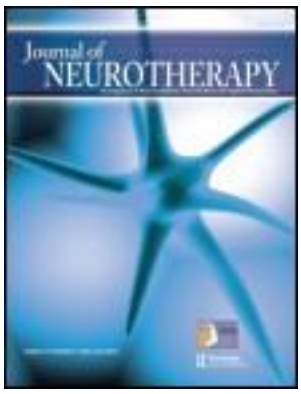

Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience

EEG-NeuroBioFeedback Treatment of Patients with Brain Injury: Part 2: Changes in EEG Parameters versus Rehabilitation

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Published online: 08 Sep 2008.

To cite this article: Dr. Rima E. Laibow MD , Albert N. Stubblebine MSc , Henry Sandground & Michel Bounias DSc (2001) EEG-NeuroBioFeedback Treatment of Patients with Brain Injury: Part 2: Changes in EEG Parameters versus Rehabilitation, Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience, 5:4, 45-71, DOI: 10.1300/J184v05n04_04

To link to this article: http://dx.doi.org/10.1300/J184v05n04_04

EEG-NeuroBioFeedback Treatment of Patients with Brain Injury: Part 2: Changes in EEG Parameters versus Rehabilitation

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ABSTRACT. *Background*. A sample of 27 patients with brain injury distributed in five clinical classes was examined for pre- and post-treatment symptoms and associated power spectra.

Methods. Changes in electroencephalographic (EEG) compressed spectral arrays were analyzed with respect to the rate of rehabilitation and correlated with a checklist of symptoms for each patient and the group as a whole.

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The authors thank Marie José Méhois for her assistance in the preparation of the manuscript. Michel Bounias also wishes to thank Dr. F. Ramos and Dr. T. Mulholland for the stimulating correspondence.

Results. Targeted decreases in slower (3-7 Hz) and higher (24-32 Hz) frequencies, and EMG (70-90 Hz), and increases of alpha (8-12 Hz) and mid-range beta frequencies (15-18 Hz) were achieved following NeuroBioFeedback (NBF) treatment using positive reward tones and a simultaneous visual reward. The impact of gender and age class influence was assessed against treatment results. Single lead EEG power spectra changes were analyzed for hemispherectomized patients, stroke, car accident and trauma patients. A common EEG pattern was observed for a group of patients exhibiting vertigo with two subgroups in which vertigo resolved or did not resolve showing EEG differences.

Conclusions. EEG NeuroBioFeedback can successfully treat patients with brain injury with highly clinically-meaningful clinical results. Changes in Cz power spectra generally occur, but do not always immediately follow resolution of symptoms. Since EEG-NBF is limited to recording cortical surface potentials, it is possible that changes induced by the treatment which result in clinical changes may not always be reflected at the cortical surface and hence may not be available for recording and analysis there, despite subcortical integration.

KEYWORDS. EEG-NeuroBioFeedback, brain injury, EEG power spectra, concussion, gender influence

INTRODUCTION

Behavioral medicine has long attempted to induce voluntary control of physiological processes altered by pathological disorders. While biofeedback has been recommended primarily for psychophysiological disorders, such as high blood pressure, vascular migraine, cardiac arrhythmia and neuromuscular abnormalities (Shapiro, 1979; Hatch & Riley, 1985), a major step was toward direct central nervous system regulation followed the development of computer-assisted electroencephalography (EEG) (see also Nuwer, 1988a, 1988b; Lopes da Silva, 1993, for review), for monitoring voluntary regulation of brain activity (Mulholland & Runnals, 1963). In particular, the automation of fast Fourier transforms, originating with the work of Dietsch (1932) and Walter (1943), made the system available for clinical practice and marked the emergence of NeuroBioFeedback (NBF) as a new medical

discipline (Lubar & Bahler, 1976; Laibow, 1999) in which behavioral medicine is basically involved (Schwartz, 1979).

NeuroBioFeedback has been extended to a wide variety of psychopathological disorders, including epilepsy and seizures, Alzheimer's disease, schizophrenia, autism, ischemia, tumors and AIDS (Laibow & Stubblebine, 1994; Byers, 1995; Laibow, 1999). A recent trend also supports the interest of neurotherapy and NBF in toxicology (Laibow, Stubblebine, Sandground, Bonaly, & Bounias, 1996; Bounias, Laibow, & Stubblebine, 1998). Patients with brain injury, including concussion, stroke and even hemispherectomy have shown noticeable rehabilitation success through EEG-NeuroBioFeedback (Laibow, Bounias, Stubblebine, & Sandground, 1996). The case of brain injury is particularly dramatic, since the problems raised by its consequences can extend to family and friends in addition to the patient (Stratton & Gregory, 1995). Personal and economic consequences are often long lasting and tragic. This is especially the case for children (Greenwald, Ghajar, & Nottermann, 1995). Home settings take on a crucial importance in brain injury of all types (Schwartz, 1995). The role of psychosocial variables is therefore a major component of the system (Webb, Wrigley, Yoels, & Fine, 1995). In all cases, the level and duration of the patient's disability are key factors (Granger, Divan, & Fiedler, 1995), and make accurate prediction of recovery difficult (Levin, 1995).

The goal of this paper is to provide clinical, EEG and physiological data associated with a high level of rehabilitation through EEG NeuroBioFeedback in a set of patients with brain injury. For the purpose of this study, all categories of brain injury, while separately noted, were grouped together for treatment purposes since the therapeutic modality was similar for all types of brain injury.

MATERIALS AND METHODS

Patients and Clinical Symptoms

An unselected sample of 29 patients who presented themselves to our clinic for treatment of brain injuries was initially examined for clinical symptoms, EEG parameters and physiological (blood pressure, pulse and finger temperature) parameters. Two patients could not be appropriately followed. Twenty-six of the remaining 27 underwent a complete EEG study, while 17 patients provided physiological data.

A reference set of 48 clinical symptoms, found in at least one patient, was established following evaluation of the patients. These symptoms were unequally distributed among the various categories of lesions. Therefore, a classification was established as follows: (a) medical criteria were combined with statistical clustering into seven classes of major syndromes and subclasses, and (b) membership of patients was established in five of these classes by using numerical indices (Bounias, Laibow, Bonaly, & Stubblebine, 2001). Table 1 details the classification and memberships, together with some specific characteristics of individual patients.

Symptom loads for each patient before treatment and at the end of treatment were calculated as follows: let (N) the number of clinical symptoms in the check-list used as the basis for the assessment of the symptom load index (SL%) in clinically characterized patients. A general index SL_i is given by the percentage of checklist symptoms exhibited by each patient (i) before treatment. Specific parameters can be optionally introduced for the fitting of the basic indices to defined symptomatologic reference scales:

$$SL_i = 100\,[\Sigma_N(k_i \times S_i)_a/\Sigma_N(k_o \times S_o)_a]\%$$

with (a) indexing the sequence of symptoms, (S_o) summed reference symptoms, (S_i) summed symptoms observed in patient (i), and (k_o), (k_i) the respective optional coefficients specifically applying, eventually, on the considered class of disorders, with ($k_o \geq 1$), ($k_i \geq 0$). Symptoms that are always (or never) associated will receive relevantly appropriated (zero or one) indices (i.e., indicative functions). Currently, N = a stands for the indexing summation factor. For example, patient #2 initially exhibited 21 symptoms which in this case were given coefficient 1 each (no weighting): thus, $SL_i = 100[(21 \times 1) + (26 \times 0)/(47 \times 1)] = 44.7\%$. At the end of treatment, two of these symptoms remained, thus: $SL_d = 100 \times (2/47) = 4.2\%$. A global (here unweighted) improvement rate was finally given by the ratio: $IMP\% = 100 \times (44.7 - 4.2)/44.7 = 90.6\%$. The results are summarized in Table 2.

