitus of the severe disabling type of 1 year's duration or longer were selected for QEEG as part of an MATPP [1]. The patient pool included 15 men with an age range of 29–77 years and an average of 45.8 years, and 6 females with an average age of 49.4 years and a range of 29–88 years. The normative database used included normative data for the metrics of relative power, amplitude, asymmetry, phase, and coherence [6]. The age range of the database is 2 months to 83 years of age and includes 625 subjects. Delta is 0.5–3.5 Hz, theta 3.7–7.5, alpha 7.5–13.5, and beta 13.5–22.0.The QEEG test was performed with the eyes open and closed in a quiet, darkened room with the patient sitting relaxed in a chair in an upright position.

The Neurosearch 24 QEEG equipment was used for the QEEG examination [27]. Nineteen (19) electrodes were placed on the scalp of the patient, using the international 10/20 montage, a montage being a standardized array of electrode sites used to ensure consistent results. The impedance measured at each electrode site with respect to the reference was less than 5,000 Ohms (5k Ohms). The high filter was set at 0.5 Hz and the low filter at 32 Hz. Three hundred (300) epochs were recorded, and 25 epochs were selected as being representative and artifact-free and were processed and compared with the normative database. The gain was 32k, with a sampling rate of 128k.

The raw EEG was submitted to the Lexicor Co. (Boulder, CO) for analysis, and a report called the *Datalex* report was generated for clinical application [28]. The Datalex report is presented in two sections. Section I includes normative reference database comparisons for the metrics of relative power, amplitude asymmetry, coherence, and phase [6]. Section II includes graphic representations of the raw data by means of color topographic maps of absolute peak-to-peak microvolt amplitude at 1-Hz intervals in the frequency domain, along with a numerical table from which the topographic maps are derived. This section also includes 8 topographic maps of the absolute power in 8 defined bands in the frequency domain and is accompanied by a numerical table containing the data from which the maps were derived. In addition, section II includes percent power ratios computed at each of the 19 locations for each of the 8 bands compared to the total power measured at that location. Compressed spectral arrays (CSAs) also are displayed that illustrate the evolution of the frequency spectrum over time at each of the 19 electrode locations in the montage [28].

Adjacent to each CSA is a bar graph displaying the averaged response over the time interval encompassed by each CSA in each of 8 different bands. All of the aforementioned frequency domain data are derived from the raw EEG data by means of the commonly used fast Fourier transform (FFT). The epochs selected for transformation into the frequency domain are chosen based on their being uncontaminated by movement artifacts such as those caused by excess muscle (electromyographic) or eye (electrooculographic) movements [28].

In section I, the relative power tables display the relative distribution of activity over the delta, theta, alpha, and beta frequency bands. The power values are reported for the left (L) and right (R) hemispheres as both percent power and power *Z*-scores (i.e., the numerical designation of each band's deviation from the normative data for that particular band and location). Those band locations for which the deviation is greater than 1.96 or less than –1.96 are automatically highlighted in red or blue depending on the direction of deviation. The average total power would be computed by summing the power values from all of the electrode locations on the left and right sides of the montage and dividing by 19, the total number of electrodes [28].

Asymmetry *Z*-scores compare the power balance between pairs of symmetrical or homologous electrode sites. Increased asymmetry indicates R>L, whereas decreased asymmetry reflects L>R. The asymmetry *Z*-scores, as with all of the other metrics discussed here, reflect an average value over all of the 25 selected data epochs included in the report.

Coherence is a measure of the shared electrical activity between pairs of electrode sites as a function of frequency. Coherence implies unification of action and is independent of amplitude. A more technical definition of coherence would be the degree of correlation between two montage electrode locations at a particular frequency. Coherence in a band is computed by averaging all of the individual coherences for each frequency that composes the band. One speaks of coherence being elevated or reduced. Increased coherence reflects an increased amount of "coordination" between brain subsystems or identified areas. A reduced coherence implies a "disconnect" at a frequency or over a band of frequencies. If the coherence is reduced, the findings

reflect a lack of connection or too much differentiation of signal processing in brain subsystems or between regions [28].

