QEEG, Brain Rate, Executive Functions and Neurofeedback Training in Patients with Traumatic Brain Injury

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SUMMARY
Traumatic brain injury (TBI) is a serious and growing problem, and long-term consequences become more widely acknowledged recently. A group of six patients with traumatic brain injury have been accepted for neurofeedback training. All of them have been injured by ar accident. Mild motor impairment was apparent in all patients; however, cognitive difficulties were the main problem. Preliminary qEEG assessment showed generally predominance of slow brain waves in fronto-parietal regions. This finding indicated the type of applied training protocols. We organized 20 sessions of neurofeedback, two times a week, each 40 minute duration. Subjective assessment concerning mood, quality of sleep, ever day's activity and cognitive abilities, as well as the changes of qEEG findings promised good outcome. All patients, except one, continued normal education as well as normal life. It is the first application of neurofeedback for treatment TBI in our region.
Key words: neurofeedback, traumatic brain injury, qEEG, accidents, cognitive impairment.

1. INTRODUCTION

Traumatic brain injury (TBI) is a serious and growing problem, and long-term consequences become more widely acknowledged recently. New studies are continually being conducted to try to gain a better understanding of how the brain is impacted, as well as which new treatments or therapies are available to help.

Persons suffering loss of functions due to head injuries were usually examined with CT and MRI scans, which in some cases might not reveal any serious organic lesion. In addition, quantitative EEG with brain mapping and event related potentials can reveal changes in cortical activation (1, 2).

The symptoms which accompany head injury include

- Physical - headaches, sleep disturbance, fatigue, nausea or seizures;
- Emotional - depression, anxiety or agitation, anger or explosiveness, and mood swings;
- Cognitive - attention problems, memory problems or confusion.

Usually, the more severe the trauma, the more severe the cognitive deficit is. However, sometimes the apparent severity of the injury, including the length of period of unconsciousness (if any), has little influence to the severity of subsequent symptoms. New symptoms may arise months or even years after the head injury. In adolescents, if there are not big muscular-skeletal handicap, the main problem arises with post-traumatic poor school achievement due to cognitive impairment.

Most brain injuries are directly related to car accidents, whose number is growing every day. The consequences of TBI depend on the situation and person, but the most common effects involve psychological and cognitive functioning. This means that the person's ability to reason, solve problems, or concentrate become challenged. Along with these, other problems develop, including depression, fatigue, irritation, and lack of motivation, which is understandable.

Following acute TBI rehabilitation, a limited number of strategies have been used for treatment of cognitive impairments. These methods have included restorative cognitive rehabilitation procedures that utilize stimulation and practice as well as medications directed at arousal, attention and/or memory. However, all these methodologies may provide only modest improvements, so that it is still common for patients with TBI to be told that they must simply adjust to the current state of situation.

In the last ten years the application of biofeedback arises as a new method in cognitive rehabilitation of patients with TBI.

Generally, biofeedback means learning process to obtain control over unconscious functions (skin conduction, temperature, heart rate, breathing, or brain activity). In fact, neurofeedback is central biofeedback based on brainwave modulation. The process consists of placing the electrodes on the scalp which allows to see in real time the screen representation of brainwave activity a few thousands of a second after it occurs, and to influence this activity. A computer display may be as simple as two bar graphs, with one representing inefficient brain activity, and another the efficient one. When the patient concentrates on the display and through this concentration decreases slow (e. g., theta or alpha) activity and slightly increases the efficient activity (e. g. SMR or beta), both visual and auditory feedback are received. Change occurs through a process of operant conditioning, gradually reconditioning and retraining how the brain is functioning.

Our team uses neurofeedback treatment for many stress-related disorders (3, 4, 5. 6) as well as for ADD/ADHD children (7, 8). In addition, using neurofeedback we have obtained very positive results for better school achievement in healthy students (9), as well as for music and sport performance (10). In those studies we have used neurofeedback equipment made by Thought Technology, Canada. It allowed more interesting manner of training consisted of video games related to the brain electrical functioning. The game is going if the client produces needed brain waves and stops in opposite cases.