Apparatus and Protocols

Diagnostic sessions. Every patient had a history of brain-related disease or injury and a complete work up which led to a decision to treat. In all cases complete topography maps were performed by recording 25-electrode brain maps, providing both imagery of wave distribution

TABLE 1. Classification of Patients into Clinical Syndrome Classes. Patients Are Given the Same Reference Numbers as Previously (Bounias, Laibow, Bonaly, & Stubblebine, 2001).

Classes and patient nrs.		Ao	AT	NSi	NSd
Q1 = Motor dysfunction					
10	M	26	27	25	5
20	M	25	29	35	1
24	F	67	70	14	13
25	M	68	70	30	4
26	F	30	37	27	6
27	M	66	67	33	3
28	M	56	60	34	6
29	F	23	27	36	3
Q3 = Cognitive dysfunction					
4	M	20	29	32	7
5	F	12	12	16	2
6	F	39	39	13	2
11	F	14	25	23	5
13	M	49	51	17	1
16	F	20	55	28	4
18	M	0	41	13	1
21	F	20	20	31	0
22	M	38	58	18	3
Q4 = Psychosocial disorders					
14	M	13	19	23	9
15	M	30	43	26	3
17	M	14	23	27	5
Q5 = Pain related syndrome					
2	F	34	35	21	2
7	F	62	63	10	3
12	F	40	47	29	6
Q6 = Neuropsychiatric disorders					
6a: physiological subclass					
8	F	not known	34	20	3
19	M	0	41	20	3
6b: emotional subclass					
9	F	10	20	14	5
23	F	56	56	8	8

Ao = Age at Accident; AT = Age at Treatment Start (Years); Age Zero Means at Birth. NSi = Initial Number of Symptoms; NSd = Number of Symptoms Remaining at Termination of Treatment. M = Male; F = Female.

TABLE 2. Symptom Loads (SL%) Given as Unweighted Average Ratios of Symptoms Detected in Patients of the Class Against the Total Number of Symptoms Present in the Whole Group of Brain Injured Patients, and Class Averages Rehabilitation Ratios (IMP%). Numbers (N) of Patients Populating Each Class Are Given in Parentheses.

Classes	Q1 motor	Q3 cognitive	Q4 psychosoc.	Q5 pain	Q6a,b neuropsych.
SL ± SD	61 ± 15	44 ± 15	53 ± 4	42 ± 20	32 ± 12
IMP%	77 ± 29	87 ± 7	77 ± 14	80 ± 10	68 ± 23
(N)	(8)	(9)	(3)	(3)	(4)

of intensity and spectral patterns for each electrode. This initial evaluation helped to determine what was happening in the brain topologically, as well as to assess symmetry, power, amplitude, cerebral blood flow and the assessment of damage as well as to assist in a host of clinical and therapeutic determinations in which the visualized electrical activity of the brain would be significant.

NBF protocols. Treatments were performed using computer-assisted electroencephalographic NeuroBioFeedback (EEG-NBF) (Laibow, Stubblebine, Sandground, Bonaly, & Bounias, 1996). Patients and caregivers were provided with information about those areas of frequency responses which were not functioning properly, and the rationale of voluntary regulation of these frequencies was carefully explained. All patients and caregivers agreed to a minimum of three, and a maximum of five, sessions of NBF per week in which patients would learn to regulate the frequencies at which specific sites of their brains were operating via contingent EEG feedback.

Patients were treated using either a Capscan 880, Capscan Prism V, Lexicor NRS-24, NRS-4 or NRS-2D training device for NBF. Prior to treatment, full cap EEG data were collected using an electrocap of appropriate size. Data were processed by fast Fourier transform after eliminating artifacts. Dominant frequencies and relative power in delta (0-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-28 Hz), and EMG (28-32 Hz) frequency ranges were determined in the eyes-open and eyes-closed states. Frequency ratios and power spectra were also computed as well as bilateral and anterior-posterior symmetry. For NBF sessions, one electrode was placed on the scalp (Cz) and a reference electrode on the ipsilateral ear. A ground electrode was placed on the contralateral ear. In the two cases in which an entire hemisphere was missing, the active and reference electrode were both placed on the scalp over the remain-

ing hemisphere, with site placement determined through history, examination and clinical data.

Reward for patients consisted of sound (via headphones) and if working eyes open, light (via a computer screen). Both were produced when the desired conditions were met in the EEG training protocol. In general, excess slow wave amplitude needed to be inhibited (typically between 2 and 7 Hz), excess fast frequencies, possibly linked with excessive sympathic arousal, had to be inhibited (typically between 24 and 32 Hz) and mid-range beta frequencies (typically between 15 and 18 Hz) were rewarded (full data of EEG procedure and results will be presented in another paper). When any of the targeted conditions were not met, no reward was offered for that condition. Patients were rewarded with feedback for discrete frequency successes and for grouped success in controlling several parameters simultaneously when these requirements were all met at once. Reciprocally, groups of unmet requirements could shut off grouped reward stimuli, but no negative feedback of any type was ever given.

Each NBF session lasted 30 minutes and was immediately followed by a post session assessment and review of the patient's experimental assessment, scores and performance characteristics achieved in that session and in the treatment overall.

Choice of electrode. All patients, except the two with hemispherectomy, fell into the class in which Cz was indicated for anatomical and electrical access to the deep structures. In all patients an auricular electrode was adjusted to a resistance of below 5KΩ (average = 3.5 ± 0.6 KΩ). This initial evaluation also allowed the identification of the main frequencies to be targeted. The initial power spectra were used for the calculation of inhibition and reward thresholds. Diagnostic spectra were obtained pre- and post-treatment for 40 seconds eyes-closed (EC) or eyes-open (EO).

Initial power spectra and protocols setting. Power spectra were computed for Delta (.5-4 Hz), Theta (4-8 Hz), Alpha (8-13 Hz), SMR (12-16 Hz), Beta 1 (16-20 Hz) and Beta 2 (20-32 Hz). The ratios of frequency bands were examined in both EC and EO conditions.

The selected thresholds are indicated in Table 3 for individual patients at the beginning of treatments and averaged for each of the clinical classes. Generally, excess slow wave (3-7 Hz), as well as fast frequency (24-32 Hz) and EMG (70-90 Hz) wave amplitudes were inhibited, while alpha (8-12 Hz) and mid-range beta frequencies (15-18 Hz) were rewarded. Treatment involved specific signals made available

TABLE 3. Initial Thresholds for Inhibition or Reward Tone Signals. Values Are Given in Hz Range. EMGs, in the Range of 70 to 90 Hz, Are Inhibited in Each Class.

Classes and patients nrs.	Inhibit (Hz)	Reward (Hz)
Q1 (motor)		
10-24-25-29	2-7	15-18
20-27-28	2/3-8/9	15-18
26	20-32	15-18
Q3 (cognition)		
4-11	3-7	9-14
5-6	3-7	9-14
13	2-7	15-18
16	20-32	13-15
18-22	3-7	13-15
21	4-8	13-15
Q4 (psychosocial)		
14	3-7	8-12
15	20-32	8-12
17	4-8	10-16
Q5 (pain)		
2	3-8	9-12
7	3-9	8-12
12	3-9	15-18
Q6a (neuropsych.)		
8	3-9	13-15
19	3-9	8-12
Q6b		
9	3-7	15-18
23	2-7	15-18

Class-averaged values	(N)	Inhibition (Hz)	Reward (Hz)
Q1	(7)	2.1 ± 0.4 to 7.7 ± 0.9	15.0 ± 0.0 to 18.0 ± 0.0
	(1)	20 to 32	
Q3	(8)	3.1 ± 0.6 to 7.2 ± 0.9	12.3 ± 2.0 to 12.9 ± 4.9
	(1)	20 to 32	
Q4	(2)	3.5 ± 0.5 to 7.5 ± 0.5	8.7 ± 1.1 to 13.3 ± 2.3
	(1)	20 to 32	
Q5	(3)	3.0 ± 0.0 to 8.7 ± 0.6	10.6 ± 3.8 to 14.0 ± 3.5
Q6	(4)	3.0 ± 0.8 to 8.0 ± 1.1	13.7 ± 1.5 to 16.5 ± 1.7
Q6a	(2)	3.5 ± 0.5 to 9.0 ± 0.0	12.5 ± 0.5 to 15.0 ± 0.0
Q6b	(2)	2.5 ± 0.5 to 7.0 ± 0.0	15.0 ± 0.0 to 18.0 ± 0.0

to the brain when the desired condition was reached as a self-training tool for further correction. Thresholds and frequencies were adjusted at demand in further sessions whenever the responses were not sufficient or the conditions had become too easy for the patient to achieve. No change of apparatus was made once a patient had begun treatment. Headphones provided tones, while visual signals were displayed on a computer screen, especially during EO sessions (i.e., for beta reinforcement).

