Neurofeedback Therapy of Attention Deficits in Patients with Traumatic Brain Injury

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ABSTRACT. *Background*. Impairments of attention are a frequent and well documented consequence of head injury. The purpose of this study was to evaluate if Neurofeedback Therapy (NFT) can enhance remediation of attention deficits in patients with closed head injuries (CHI) who are still in the phase of spontaneous recovery.

Method. Feedback of beta-activity (13-20 Hz) was used for the treatment of attentional impairments in twelve patients with moderate closed head injuries. A matched control group of nine patients was treated with a standard computerized training. All patients were tested before and after treatment with a set of attention tests.

Results. After ten sessions the analyses of beta activity showed that eight patients were able to increase their beta activity while the remaining four patients showed a decrease of beta activity. Mean duration of beta activity was prolonged about 50% after training. Patients who received NFT improved significantly more in the attention tests than control patients.

Conclusion. The results suggest that neurofeedback is a promising method for the treatment of attentional disorders in patients with traumatic brain injuries. It is suggested that NFT should focus not only on the enhancement of beta activity, but also on the duration patients are able to hold beta activity. It is proposed to use NFT also with patients in the early phase of rehabilitation.

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INTRODUCTION

Since the first publication by Conkey (1938), it is well documented that one major consequence of brain injury is an impairment of attention. A manifestation of this impairment is a reduction of information processing speed, reflected in lengthened reaction times, which has often been reported for injuries of different aetiologies (Miller, 1970; Van Zomeren & Deelman, 1976; Brouwer, 1985; Braun, Daigneault & Champagne, 1989; Tartaglione, Inglese, Bandini, Spandavecchia, Hamsher & Favale, 1991; Keller, Schlenker & Pigache, 1995). In addition to impaired information processing speed, many studies have shown deficits of divided attention (Miller, 1970; Gronwall & Sampson, 1974; Van Zomeren & Deelman, 1976; Levin, High, Goldstein & Williams, 1988; Keller, 1998) and of sustained attention (Cohen, Semple, Gross, Holcomb, Dowling & Nordahl, 1988; Deutsch, Papanicolaou, Bourbon & Eisenberg, 1988; Levin et al., 1988; Parasuraman, Mutter & Molloy, 1991), mainly in patients with closed head injuries (CHI).

There is good evidence that attentional impairments in head injured patients are connected to specific changes in the electroencephalogram (EEG). Thatcher, Biver, McAlaster and Salazar (1998) compared data from conventional magnetic resonance tomography (MRT) with EEG coherence in two independent groups of patients with closed head injury. The analysis showed that lengthened 1H T2 relaxation times of the cortical gray and white matter were related to decreased EEG coherence between short interelectrode distances (e.g., 7 cm) and increased EEG coherence between long interelectrode distances (e.g., 28 cm). Differences in EEG frequency in which T2 relaxation time was most strongly related to the gray matter in the delta and theta frequencies in CHI patients, and increased T2 relaxation time and decreased short-distance EEG coherence were related to reduced cognitive function. The results were interpreted in terms of reduced integrity of protein/lipid neural membranes and the efficiency and effectiveness of short- and long-distance neural synchronization following traumatic brain injury.

Hoffman, Stockdale, Hicks and Schwaninger (1995) proposed that changes in coherence and phase-shift of the EEG in patients mainly lead to a decrease of multi-tasking and slowing of mental processing. One reason for these abnormalities of the EEG are axonal injuries which produce a diffuse slowing of the EEG with an enhancement of slow theta (4-7 Hz) activity and suppression of fast beta (13-20 Hz) activity (Schaul, 1998).

There are several studies showing that Neurofeedback Therapy (NFT) can improve cognitive and emotional deficits in patients with mild head injury. Ayers (1993) compared 12 patients treated with NFT and psychotherapy with a group of six patients exclusively treated with psychotherapy. The patients in this study were trained to enhance beta (15-18 Hz) while suppressing the slower theta (4-7 Hz) activity. Individuals who received only psychotherapy did not improve in symptomatology, whereas patients who received NFT with psychotherapy had symptomatology subside and reported progress in therapy. Byers (1995) trained a 58-year-old female with a mild traumatic head injury with NFT. The treatment consisted of 31 sessions designed to enhance the sensorimotor rhythm of 12-15 Hertz and the beta (15-18 Hz) frequency bands of the EEG while at the same time suppressing the theta (4-7 Hz) frequency band. Efficiency of the NFT was supported with neuropsychological evaluations and quantified electroencephalograms (QEEG). The comparison of the pre- and post-measures as well as the process measures showed several improvements. Especially tests on cognitive flexibility and executive functioning improved significantly after NFT. Hoffman and Stockdale (1996) treated 50 patients with mild traumatic brain injury beyond the time interval when one would expect treatment changes to be attributed to spontaneous recovery. They tracked 24 physical, emotional and cognitive symptoms at regular intervals and observed significant improvements in 78 percent of the patients.