The neurofeedback (EEG biofeedback) represents a relatively new approach in the treatment of TBI patients. In a few published studies, neurofeedback was applied for 20-40 training session in central head points (mainly in Cz) and rewarding high alpha brain activity, showed improvement of the cognitive functioning (11, 12, 13). Thornton and Carmody found 186% improvement in memory scores in TBI patients treated with neurofeedback [14]. When these authors compared neurocognitive rehabilitation strategies, medication treatment, and neurofeedback treatment in an effect size analysis, neurofeedback appeared more efficacious than other treatment strategies. Ayers have even brought many patients out of coma using neurofeedback (15).

2. AIM OF THE STUDY

The aim of this study was:

a) to analyze qEEG findings of injured patients and to compare the results with data base; b) to improve neurofeedback training with parallel application of peripheral biofeedback; c) to introduce the calculation of brain rate parameter as an indicator of general mental arousal in TBI patients and

d) to assess the executive functions before and after application of biofeedback.

3. SUBJECTS AND METHODOLOGY

Six patients of different age and gender with TBI have been accepted for neurofeedback training. Interviews, data from the medical history as well as CT and MRI scans have been elaborated. Intelligence was assessed with Koch's cube test.

The patients were recorded with qEEG (MITSAR, Russia) in eyes open (EO) and eyes closed (EC) conditions for 5 minute duration, as well as during visual (VCPT) and auditory cognitive performance tasks (ACPT). The data was compared with data-base obtained from Human Brain Institute, St Petersburg, 2009.

It is important to stress that regardless of the site of injury, real-time digital EEG assessment always involves recording sensorimotor cortex (sites T4, C4, T3, C3 and Cz). Sensorimotor cortex controls all sensory and motor functions and mediates behavior based on incoming sensory input and past experience. In general, higher amplitudes of slow waves in some region indicate the site of impact, while beta amplitude can be increased in an effort to compensate. So, the goal of neurofeedback is mainly to reduce the theta activity. Beta amplitude automatically increases, and there it is no need for special training of beta activity.

Individual protocols for neurofeedback training are adapted concerning qEEG findings. Generally, all patients were trained for SMR rhythm (high alpha) for 20 sessions. The position of the active electrodes for training was in Fz and Cz. The goal was to inhibit theta (4-7 Hz), rewarded sensory motor rhythm (high alpha 10-14 Hz), and inhibit muscle activity/tension. In addition to neurofeedback, some modalities for peripheral biofeedback (namely, skin conductance or pulse balance) have been used for obtaining control of the autonomous nervous system.

As shown in our previous publications, the brain rate (EEG spectrum weighted frequency) can be considered as an integral state attribute correlated to brain electric, mental and metabolic activity. In particular, it can serve as a preliminary diagnostic indicator of general mental activation (i.e. consciousness level), in addition to heart rate, blood pressure or temperature as standard indicators of general bodily activation (16).

It was shown that bran rate can be used to discriminate between the groups of under-arousal and over-arousal disorders, to assess the quality of sleep, as well as to indicate the IQ changes caused by some environmental toxins (17). Brain rate is also suitable to reveal the patterns of sensitivity/rigidity of EEG spectrum, including frequency bands related to permeability of corresponding neuronal circuits, based on which the individually adapted neurofeedback protocols can be elaborated (18).

Brain rate is calculated by following formula:

$$f_b = \sum_i f_i P_i = \sum_i f_i \frac{V_i}{V},$$

with

$$V = \sum_i V_i$$

where the index i denotes the frequency band (for delta $i = 1$, for theta $i = 2$, etc.) and V_i is the corresponding mean amplitude of the electric potential. Following the standard five-band classification, one has f_i = 2, 6, 10, 14 and 18, respectively.

In this context, brain rate can serve as an indicator of total brain activity in TBI patients.

Executive functions (EF) are set of cognitive processes which function is the optimization of the complex situation efficiency, requiring a large number of cognitive functions. Main characteristics of executive functions are planning, looking for alternative solutions, strategies for executing plans and inhibitions of the unsuitable answers. Localization of EF is in the prefrontal cortex, which reaches its maturity in the adulthood. Evaluation of executive functions was performed with psychometric instruments Wisconsin Card Sorting Test (WCST) and Stroop Color Word Test (19, 20).