EEG records were compared from the beginning of treatment to the last sessions, respectively noted treatment start (TS) and treatment discontinuation (TD), in an attempt to check to what degree initial deviations were corrected on the power spectra. No smoothing has been done over several sessions in order to avoid biasing the results.

Neurological examinations were completed by continuous performance tests (Test Of Variables of Attention: TOVA), and by neuropsychiatric examination. Medication history was noted, and absolutely no medication was administered during treatment for any patient.

Cardiac parameters. Blood pressure, pulse, and finger temperature were systematically recorded before and after sessions. These results will be the subject of a separate report.

Spectra analysis. Raw data were first examined for artifact elimination (Anderer, Semlitsch, Saletu, & Barbanoj, 1992; Thornton, 1996). Fast Fourier transforms were then computed from artifact-free records.

Statistical treatment of the results included comparisons of means ± SD (from N independent determinations) by Student's "t" test and by Mann and Whitney non-parametric test when needed. Variance analysis included two-way ANOVA with interaction and paired data analysis. Factors were tested two by two: once one was found active, it was then tested against a new one. Correlation and regression parameters were calculated according to least square fitting. Risk levels were calculated from the unit deviations at the corresponding number of degrees of freedom. Since the acceptance levels in subsequent comparisons of means may be corrected for multiple comparisons, modified risks were indicated as $\alpha_k = 2\alpha/(k(k-1))$, that is the Bonferroni correction for k simultaneous comparisons, slightly lower than the $C(k) = 1-(1-\alpha)^{1/k}$ of Holland, DiPonzio, and Copenhaver (1987). Corrected comparisons of means are plotted against the residual variance σ_ε^2 as the common variance, and the residual number of freedom degrees. However, it should be noted that such a correction may be relevant if, and only if, no particular significant differences were expected from some of the treat-

ments and settings (Perneger, 1998). F-tests need not be corrected. Detailed statistical parameters are given in the Appendix tables.

RESULTS

Initial Recordings

Initial Power Spectra

Changes from EC to EO are negative in all but the following patient cases: Delta/Theta: cases 3, 5, 6, 12, 16, 19; Alpha/SMR: cases 24, 28; Beta 2: cases 7, 10, 12, 18. None of these classes of frequencies is restricted to one single class of syndrome. A large variability is therefore observed for the deviation percentage from EC to EO in the various syndrome classes (Figure 1).

In averaging over the five syndrome classes, deviations were not significant for Delta/Theta ($P > 0.50$) and for Beta frequencies ($P > 0.10$), whatever the kind of test used, while for Alpha waves, paired data comparison provided high significance ($0.001 < P < 0.01$) to the observed decrease ($-23.3 \pm 8.9\%$).

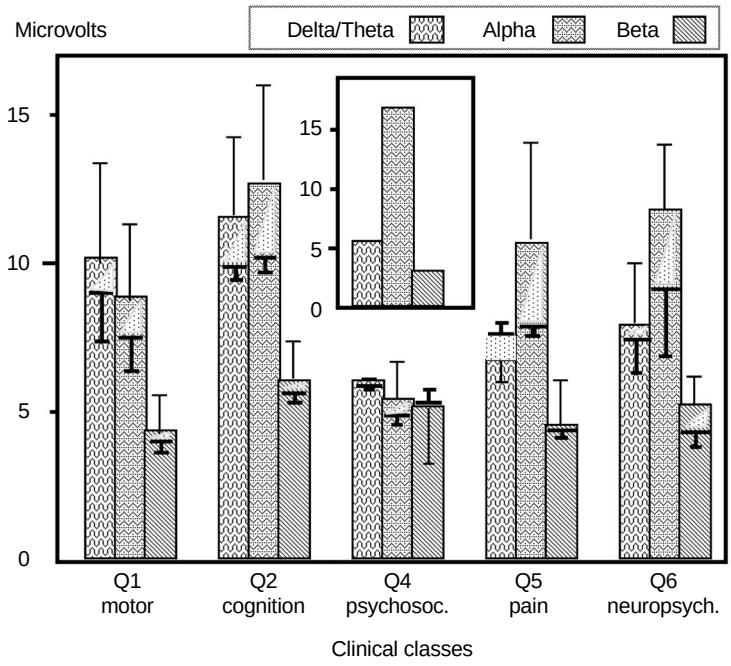
Feedback Thresholds

As appropriate, thresholds were adjusted during treatment by shifting the working frequencies to more appropriate values. The problem of controls remains a challenging one (Hatch, 1982; London & Schwartz, 1984). However, the task here was not to compare the data of brain-injured to healthy people, but to examine EEG deviations in patients, in order to evaluate frequencies to be inhibited or rewarded. Generally, excess of slow wave (Delta/Theta: 3-7 Hz), fast frequency (Beta: 24-32 Hz) and EMG (70-90 Hz) wave amplitudes were inhibited, while Alpha (8-12 Hz) and mid-range beta frequencies (SMR: 12-15 Hz or Beta 1: 15-18 Hz) were rewarded. It is noteworthy that some homogeneity was observed within classes. In particular, the previously computed subdivision of class Q6 into Q6a and Q6b actually corresponded to two distinct threshold classes.

Factors: Age and Gender

The various EEG power spectra have been compared between male and female patients, according to age classes. The influence of age,

FIGURE 1. Simplified Power Spectra Calculated Before Treatments for the Various Clinical Classes. Means (mV) ± SD Are Given for (N) Values in Eyes-Closed (EC) Conditions. The Values Recorded for Eyes-Open (EO) Are Given in Bold Lines with Their SD. General Average Spectra from Control Populations with No Detectable Pathology Shown as Reference in the Inset.



gender, frequencies (Table 4), additionally of treatments, and their interactions have then been tested by variance analysis adjusted for heterogeneous samples. The results are intended to reflect the characteristics of the group of patients studied here, not to revisit general observations previously established for age and gender characteristics in a broader sense. Factor frequency band (Bd) was expectedly found significantly active for both female ($P_{(Bd)} = 0.026$) and male patients ($P_{(Bd)} = 0.00014$), while age classes were not globally active ($P_{(Age)} = 0.23$).

Analysis of female and male values (F/M) against the active variable frequency yielded significance for both of factors ($P_{(F/M)} = 0.013$; $P_{(Bd)} = 0.0003$) and to a much lesser extent to interaction ($P(*) = 0.067$.

Male and female means were significantly different ($P(F/M) = 0.0067$) and beta 2 power reacted differently from delta-theta and from al-

TABLE 4. Comparative Initial Power Spectra for Male and Female of Various Age Classes.

Age class	F/M	Delta/Theta	Alpha + SMR + β1	Beta 2
0-20:				
	F	12.2 ± 4.6 (3)	13.7 ± 4.9 (3)	13.7 ± 13.2 (3)
	M	8.7 ± 3.8 (2)	4.9 ± 1.13 (2)	3.0 ± 0.2 (2)
21-40:				
	F	7.4 ± 1.3 (4)	14.0 ± 7.3 (4)	4.5 ± 1.8 (4)
	M	9.8 ± 6.1 (4)	6.0 ± 3.5 (4)	3.1 ± 0.8 (4)
41-60:				
	F	8.8 ± 1.9 (3)	14.2 ± 3.8 (3)	6.5 ± 1.3 (3)
	M	9.9 ± 4.6 (5)	8.1 ± 1.9 (5)	4.8 ± 1.5 (5)
60-80:				
	F	9.5 ± 0.03 (2)	8.0 ± 2.2 (2)	4.2 ± 0.14 (2)
	M	10.5 ± 0.7 (2)	7.7 ± 0.3 (2)	3.2 ± 0.3 (2)
Average:				
Female		9.4 ± 1.2 (13)	12.5 ± 3.0 (12)	7.2 ± 4.4 (12)
Male		9.7 ± 0.7 (13)	6.7 ± 1.5 (13)	3.5 ± 0.8 (8)

pha-beta1, with same levels of significance (P = 0.004, with $\alpha_{k = 3}$ = 0.017).