Phase measurements reflect the degree to which the electrical activity of one location "leads" or "lags" another location in a pair of electrodes. Phase in a connected system, as in the cerebral cortex, is a function of EEG frequency, distance between sites, and conduction velocity. Phase is often expressed in terms of positive or negative phase delays. Phase *Z*-scores express the extent to which the lead or lag at one or more frequencies between two electrode locations deviates from normative data for those locations and frequencies. Phase relationships between channels may also be interpreted as reflecting the degree of functional differentiation between neuronal systems. Lag or phase delay reflects a decrease in velocity and therefore a longer processing time of the signal in the region of the recording. Lead or phase increase reflects an increase in velocity and therefore a shorter processing time of the signal in the region of the recording [28].

Although all of the aforementioned metrics may vary from session to session within and between individuals owing to small differences in electrode placement, individual variances in skull thickness, different genotypes and phenotypes, and pathologies, it is nevertheless possible to determine age-matched norms for both normal subjects and various pathologies. Thus, despite all the factors contributing to intra- and intersubject differences, it is possible to say that certain complex relationships of frequencies or bands of frequencies are repeatedly found in the EEG as a function of both physiological state and underlying pathology [29].

RESULTS

The QEEG data recorded from 19 montage sites in each of 21 patients with tinnitus of the severe disabling type was submitted to the Lexicor Company for analysis and generation of the Datalex report [28]. The quality of the raw EEG data to be analyzed was rated on a scale from 1 (excellent) to 5 (poor). The quality of data for analysis in this report of 21 patients averaged 1.5. The results with eyes closed include the following highlights: abnormal incidence of significant CNS electrical dysfunction in all 21 patients; relative power increase-decrease identified in the temporal regions of 10 of 21 patients; relative power increase-decrease in temporofrontal regions identified in 20 of 21 patients; and coherence irregularity in all 21 patients.

The following case report is a demonstration of the Datalex report obtained from a male patient, age 68, with severe disabling type tinnitus. The tinnitus was described as lasting more than 1 year. The location was in the ear and head, with ear disturbance greater than that in the head and left ear disturbance greater than that in

Relative Power Values

Left	Delta	Theta	Alpha	Beta	Right	Delta	Theta	Alpha	Beta
FP1	8.83	8	33.45	49.71H	FP2	9.05	8.28	32.54	50.13H
F7	9.05	7.39	29.31	54.26H	F8	9.05	6.88	29.26	54.80H
F3	8.8	9.34	33.94	47.93H	F4	8.26	9.03	33.86	48.85H
T3	10.5	7.54	35.37	46.59	T4	11.13	8.46	38.94	41.47
C3	9.1	9.37	38.73	42.79	C4	8.46	8.82	41.12	41.59
T5	9.3	8.87	40.24	41.59	T6	8.11	7.31	48.87	35.71
P3	8.53	8.39	42.32	40.76	P4	8.53	8.3	47.54	35.63
O1	6.75	7.1	55.25	30.9	O2	9.1	9.42	50.74	30.73

Relative Power *Z*-Scores

Left	Delta	Theta	Alpha	Beta	Right	Delta	Theta	Alpha	Beta
FP1	−0.87	−1.2	−0.61	2.16	FP2	−0.83	−1.11	−0.7	2.31
F7	−0.88	−1.46	−1.13	2.77	F8	−0.77	−1.29	−1.16	3.05
F3	−0.61	−1.18	−0.78	2.39	F4	−0.75	−1.11	−0.78	2.17
T3	0.1	−0.86	−0.39	0.56	T4	0.18	−0.71	−0.21	0.54
C3	−0.31	−0.82	−0.44	1.35	C4	−0.37	−0.85	−0.3	1.31
T5	0.01	−0.56	−0.7	1.52	T6	−0.15	−0.65	−0.24	0.88
P3	−0.17	−0.58	−0.59	1.41	P4	−0.18	−0.6	−0.28	0.93
O1	−0.31	−0.57	−0.15	0.85	O2	0.22	−0.21	−0.49	0.88

= ± 0.025 significance level ($|z| > 1.96$).