	I	K	M	V	B	G	Mean
Age	18	15	19	15	55	15	22.83
Duration of the brain injury (years)	5	5	3	2	5	5	4.16
Length of coma(days)	95	2	15	25	3	3	23.83
Estimated pre-morbid IQ	120	135	120	100	110	110	115.83
Post-morbid IQ	75	140	80	75	82	85	89.5

Table 1. Some specifics of TBI patients

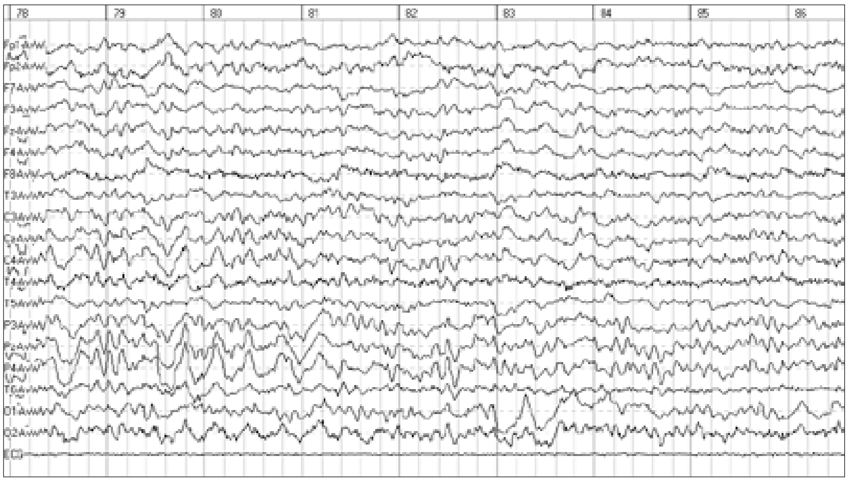

Figure 1. Row EC recording of the TBI patient I.

4. RESULTS

4.1. Psychophysiological data

Table 1 shows some general characteristics of our TBI patients. It is clear that the patients differ in age, duration of coma as well as years since brain injury. Concerning cognitive functions, all of them (except the patient K) manifested problems with concentration, memory and attention, as well as decreased IQ.

MRI generally showed small degree of lesions in the fronto-parietal zones, except in patient K. which MRI showed minimal interne hydrocephalus without any cortical impairment.

On Figure 1 a row EC recording for one patient (I) is presented. The more typical are slow brain waves in central and parietal parts of the brain.

On Figure 2. EEG spectra and brain mapping for the same patient is presented.

4.2. Brain rate

In addition to qEEG analysis we calculated brain rate for each point of the scalp.

As we expected, brain rate in all patients showed underarousal if it is compared with normal or anxious patients (Table 2). In patients with anxiety we showed in previous studies the existence of so called “inner arousal” where brain rate is higher in EC condition (21, 22, 23, 24). Also, it is clear the difference between eyes open (EO) and eyes closed (EC) condition as well as during visual or auditive tasks.

The ANOVA test for calculated brain rate in all scalp points (10/20 international system) showed significant differences for both EO and EC conditions (Table 3).

It means that brain rate is different in specific cortex area corresponding to the level of arousal. For practical reason, the more important is mean brain rate showing general mental arousal. In patients with TBI mean brain rate corresponds to under arousal state.