When compared two by two, class ages expectedly showed weak global differences (protected $\alpha_{k = 4}$ = 0.008) in female patients: P(0-20/61-80) = 0.023; P(0-20/41-60) = 0.027 and in male: P(0-20/41-60) = 0.08. Similarly, female vs. male comparisons yielded weak significance for: age class 0-20 years (P(0-20) = 0.016), while significance was found high for the (Alpha-β1) frequency bands: $P(_{\text{Alpha-}\beta1})$ = 0.00007 (protected $\alpha_{k = 3}$ = 0.017) and weak for β2: $P(_{\beta2})$ = 0.05.

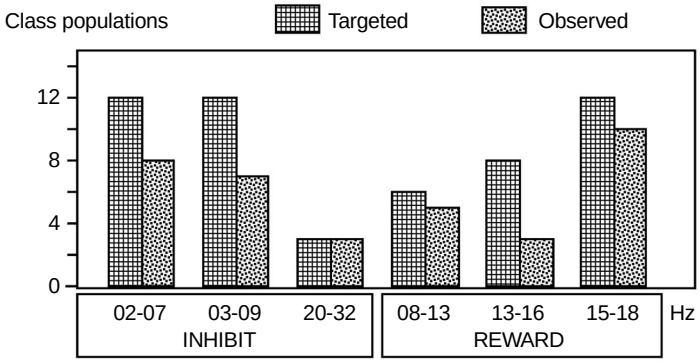
Further data on age activity for specific bands appears with treatment-associated changes and is examined below.

Treatment Associated Changes in Power Spectra

Responses to Threshold Goals

The number of patients assigned a defined goal (inhibition or reward) was taken as the theoretical population for defined classes of frequencies. Then, the distribution of observed deviations from before to after treatments was compared by chi square test. Figure 2 illustrates the observed versus targeted distributions, thus reflecting a first picture for all patients considered individually, independently of clinical classes. A

FIGURE 2. Distribution of the 27 Patients in Classes of Targeted versus Observed Changes in EEG Power for Various Frequency Bands.



$\chi^2 = 7.45$ was found, that is an insignificant difference (P = 0.20) indicating a correct fitting of the results to the goals. The covariance of observed targeted populations yielded a significant correlation (P = 0.009) with a regression slope of $b = 0.56 \pm 0.15$ and a vertical intercept of a = 0.88, which is a fairly linear response.

Relations with Clinical Classes

Table 5 presents the general patterns obtained for each class of clinical symptoms. ANOVA was performed for clinical classes versus treatment, and their interaction at each frequency class (Table C in the Appendix). Significant activity was found globally for interaction in the 2-7 Hz class ($P = 8 \times 10^{-8}$), the 8-12 Hz class (P = 0.034), the 15-18 Hz class (P = 0.015), the 20-32 Hz class ($P = 3 \times 10^{-10}$), and the 70-90 Hz class ($P = 1.8 \times 10^{-5}$). Factor class was active in the 20-32 Hz band ($P = 6 \times 10^{-8}$) and factor treatment was active in the 70-90 Hz band (P = 0.008). In the latter case, the "t" test gave P = 0.004, for a corrected threshold $\alpha_{k=2} = 0.05$ (Bonferroni) or 0.0025 (Holland, DiPonzio, & Copenhaver, 1987).

The activity of factor treatment was examined for specific frequency classes with respect to expected changes. For band 8-12 Hz, class Q1 was not affected, while all others were assigned a reward goal. Paired data comparison over Q3 to Q6 gave a significant increase: P = 0.012. Factor treatment was active against clinical classes (protected $\alpha_{k=2} = 0.05$) for the frequency band 70-90 Hz: P = 0.004. Comparisons of

TABLE 5. EEG Data as the Amplitude (mV) Recorded at the Various Ranges of Frequencies. Means ± SD (in Parentheses) Are Given at the Beginning (TS) and at the End (TD) of Treatment. The Variation Percentage from TS to TD Is Noted by d%.

	Frequency Classes (Hz)					
Syndrome classes:	02-08 Hz	08-12 Hz	13-15 Hz	15-18 Hz	20-32 Hz	70-90 Hz
Q 1 (N)	N = 8	N = 5	N = 1 × 2	N = 8	N = 4	N = 5
TS	15.5 (2.7)	8.85 (0.94)	4.0 (1.9)	4.3 (2.1)	6.0 (1.4)	2.9 (0.5)
TD	15.9 (9.4)	7.24 (1.05)	3.6 (1.2)	3.8 (2.2)	5.7 (0.9)	2.4 (0.6)
d%	+2.6%	−18.2%	−10.0%	+8.6%	−5.0%	−8.7%
Q 3 (N)	N = 9	N = 4	N = 6	N = 2	N = 2	N = 8
TS	9.1 (1.9)	5.4 (0.9)	4.0 (0.8)	3.1 (0.3)	4.5 (0.3)	2.2 (0.4)
TD	10.8 (5.1)	7.9 (3.3)	5.1 (2.2)	2.8 (0.3)	4.0 (0.2)	1.9 (0.2)
d%	+18.7%	+46.3%	+27.5%	−9.7%	−11.1%	−13.6%
Q 4 (N)	N = 3	N = 2	N = 2	N = 1	N = 2	N = 2
TS	9.3 (2.0)	6.0 (0.3)	3.9 (0.3)	4.5 (0.0)	4.5 (0.8)	2.6 (1.0)
TD	9.0 (2.3)	6.6 (0.9)	3.3 (0.3)	4.5 (0.0)	6.3 (0.7)	3.1 (0.3)
d%	−3.2%	+10.0%	−15.4%	0.0%	−19.2%	+16.1%
Q 5 (N)	N = 3	N = 2	N = 1 × 2	N = 2	N = 2	N = 3
TS	9.9 (0.8)	6.8 (1.6)	3.9 (0.3)	3.1 (0.2)	5.4 (0.2)	2.4 (0.1)
TD	8.5 (0.9)	7.9 (0.3)	3.3 (0.3)	3.3 (0.1)	6.0 (0.3)	1.1 (0.1)
d%	−14.1%	+16.2	−15.4%	+ 6.4%	+11.1%	−54.2%
Q 6 (N)	N = 4	N = 2	N = 2	N = 2	N = 2	N = 3
TS	14.0 (0.9)	7.8 (2.0)	4.0 (0.14)	5.2 (0.3)	12.0 (1.2)	2.4 (0.3)
TD	11.0 (1.4)	8.3 (2.8)	3.6 (1.2)	2.2 (1.1)	10.1 (1.2)	1.3 (0.1)
d%	−21.4	+ 6.4%	−10.0%	−57.6%	−15.8%	−39.1%
Eyes:	EO	EC	EO	EO	EO	EO

means also raised a treatment effect against age classes for 8-12 Hz: P = 0.047 (for a protected $\alpha_{k=2} = 0.05$).

Class comparisons revealed some specificity at two particular frequency bands. Band 2-7 Hz raised differences between Q1 and Q3 (P = 0.0004), Q1 and Q4 (P = 0.0025), Q1 and Q5 (P = 0.003).

