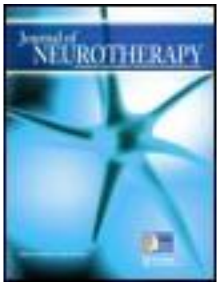

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EEG-NeuroBioFeedback Treatment of Patients with Brain Injury Part 3: Cardiac Parameters and Finger Temperature Changes Associated with Rehabilitation

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ABSTRACT. *Background.* Twenty-seven patients with brain injury were treated by computer-assisted electroencephalographic NeuroBioFeedback (EEG-NBF). All patients were medication-free during treatment.

Methods. Parallel to targeted changes in EEG power spectra, secondary effects were monitored for heart rate, systolic and diastolic pressures, pulse rate and fingertip temperature.

Results. Extreme blood pressure values generally responded by up- and down-regulation toward normal values. Fingertip temperature (FT°) increased in both kinetic movement and amplitude from the beginning to the end of treatment and correlated directly with the rate of the patient's rehabilitation, reflecting an improvement of blood circulation. Blood pressure, pulse and FT° ranks in numerical values were compared by rank correlations.

Conclusions. NBF in patients with brain injury results in beneficial physiological regulation in addition to initially targeted improvements in brain functions. Symptom associations versus the success or failure of EEG treatment and improvement rates reflected correction of symptoms as well as freedom from the bias of expectation in response to treatments.

KEYWORDS. Clinical classes, fingertip temperature, heart rate, systolic/diastolic pressure and ratios, up/down regulation, EEG biofeedback

INTRODUCTION

The search for ways to enhance voluntary control of physiological processes altered by pathological responses or disorders led to the emergence of behavioral medicine in the early 1960's (Luthe, 1969; Schwartz, 1979). While biofeedback came into its own as a part of medical practice in the 1960's and 1970's (Sterman & Friar, 1972), the fusion of computer-assisted interpretation of EEG (Nuwer, 1988) and a deepening understanding of the importance and potential inherent in voluntary regulation of EEG and other physiological processes resulted in the emergence and development of NeuroBioFeedback (NBF) as a new medical discipline (Lubar & Deering, 1981).

Behavioral medicine has been used for the treatment of cardiovascular diseases (Surwit, Williams, & Shapiro, 1982) although systolic blood pressure showed better responsiveness to feedback training than diastolic blood pressure (Shapiro, 1979). It has also been reported that EMG biofeedback reduced blood pressure via reduction of skeletal muscle tension in patients with essential hypertension (McGrady, Yonker, Tan, Fine, & Woerner, 1981). In these cases, it was also shown that a reduction of plasma aldosterone and urinary cortisol occurred, indicating a decrease in Hypothalamic Pituitary Adrenal axis (HPA) mediated stress. Because some correlation exists between blood flow and skin temperature (see Remond & Remond, 1994 for review), finger temperature also serves as an index of the functioning of the cardiovascular system and has been used in feedback techniques. Increases in finger temperature may result from biofeedback training and be correlated with an enhancement of alpha frequencies (Gillespie & Peck, 1980).

In the present study, the NeuroBioFeedback treatment used with patients with brain injury was not targeted to alter blood pressure. Primary attention was focused on brain self-regulation of EEG parameters under feedback information conditions, in correlation with the rate of a patient's rehabilitation. However, subsequent restoration of homeostatic control could be expected to extend to some related disorders. Thus, because of the potential responsiveness of cardiovascular parameters it seemed important to simultaneously monitor heart rate, blood pressure, and fingertip temperature.

MATERIALS AND METHODS

Patients. A population of 27 patients with brain injury was examined for pre- and post-treatment clinical symptoms, EEG parameters and physiological (cardiac and fingertip temperature) parameters (Laibow, Bounias, Stubblebine, & Sandground, 1996). The initial diagnosis and clinical status of the patients has been detailed in previous reports (Bounias, Laibow, Bonaly, & Stubblebine, 2001a).