The NFT procedures used in most of these studies were designed to enhance the EEG frequency band in the range of 12-20 Hz while at the same time suppressing a slower frequency band in the range of 4-8 Hz.

However, none of these studies was designed for patients admitted to an inpatient neurorehabilitation program defined as an interdisciplinary approach for the intensive remediation of motor-deficits as well as deficits of language, cognition and psychological functions. Although most patients with brain injuries suffer from deficits of attention, none of the previous studies focused on attentional impairments. Therefore, the purpose of the present investigation was to determine if NFT can also enhance remediation of attention deficits in CHI patients who are still in the phase of spontaneous recovery. Since patients in the early phase of recovery from a head trauma are not able to perform complex tasks, the feedback procedure was made as simple as possible providing a training to enhance beta activity only.

METHODS

Patients

All patients were recruited from the Neurological Clinic Bad Aibling, Germany. The sample included 21 moderate CHI patients (mean age: 31.9, range 21 to 42 years; mean years of education: 13.4, range 9 to 18 years). Severity of brain damage was classified with the initial Glasgow Coma Score (GCS, Teasdale and Jenett, 1974). The mean GCS was 11.8 (range 7 to 12). Computerized tomography (CT) scans showed the following lesions: bilateral haematoma (4), frontoparietal haematoma (5), temporal lobe contusions (7), frontotemporal contusions (13) and bilateral contusions (8). The CT scans of the remaining eight CHI patients were normal. It can be assumed that as a result of traumatic rotation and white matter shearing, all CHI patients were likely to have suffered diffuse brain damage which is known to disconnect neural transmission. Except one, none of the patients sustained lesions of the midbrain or brainstem. For all patients, the mean injury-to-test interval was 3.8 months (range one to eight months), the mean duration of posttraumatic amnesia (PTA) was 6 days (range 5 minutes to 20 days). All patients were examined by a clinical neuropsychologist and in all cases a normal level of intelligence was ascertained by the Raven Progressive Matrices (Raven, 1996), a nonverbal test of intelligence. The mean IQ for CHI patients was 108 (range 90 to 133). None of the patients showed signs of aphasia. All patients performed within the normal range in tests sensitive to working memory (Digit Span, Block tapping, free recall of a 57-unit story, Shuri, 1993). Some patients showed slightly subaverage performance in a verbal learning task (Auditory Verbal Learning Test, Spreen & Strauss, 1998). Deficits in verbal learning were associated to attentional problems and did not significantly interfere with the task demands. All patients showed attention deficits in three different attention tasks. Subjects with a similar initial GCS (±2 scores) and time since injury (±1 week) were alternately assigned to receive NFT or participated in a computer-based attention training (control group).

Attention Tasks

Three different attention tests were presented before and after treatment. The first procedure was a letter cancellation task (d2; Brickenkamp, 1962). The test presents rows of b's and d's while some of these letters were labeled with primes. Using a pencil, the patient was required to cross out only labeled d's as rapidly as possible. The number of crossed out stimuli during 280 seconds was taken as a measure of speed of information processing. The sum of ommission and commission errors served as a measure for accuracy.

The second task was a simple choice reaction task (DR2; Bukasa & Wenninger, 1986). The test material comprised 48 visual and/or acoustic signals. The signals or combination of signals "red," "yellow," "beeper," "red and beeper" appeared eight times each, "yellow and beeper" 16 times. The patient was required to react only to the signals "yellow and beeper." The number of errors indicated accuracy of performance.

The third task tested for sustained attention (TAP; Zimmermann & Fimm, 1989). Patients had to listen for 15 minutes to alternating tones of different frequences (1000 and 440 Hz). They were asked to press a response key whenever the same tone appeared two times. The probability for the appearance of the critical stimuli was five percent.

EEG Recording

EEG recording was performed with a FlexComp© EEG feedback system. The Fz scalp location was used as the active lead (according to the international 10/20 system) with linked ear reference (both ears are used as a reference to the active lead with a ground on the forehead). Connections were made using an electrode cap (Mind Media Feedback Systems) and electrogel was inserted through each sensor to improve conductance. Impedance measures for all channels were less than 3 K Ohms. The EEG of all patients was recorded for 30 minutes during an eye-open listening condition after the first, fifth and tenth training session.