With band 20-32 Hz, Q6 was different from each of the others. For example, Q6-Q1: $P = 6 \times 10^{-5}$, Q6-Q3: $P = 1 \times 10^{-7}$, Q6-Q1: $P = 4 \times 10^{-7}$, Q6-Q1: $P = 8 \times 10^{-7}$. The protected level was $\alpha_{k=5} = 0.005$ for each case. These data are indicative of EEG peculiarities associated with symptom classes. This strengthens the meaning of the classification.

With age classes as the alternative variable, the comparison of means before and after treatment gave $P = 0.052$ for 13-18 Hz and $P = 0.0036$ for 70-90 Hz, with a protected $\alpha_{k=2} = 0.05$.

Last, a chi square test was performed with respect of class-averaged thresholds. The following enumeration gives the number of patients involved for targeted inhibition and reward in each clinical class, together with the number of patients for which paired data test was significant for inhibition and for reward. Q1: {targeted (8 + 8)/observed (7 + 5)}; Q3: {(8 + 8)/(5 + 4)}; Q4: {(3 + 3)/(1 + 1)}; Q5: {(3 + 3)/(2 + 2)}; Q6: {(4 + 4)/(3 + 1)}. The Yates-corrected test was computed for N = 10 classes, and the classical test was tried after gathering inhibition and reward classes under each clinical class, that is N = 5 classes. The results were: $\chi^2_{yates} = 9.95$ (9 df) ($0.2 < P < 0.3$ and $\chi^2 = 9.40$ (4 df) ($0.05 < P < 0.1$). None were significant, which again means that targeted EEG changes were correctly reached. Notable exceptions were found in individual cases: in Q1 patients, 27 did not reach inhibition goals, while patients 26 and 29 did not achieve reward conditions. In Q3, patients 4, 11 and 21 did not reach inhibition goals and patient 5 did not achieve reward conditions. In Q5, patient 7 did not achieve reward conditions, while other exceptions were represented by absence of variations. Thus, high rehabilitation rates could be attained before clinical changes were reflected at the cortical surface.

Since major post-traumatic symptoms (primary and secondary complaints) disappeared with treatment in all but one case (patient 23 provided consistently contradictory reports), it should be pointed that since EEG changes were sometimes only partly elicited to the desired direction, both healing and EEG are the final expression of a common underlying causality. This strongly suggests that the expression of cortical EEG is only one part of cortical and subcortical neuronal activities related to improvement (Nunez & Srinivasan, 1993; Nunez et al., 1994).

Further Assessment of Treatment with Age and Gender Activity

Two series of ANOVA were performed for female and male, respectively, at each frequency class, with treatment against age classes activ-

ity (Tables D1 and D2 in the Appendix). Interaction was significant in females at 8-12 Hz (P = 0.007) where age was also active (P = 0.0014) but to a lesser extent for treatment (P = 0.09). Treatment was active in class 70-90 Hz (P = 0.006) where the interaction was slightly marked (P = 0.09). No significance was found in males.

Comparisons of means in the female group showed the following differences: for class 3-9 Hz, age class 61-80 years against classes 12-40 years (P = 0.0045), 41-60 years (P = 0.012) and 0-20 years (P = 0.05) with a protected threshold $\alpha_{k=4} = 0.008$. For class 8-12 Hz, class 41-60 years differed from 0-20 years (P = 0.0002), 21-40 years (P = 0.00008) and 61-80 years (P = 0.017), while class 61-80 years differed from 0-20 years (P = 0.0045) and from 21-40 years (P = 0.0013) against a protected level $\alpha_{k=4} = 0.008$.

Comparisons in males showed only one difference, at frequency band 3-9 Hz, between class 21-40 years and class 61-40 years (P = 0.009).

These data show that treatment raised age-related changes to the EEG patterns.

Results from Classes of Similar Lesions

Stroke and Concussion Classes

It is noteworthy that class Q1 gathers all cases of vascular strokes except one (patient 23: cerebellum stroke). Pooling case numbers. 23, 24, 25, 26, 28 and eventually 27 (although the latter also exhibited seizure, in contrast with former ones), represents a single class of specific organic lesion (STRK).

The two cases of hemispherectomy (numbers 10 and 29) also pertaining to Q1 (serving as extremes) represent a particular case, worthy of specific examination (HMSPHCT). Patient 10 lost his left hemisphere subsequent to a gunshot wound, while patient 29 lost her right hemisphere as a result of a car accident. Lastly, two classes of concussion syndromes come from two sources: car accidents (numbers 2, 9, 13, 16, 19 and 20) provide one class (CAR ACCDT) and falls (numbers 8, 12, 21, and 22) another (FALL).

Some interesting observations concerning these classes for the various clinical parameters are summarized in Table 6.

ANOVA was performed at each class of frequency by testing treatment against classes of lesions and interaction (Table E in the Appen-

TABLE 6. Clinical Data Relative to Defined Classes of Lesions and Origin of Concussion. Values Are Given at Treatment Start (TS) and Discontinuation (TD). Means ± SD Are Given in the Same Units as Previously with the Number of Data Available in Parentheses.

		STRK N = 6 cases	HMSPHCT N = 2 cases	CAR ACCDT N = 6 cases	FALL N = 4 cases
EEG (mV) at					
02-09 Hz	TS	17.0 ± 5.1 (6)	12.0 ± 3.6 (2)	10.4 ± 5.9 (6)	11.8 ± 2.2 (4)
	TD	16.1 ± 5.7 (6)	10.6 ± 6.6 (2)	9.2 ± 5.1 (6)	10.3 ± 5.0 (4)
08-12 Hz	TS	9.0 ± 2.5 (6)	9.1 ± 0.0 (1)	8.1 ± 1.8 (6)	12.7 ± 3.0 (4)
	TD	13.9 ± 3.8 (6)	7.7 ± 0.0 (1)	12.0 ± 5.0 (6)	14.0 ± 3.5 (4)
15-18 Hz	TS	5.2 ± 1.9 (6)	2.9 ± 1.5 (2)	4.3 ± 1.7 (6)	4.3 ± 1.2 (4)
	TD	5.7 ± 1.8 (6)	2.4 ± 1.3 (2)	4.5 ± 1.3 (6)	4.1 ± 1.4 (4)
70-90 Hz	TS	3.0 ± 0.5 (4)	3.1 ± 0.6 (2)	2.3 ± 0.2 (4)	2.5 ± 0.7 (4)
	TD	2.4 ± 0.6 (4)	1.8 ± 0.3 (2)	1.75 ± 0.72 (4)	1.5 ± 0.5 (4)

dix). Treatment was significant in class 8-12 Hz ($P = 0.008$) and class 70-90 Hz ($P = 0.0018$) with a protected $\alpha_{k=2} = 0.05$. Factor lesions was significant for class 15-18 Hz ($P = 0.005$) and to a lesser extent in 2-9 Hz ($P = 0.054$), against a protected $\alpha_{k=4} = 0.008$. Interaction was significant in class 15-18 Hz ($P = 1.2 \times 10^{-5}$), and very slightly in 70-90 Hz ($P = 0.09$).

Comparisons of means before and after treatments gave several significant results in consistency with assigned thresholds: (a) for stroke, an increase at 8-12 Hz ($P = 0.015$) and a weak decrease at 70-90 Hz ($P = 0.08$); (b) in hemispherectomized patients, the 70-90 Hz decrease was seen at $P = 0.028$; (c) for car accidents, a decrease at 70-90 Hz ($P = 0.002$) and a slight increase at 8-12 Hz ($P = 0.04$); (d) for fall, a decrease at 70-90 Hz ($P = 7 \times 10^{-6}$). All comparisons admit a protected $\alpha_{k=2} = 0.05$.