Figure 1. Relative power. The record contains a disproportionate distribution of power. There is increased percentage of power in bilateral frontal regions (beta).

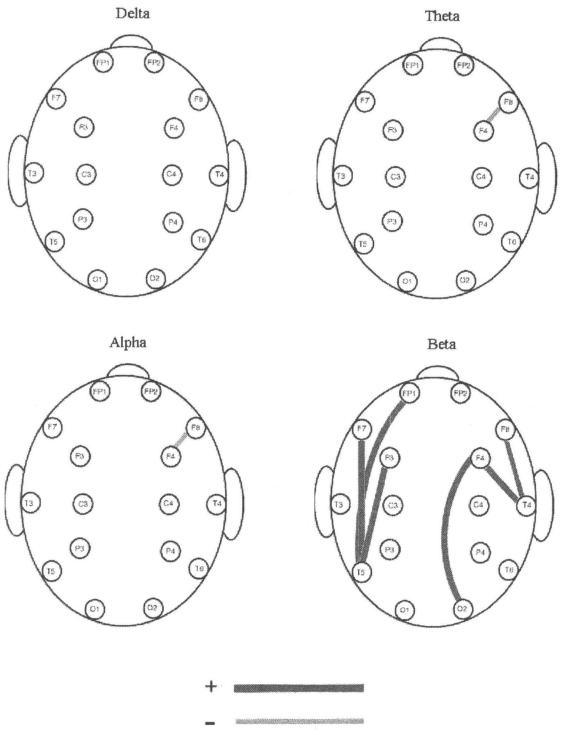

Figure 2. Asymmetry *Z*-scores. The record contains increased and decreased amplitude asymmetry. Increased amplitude asymmetry (L > R) is present in the left hemisphere with a focus at T5, as well as in the right-hemisphere long distant fronto-occipital connection and the T4 connections (beta). This finding reflects a significant increase in power (L > R) in these regions. Decreased amplitude asymmetry (L < R) present in the right hemisphere local frontal-frontal region (theta, alpha). This finding reflects a significant reduction of power (L < R) in these regions.

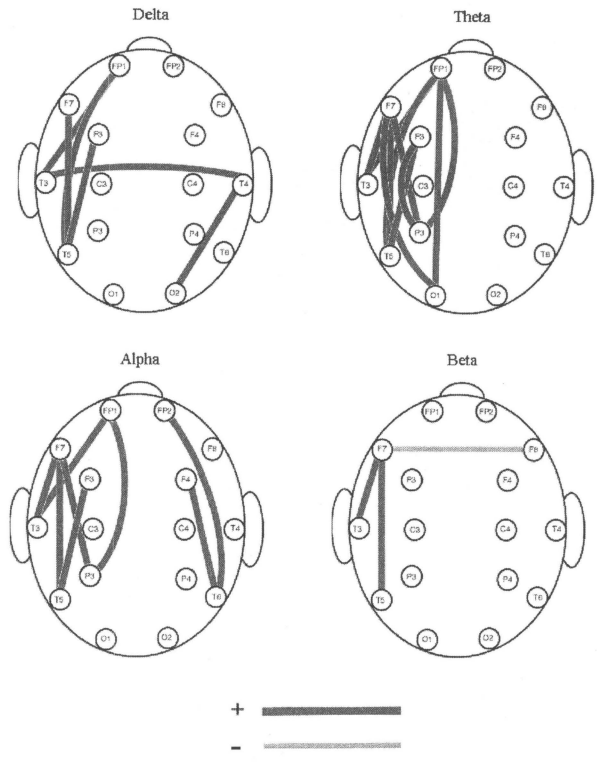

Figure 3. Phase *Z*-scores. The record contains excessive positive and negative phase delays. Excessive positive phase delay between hemispheres in frontal and central connections (beta); bilateral frontal connections with greater incidence in the right hemisphere (alpha). This finding would reflect a significant decrease in velocity and a longer signal-processing time than would be expected in these regions. There is excessive negative phase delay in the left-hemisphere short distant frontocentral connection (delta). In the right hemisphere, note the long- and medium-distant frontal connections (delta/theta). This finding would reflect a significant increase in velocity and therefore a shorter signal-processing time than would be expected in these regions.