Symptoms. A checklist of 48 clinical symptoms, each present in at least one patient, was established following a patient-by-patient case-by-case examination. Six main classes of syndromes of alteration of major functions were classified according to consistent clinical and statistical criteria (Bounias et al., 2001a): *Q1* = Motor function (case numbers 10, 20, 24, 25, 26, 27, 28, and 29); *Q2* = Language function (a theoretical class since no patient of this group was in Q2); *Q3* = cognitive deficits and related disorders (case numbers 4, 5, 6, 11, 13, 16, 18, 21, and 22); *Q4* = psychosocial disorders (case numbers 14, 15, and 17); *Q5* = pain-related disorders (case numbers 2, 7, and 12); *Q6(a + b)* =

neuropsychiatrically quoted functions (case numbers 8 and 19 in the physiological subclass Q6a, and case numbers 9 and 23 in the physiological subclass Q6b). Another theoretical class was identified for metabolic disorders; no patient belonged to this class. A general index of initial symptom load was defined as the percentage of symptoms present in each patient before treatment. The percentage of symptoms eliminated after a given number of treatment sessions provided an index of improvement or rehabilitation rate.

The following average rehabilitation rates were reached for each class at the conclusion of treatment (Bounias et al., 2001a; Bounias, Laibow, Stubblebine, Sandground, & Bonaly, 2001b): Q1: 77 ± 29%; Q3: 87 ± 7%; Q4: 77 ± 14%; Q5: 80 ± 10%; Q6: 67 ± 28%.

EEG techniques. All techniques were performed as described in Bounias et al. (2001a) and Laibow, Stubblebine, Sandground, & Bounias (2001). Three types of EEG NBF devices were used according to the various needs for improvements: Capscan 880 or Prism V, Lexicor NRS-24, NRS 2-D and Focus Technology F-1000. Ongoing assessment sessions were first performed for forty seconds for pre- and post-treatment sessions, both in the eyes-closed and eyes-open condition, by a compressed spectral analysis at the site of treatment, providing both imagery of wave distribution of intensity and spectral patterns for the treatment site. Power spectra were analyzed with a Fast Fourier Transform 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).

Feedback corrections. Excessive slow waves (3-7 Hz), as well as of fast frequencies (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. Training sessions lasted thirty minutes and feedback signals were emitted as both tones and visual displays indicating the success of brain self-regulation with respect to pre-established thresholds. Sessions were performed in individual rooms eliminating undesired noise and other extraneous sensory stimuli.

Cardiovascular parameters. Systolic and diastolic blood pressure as well as heart rate changes were monitored from the beginning to the end of each session (and therefore from beginning to end of the entire treatment) in order to examine whether physiological effects could be observed at the cardiovascular level. An influence of biofeedback on heart rate was recently reported, in connection with EMG and breathing patterns (Blumenstein, Breslav, Bar-Eli, Tenenbaum, & Weinstein, 1995). Although the treatment goal was not to directly influence pulse rate in the Blumenstein et al. report or in our study, this parameter was recorded before and after each session.

Fingertip temperature. FT° was systematically recorded at seven to eight minute time intervals during the sessions. Care was taken to account for side effects, which could impair the accuracy of data (e.g., the occurrence of transient decreases at the beginning of sessions, Okouchi & Sugiwaka, 1995).

Statistical treatment. The results included comparisons of means, by unpaired or paired student's "t" tests, or by the Mann-Whitney nonparametric test. Multivariate analysis was originally performed to produce clinical classifications through the analysis of principal components combined with factorial correspondence analysis and typology (Bounias et al., 2001a). Correlation and regression parameters were calculated using least squares estimation. Additionally, matrices of Spearman rank correlation coefficients are reported between different cardiac measurements.

RESULTS

Blood Pressure

Table 1 shows the data obtained for systolic and diastolic blood pressure and their difference (S-D), as well as pulse rate.

Systolic Blood Pressure

When initial (pre-session) values were comparatively examined at the beginning and at the end of treatment, it become apparent that up- and down-regulation occurred for groups of patients respectively exhibiting lower and higher systolic pressures. The intermediate group showed no change.

i. The lower pressure group included patients 2, 8, 9, 11, 12, 14, 27 and 29, all exhibiting initial $S < 110$ mm Hg. Changes ranged from an average 100.25 ± 6.1 mm Hg (pre-treatment) to an average 103.5 ± 8.6 mm Hg at treatment conclusion. Significance by paired t-test was $p = .015$ (observed $t = 3.20$).

ii. The higher pressure group included patients 13, 20, 23, 24, and 25, all exhibiting initial $S > 125$ mm Hg. From start to end of treatment changes ranged from an average 141.7 ± 8.9 mm Hg to an average 132.0 ± 11.9 mm Hg. Significance by paired t-test was .013 (observed t = 5.35).

iii. Other patients had blood pressure within the interval 110 ≤ S ± 125 mm Hg. Their values remained stable, averaging from 114.7 ± 4.7 to 116.2 ± 14.6 mm Hg (no significant change).