The variations of EEG parameters from the beginning of treatment to the end generally exhibited changes in the expected way (i.e., decreases for low and high frequencies, and increases at 8-12 Hz). For the hemispherectomized patient 10, the diagnostic session showed a decrease in

amplitude (μV) (eyes open) for Theta, Alpha and Beta waves. Comparison by "t" test for N = 10 replications gave the following results:

Theta: EC $\rightarrow 9.32 \pm 0.88$; EO $\rightarrow 8.36 \pm 1.16$; $(0.1 < P < 0.2)$

Alpha: EC $\rightarrow 9.06 \pm 0.38$; EO $\rightarrow 7.04 \pm 0.62$; $(P < 0.001)$

Beta: EC $\rightarrow 4.26 \pm 0.35$; EO $\rightarrow 4.01 \pm 0.21$; $(0.1 < P < 0.2)$

Thus, alpha waves behaved normally, in contrast to theta and beta. The same pattern was unfortunately not retrievable in the computer records for patient 29, due to software constraints.

The significance in spectral changes from treatment start (TS) to treatment discontinuation (TD) was also calculated from a series of 10 measurements, for theta (3-7 Hz), SMR (15-18 Hz) and EMG (70-90 Hz). Data are given in Table 7.

Down-regulation is thus observed in all cases but the left hemispherectomy patient for theta waves, which exhibited an increase in averaged signal amplitude.

Remission of Vertigo versus Power Spectra Changes

In the present study, we were able to conduct an experimental study of two subsets of patients exhibiting vertigo. One remitted and the other did not remit after successful treatment for various post concussion symptoms. Both groups were selected for a total load of symptoms below 50% (i.e., respectively $39.9 \pm 10.1\%$ for the group remitted [N = 5]

TABLE 7. Particular Features on Patients with Right and Left Hemispherectomy. TS: Treatment Start; TD: Treatment Discontinuation. Means ± SD (mV).

Cases/Waves	TS	TD	Risk
Left HMSPHCT:			
Theta:	4.27 ± 0.12	4.60 ± 0.23	$0.01 < P < 0.02$
SMR :	1.64 ± 0.13	1.49 ± 0.09	$0.02 < P < 0.05$
EMG :	2.63 ± 0.59	2.10 ± 0.54	not significant
Right HMSPHCT:			
Theta:	9.61 ± 0.45	5.96 ± 0.11	$P < 0.001$
SMR :	3.41 ± 0.37	1.73 ± 0.11	$P < 0.001$
EMG :	3.50 ± 0.94	1.59 ± 0.50	$P < 0.001$

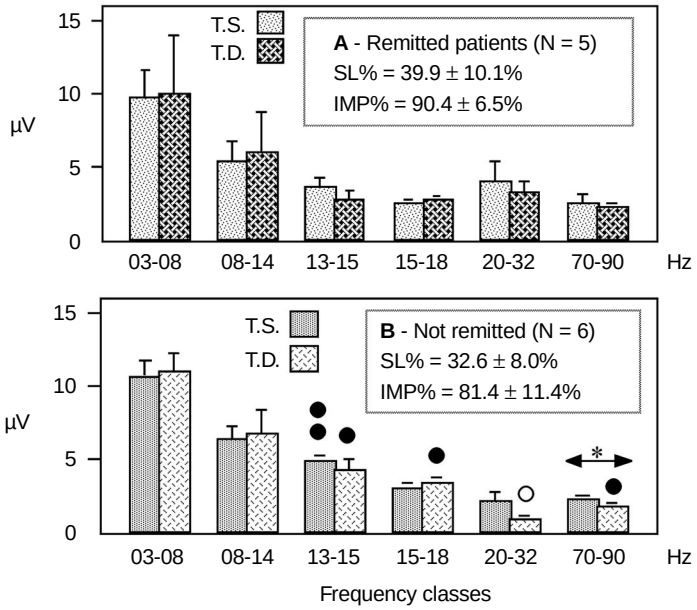
and 32.6 ± 8.0% for the group with vertigo remaining after treatment). All major symptoms remitted in both groups, while the percentages of secondary symptoms remitted were respectively 90.4 (± 6.5)% in the first group and 81.4 (± 11.4)% in the second (not significantly different). Figure 3 shows a remarkable analogy of power spectra in both cases of vertigo-positive patients, before (TS) or after treatment (TD).

Correlations are respectively:

TS: r = 0.930 (0.001 < P < 0.01); b = 1.11 ± 0.0.21 (N = 6 pairs)

TD: r = 0.934 (0.001 < P < 0.01); b = 1.17 ± 0.0.22 (N = 6 pairs)

FIGURE 3. Averaged Power Spectra for Two Cluster Subsets of Patients with Vertigo as Common Symptom. (A): Group of N = 5 Patients with Remission of Vertigo at Treatment Conclusion. (B): Group of N = 6 Patients with Remaining Vertigo at Treatment Conclusion. Left Blocks Represent Patterns at Treatment Start (TS), and Right Blocks Depict Patterns at Treatment Discontinuation (TD). Asterisk (*) Indicates Significant Difference Between TS and TD (0.001 < P < 0.01). Circles Indicate Significant Differences Measured in Homologous Classes Between Group (A) and Group (B): (○): (0.02 < P < 0.05); (●): (0.01 < P < 0.02); (●●): (P < 0.001).



The main difference between these groups emerges from class 20-32 Hz, which is of higher amplitude in remitted patients. The difference is statistically significant in the non-remitted group ($P < 0.001$). When this class is discarded, the correlations are improved as assessed by the coefficients associated to both cases:

TS: $r = 0.979$ ($0.001 < P < 0.01$); $b = 1.07 \pm 0.13$ ($N = 5$ pairs)

TD: $r = 0.981$ ($0.001 < P < 0.01$); $b = 1.08 \pm 0.13$ ($N = 5$ pairs)

The interaction of vertigo with influence of other symptoms on the power spectra cannot be precluded. However, the patterns observed in these two independent vertigo positive groups, both exhibiting reduced loads of secondary symptoms and high rates of remission of other symptoms, suggests that specificity could be expected from EEG patterns, and that attention should be paid to the 20-32 Hz class which might be connected to the remission of vertigo.

When cortical EEG activity does not reflect the success of the treatment, it does not mean that brain activity is unchanged. Depth EEG could provide different patterns which, however, could be in some way be "filtered," therefore not revealed on cortical recording.

One final observation worth mentioning with regards to the variability of the responses, as assessed by the coefficients of variation (CV), is the ratio of the standard deviation to the mean. This parameter is neither a frequency nor a probability, but rather a dimensionless quantity. It can thus be statistically treated like any other parameter having a roughly normal distribution.

In the remitted patients group, the CV averaged over the six frequency classes reaches $CV_s = 0.21 \pm 0.1$ at treatment start and $CV_d = 0.25 \pm 0.18$ at the end of treatment. This reflects a large variability between patients, with no link to the remission for this parameter. In the non-remitted patients group, values become respectively $CV_s = 0.14 \pm 0.1$, and $CV_d = 0.15 \pm 0.07$. Here, the CV is significantly lowered at treatment start ($0.02 < P < 0.05$ by paired "t" test). Hence, this change in the variability may suggest a kind of compression of the spectral amplitude seen in refractory cases, which contrasts to responsive patients. Further observations should be made in order to check whether such a phenomenon is a fortuitous one or an important and clinically relevant sign.

DISCUSSION AND CONCLUSIONS

In 1995, Rozelle and Budzynski reported a case of successful biofeedback rehabilitation of a patient following stroke injury. The patient was trained to inhibit 4-7 Hz range and to increase 15-21 Hz. At the conclusion of the treatment, only the 4-7 Hz waves were reduced, although the improvements were considerable. In our study, the class of stroke patients exhibited a decrease of slow waves, but also demonstrated an increase in alpha waves. Similarly, the response of patients from class Q5 supported benefits of biofeedback on headache, as previously reported (Borgeat, Elie, & Larouche, 1985).

One very particular case is that of hemispherectomized patients, who require special attention, since unusual behavior of brain wave patterns were observed. However, it has been shown that patients can be trained to shift EEG responses from right to left temporal channels (Ray, Frediani, & Harman, 1977). This might partly explain the spectacular success obtained in the rehabilitation of these patients, following an appropriate number of sessions.

