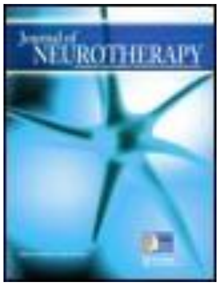

Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience

Impact of qEEG-Guided Coherence Training for Patients with a Mild Closed Head Injury

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Published online: 08 Sep 2008.

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ABSTRACT. *Background.* Mild closed head injury (MHI) is a major problem in our society. Traditional methods of treatment such as cognitive rehabilitation or behavioral training are time consuming, expensive, and of questionable effectiveness. Anecdotal reports indicate that neurofeedback can remediate the symptoms of MHI in a rapid and cost effective way. The purpose of this study is to evaluate whether quantitative electroencephalography (qEEG) guided coherence training is effective in remediating residual symptoms of MHI.

Methods. Twenty-six patients with persistent post-traumatic symptoms (PTS) were seen by the first author 3 to 70 months after a MHI and had a quantitative EEG (qEEG). Neurofeedback therapy designed to normalize abnormal qEEG coherence scores was provided to determine the effectiveness of this approach. Five training sessions addressed each qEEG abnormality. Training continued until the patient, by self-report, indicated that significant improvement had occurred or until a total of 40 sessions were given.

Results. Significant improvement (>50%) was noted in 88% of the patients (mean = 72.7%). All patients reported that they were able to return to work following the treatment, if they had been employed prior to the injury. On average, 19 sessions were required, less than the average of 38 sessions required using power training of Cz-Beta in our previous unpublished study.

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Journal of Neurotherapy, Vol. 6(2) 2002

Conclusions. In this uncontrolled open trial of qEEG guided coherence training, the majority of patients with MHI experienced substantial and rapid symptomatic improvement, including return to work. Further study with controls and additional outcome measures is warranted.

KEYWORDS. Closed head injury, quantitative EEG, neurofeedback, outcome study, coherence training

INTRODUCTION

A closed head injury (CHI) is a traumatic brain injury (TBI) in which the skull is neither fractured nor penetrated. The CHI usually results from rapid acceleration and/or deceleration trauma (Alexander, 1995) and while post-traumatic symptoms (PTS) are usually reported when a mild head injury (MHI) occurs, standard neurological assessments such as the MRI and CAT scan most often show little or no damage. Fatal cases reveal microscopic changes (axonal fractures) which are assumed to underlie the post-traumatic symptoms seen in surviving patients (Alexander, 1995; Packard & Ham, 1994).

While there is not a generally accepted definition of a mild brain injury (McAllister, 1994), most often the presence and severity of the head injury are determined in three dimensions: loss of consciousness (LOC), coma, and post-traumatic amnesia (PTA). Mild closed head injury (MHI) is the most common neurological problem (Alexander, 1995), and is identified as a LOC of 20 minutes or less, a Glasgow Coma Score between 13 and 15, and a PTA time of 48 hours or less (Hoffman, Stockdale, Hicks, & Schwaninger, 1995). While these three measures are important in understanding the general severity of the neurological insult, there is much variation within the category of MHI, and the meaningfulness of these three scores on establishing a valid prognosis has been questioned (Kibby & Long, 1996).

Post-traumatic symptoms (PTS) are often, but not always, the result of a CHI, and these symptoms can be debilitating. Packard and Ham (1994) reported that for many individuals with MHI, the PTS are often more intense than for individuals diagnosed with a severe head injury. Oddy, Humphrey, and Uttley (1978) noted that when a MHI exists, depression in the family members is not as much related to the severity of the head injury as it is to the extent of PTS, and to failure to return to work.