Cases 22 [Q3], 26 [Q1], 29 [Q1], 14 [Q4], and 8 [Q6] did not show these patterns and were associated with incomplete EEG responses. Five cases out of eight in Q1, three cases out of four in Q6, two cases out of nine in Q3 and one case out of three in Q4 exhibited regulation re-

TABLE 1. Variations Observed for Cardiac Parameters in Clinical Classes of Major Syndromes of Altered Functions: Sys = Systolic Pressure (mm Hg); Dia = Diastolic Pressure (mm Hg); S-D = Difference Between Systolic and Diastolic Pressures (mm Hg); PR = Pulse Rate (bpm). Means and SD Are Given for (N) Values.

		Treatment start		Treatment discontinuation	
Classes		Before session	End of session	Before session	End of session
Q1 (N = 8) Motor	Sys.	126.0 ± 23.4 (a)	122.4 ± 20.3 *	120.7 ± 20.3 (‡)	125.3 ± 22.1
	Dia.	75.9 ± 29.2	72.6 ± 9.8 *	76.3 ± 10.5	78.0 ± 8.9
	S-D	50.1 ± 16.0 (d)	49.8 ± 15.7	44.4 ± 13.7	45.4 ± 16.1 *
	P.R.	69.1 ± 5.6 (e)	70.9 ± 5.8	67.4 ± 6.2	67.7 ± 6.9 *
Q3 (N = 9) Cognitive	Sys.	116.8 ± 11.3	116.4 ± 5.4	122.5 ± 7.5	123.8 ± 10.9
	Dia.	73.9 ± 9.9(b)	74.8 ± 9.2	75.1 ± 10.1	73.1 ± 15.2
	S-D	42.0 ± 6.1	41.5 ± 7.3	47.8 ± 5.2	50.1 ± 4.7 *
	P.R.	70.9 ± 10.4	66.1 ± 15.4 *	75.5 ± 9.3 *	72.8 ± 6.5 *(‡)
Q4 (N = 3) Psychosocial	Sys.	97.4 ± 10.8 (a)	96.7 ± 9.8	97.8 ± 8.5	96.0 ± 11.8
	Dia.	58.0 ± 1.1 (b,c)	56.6 ± 0.2	55.4 ± 1.2	57.2 ± 0.4
	S-D	39.4 ± 1.1	40.1 ± 1.2	42.4 ± 1.2	38.8 ± 2.4
	P.R.	82.2 ± 4.0 (e)	88.0 ± 3.5	88.5 ± 4.4	82.5 ± 4.1
Q5 (N = 3) Pain-related	Sys.	104.0 ± 0.1	114.8 ± 4.8*	106.4 ± 1.6	107.6 ± 5.4
	Dia.	69.1 ± 4.1 (c)	70.7 ± 2.2	72.3 ± 1.9	74.8 ± 5.4
	S-D	34.9 ± 4.1 (d)	40.6 ± 0.3	34.0 ± 0.3	32.7 ± 2.2 *
	P.R.	67.3 ± 12.2	62.2 ± 4.9	69.6 ± 15.3 *	62.9 ± 10.2
Q6 (N = 4) Neuro-psychiatric	Sys.	110.2 ± 22.1	107.3 ± 18.3	107.2 ± 14.7 *	108.5 ± 20.7
	Dia.	67.4 ± 10.4	66.3 ± 11.2	68.6 ± 9.6	68.5 ± 10.1
	S-D	42.9 ± 13.3	41.0 ± 7.6	38.4 ± 10.1	40.0 ± 11.5
	P.R.	72.9 ± 6.8	72.1 ± 9.8	69.1 ± 3.4 *	67.9 ± 4.0 *

Some significant changes through appropriate tests (see text) are denoted horizontally by (*) (before to end, at treatment start) and (‡) (start to discontinuation for corresponding before and end sessions) and vertically by same letters (a,b,c,d,e) for parameters with significant changes observed between classes.

sponses. Cases 24, 25, 27, and 29 of class Q1 all belong to a category of vascular accidents and all were responsive to treatments with favorable outcomes. Male and female patients contributed about equally to these results.

Paired data analysis allowed significant changes to be evidenced from the raw data for class 1: (a) at the start of treatment, a 2.8% global decrease was observed from before to end of sessions ($p = .011$), (b) averaged values at treatment onset to discontinuation showed a 4.5% decrease ($.001 < p < .01$), and (c) the up-regulation noted for class Q-5 (pain-related disorders) at treatment onset, from the beginning to the end of sessions was also significant using a t test ($p = .017$).