The observed responses are associated with a homogeneous set of improvement rates and no correlation was found between these parameters. However, a positive correlation was found between the load of symptoms and the duration of treatment as assessed by the number of sessions (Bounias, Laibow, Bonaly, & Stubblebine, in press). Both of these parameters will be compared to clinical factors in forthcoming studies.

Gunshots are rather unusual causes of brain injury (Aarabi, 1995). Their consequences may be extremely severe and pose ethical problems with respect to patient's psychical autonomy (Callahan & Hagglund, 1995). However, they do not necessarily lead to complete hemispherectomy, which remains a more exceptional kind of lesion. That finger temperatures respond in a negative sense could be a specific feature of such trauma and deserve special attention in the future. On the opposite end of the spectrum, even mild brain injury may exhibit a wide range of various short or long term symptoms (Esselman & Uomoto, 1995). Stress symptoms may elicit severe health impairment, such as immune disorders, and deserve careful management (Taylor, 1995). Attention deficit/hyperactivity disorders have already been treated by EEG-biofeedback (Lubar, 1991). Such symptoms were encountered in our classes Q3 and Q6, and were successfully treated with low to moderate session numbers (see Table 2), consistent with Ramos (1998).

NeuroBioFeedback showed a wide range of applications in various cases of brain injuries ranging from mild to severe levels of damage. However, this powerful technique deserves much care, particularly at the stage of diagnosis concerning treatment choice for inhibition or reward of specific frequencies and decisions concerning the definition and adjustment of threshold levels. Care should be taken similarly in applications to non-injured people for the improvement of intellectual performance (Rasey, Lubar, McIntyre, Zoffuto, & Abbott, 1996) or sports scores (Landers et al., 1991), since the latter cases show that opposite results could be attained with erroneous management of the process.

REFERENCES

Aarabi, B. (1995). Management of traumatic aneurisms caused by high velocity missile head wounds. *Neurosurgical Clinics of North America*, *6*, 775-797.

Anderer, P., Semlitsch, H. V., Saletu, B., & Barbanoj, M. J. (1992). Artifact processing in topographic mapping of electro-encephalographic activity in neuropsycho-pharmacology. *Psychiatry Research: Neuroimaging*, *45*, 79-93.

Bickford, R. G., Brimm, J., Berger, L., & Aung, M. (1973). Application of compressed spectral array in clinical EEG. In: P. Kellaway & I. Petersen (Eds.) *Automation of clinical electroencephalography* (pp. 55-64). New York: Raven Press.

Borgeat, F., Elie, R., & Larouche, L. M. (1985). Pain response to voluntary muscle tension increases and biofeedback efficacy in tension headache. *Headache*, *25*, 387-391.

Bounias, M., Laibow, R. E., Bonaly, A., & Stubblebine, A. N. (2001). EEG-Neuro-BioFeedback treatment of patients with brain-injury. Part 1: Typological classification of clinical syndromes. *Journal of Neurotherapy*, *5* (4), 23-44.

Bounias, M., Laibow, R. E., Bonaly, A., & Stubblebine, A. N. (2002). EEG-Neuro-BioFeedback treatment of patients with brain-injury. Part 4: Duration of treatments as a function of both the initial load of clinical symptoms and the rate of rehabilitation. *Journal of Neurotherapy*, in press.

Bounias, M., Laibow, R. E., & Stubblebine, A. N. (1998). From lethality to neuropsychotoxicology: A major paradigm shift to toxicology. *Journal of Environmental Biology*, *19*, 221-229.

Byers, A. P. (1995). *The Byers neurotherapy reference library* (p. 393). WheatRidge, CO: The Association for Applied Psychophysiology and Biofeedback.

Callahan, C. D., & Hagglund, K. J. (1995). Comparing neuro-psychological and psychiatric evaluation of competency in rehabilitation: A case example. *Archives of Physical Medical Rehabilitation*, *76*, 909-912.

Dietsch, G. (1932). Fourier-analysevon elektrenkephalogrammen des menschen. *Pflugers Archive*, *230*, 106-112.

Esselman, P. C., & Uomoto, J. M. (1995). Classification of the spectrum of mild traumatic brain injury. *Brain Injury*, *9*, 417-424.

Granger, C. V., Divan, N., & Fiedler, R. C. (1995). Functional assessment scales. A study of persons after traumatic brain injury. *American Journal of Physical Medical Rehabilitation, 74*, 107-113.

Greenwald, B. M., Ghajar, J., & Nottermann, D. A. (1995). Critical care of children with acute brain injury. *Advances in Pediatrics, 42*, 47-89.

Hatch, J. P. (1982). Controlled group designs in biofeedback research: Ask, "What does the control group control for?" *Biofeedback & Self-Regulation, 7*, 377-401.

Hatch, J. P., & Riley, P. (1985). Growth and development of biofeedback: A bibliographic analysis. *Biofeedback & Self-Regulation, 10*, 289-299.

Holland, B., DiPonzio, M., & Copenhaver, M. (1987). An improved sequentially rejective Bonferroni test procedure. *Biometrics, 43*, 417-423.

Laibow, R. E. (1999). Medical applications of NeuroBioFeedback. In J. Evans & A. Abarbanel (Eds.), *Introduction to quantitative EEG and neurofeedback* (pp. 83-102). New York: Academic Press.

Laibow, R. E., Bounias, M., Stubblebine, A. N., & Sandground, H. (1996). Rehabilitation of brain injured adults and adolescents through neural therapy (voluntary regulation of EEG activity). Effective strategies for assessment and intervention. *Proceedings 20th Annual Postgraduate Course on Rehabilitation of the Brain Injured Adult and Child* (pp. 153-155). Williamsburg, VA: Virginia Commonwealth University, Medical College.

Laibow, R. E., & Stubblebine, A. N. (1994). *NeuroBioFeedback bibliography*. Unpublished.

Laibow, R. E., Stubblebine, A. N., Sandground, H., Bonaly, A., & Bounias, M. (1996). Neuro-psycho-toxicology and EEG: NeuroBioFeedback potential in diagnosis and rehabilitation. *Journal of Clean Technology, Environmental Toxicology & Occupational Medicine, 4*, 325-338.

Landers, D. M., Petruzzello, S. J., Salazar, W., Crews, D. J., Kubitz, K. A., Gannon, T. L., & Han, M. (1991). The influence of electrocortical biofeedback on performance in pre-elite archers. *Medicine and Science in Sport and Exercise, 23*, 123-129.

Levin, H. S. (1995). Prediction of recovery from traumatic brain injury. *Journal of Neurotrauma, 12*, 913-922.

London, M. D., & Schwartz, G. E. (1984). The effect of activation versus inhibition of feedback on perceived control of EEG activity. *Biofeedback & Self Regualation, 9*, 265-278.

Lopes da Silva, F. (1993). Computer-assisted EEG diagnosis: Pattern recognition and brain mapping. In E. Niedermeyer & F. Lopes da Silva (Eds.). *Electroencephalography. Basic principles, clinical applications and related fields* (3rd ed., pp. 1063-1086). Baltimore, MD: Williams & Wilkins.

Lubar, J. F. (1991). Discourse on the development of EEG diagnostics and biofeedback for attention-deficit/hyperactivity disorders. *Biofeedback & Self-Regulation, 16* (3), 201-225.

Lubar, J. F., & Bahler, W. W. (1976). Behavioral management of epileptic seizures following EEG biofeedback training of the sensorimotor rhythm. *Biofeedback & Self-Regulation, 7*, 77-104.

Mulholland, T., & Runnals, S. (1963). The effects of voluntary directed attention on successive cortical activation responses. *Journal of Psychophysiology, 55*, 427-436.

Nuwer, M. R. (1988a). Quantitative EEG: I. Techniques and problems of frequency analysis and topographic mapping. *Journal of Clinical Neurophysiology, 5*, 1-43.

Nuwer, M. R. (1988b). Quantitative EEG: II. Frequency analysis and topographic mapping in clinical settings. *Journal of Clinical Neurophysiology, 5*, 45-85.

