

Neurofeedback and Quantitative Electroencephalography

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Abstract: This study was conducted in an attempt to determine the efficacy of neurofeedback (NFB) in the treatment of patients suffering from vertigo or tinnitus. Results indicated that after NFB, power for delta and theta bands was reduced; however, an increase of power was noted for the alpha bands. Furthermore, normalization was observed for the vestibular evoked potentials (VestEP). After NFB, a normalization of the VestEP was also demonstrated in a patient suffering from a bilateral tinnitus. A follow-up study (12 months after NFB) demonstrated that the VestEP were normal.

Key Words: neurofeedback; quantitative electroencephalography; tinnitus; vertigo; vestibular evoked potentials

Quantitative electroencephalography (QEEG) is a measurement that uses digital technology of electrical wave patterns at the surface of the scalp. These patterns generally are considered to reflect cortical electrical activity or so-called brain waves. Recorded electroencephalography (EEG) data are quantified subsequently through fast Fourier transform analysis.

The recorded EEG wave patterns are subdivided on the basis of frequency ranges, which clinically are defined routinely as delta, theta, alpha, and beta. Over the last 25 years, advances in signal processing have made possible the sampling of these waves many times per second (usually 128 or 256 samples per second) and their quantitative analysis in various ways. Using this technology, we can now measure the amplitude and content of specific wave frequency bands and their distribution over the scalp surface and can even compare a client's QEEG data to a normative reference database [1].

For some time, EEG has been employed clinically in behavioral medicine as a measure of brain function,

with the hope of determining and differentiating certain functional conditions of the brain. QEEG is employed also in treating patients who suffer from cognitive dysfunction resulting from either a general decline of overall brain function or a localized or lateralized deficit. This technology can be employed in working with patients suffering from tinnitus [2,3], wherein the analysis and evaluation of the QEEG data are essential for the design of appropriate neurofeedback (NFB) therapy.

NFB, also known as *EEG biofeedback*, is a computerized learning strategy that enables people voluntarily to alter their own brain activity. The EEG is monitored, and clients are shown components of their momentary EEG signature. Then subjects are asked to alter specific components of the brain waves (and thus the underlying physiology and biochemistry) toward a more appropriate functional balance. The modification of specific brain wave rhythms at appropriate regions of the brain follows, with improvement in function.

Operant conditioning of EEG characteristics is well documented in the scientific literature [4-7]. Training to decrease slow activity and to increase fast, desynchronized EEG activity has been used for more than 20 years to ameliorate attention deficit hyperactivity disorder and epilepsy [8-10]. More recently, EEG operant conditioning has been successfully applied to patients with mild traumatic brain injury [11,12]. Application of this technology in various forms has been reported for a

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wide range of injuries and diseases [13–20]. In this study, we report the effects of NFB on patients suffering from vertigo or tinnitus, employing EEG technology to verify NFB benefits.

METHODS

Quantitative EEG

We acquired the brain waves (EEG signals) 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 QEEG was taken using the Electro-Cap (Electro-cap International, Inc., Eaton, OH), an EEG electrode application technique. The Electro-Cap is made of an elastic spandex-type fabric to which recessed, pure tin electrodes are attached. The electrodes on the standard caps are positioned according to the international 10/20 method of electrode placement. Each lead was checked separately. Impedance was judged acceptable when electrode impedance registered below 5,000 Ω . 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 more than 70-M Ω 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, the sampling interval of which was governed by a 50-kHz crystal oscillator.

All EEG data were visually inspected for artifacts due to movements and to muscular activity before the records were subjected to quantitative analysis and interpretation. Frequency analysis was performed using a fast Fourier transform. The QEEG frequency bands chosen were delta (2–4 Hz), theta (4–7 Hz), alpha (8–13 Hz), and beta (14–21 Hz), with sub-alpha bands of α_1 (7–9 Hz), α_2 (9–11 Hz), and α_3 (11–13 Hz). Statistical calculations were performed using only artifact-screened data.

All EEG data were collected under controlled conditions with subjects 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.