Regarding class-related results, the higher values were observed in class Q1, in which most patients were victims of cardiovascular lesions, followed by Q3, cognitive function alteration syndrome.

Diastolic Blood Pressure

Although the diastolic blood pressure (D) is usually less responsive than the systolic blood pressure (Shapiro, 1979) up- and down-regulation was again observed above or below a threshold at 75 mm Hg. Up-regulation occurred for patients 8, 9, and 23 of class Q6 (all female), 2 and 12 of class Q5, and for patients 11 (Q3), 14 (Q4) and 27 (Q1). Since only cases 14 and 27 were male, taking the set of female patients with diastolic blood pressures below 75 mm Hg, paired data analysis showed a significant ($p = .011$) 3 mm Hg decrease of values measured from the start to the conclusion of treatments. A 6.2 mm Hg down-regulation was noted with $p = .05$ significance level for class Q1 (case numbers 24, 25, and 26), Q3 (cases 13 and 22) and Q6 (case 19), represented by four female and three male patients. Case numbers 14 (Q4), 16 (Q3), 20 (Q1) and 23 (Q6) did not show regulation of diastolic blood pressure.

Regarding particular features in each of the clinical classes, again class Q1 exhibited the highest values, closely followed by classes Q3 and then Q5, Q6 and Q4. On average, class Q4 showed significantly lower pressure than Q1, Q3, and Q5 ($p < .001$).

Systole to Diastole Ratio and Deviation

The systole to diastole ratio did not reach statistical significance. In contrast, the deviation (either S-D in mm Hg or S-D/S %) showed up- and down-regulation, respectively, below and above a threshold of 45 mm Hg. Up-regulation occurred for cases 11, 16, and 22 (class Q3), 26

(Q1), 14 (Q4), 12 (Q5), and 8 (Q6), shown by two male and five female patients. Paired data analysis showed significance for deviations observed for the whole group ($p = .0105$) as well as for female only ($p = .05$). Patients 27, 28 and 29 (Q1), 2 (Q5) and 19 (Q6) resisted diastolic regulation.

Average values confirm a global trend towards up-regulation particularly for class Q3 and towards down-regulation for Q1 and Q5.

Pulse Rate

A significant ($p = .016$) difference was noted between male (65.0 ± 5.0 bpm) and female (72.7 ± 5.1 bpm) patients belonging to the same clinical class, Q1. This dimorphism was consistent with data previously observed (Sharpley, 1994) in healthy subjects who exhibited higher coefficients of variation. This gender effect provided an understanding of the way regulation occurred. In effect, since females exhibited higher basic levels, they down regulated at a threshold above 75 bpm, whereas males down regulated in the range of 60 bpm to 75 bpm. The set of female patients included cases 24 and 29 (Q1), 8 and 19 (Q6), 9 and 16 (Q3), and 2 (Q5), with an average decrease of 3.3 bpm ($p = .05$ from paired data analysis), from treatment start (77.6 ± 2.4 bpm) to treatment discontinuation (74.3 ± 2.0 bpm). The set of male patients included cases 20, 25, and 27 (Q1), 13 and 22 (Q3), with a 2.1 bpm decrease in the same conditions ($p = .018$) from 67.2 ± 4.5 to 65.1 ± 3.8 bpm.

Up-regulation was consistently noted for female patients if below 75 bpm, with an average 8.5 bpm increase from 68.7 ± 9.6 to 77.3 ± 4.5 bpm.

As seen in Table 1, heart rates were highest on average for patients of class Q4 (syndrome of psychosocial behavior alterations), followed by the patients of set Q3, Q1, and Q6 and lower for Q5 (pain-related disorders). Neither class Q4 nor class Q5 responded with global up- or down-regulation. In contrast, patients of class Q1 (most with vascular diseases) down regulated with significance ($p = .022$) from an initial 70.0 ± 5.8 bpm to a final 67.7 ± 6.9 bpm. Patients of class Q6 (neuropsychiatric disorders) also down regulated from an initial 72.9 ± 6.8 bpm to a final 69.1 ± 9.0 bpm ($p = .032$). Up-regulation globally occurred in class Q3 (syndrome of impairment of cognitive functions) with significance ($p = .043$) from an average 68.5 ± 13.0 to 74.1 ± 8.0 bpm. In class Q5 (pain-related disorders), patient response showed only mild down-regulation. More marked change occurred at the conclusion of treatment, from the beginning to the end of sessions ($.05 < p < .10$).