the right ear. The patient reported constant duration and fluctuant intensity, with an average of 5 on a tinnitus intensity index scale of 0–7 (where 0 means tinnitus is gone and 7 is tinnitus intensity at its worst). The Feldman Masking Curve was IV.

Relative power readings are seen in Figure 1. Asymmetry *Z*-scores are displayed in Figure 2. Figure 3 contains the coherence *Z*-scores, and Figure 4 shows the phase *Z*-scores.

DISCUSSION

The highlights of the QEEG findings in this preliminary report support continued QEEG use to attempt to improve the accuracy of the tinnitus diagnosis. The potential application of QEEG for tinnitus treatment with a method of neurobiofeedback (neurotherapy) is equally substantiated. Significant clinical application of QEEG is reflected in the EEG severity index of traumatic brain injury [9] and computer-assisted differential diagnosis of brain dysfunctions [20]. QEEG analysis provides a "level of specificity and sensitivity that is comparable to sonograms, blood tests, MRIs and other diagnostic measures commonly used in clinical practice" [6–9].

QEEG data obtained for this preliminary report in EEG recordings from multiple electrode montage sites in patients with a severe disabling tinnitus reveal significant alterations in electrical activity in the CNS. The QEEG data of distribution of brain rhythms are considered to reflect brain function-dysfunction in all the reported tinnitus patients (N = 21). Clinically, support is found in the present QEEG data for the clinical impression of a probable significant correlation with perfusion asymmetries in regions of interest in brain SPECT in patients with severe disabling tinnitus [2]. Data from

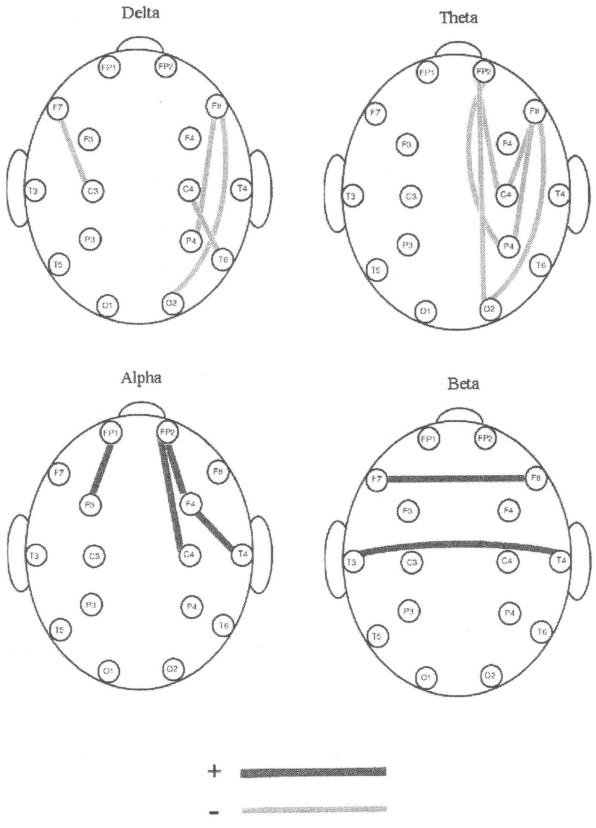

Figure 4. Coherence *Z*-scores. There is elevated coherence between hemispheres in the central temporal connections in the left hemisphere, diffuse frontal connections (all frequencies); in the right hemisphere, medium-distant temporo-occipital connection (delta); in the right hemisphere, medium- and long-distant frontotemporal connections (alpha). This finding reflects a lack of differentiation or excessive similarity of cortical signal processing in brain subsystems and between regions in the identified area.

both, when coregistered, may provide an objective demonstration of different clinical types of tinnitus. The EEG/SPECT data may reflect an underlying neurochemistry of neurotransmitter systems, with the probability of multiple sites and activities within cellular, neuronal, and interneuronal substrates of neurotransmitter systems, the site and pharmacokinetic activity specificity of which is genetically controlled at specific receptor sites [30, 31].