Vestibular Evoked Potentials

The vestibular evoked potentials (VestEP) were performed by Dr. D. Schneider at the University Head

Center, Department of Ear, Nose, and Throat at the Neurotology Unit, Würzburg, Germany. The vestibular stimuli applied were repetitive short-duration rotatory movements (stepwise angular accelerations, clockwise, and counterclockwise) of the subject's entire body around a vertical axis. The onset of the positive acceleration served as a trigger impulse for averaging the EEG segments. To prevent emotional stress and muscle artifacts, a slow deceleration was applied. The rotational motion thus consisted of trials of clockwise and counterclockwise constant acceleration impulses. The inter-stimulus interval was 14 seconds, and the duration of acceleration and deceleration was 1,000 msec each. An angular acceleration and deceleration intensity of 15 degrees/sec² was chosen such that the angular velocity rose from 0 degrees/sec to a maximum peak velocity of 15 degrees/sec. The common step amplitude for the positive and negative acceleration phases was 30 degrees. After the onset of the stepwise acceleration stimulus, a period of 1,000 msec was used for analysis of the rotatory evoked brain electrical events. Peak-to-peak amplitudes and principal component latencies were measured and subsequently computed for their mean values and standard deviations [21].

Neurofeedback

EEG treatment protocols varied and depended on the presenting symptoms and on the baseline QEEG test results obtained from each patient. The Biolex EEG computerized biofeedback software was used with the Neurosearch 24, as described. The same settings, analysis, and electrode impedance criteria were used during the NFB training sessions. However, in the NFB training sessions, the frequency bands used were alpha (8.0–13.0 Hz; sensorimotor rhythm [also known as SMR]; 12.0–15.0 Hz) and beta (19.0–23.0 Hz and 13.5–14.5 Hz). The purpose of the study was to examine the efficacy of NFB in patients suffering from either tinnitus or vertigo.

RESULTS

Patient 1

A 33-year-old female medical technician and firefighter fell from a fire engine in September 2001. She landed on her buttocks and subsequently on the back of her head. After the fall, the patient reported concentration problems, headache (in the area of the forehead), and vertigo (fast-turning wheel in the back of her head). The patient underwent an NFB treatment program. A total of 10 NFB sessions over a period of 2 weeks were performed.

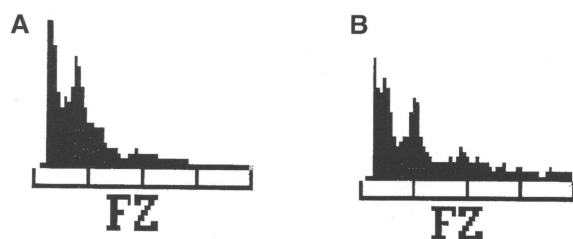


Figure 1. Power spectra before (A) and after neurofeedback (B) in Patient 1.

A comparison of the QEEG data before and after NFB revealed a reduction of the delta power (Fig. 1). The theta band was no longer present. After NFB, an 8-Hz band was demonstrable. Before NFB, we recorded a shortening of the latencies for waves III, IV, V, and VI during the rotation to the right and a shortening of the latencies for waves V and VI during the left rotation (Table 1). After NFB, we noted a normalization of the latencies except for wave V (rotation to the left; Table 2).

Before NFB, a DC shift of waves I, V, and VI toward the negative pole (Fig. 2, black area) was observed when rotation to the right occurred. After NFB, a normalization was noted with the exception of wave V. Also after NFB, the patient reported no further disorder from vertigo, headache, and concentration problems.

Patient 2

A 44-year-old woman received a mild traumatic brain injury in a car accident. After the accident, the woman

reported the following complaints: vertigo, double vision, nausea, concentration problems, and aggressive and depressive behavior patterns.

The QEEG data analysis revealed a slowing of the EEG pattern, with dominant frequency bands at 2 Hz and 8 Hz. A comparison of the QEEG data before and after NFB indicated a reduction of power for the 2-Hz band and the 8-Hz band (Fig. 3). However, an increase of power was noted for the 10-Hz band.

Under the condition of eyes closed, a significant decrease of power was noted for the delta and theta bands and a significant increase of power for the alpha band. Further subdivision of the alpha band revealed a significant decrease of power of the α_1 band and a significant increase of power of the α_2 and α_3 bands. Under the condition of eyes open, a significant increase of power was noted for the alpha band and the α_2 and α_3 bands (Table 3).