Fingertip Temperature

Values were noted at four intervals, and the corresponding regression slopes were calculated for each session (slope b adjusted to °F $\times$ 10^2 per minute for compression of data). The results reported in Table 2 provide the average values calculated respectively at treatment onset and at the end of treatment. Positive slopes were noted in all cases except Q5. Class Q4 exhibited a restored ability to reach positive values at the end of the treatment period. Significance was found in the comparisons of the overall mean values (treatment start and discontinuation) to zero for three classes: Q1, Q3, and Q6. For Q4, slopes increased from the beginning to conclusion of treatments. Besides these global results, it was noted that slopes, which were negative in Q4 at treatment onset, became positive ($p = .05$) at the end.

Table 3 gives the various values of FT° measured for each clinical class. Session-averaged FT° of patients from class Q1 fell from 92.1 ± 3.4 to 90.8 ± 3.0°F ($p = .08$), although values increased with a low level of statistical significance ($p = .052$) during sessions either before, or at the end of, the period of treatments. Patients of class Q6 exhibited a global increase from 92.0 ± 7.7 to 95.9 ± 1.7°F ($p = .014$, from paired data test), with the increase from beginning to end of session as well as

TABLE 2. Regression Slopes of Finger Temperatures (°F) vs. Time, Measured During Sessions for the Various Clinical Classes. Means and SD Are Given for (N) Values. Units Are °F per Minute $\times$ 10^2.

Clinical classes	Treatment start	Treatment discontinuation	Averaged slopes
Q1	+5.75 ± 11.2 (6)	+20.1 ± 11.6 (6)	+12.9 ± 13.2 (12) **
Q3	+11.5 ± 17.2 (9)	+9.6 ± 11.7 (9)	+10.6 ± 14.3 (18) *
Q4	−4.0 ± 1.4 (6)	+ 18.0 ± 11.3 (2) °	+7.0 ± 11.0 (8)
Q5	−1.0 ± 8.2 (3)	−4.7 ± 22.1 (3)	−2.8 ± 15.1 (6)
Q6	+7.0 ± 9.6 (4)	+6.6 ± 2.5 (4)	+6.8 ± 6.5 (8) *
Q6a	+9.0 ± 9.9 (2)	+4.8 ± 1.8 (2)	
Q6b	+5.0 ± 12.7 (2)	+8.3 ± 1.6 (2)	

Significance from comparisons to zero: $p < .05$ *; $p < .01$ **.
Significance from regular t-test: $p < .01$ °.

TABLE 3. Finger Temperatures (°F) Measured for the Various Clinical Classes. Means and SD Are Given for (N) Values.

Classes	Treatment start (S)		Treatment discontinuation (D)		Mean (S) to (D) variations
	Before session	End of session	Before session	End of session	
Q1 (N = 8) Motor	91.9 ± 2.6	92.4 ± 4.1	89.9 ± 3.1	91.8 ± 2.9	3.6 ± 3.4 *
Q3 (N = 9) Cognitive	90.5 ± 7.1	93.9 ± 3.8 **	91.4 ± 5.5	94.4 ± 3.7	3.00 ± 3.3 **
Q4 (N = 3) Psychosocial	96.1 ± 1.9	95.5 ± 1.5	91.0 ± 2.0	96.4 ± 0.4	
Q5 (N = 3) Pain-related	88.6 ± 9.1	88.6 ± 10.8	90.3 ± 6.4	88.8 ± 12.9	
Q6 (N = 4) Neuro-psychiatric	90.9 ± 7.0	93.1 ± 8.5	94.9 ± 1.5	96.9 ± 1.2 **	2.15 ± 1.8 ***

Significance in comparison to zero: .05 < p < .1 *; .02 < p < .05 **; .01 < p < .02 ***.
Q4 and Q5 showed no significant changes.

at treatment conclusion also significant (p = .024). For class Q3, values increased during sessions in a similar way at the beginning or at the end of the treatment period (p = .023). Thus, we saw two kinds of variations: during sessions and over the whole course of treatment. The latter are parallel in Q6 and nearly anti-parallel in Q1 and Q5.

Besides the general behavior of significant up-regulation (no significant down-regulation was found globally), three patients exhibited sustained decreases in FT°: patients 10 and 29 (Q1) and patient 12 (Q5). These cases will be discussed below.