Information About Underlying Mechanisms of Tinnitus Production

The data raised several questions. For example, do the data provide any information of underlying mechanisms of tinnitus production? The high incidence of occurrence of significant CNS electrical dysfunction in all 21 patients with a severe disabling type of tinnitus is considered to be a source of information and investigation of underlying mechanisms of tinnitus production. Tinnitus has been proposed to be a "phantom phenomenon" [32]. However, the term *phantom phenomenon* implies a phenomenon that lacks the identification of a neuronal substrate. The QEEG findings reported at this time in this limited group of patients are clinically considered to reflect multiple locations of activities of cellular, neuronal, and interneuronal substrates underlying brain rhythms. The present QEEG data support the clinical contention that tinnitus should not be generalized, or considered to be a phantom phenomenon for all tinnitus patients [2,30,31].

The concept that tinnitus is a body "noise" that, in the sense of an aberrant auditory signal, becomes clinically manifest as a particular clinical type of tinnitus (i.e., a somatic phenomenon) must be considered in the interpretation of QEEG activity results patterns [33]. Does this mean that a particular type of tinnitus is a somatosensory disorder? To what degree do the QEEG data reflect "noise" or a somatosensory stimulus resulting in tinnitus or do the QEEG data reflect the aberrant auditory stimulus (i.e., tinnitus)? Some of the answers may come from the QEEG analysis of the various brain rhythms alone or in combination with data obtained from evoked potentials and nuclear medicine brain imaging.

Does the synchronization-desynchronization of cellular, neuronal, and interneuronal substrate activity, as reflected in the data patterns of brain rhythms with the QEEG, reflect underlying mechanisms for production of different types or subtypes of tinnitus? It is important to consider in this regard the alterations observed in the lower band frequencies of delta and theta and the higher-end frequencies of beta and their relationship to specific neurotransmitter receptor systems. A given frequency can be considered to be abnormal by excessive voltage. This is true for all frequencies and is particularly important for the fast (beta) band. Unusually low voltages can also be indicative of an underlying abnormality.

In general, EEG recordings of low voltage and low amplitudes indicate life-threatening decline of cerebral voltage output. The vast majority of low-voltage recordings are "desynchronized." Synchronization-desynchronization of the auditory signal is significant for central auditory function. The identification of synchrony-dyssynchrony with multimetric QEEG analyses will help to establish the significance of synchrony of neural activity for a particular central type or subtype of severely disabling tinnitus.

Synchronization or desynchronization of the auditory signal has been proposed as a theory for tinnitus production for all clinical types of tinnitus [4]. QEEG multimetric analyses are considered to support this theory. QEEG

recordings in both the awake (with the eyes open and closed) and the sleep condition of tinnitus patients may provide significant information for understanding the underlying electrophysiological processes involved in the clinical course of severely disabling tinnitus. In this article, findings only with the eyes closed have been reported. Further discussion awaits results of our ongoing QEEG evaluation of a larger cohort of such patients.

Significance of the QEEG Data

What is the significance of the QEEG data in this report? The high incidence of occurrence of significant alterations in electrical activity in the CNS of all 21 patients provides objective evidence to support a clinical diagnosis of a central component for tinnitus patients. Correlation of the history with MATPP establishes the clinical type of tinnitus. Is the recording at the cortex due to an abnormality arising primarily in the cortex or does it secondarily reflect projected neuronal activity from subcortical areas of excitation or inhibition or peripheral input reflecting itself at subcortical or cortical levels?