After NFB, the patient no longer experienced vertigo and nausea. She reported a decrease of her double vision, restored emotional stability, and improved concentration.

Patient 3

A 38-year-old woman experienced bilateral tinnitus for 8 months. A sudden loss of hearing preceded the onset of tinnitus. Subsequent treatments, including infusion therapy, acupuncture, and physical therapy, were unsuccessful. With the onset of tinnitus, the patient reported mood swings, panic attacks, and concentration problems.

Table 1. Mean Peak Latencies of the Vestibular Evoked Potentials Component Before Neurofeedback

Rotation	Mean Peak Latencies (msec)					
	Wave I	Wave II	Wave III	Wave IV	Wave V	Wave VI
Right	140	200	270	375	555	660
Left	125	230	390	450	555	640
Control*	77 ± 10	182 ± 9	336 ± 18	476 ± 16	632 ± 19	802 ± 19

* Values expressed as mean plus or minus the standard deviation.

Table 2. Mean Peak Latencies of the Vestibular Evoked Potentials Component After Neurofeedback

Rotation	Mean Peak Latencies (msec)					
	Wave I	Wave II	Wave III	Wave IV	Wave V	Wave VI
Right	115	180	300	480	605	785
Left	125	235	390	450	520	790
Control*	77 ± 10	182 ± 9	336 ± 18	476 ± 16	632 ± 19	802 ± 19

* Values expressed as mean plus or minus the standard deviation.