PROCEDURE

Neurofeedback

Twelve CHI patients participated in the NFT. Before treatment all patients signed a consent for treatment. Following preparation, a five minute baseline-EEG was recorded for an eye-open listening condition. The mean amplitude of beta-activity (13-20 Hz) during baseline was then used as the threshold during NFT. The first aim of beta training was to increase the mean amplitude of 13-20 Hz EEG activity. The second aim was to extend the time in which patients were able to hold their beta activity above the threshold. The training was conducted with eyes open watching a bar graph on the monitor for beta activity. The threshold was superimposed as a dotted line on the bar graph. The patients were instructed about the concept of attention and beta-activity. Then they were asked to exceed the pre-set beta amplitude threshold setting. Patients were told to learn to discover the mental set or strategy that would keep the bar above the threshold. When beta-activity dropped below the threshold, patients had to perform silent arithmetics (e.g., counting backwards from 200 in steps of 7) or to detect defined words in an acoustically presented story. This was done until the beta amplitude exceeded the threshold again. Ten NFT sessions were conducted in two weeks. Each session lasted 30 minutes. During NFT, patients were instructed to avoid eye movements and motor acts of their limbs.

Computer-Based Attention Training

Nine patients took part in a computerized attention training. Only commercially available training programs designed for the remediation of patients with cognitive impairments were used (COGPACK© by Marker; 1996; Neurosoft© by Siegmund, 1999). Ten different tasks selected for the training of speed of information processing and selective attention were applied. The complexity of each task could be adjusted to improvements in performance. Feedback concerning speed and accuracy was immediately provided by the microcomputer during the task. At the end of each task a score indicating the overall level of performance was administered. Patients had to write down the score to track their performance from trial to trial. Participants progressed from one difficulty level to the next if performance in speed and accuracy was considered to be stabilized for three consecutive trials. Ten 30-minute training sessions were conducted in two weeks.

RESULTS

Because electrophysiological and behavioral data of patients were not symmetrically distributed and mean values would have been affected by extreme scores, all statistical analyses were performed using nonparametric statistics. Statistical analyses within groups were calculated with the Wilcoxon test for matched samples (Wilcoxon & Wilcox, 1964). Trend analysis was calculated by the Friedman two-way analysis of variance. A time series analysis using ARIMA (auto-regressive integrated moving average) models (Box & Jenkins, 1970) was used to estimate significance of change of beta activity duration following onset of treatment. The statistical analysis of demographical data (age, years of education, injury-test interval, IQ) indicated no significant differences between the patient groups.

Table 1 shows the median values of the beta amplitude for the first, fifth and tenth training session for all patients.

Eight patients of the neurofeedback group started with low beta amplitudes which then increased continuously (NFT+). The increase of beta amplitude from the fifth to the tenth training session was statistically significant ($p = 0.028$; Friedman two-way analysis of variance). The remaining four patients of this group started with a high level of beta amplitudes which then decreased from the first to the tenth training session (NFT−). The beta amplitudes of control patients did not show any systematic variation.

Figure 1 shows that patients of the NFT group increased the duration they were able to sustain beta activity above the threshold. This increase was statistically significant ($p = 0.012$; t-test of ARIMA).

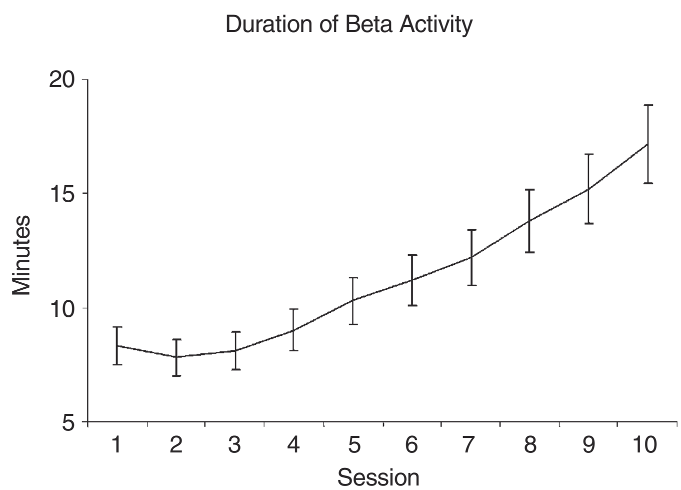
The results of accuracy in the attention tasks showed improvements for both patient groups (Table 2). The average number of errors in the choice reaction task and sustained attention task decreased after NFT and computer-based treatment, although this decrease was not statisti-

TABLE 1. Mean Values and Standard Deviation (SD) in Microvolts (μV) of Beta Amplitudes for the First, Fifth and Tenth Session for Patients Who Increased Their Beta Amplitude (NFT+), Patients Who Decreased Their Beta Amplitude (NFT−) and Control Patients Treated with a Computer-Based Therapy. The Difference Between the Fifth and Tenth Session in the NFT+ Group Was Statistically Significant.