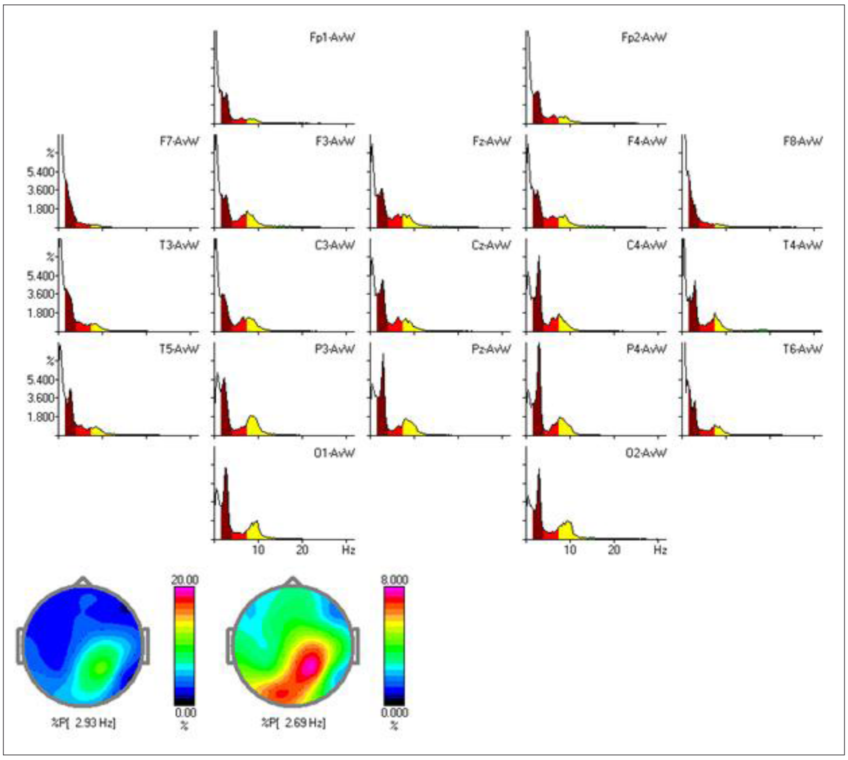

Figure. Spectra with brain map showing significant slowing in centroparietal region

	Brain rate EC	Brain rate EO
Normal adults	8,56	10,54
Adults with ADD	7.60	7.86
Anxious patients	10, 85	9,73
TBI	4,81	6,87

Table 2. Brain rate in different groups of clients

	ANOVA	significance
eyes open	F=9.43	p=0.000000
eyes closed	F=14.5	P=0.000000

Table 3. Analysis of variance for brain rate values

In Figure 3 the difference between brain rate during EC, EO and cognitive performance tasks is presented. It is clear that brain rate, measuring general mental arousal, is higher during cognitive performance tasks and slower in EC condition.

On Figure 4 brain rate in eyes open and eyes closed conditions for all patients is shown. The difference between the two conditions is minimal in parietal ant occipital regions.

In Table 4 mean values for brain rate for all patients in EO and EC conditions are displayed. It is clear that in EO conditions brain rate is much higher due to the sensory influences. In patients with anxiety we showed in previous studies the existence of so called "inner arousal" where brain rate is higher in EC condition.

EC	mean	min.	max	EO	mean	min.	Max
Fp1	4,121	5,435	6,66	FP1	6,76	5,435	7,176
Fp2	4,11	6,449	6,164	FP2	6,53	5,4	10,46
F7	2,18	5,257	4,355	F7	6,60	5	7,704
F3	4,051	5,404	6,075	F3	7,58	5,404	7,696
Fz	4,176	5,462	6,264	FZ	6,34	4,927	5,877
F4	4,229	6,195	6,342	F4	6,40	6,195	5,927
F8	3,683	5,145	5,758	F8	7,70	5,145	6,405
T3	3,933	3,694	6,26	T3	5,79	3,694	12,064
C3	4,072	4,861	6,26	C3	7,57	4,861	6,877
Cz	3,759	5,212	5,65	CZ	6,65	5,212	8,1
C4	4,57	6,423	7,27	C4	7,99	6,423	8,1
T4	4,468	8,32	7,27	T4	8,42	8,32	8,1
T5	2,513	4,232	4,99	T5	6,02	4,232	7,157
P3	6,9	4,309	10,4	P3	6	4,309	6,975
Pz	6,9	5,744	10,3	PZ	6,31	5,744	7,249
P4	6,9	4,628	10,4	P4	6,66	4,699	7,249
T6	6,9	6,673	10,3	T6	7,04	6,673	7,249
O1	6,96	5,249	10,3	O1	7,05	5,249	6,278
O2	7,037	6,519	10,4	O2	7,23	6,519	6,206

Table 4. Mean values for brain rate in EO and EC conditions for all patients

4.3. Biofeedback treatment

The neurofeedback protocol we applied was SMR training in Cz and Fz for all patients two times a

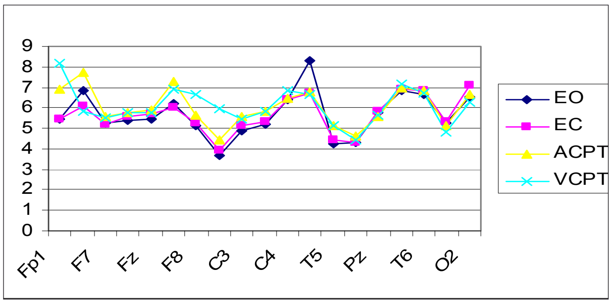

Figure 3. Brain rate in different conditions obtained during qEEG assessment (patient M)