Future correlations of QEEG with nuclear medicine imaging techniques of SPECT, positron emission tomography, functional magnetic resonance tomography, and magnetoencephalography and results of cochleovestibular testing in the MATPP will provide an insight into brain function and establish what, if any, relationship exists for severe disabling tinnitus between brain lesions, focal EEG abnormalities, and metabolic disturbances.

How to Record, Analyze, and Interpret the QEEG Data for Severe Disabling Tinnitus

How should the QEEG data be recorded or analyzed or interpreted for severe disabling tinnitus? In general, first the conditions under which the QEEG is being performed and the method of recording must be specified in each report. Specification is recommended for the hardware used for the recordings, methods and conditions used to obtain the recordings (e.g., match of amplifiers and filters), and the database to which reference is being made. The environment must be conducive to quiet. The recordings must be obtained with the eyes open and then closed, and these results must be compared. The eyes-closed recordings are reported at this time. The data with eyes open and closed will be reported in future articles.

Second, there is a need for investigators and clinicians to specify in the report the reference database on which the interpretation is based. The issue of interpretation of what is significant in the QEEG data may vary with the referenced normative database. Different normative databases reflect variances for the basic frequency bands that can significantly influence the interpretation of the data. The application of a large normative database [6–9] has increased the reliability of interpretation of normal and abnormal brain recordings.

Third, multiple metric analyses of the QEEG data have been found to be critical for interpretation and attempts to establish an understanding of the significance of the data for the patients with severely disabling tinnitus. The Datalex report has provided access to experts in the field of EEG for such analyses. The metrics selected for analysis include relative power, amplitude asymmetry, phase *Z*-scores, and coherence. The interpretation of the QEEG data and the Datalex report is based not on any single analysis but rather on a number of metric analyses [28].

Data Display

How should the data be displayed? Multiple visual displays of the raw EEG data in the Datalex report, section II, have been found to assist in understanding the significance of the QEEG data, particularly for the clinical course of severely disabling tinnitus [28]. No single metric analysis or single montage site activity is considered sufficient as a basis for interpretation of the data's significance for severely disabling tinnitus. The alterations in the frequency band distribution varied with the particular metric analysis. The analysis of the frequency band distribution is in progress, and results will be reported in the future.

Significance of the High Electrical Dysfunction in the CNS

What is the significance of the high electrical dysfunction in the CNS as demonstrated by a relative power increase-decrease in the temporal and temporofrontal regions? The multiple metric analyses are highlighted by irregularities in coherence, phase, amplitude asymmetry, and relative power distinguished by the temporal and temporofrontal brain regions. In general, the incidence of occurrence of a given frequency band at a montage site varies with the generator site. The high incidence reported at this time of temporal and temporofrontal electrical dysfunction is compatible with brain SPECT reports of perfusion asymmetries in multiple regions of interest in brain highlighted by the MTLS [2].

One must consider whether EEG activity in homologous pairs, both global and interhemispheric, particularly between the temporal and frontal areas, may reflect the establishment of a short working memory with frontal involvement and site of sensory and affect transformation of an aberrant auditory signal (i.e., tinnitus).

In the hypothesis of a final common pathway for tinnitus, the initial process was suggested to be the establishment of a paradoxical auditory memory. The MTLS was proposed to be the involved neural substrate and a key component in this process [2].

Information from the QEEG Data for Tinnitus Patients

What information do these QEEG data provide to tinnitus patients? First and foremost is the identification of an abnormally high incidence of occurrence of significant CNS electrical dysfunction in such patients reported at this time. The current QEEG data for patients with tinnitus of the severe disabling type support previous reports [11–13]. Second, the clinical application of data from QEEG has improved the accuracy of the tinnitus diagnosis by identifying a significant central component of severely disabling tinnitus and provides a basis for a method of drug selection and treatment and a method to monitor the efficacy of therapeutic modalities attempting tinnitus relief.