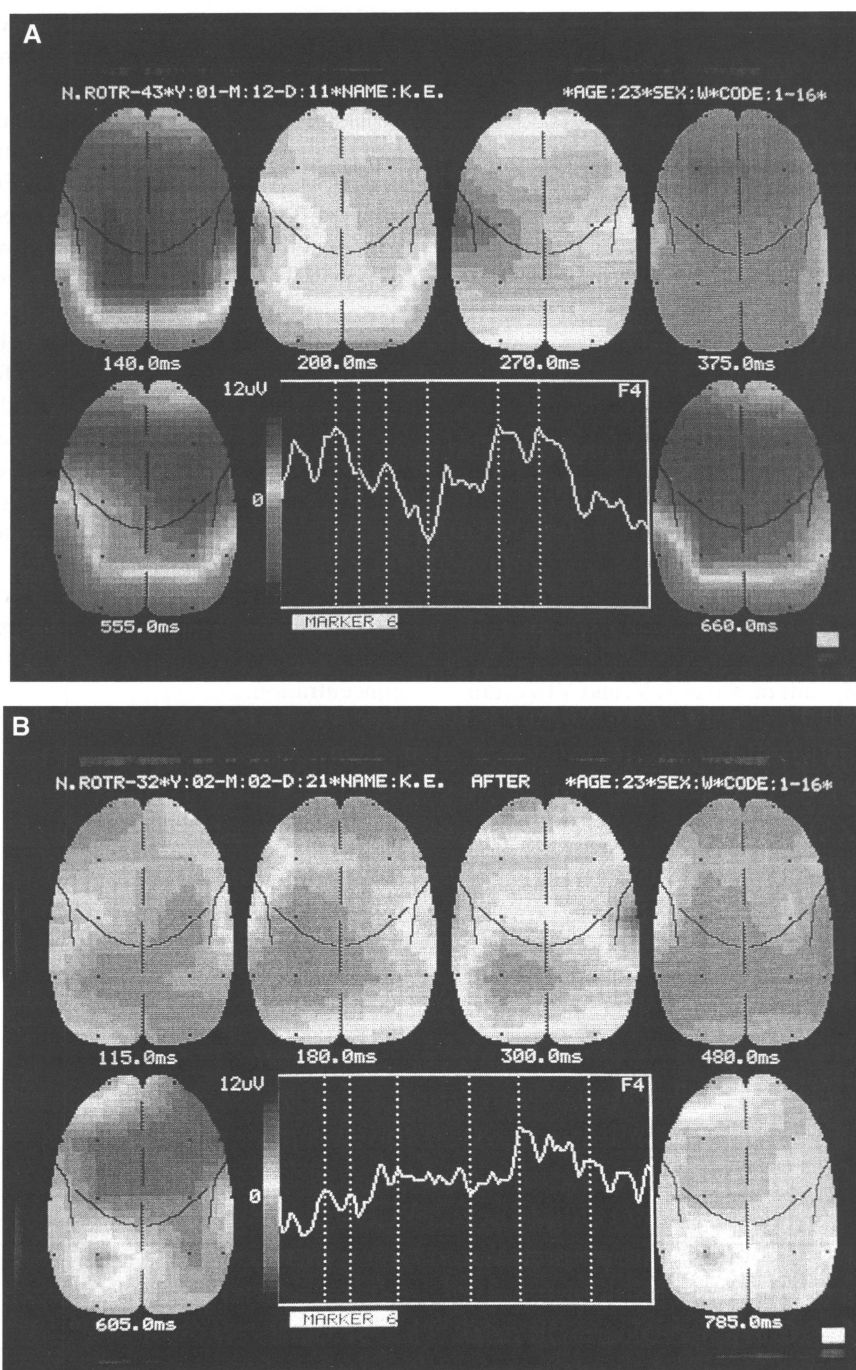


Figure 2. Brain electrical activity mapping before (A) and after neurofeedback (B) in Patient 1.

Average Total Power

The average total power for this patient was calculated by averaging the total power from each of the 19 electrode leads. The average total power for the patient ($7.3 \pm 0.3 \mu V^2$) was significantly lower than the average total power of the control subjects ($N = 20$; $25.1 \pm 0.8 \mu V^2$; $p < .0001$).

Average Power with Respect to Frequency Bands

Average power was calculated for the following four frequency bands (Table 4): delta (2–4 Hz), theta (4–7 Hz), alpha (8–13 Hz), and beta (14–21 Hz). The average total power of these frequency bands was significantly reduced when compared to control values. Subdividing the alpha band into α_1 , α_2 , and α_3

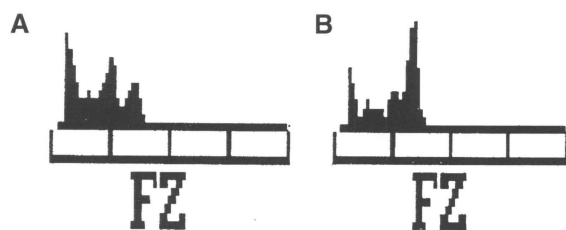


Figure 3. Power spectra before (A) and after neurofeedback (B) in Patient 2.

revealed significant differences for all three bands (Table 5). The average power of all three alpha subgroups was significantly reduced when compared to control values.

Topographical illustration of the QEEG data revealed two beta foci located in C3 and C4 (Fig. 4). Over a period of 1 week, nine NFB sessions (each 90

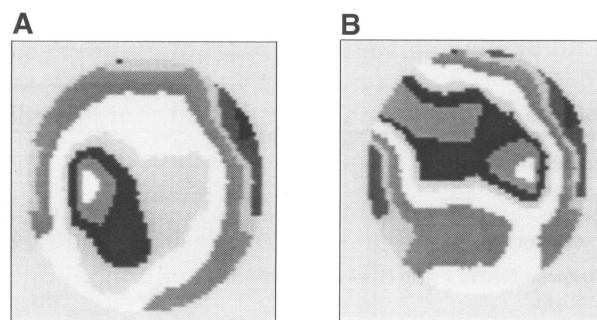


Figure 4. Topographical illustration of the distribution pattern of the 18- to 22-Hz (A) and the 22- to 26-Hz bands (B) in Patient 3.

minutes long, two sessions per day) were performed. Measurements of the VestEP (Table 6) revealed shortened latencies for the rotation to the right and to the left. After NFB, a shortened latency was noted only for wave V when rotating to the left. A further improvement of the latencies was noted 12 months after the cessation of NFB therapy.

The comparison of the results of the SCL-90-R questionnaire indicated normalization of depression, fear, and phobia (Table 7). After NFB, the patient suffered no more panic attacks and was emotionally stable, and her tinnitus was only occasionally present.