Results from Classes of Similar Lesions

Patients have been alternatively considered by classes of the same types of lesions as previously (Laibow et al., 2000). Pooling trauma case numbers 23, 24, 25, 26, and 28 (stroke) and eventually 27 (the latter also exhibiting seizure) represents a single class of organic lesion (STRK). The two cases of hemispherectomy (case numbers 10 and 29) represent a unique case (HMSPHCT). Lastly, two classes of concussion syndromes emerge from two origins: (i) car accidents–case numbers 2, 9, 13, 16, 19, and 20 (CAR ACCDT) and (ii) falls-case numbers 8, 12, 21, and 22 (FALL).

Table 4 summarizes some interesting observations for the various

TABLE 4. Clinical Data Relative to Classes of Lesions and Origin of Concussion. Values Are Given at Treatment Start (TS) and Discontinuation (TD), and When Needed, at Beginning (BS) and End (ES) of Sessions. Means and SD (in Parenthesis) Are Given for N Measurements.

	STRK N = 6	HMSPHCT N = 2 × 4	CAR ACCDT N = 6	FALL N = 4
EEG (mV) at				
02-09 Hz . . . . TS	24.2 (4.2)	7.0 (2.6)	10.4 (5.9)	11.8 (2.2)
. . . . TD	20.8 (8.4)	5.3 (0.7)	8.2 (4.3)	10.2 (5.0)
8-12 Hz . . . . TS	9.0 (2.5)	9.1 (4.8)	7.0 (1.8)	10.2 (7.2)
. . . . TD	14.0 (3.8)	7.7 (4.0)	11.9 (3.9)	13.9 (3.5)
15-18 Hz . . . . TS	5.2 (1.9)	2.8 (0.7)	4.3 (1.7)	4.3 (1.2)
. . . . TD	5.7 (1.9)	1.6 (0.1)	4.5 (1.3)	4.1 (1.4)
70-90 Hz . . . . TS	2.8 (0.4)	3.1 (0.4)	2.4 (0.2)	2.5 (0.7)
. . . . TD	2.4 (0.05)	1.8 (0.3)	2.1 (0.4)	1.5 (0.5)
Systolic pressure				
mm Hg . . . . TS	132.0 (21.0)	96.3 (1.5)	110.6 (13.9)	108.1 (11.7)
. . . . TD	125.3 (18.9)	101.0 (4.6)	106.2 (13.0) **	113.0 (13.1)
Diastolic pressure				
mm Hg . . . . TS	78.8 (8.0)	64.2 (0.2)	68.7 (6.3)	65.9 (9.3)
. . . . TD	77.1 (9.7) °	67.7 (1.8)	72.2 (8.5) °	68.7 (7.7)
Ratio S/D . . . TS	1.67 (0.16)	1.5 (0.06)	1.61 (0.40)	1.64 (0.20)
. . . . TD	1.62 (0.16)	1.5 (0.09)	1.47 (0.40)	1.64 (0.20)
S-D . . . . TS	53.3 (15.0)	32.0 (1.7)	42.2 (7.0)	42.1 (5.1)
. . . . TD	38.3 (24.5)	33.3 (2.7)	37.8 (6.8)	44.3 (5.3)
Pulse . . . . . . TS	70.0 (6.6)	68.9 (0.7)	73.0 (4.6)	68.3 (9.3)
bpm . . . . . . TD	69.0 (8.4)	64.1 (0.8)	67.0 (7.3) °	65.9 (7.2)
F T°F				
TS: . . . . BS	92.3 (3.4)	92.6 (0.9)	94.3 (2.3)	91.5 (8.5)
. . . . ES	94.8 (3.4) **	87.5 (0.9) *	96.3 (1.4) ***	90.1 (9.4) °
TD: . . . . BS	87.8 (1.9)	91.8 (0.3)	93.1 (4.0)	93.2 (6.7)
. . . . ES	92.7 (1.8) **	88.2 (0.1) *	94.6 (2.8) **	91.7 (11.8) °

A specific exception *; p < .05 **; .001 < p < .01 ***; No significance °.

clinical parameters concerning these classes. Some variations of EEG parameters from the beginning of treatment-to-treatment termination were noted to exhibit changes in the expected way (that is, decreases for low and high frequencies, and increases in 8-12 Hz). In these cases, NBF proved helpful with regard to blood pressure. Systolic pressures revealed down-regulation in stroke cases, where initial pressures were elevated, and up-regulation in fall cases, where values were originally reduced. Relevant changes were observed in stroke cases for both the ratio (S/D) pressures, and the difference (S-D).