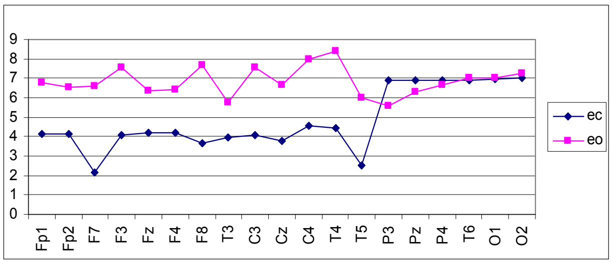

Figure 4. Brain rate in EO and EC conditions

week, 40 minute duration. Because general anxiety was present in all patients, we included also EDR biofeedback as well as pulse–related peripheral biofeedback to obtain relaxed state. So, our protocol consisted firstly the application of peripheral biofeedback for 10-15 minute duration and after obtaining stable autonomous nervous activity, the neurofeedback training was the following step.

On Table 5 significant changes of low and high brain waves in central brain parts for the whole group are displayed.

Along with the changes in EEG spectra, the improvements of general mood, quality of sleep, and cognitive abilities are obtained. Four of our patients were considerably improved and continued with studies, and only the patient (I) has not significant improvement of cognitive abilities.

4.4. Executive functions

In addition, we have performed the assessment of executive functions before and after biofeedback treatment with WCST and Stroop Test. The obtained results showed that our subjects are presenting smaller number of perseverative errors after the biofeedback application (Table 6 and 7). The Student *t*-test was used to establish if there

location	delta	theta	alpha	beta
Fz	0.056*	0.001*	0.788	0.423
Cz	0.131	0.023*	0.196	0.004*

Table 5. Statistically significant change (p-values) in absolute power following neurofeedback * significant change

is statistical significance between the tests scores before and after the treatment.

5. DISCUSSION

The application of neurofeedback methodology in the rehabilitation of TBI patients is rapidly growing. It is probably the results of very moderate effectiveness of other therapeutic procedures.

For individual protocol adjustment the qEEG recording is necessary.

The results we obtained in qEEG recording correspond to the finding of Ayers [1,13, 18], Thatcher[15] and Thornton [17]. The main find-

Stroop Test categories	T-values before biofeedback	Test significance	T-values after biofeedback	Test significance	p
errors (St) II	52	average	55	average	0,25
errors III	50	average	53	average	0,17
errors III/II	49	low average	53	average	0,79
St III-St II	50	average	53	average	0,92

Table 6. T-value and statistically significant change for Stroop Test before and after biofeedback application

WCST categories	T-values before biofeedback	Test significance	T-values after biofeedback	Test significance	p
N categories	50	average	52	average	0,77
N perseverations 2	42	low average	50	average	0,00000*
N errors	45	low average	51	average	0,14
cards total	47	low average	52	average	0,32
M categories	47	low average	51	average	0,42

Table 7. T-value and statistically significant change for WCST before and after biofeedback application * significant change

ing is slowing of the brain electrical activity in frontal region of the brain which is important for executive functions.

A number of published studies have explored much more the effectiveness of cognitive rehabilitation as treatment for various squeal following TBI. Most studies in the EEG biofeedback field have failed to compare this relatively new technique to well established techniques being employed within the TBI population. Despite using a small sample size, the present study is aimed to evaluate EEG biofeedback within the TBI population as an additional treatment used after all other therapies applied to the injured patients. In addition to EEG biofeedback, we introduced peripheral biofeedback in order to obtain the balance of Sympathetic/Parasympathetic nervous system.

Our original approach in this study is the calculation of brain rate as a measure of general mental arousal. Having in mind that TBI generally induce slow cortical activation, especially in the frontal regions, the calculation of brain rate helps in the planning of training protocol. The present study implemented a treatment program tailored to the individual, which was consistent with treatments being proved by clinicians in real life.

6. CONCLUSION

Overall, the findings provide preliminary support for the efficacy of EEG biofeedback in the rehabilitation of a broad range of squeal following TBI such as cognitive abilities, executive functions, and emotional stability.

Future research assessing the efficacy of EEG biofeedback in the TBI population is needed, in particular to directly compare this treatment to a widely and commonly used treatment (e.g. cognitive rehabilitation) but using a larger sample size.

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