	NFT+ N = 8		**NFT−** N = 4		**Control** N = 9	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
First Session	2.6 μV	0.6 μV	3.7 μV	0.5 μV	2.6 μV	0.4 μV
Fifth Session	2.9 μV	0.7 μV	3.5 μV	0.6 μV	2.4 μV	0.3 μV
Tenth Session	3.6 μV*	0.6 μV	3.5 μV	0.6 μV	2.5 μV	0.5 μV

*p = 0.028; Friedman two-way analysis of variance

FIGURE 1. Mean (± Standard Deviation) of Duration Patients Were Able to Hold Beta Activity Above the Threshold for Each Session.



cally significant. In contrast, the number of errors in the cancellation task significantly decreased in the NFT group ($p = 0.032$, Wilcoxon test for matched samples).

Speed of information processing also improved in both groups (Table 3). The number of detected stimuli in the cancellation task as well as reaction times in the choice reaction task decreased significantly ($p = 0.009$, $p = 0.013$ for the NFT group; $p = 0.012$, $p = 0.04$ for the control group, Wilcoxon-test for matched samples). Nevertheless, a statistically significant decrease of reaction time in the sustained attention task was only observed for patients treated with NFT ($p = 0.006$, Wilcoxon test for matched samples).

DISCUSSION

Eight of twelve patients treated with NFT learned to increase their beta amplitudes. In contrast, four patients starting with a high level of beta activity showed a decrease of amplitudes after NFT. Nevertheless, patients of the NFT group doubled the duration of beta activity above threshold from the first to the tenth training session. This result suggests, that amplitudes may not be the most important factor in cognitive change. The time patients are able to hold beta activity may describe the

TABLE 2. Means and Standard Deviations (SD) of Errors Before and After Treatment for All Attention Tasks in the NFT Group and Computer-Based Training Group.

Neurofeedback Group (N = 12)

	Pre-Treatment		**Post-Treatment**		**Level of Significance**
	Mean	*SD*	*Mean*	*SD*	
Number of Errors in the Cancellation Task	17.2	3.2	6.2	2.1	p = 0.032
Number of Errors in the Choice Reaction Task	2.7	1.1	1.9	0.9	Not Significant
Number of Errors in the Sustained Attention Task	6.6	2.1	4.0	2.5	Not Significant

Wilcoxon test for matched samples

Computer-Based Training Group (N = 9)

	Pre-Treatment		**Post-Treatment**		**Level of Significance**
	Mean	*SD*	*Mean*	*SD*	
Number of Errors in the Cancellation Task	13.5	4.8	11.5	2.8	Not Significant
Number of Errors in the Choice Reaction Task	2.5	1.2	1.5	0.7	Not Significant
Number of Errors in the Sustained Attention Task	8.5	3.3	5.5	0.9	Not Significant

Wilcoxon test for matched samples

process of focusing attention more precisely than a model of intensity. Being able to hold beta activity for a certain period of time also corresponds to the data of the sustained attention task, where patients of the NFT group improved more than patients of the control group. The prerequisite for a sustained attention task is the ability to maintain a certain amount of arousal for a long period of time. Although duration of beta activity has not been measured in patients of the control group, it seems plausible that this may have been the advantage of patients who received NFT.

In agreement with other studies (Ayers, 1993; Byers, 1995; Hoffman & Stockdale, 1996) NFT led to significant improvements of cognitive functions. However, patients treated with a computer-based attention training also improved in some of the attention tests, although their beta amplitudes did not change over time. One possible explanation for this result is that treatment effects can be attributed to spontaneous recov-

TABLE 3. Means and Standard Deviations (SD) of Number of Crossed Out Stimuli in the Cancellation Task and Reaction Times (ms) Before and After Treatment for the Choice Reaction and Sustained Attention Tasks in the NFT Group and Computer-Based Training Group.