Pulse rates show mild down-regulation in all four classes. The variations of finger temperature exhibited significant increases for vascular strokes from the beginning to end of sessions, both at treatment start and end of treatment (paired data analysis: $p = .036$). In contrast, they significantly decreased in the case of hemispherectomized patients ($p = .008$ during four replications in each case).

DISCUSSION AND CONCLUSIONS

Although regulation of cardiac parameters was not the goal of this study, given the system-wide regulation seen with NBF, it seems legitimate to consider the hypothesis that variation of blood pressure and heart rate can emerge as a possible consequence of a more general homeostatic regulation catalyzed by brain wave training.

During training sessions of patients with essential hypertension, blood pressure has been successfully lowered from 144/90 to 133/84 at the same time as decreases in plasma aldosterone and urinary cortisol suggested that a decrease in HPA-mediated stress had been achieved (McGrady et al., 1981). In our patients with brain injury, mild effects of systolic down-regulation and up-regulation were observed, respectively, in class Q6 and Q3. Down-regulation was also observed for stroke cases exhibiting high pressures, and up-regulation in patients with low pressure following a fall. Consistent with Surwit et al. (1982), no meaningful changes were noted for diastolic pressure. Homeostasis, however, appeared in the normalization of the ratios of systolic to diastolic pressures and on the difference between these two parameters. It is noteworthy that this also occurred in the case of vascular injuries (strokes). Finally, it may be that apparently random diastolic variability simply reflected the adjustment through which diastolic pressure restored normal ratios and differences. Blood pressure regulation might therefore contribute to biofeedback success in headache cases (Borgeat, Elie, & Budzynski, 1995). Table 1 thus consistently shows down-regulation of absolute values and differences at end of sessions, from the start to the end of treatments in class Q5, which accounts for pain, including headaches. That the session effect is required may indicate that pain itself has not been primarily corrected, but requires a relaxation phase. In these cases, improvement was noted in delta/theta, alpha, and EMG frequencies.

Heart rate also appears among the parameters that can be regulated on instruction (Steptoe, 1976). However, decreasing effects could take longer than increasing effects; it is noteworthy that class Q1, in which patients were responsive to treatments with respect to pressure and pulse, corresponds to the higher number of sessions needed for rehabilitation of patients (i.e., 132 ± 54 sessions).

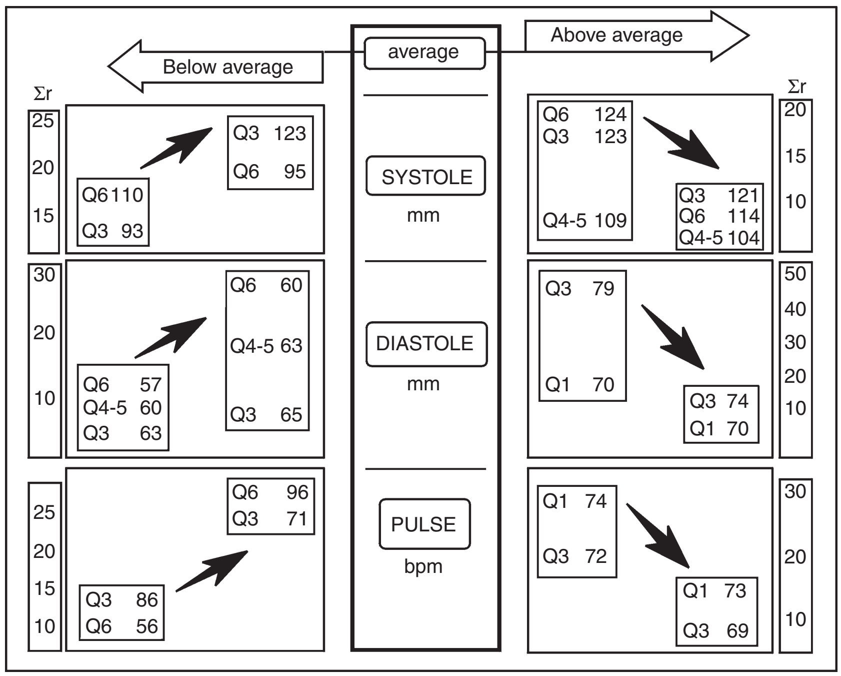
For the whole set of patients, the deviation in pulse rate from beginning to end of treatments was negatively correlated with the number of sessions required for rehabilitation of patients. Parameters were $r = -.777$ ($p < .001$); $b = -138.4 \pm 6.3$ sessions per percent improvement ($N = 27$). Interestingly, the percentage of deviation of systolic pressure at the beginning of treatments was also correlated to the number of additional sessions required for rehabilitation of patients. Except for cases 11, 12, 13, and 27, which had nonsignificant correlations, the parameters were $r = -.78$ ($p = 0.001$); $b = -16.0 \pm 2.8$ sessions per percent ($N = 23$). This suggests that the systolic pressure response during the first sessions might provide an index of the number of additional sessions required for rehabilitation. Although these findings emphasize the consistency of our results, using larger numbers of well-described cases should control them further. It is noteworthy that heart rates are connected to breathing patterns, which have in turn been considered to be a sensitive psychophysiological index for sportsmen (Blumenstein et al., 1995). These results could be associated with the reduction of pain achieved for patients of class Q5, consistent with previously reported success in similar cases (Borgeat, Elie, & Larouche, 1985).