Nunez, P. L., Silberstein, R. B., Cadusch, P. J., Wijesinghe, R. S., Westdorp, A. F., & Srinivasan, R. (1994). A theoretical and experimental study of high resolution EEG based on surface Laplacians and cortical imaging. *Electroencephalography and Clinical Neurophysiology, 90*, 40-57.

Nunez, P. L., & Srinivasan, R. (1993). Implications of recording strategies for estimates of neocortical dynamics with electroencephalography. *CHAOS, 3*, 257-266.

Perneger, T. (1998). What's wrong with Bonferroni adjustments? *British Medical Journal, 316*, 1236-1238.

Ramos, F. (1998). Frequency band interaction in ADD/ADHD neurotherapy. *Journal of Neurotherapy, 3* (1), 26-41.

Rasey, H. W., Lubar, J. F., McIntyre, A., Zoffuto, B. S., & Abbott, P. L. (1996). EEG biofeedback for the enhancement of attentional processing in normal college students. *Journal of Neurotherapy, 1* (3), 15-21.

Ray, W. J., Frediani, E. W., & Harman, D. (1977). Self-regulation of hemispheric asymmetry. *Biofeedback & Self-Regulation, 2*, 195-199.

Rozelle, G. R., & Budzynski, T. H. (1995). Neurotherapy for stroke rehabilitation: A single case study. *Biofeedback & Self-Regulation, 20*, 211-228.

Schwartz, G. (1979). Disregulation and systems theory: A behavioral framework for biofeedback and behavioral medicine. In: N. Birbaumer & H. D. Kimmel (Eds.) *Biofeedback and Self-Regulation* (pp. 19-48). Hillsdale, NJ: Lawrence Erlbaum Associates.

Schwartz, S. M. (1995). Adults with traumatic brain injury: Three case studies of cognitive rehabilitation in the home setting. *American Journal of Occupational Therapy, 49*, 655-667.

Shapiro, D. (1979). Biofeedback and behavioral medicine: An overview. *Psychotherapy and Psychosomataics, 31*, 24-32.

Stratton, M. C., & Gregory, R. J. (1995). What happens after a traumatic brain injury? Four case studies. *Rehabilitation Nursing, 20*, 323-327.

Taylor, D. N. (1995). Effects of a behavioral stress-management program on anxiety, mood, self-esteem and T-cell count in HIV-positive men. *Psychology Reports, 76*, 451-457.

Thornton, K. E. (1996). On the nature of artifacting the QEEG. *Journal of Neurotherapy, 1* (3), 32-39.

Walter, W. G. (1943). An automatic low frequency analyzer. *Electronic Engineering, 16*, 9-13 and 236-240.

Webb, C. R., Wrigley, M., Yoels, W., & Fine, P. R. (1995). Explaining quality of life for persons with traumatic brain injuries 2 years after injury. *Archives of Physical Medical Rehabilitation, 76*, 1113-1119.

RECEIVED: 10/11/99
REVISED: 03/10/00
11/22/00
05/14/01
ACCEPTED: 05/31/01

APPENDIX

TABLE A. ANOVAR Data for Frequency Against Age Classes in Initial Spectra Respectively in Male and Female Patients. (ndf = Number of Degrees of Freedom; SSD = Sum of Square Deviations; MS = Mean Squares; Asterisks (*) Denote Interaction).

Parameters	Female		Male	
SSD Total (ndf)	1248.3 (38)		542.3 (38)	
MS residual (ndf)	28.8 (27)		9.2 (27)	
MS power (ndf)	121.6 (2)	F(2/27) = 4.2	115.5 (2)	F(2/27) = 12.6
MS age (ndf)	40.2 (3)	F(3/27) = 1.48	17.1 (3)	F(3/27) = 1.86
MS * (ndf)	17.5 (6)		7.7 (6)	

TABLE B. ANOVA for Factor Frequency Classes Against Gender in Initial Spectra. (Abbreviations as in Table A)

Parameters	Frequency/Gender
SSD total (ndf)	344.4 (23)
MS residual (ndf)	5.99 (18)
MS F/M (ndf)	45.1 (1)
MS power (ndf)	76.9 (2)
MS* (ndf)	18.8 (2)

TABLE C. ANOVA for Treatment Against Clinical Classes Activity, Globally Plotted for the Various Frequency Bands. (Same Abbreviations as in Table A, plus: res. = Residual; Q = Clinical Classes; T = Treatment)

Frequency Classes	02-08 Hz	08-12 Hz	13-15 Hz	15-18 Hz	20-32 Hz	70-90 Hz
SSD total (ndf)	2279 (53)	263 (29)	63 (23)	124 (29)	555 (24)	22.6 (41)
MSres. (ndf)	21.5 (44)	7.9 (20)	2.5 (14)	3.3 (20)	0.9 (14)	0.27 (32)
MS(T) (ndf) F values	2.4 (1)	1.45 (1)	2.15 (1)	3.7 (1)	0.08 (1)	2.15 (1) 8.02
MS(Q) (ndf) F values	10.5 (4)	0.72 (4)	0.6 (4)	0.22 (4)	42.1 (4) 46.7	0.21
MS (*) (ndf)						

TABLE D-1. ANOVA for Treatment Against Age Classes Activity, Plotted for Different Frequency Bands in Female Patients Only. (Same Abbreviations as in Table A, plus: A = Age Classes; T = Treatment)

Frequency Classes	03-09 Hz	08-12 Hz	13-18 Hz	70-90 Hz
SSD total (ndf)	1107.5 (27)	245. (13)	60.6 (19)	12.2 (27)
MSres. (ndf)	35.2 (20)	2.3 (6)	3.2 (12)	0.33 (20)
MS(A) (ndf)	80.3 (3)	48.3 (3)	3.0 (3)	0.09 (3)
F values	2.28	21		
MS(T) (ndf)	0.52 (1)	8.8 (1)	9.7 (1)	2.93 (1)
F values		3.83	3.02	8.88
MS(*) (ndf)	47.7 (3)	25.8 (3)	1.17 (3)	0.77 (3)
	1.35	11.02		2.33

TABLE D-2. ANOVA Parameters for Treatment Against Age Classes Activity, Plotted for Different Frequency Bands in Male Patients Only. (Same Abbreviations as in Table A, plus: A = Age Classes; T = Treatment)

Frequency Classes	03-09 Hz	08-12 Hz	13-18 Hz	70-90 Hz
SSD total (ndf)	679. (19)	54.7 (15)	96.4 (19)	6.3 (13)
MSres. (ndf)	34.3 (12)	4.2 (10)	6.1 (14)	0.48 (6)
MS(A) (ndf)	65.4 (3)	0.5 (2)	3.3 (2)	0.08 (3)
F values	1.9			
MS(T) (ndf)	1.1 (1)	4.3 (1)	0.05 (1)	0.41 (1)
F values				
MS(*) (ndf)	22.7 (3)	3.6 (2)	3.52 (2)	0.93 (3)
				1.93

TABLE E. ANOVA Parameters for Plotting of Treatment Against Classes of Defined Lesions, at Various Frequency Bands. (Same Abbreviations as in Table A, plus: L = Lesion Classes, T = Treatment.)

Frequency Classes	02-09 Hz	08-12 Hz	15-18 Hz	70-90 Hz
SSD total (ndf)	1074.7 (35)	501.1 (33)	99. (35)	6.9 (27)
MSres. (ndf)	26.7(3)	11.4 (26)	1.17 (28)	0.345 (20)
MS(T) (ndf)	12.1 (1)	93.5 (1)	0.18 (1)	4.48 (1)
F values		8.19 (P = 0.008)		12.98 (P = 0.0018)
MS(L) (ndf)	76.5 (3)	15.1 (3)	6.16 (3)	0.19 (3)
F values < 1	2.87 (P = 0.054)	1.32	5.26 (P = 0.005)	
MS(*) (ndf)	28.5 (3)	21.6 (3)	15.8 (3)	0.84 (3)
F values		1.89	13.5 ($P = 1.2 \times 10^{-5}$)	2.43 (P = 0.09)