DISCUSSION

NFB represents a window of opportunity for assessing and shifting any given brain state [15]. NFB has been employed for treatment of patients suffering from attention deficit hyperactivity disorder, generalized anxiety disorder, depression, conduct disorder, epilepsy, post-traumatic stress disorder, and drug addiction [10,16–20]. Our study revealed that NFB is an effective therapy for the treatment of patients suffering from vertigo and dizziness or tinnitus.

Computer-assisted EEG analysis clearly demonstrated prominent differences before and after NFB for both patients suffering from vertigo and dizziness. In both cases, a decrease of the power of the delta and theta bands was observed. However, an increase of the power of the alpha band was noted after NFB. Most interestingly, in both cases, the frequency of the dominant band increased by 2 Hz, from 6 to 8 Hz and from 8 to 10 Hz. The VestEP revealed a normalization of the late latencies, which are associated with frontal areas, most likely reflecting a high level of supranodal processing with sensory information [21].

Topographical illustration of the EEG data from the tinnitus patient indicates two beta foci in the central region. Similar results have been reported by Weiler et al.

Table 3. Comparison of Pre- and Postneurofeedback Quantitative Electroencephalography Data

Frequency Bands	Eyes Closed Change (%)	Eyes Open Change (%)
Delta	-36	12.5
Theta	-23	-4.0
Alpha	52.1	26.4
Beta	6.7	10.4
Alpha ₁	-25.6	4.4
Alpha ₂	98.4	29.1
Alpha ₃	69.4	30.6

Note: Percent changes of power (μV^2) for different frequency bands.

Table 4. Average Power (μV^2) of Delta, Theta, Alpha, and Beta Frequency Bands

	Delta (μV^2)	Theta (μV^2)	Alpha (μV^2)	Beta (μV^2)
Patient*	4.9 \pm 0.3	4.6 \pm 0.4	9.4 \pm 0.9	8.6 \pm 0.7
Control group*	14.0 \pm 0.5	14.3 \pm 0.5	54.8 \pm 3.2	16.3 \pm 0.7

* Values expressed as mean plus or minus the standard deviation.

Table 5. Average Power for Alpha₁, Alpha₂, and Alpha₃ Bands

Frequency	Gender	Patient*	Control*
Alpha ₁ (7–9 Hz)	Female	3.7 \pm 0.2	18.4 \pm 1.1
Alpha ₂ (9–11 Hz)	Female	3.9 \pm 0.4	23.9 \pm 1.5
Alpha ₃ (11–13 Hz)	Female	3.1 \pm 0.2	15.6 \pm 1.4

* Values expressed as mean plus or minus the standard deviation.

Table 6. Mean Peak Latencies of the Vestibular Evoked Potentials Component Before and After Neurofeedback

Rotation	Mean Peak Latencies (msec)					
	Wave I	Wave II	Wave III	Wave IV	Wave V	Wave VI
Preneurofeedback data						
Right	85	175	250	415	535	745
Left	70	155	305	415	540	725
Control*	77 ± 10	182 ± 9	336 ± 18	476 ± 16	632 ± 19	802 ± 19
Postneurofeedback data (1 wk)						
Right	90	185	325	540	675	815
Left	110	235	325	460	555	805
Control*	77 ± 10	182 ± 9	336 ± 18	476 ± 16	632 ± 19	802 ± 19
Postneurofeedback data (12 mo.)						
Right	85	245	290	485	615	795
Left	90	235	280	485	645	775
Control*	77 ± 10	182 ± 9	336 ± 18	476 ± 16	632 ± 19	802 ± 19

* Values expressed as mean plus or minus the standard deviation.

Table 7. Results of the SCL-90-R Questionnaire Before and After Neurofeedback

Item	Pre-NFB	Post-NFB	p Value
Insecurity	56	45	NS
Depression	62	59	0.05
Fear	62	58	0.05
Aggression	56	56	NS
Phobia	62	43	0.001

NFB = neurofeedback; NS = not significant.

[2,3]. Measurements of the VestEP after NFB revealed normalization of the latencies. A follow-up measurement (12 months after NFB) of the VestEP confirmed that the NFB-induced changes of the latencies remained stable. This indicated that NFB induces lasting changes of the subject's neurophysiology and neurochemistry. In summary, NFB is a suitable tool for treating patients suffering from tinnitus or vertigo.

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