A balance of class-related up- and down-regulation observed for systole, diastole, and pulse based on nonparametric criteria is illustrated in Figure 1.

Fingertip temperature has been shown to increase during biofeedback training (Gillespie & Peck, 1980; Ikemi, Tomita, & Hayashida, 1988). This finding has found some applications to the improvement of Raynaud's syndrome (Sappington & Fiorito, 1995). However, it appeared that transient decreases could occur during early training associated with feedback features (Okouchi & Sugiwaka, 1995). In the present study, finger temperatures exhibited significant responses for classes Q1, Q3, and Q6.

When strokes (Table 4) were examined separately, the temperature responses were positive from the beginning to the end of sessions at either treatment onset or conclusion, whereas values were not increased from start to conclusion. In contrast, patients with hemispherectomy

FIGURE 1. Observations of up- and down-regulation of blood pressure and heart rate in patient subclasses with clinical values, respectively, above and below average of the corresponding class. Responsive classes are graded with respect to a nonparametric scale, indicated in left and right columns, calculated as the sum of ranks (Σr) of patients in the considered groups. Values in natural units are additionally indicated beside each class.



showed a significant decrease from the early phases of treatment to conclusion.

Not only were slopes within sessions negative, but also the decrease of basal temperature from start to conclusion was significant when examined by paired data analysis (N = 8; $.02 < p < .05$). In class Q1, increase in finger temperature was associated with positive responses of b1 frequencies, with an average gain of $9.8 \pm 6.7\%$ ($.01 < p < .02$) for patients 10, 20, 24, 25, 28, and 29. These responses were rank-correlated with the respective improvement rates: $r = .975$ ($.001 < p < .01$). This adds to the significant positive correlation found between the symptom load and the duration of treatment as assessed by the number of sessions

(Bounias et al., 2000b). Either of these parameters will thus be worth comparing to clinical factors in further studies. In the present cases, specifically for the stroke class (STRK), a highly significant correlation was found between the difference of slopes at start and conclusion of treatments (i.e., the increase in finger temperature responsivity), and the number of sessions required: $r = +.972$ ($.001 < p < .01$); $b = (1.82 \pm 2.5) \times 10^{-3}$ °F/min/session ($N = 5$).

Some other correlations were found between systolic down-regulation (mm Hg) and expected responses of EEG parameters (percentage of change) to targeted changes, regardless of particular classes of syndromes. With delta-theta: $r = -.891$ ($N = 9$: $.001 < p < .1$); with alpha: $r = -.943$, ($N = 5$: $.01 < p < .02$); with SMR: $r = .702$ ($N = 19$: $p < .001$).

Reciprocally, some cases which did not learn to correct their pulse rate (cases 9, 14, and 21); systolic pressure (cases 8, 9, and 26), diastole (case 20), pulse (case 29) and FT° (cases 10 and 12) were associated with incomplete corrections of EEG parameters. Though major symptoms resolved in above 80 percent of patients, some EEG parameters showed incomplete restoration in the delta-theta range (cases 8, 10, 14, and 29), alpha (case 14), beta (case 10 and 20), and EMG (cases 8, 9, 20, and 26).

In conclusion, NeuroBioFeedback targeted to the rehabilitation of brain injury resulted in some beneficial side effects of cardiovascular parameter improvement, thus reinforcing the hypothesis that NeuroBioFeedback provides a general improvement of the global homeostatic control over the human body. Further research will focus on examining similar parameters during the treatment of other classes of diseases.

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