A majority of diseases affecting the CNS have EEG correlates [10]. Significant QEEG studies in the past have evaluated the distribution of cortical electrical activity and brain rhythm in patients asleep and awake and with particular clinical conditions identified as attention deficit disorder, attention deficit hyperactive disorder, learning disabilities and head injuries, and psychiatric diagnoses of schizophrenia [9,20,34]. Such patients presented with problems of concentration, memory, impulse control, and mood shifts. The patterns, which are in general described as excessive slow brain waves (usually delta, slow theta, and sometimes excessive low-frequency alpha), can be accompanied by difficulty in controlling attention and emotions. The QEEG databases for these diagnoses may provide patterns of brain electrical activity for different brain rhythms that can find application not only in improving the accuracy of the tinnitus diagnosis but for tinnitus relief (i.e., neurotherapy).

Neurotherapy [20], a biofeedback system that attempts to influence rhythmicity in brain wave activity, has already been reported to provide significant tinnitus relief over the long term [12,13]. Yet to be established is which, if any, of these neuropsychological clinical experiences may be applied to patients with severely disabling tinnitus to increase our understanding of the underlying pathophysiology of the complaint of tinnitus and its clinical course. Specifically, we seek to isolate the sensory component (i.e., tinnitus) and other components of sensory disorders marked particularly by changes in affect and psychomotor response.

SUMMARY

In this preliminary report, all patients with severely disabling tinnitus of 1 year or greater duration were identified to have a predominantly central type tinnitus based on completion of the MATPP with the addition of QEEG [1]. What is evolving for tinnitus diagnosis is an objective battery of tests for diagnosis in such patients. Such a battery of objective tests already is included in the MATPP and is highlighted by objective tests of otoacoustic emissions, auditory brainstem responses, computerized rotary chair tests, and the nuclear medicine imaging technique of brain SPECT both at baseline and after the acetazolamide (Diamox) stress test [2]. QEEG, as demonstrated in this report, provides an additional objective method of testing for the recording of EEG activity. This modality may, by the future identification of EEG correlates for different clinical tinnitus types and subtypes, increase the accuracy of the tinnitus diagnosis, provide an understanding of the clinical course of severely disabling tinnitus, and find application for tinnitus treatment in the form of neurotherapy.

Correlation of QEEG and nuclear imaging techniques may provide a future objective basis on which to establish metabolic and electrophysiological correlates for the identification of different clinical types and subtypes of tinnitus. At this time, preliminary data of QEEG and SPECT display and share patterns of heterogeneity of distribution of activity in multiple regions of interest in the brain. It is, therefore, probable that EEG and nuclear medicine technologies will identify multiple—not single—electrophysiological-metabolic correlates for affected patients. No single electrophysiological-metabolic correlate that will be identified will apply for all tinnitus patients. Again, this supports the clinical impression that tinnitus is not a unitary symptom [30,31,35]. Rather, different electrophysiological-metabolic correlates will be identified and will reflect different mechanisms for different clinical types and subtypes of tinnitus, highlighting the complexity of underlying neurotransmitter-receptor systems with activity to be identified at cellular, neuronal, and interneuronal levels.

All tinnitus types and subtypes are hypothesized to share a common pathway for the sensory-affect transformation of a sensory stimulus (i.e., the aberrant auditory signal, or tinnitus) to one of affect, which binds together all clinical types and subtypes of severely disabling tinnitus [2].

CONCLUSIONS

Preliminary data from QEEG support the hypothesis that a significant role is played by the temporal and temporofrontal regions in patients with tinnitus of the

severe disabling type. QEEG provides insight into the underlying cellular, neuronal, and interneuronal substrates involved in brain rhythms and into their role in mechanisms for tinnitus production. QEEG is a significant addition to the MATPP for improvement in the accuracy of the tinnitus diagnosis by the identification of a predominantly central tinnitus. QEEG provides a method for monitoring the efficacy of instrumentation and neuroprotective pharmacological modalities of therapy attempting tinnitus relief. Finally, QEEG presents for the future the possibility of establishment of EEG correlates for different clinical types and subtypes of tinnitus.

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