Neurofeedback Group (N = 12)

	Pre-Treatment		**Post-Treatment**		**Level of Significance**
	Mean	*SD*	*Mean*	*SD*	
Numer of Crossed Out Stimuli in the Cancellation Task	175.3	11.3	268.3	18.5	p = 0.009
Choice Reaction Time (ms)	645.4	79.1	484.1	66.2	p = 0.013
Reaction Time (ms) in the Sustained Attention Task	756.0	84.3	569.2	77.1	p = 0.006

Wilcoxon test for matched samples

Computer-Based Training Group (N = 9)

	Pre-Treatment		**Post-Treatment**		**Level of Significance**
	Mean	*SD*	*Mean*	*SD*	
Numer of Crossed Out Stimuli in the Cancellation Task	166.1	13.2	235.6	15.6	p = 0.012
Choice Reaction Time (ms)	620.2	75.4	488.9	68.3	p = 0.04
Reaction Time (ms) in the Sustained Attention Task	715.3	79.8	616.6	78.2	Not Significant

Wilcoxon test for matched samples

ery. Although spontaneous recovery cannot be ruled out as a variable influencing the results partly, each therapy showed specific training effects. Patients treated with the computer-based therapy, improved mainly in computerized attention tests requiring them to focus their attention for short periods of time. This indicates that the benefit of this training procedure seems to be limited to tasks resembling those patients had exercised during therapy. In contrast, patients who received NFT improved in computer-based tests as well as in a paper-pencil task. Additionally, these patients showed a significant improvement in the sustained attention task. This provides convincing evidence that NFT had a more extensive effect on attention deficits than the computer-based therapy. Furthermore, patients of the NFT group did not have much experience with computerized reaction tasks which rules out the possibility of a simple transfer effect due to the similarity between training tasks and evaluation tests (as proposed for the control group).

As a consequence of diffuse axonal injury there is a loss of myelin integrity, possibly leading to a decrease of speed of information processing and change of the signal to noise ratio. This suggestion is in agreement with results obtained from reaction time experiments (Klensch, 1983; MacFlynn, Montgomery, Feton & Rutherford, 1984; Miller, 1970; Norman & Svahn, 1961; Van Zomeren, 1981; Van Zomeren & Deelman, 1976). Brouwer (1985) proposed that brain injuries lengthen the access time to stored knowledge by weakening the strengths between nodes of the knowledge net. Tromp and Mulder (1991) modified this theory by suggesting that the reduced access to knowledge results from a loss of redundant pathways in the knowledge net. The effect of this would be pervasive, but the retrieval of novel new information would be especially slow since it is linked by fewer redundant connections. The research of Thatcher et al. (1998) supports the suggestion that changes in coherence and time delay between different areas of the brain represent the link between observed deficits of attention and altered brain activity. The neural network which deploys attention and directs it to representations of extrapersonal space (Baleydier & Mauguière, 1980; Mesulam, 1981) includes the cingulate cortex, the frontal eye fields, the rostral bank of the intraparietal sulcus, and the reticular formation (raphe nuclei, nucleus coeruleus and intralaminar thalamic nuclei). Recent findings have extended this network to include widespread locations of the right dorsolateral prefrontal and the right superior parietal cortices (Pardo, Fox & Raichle, 1991). The anterior cingulate cortex is activated during visual and auditory discrimination tasks (Pardo, Pardo, Janer & Raichle, 1990; Cohen, Semple, Gross, Holcomb, Dowling & Nordahl, 1988), in the semantic processing of speech (Petersen, Fox, Posner, Mintun & Raichle, 1988), and when complex targets are presented at high rates (Petersen et al., 1988). The frontal eye fields are activated during visual or auditory discriminations tasks (Crowne, 1983; Roland, 1982, 1984) and the rostral intraparietal cortex (area 7a/PG in monkeys) secures, maintains and disengages the direction of visual attention and covert orienting (Lynch, Mountcastle, Talbot & Yin, 1977; Bushnell, Goldberg & Robinson, 1981; Posner, Walker, Friedrich & Rafal, 1984). The right prefrontal and superior parietal cortices are activated during sustained visual and somatosensory vigilance tasks (Pardo et al., 1991); and a right-sided dominance is manifested in the innervation of cortex by the reticular formation and locus coeruleus (Oke, Keller, Mefford & Adams, 1978). Pfurtscheller (1992) and Sterman

(1996) demonstrated that the brain's ability to desynchronize and resynchronize defines its capacity to process an ongoing task and to reenter a state of readiness for the next task. It seems obvious that a disruption of coherence and timing within the described network results in a severe deficit of attention. NFT may be seen as a method to restore the mechanisms that underlie the management of rhythmic brain activity demonstrating thereby the brain's capacity for restoring homeostasis. Therefore, it might be of interest to offer EEG-based therapy also for CHI patients in the earliest time after injury (e.g., intensive care units). By stimulating (e.g., acoustic stimulation with white noise) or deprivating the brain, arousal can be regulated to an optimum level, thus providing a necessary basis for information processing.

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