The PTS that are reported can be divided into three domains: cognitive, physical/somatic, and emotional/social (Gronwall, 1986; Hoffman et al., 1995). Headaches are most consistently reported (Alves, Macciocchi, & Barth, 1993). Eight articles were analyzed to create Table 1 as a review of the domain and frequency of PTS (Arcia & Gualtieri, 1994; Byers, 1995; Coppens, 1995; Gass & Apple, 1997; Hoffman et al., 1995; Thatcher, 2000; Triplett, Hill, Freeman, Rajan, & Templer, 1996; Wade, King, Wenden, Crawford, & Caldwell, 1998).

Byers (1995) stated that patients with MHI present with a multiplicity of symptoms with varying degrees of severity and a variety of patterns of PTS. PTS interferes with individual functioning in work and/or non-work environments for varying lengths of time. The major problem associated with MHI then is remediating these symptoms.

There are two concerns for the patient. The first concern is when to initiate treatment for remediation of the PTS. Should the intervention start soon after the injury occurs, or after a longer period of time to rule out recovery in the absence of treatment? Starting too soon may overload existing resources, while waiting for a longer period of time may put the welfare of the patient at risk. A second concern is which one of the many alternative treatments is most appropriate for the reduction or elimination of PTS for patients with MHI.

The percentage of PTS which disappear within any period of time is variable. In 1981, Rimel, Giordani, Barth, Boll, and Jane reported that in a general clinical population, at three months, 79% of MHI patients reported at least one persistent PTS; and at one year, 34% exhibited

TABLE 1. Domain and Frequency of PTS in the 8 Citied Articles

Cognitive	***Somatic***	***Emotional***
Memory (8)	Headaches (6)	Depression (6)
Attention (6)	Dizziness (4)	Anxiety (3)
Concentration (6)	Vision (4)	
Cognition (3)	Fatigue (3)	
Language (3)	Irritability (3)	
	Sleep Problems (3)	

some level of functional disability resulting from PTS. Alexander (1995) found that after three months, 30 to 50% of MHI patients that were being followed still exhibited limited functioning related to their PTS. Hoffman et al. (1995) reported that 67% of MHI patients recovered at least 80% of their pre-accident functional levels within a six-month period. If the PTS still exist at three months, it is likely to still be present at six months and often at one year as well.

Neuropsychological and cognitive rehabilitation are two traditional rehabilitation approaches used to reduce or eliminate PTS in patients with MHI (Silver, Yudofsky, & Hales, 1994). Neuropharmacological treatment, psychopharmacology, and individual psychotherapy are usually used in conjunction with neuropsychological treatment or with cognitive rehabilitation. However, for each of these traditional approaches to rehabilitation and treatment, the research literature has not shown results demonstrating significant effectiveness.

Neuropsychological testing and associated interventions are presently one of the more popular approaches to remediation. In an evaluation of a neuropsychological treatment, Niemann, Ruff, and Baser (1990) report on a controlled study of attention and memory. They conclude that changes in attention occurred which were not attributable to chance, but they were unable to find corresponding changes in neuropsychological test items related to attention and/or memory. Posthuma and Wild (1988) reported that neuropsychological assessment may miss up to 50% of the more subtle symptoms, which adversely limits neuropsychological intervention. In addition, small sample size, lack of statistical significance, and poor matching of samples are some of the other weaknesses associated with using a neuropsychological approach to treat PTS (Kraus, McArthur, & Silberman, 1994; Hoffman et al., 1995).

Cognitive interventions have been used to address problems such as memory, attention, cognition, language, and concentration. However, the cognitive approach has been used more successfully with moderate and severe injuries than with MHI. The literature is equivocal in terms of the success of cognitive rehabilitation in reducing or eliminating PTS (Rattok & Ross, 1994).

Thatcher (2000) discussed an alternative approach for the treatment of PTS in MHI patients, which incorporates data from the qEEG as an information source to direct neurofeedback therapy (NFT). He further noted that only a few individuals (Ayers, 1987; Byers, 1995; Hoffman, et al., 1995) have reported using NFT with HI populations. NFT has been effective in treating children in a clinical setting who exhibited

ADD problems, specifically with those who produce excessive theta activity and relatively low beta (Lubar, 1991).

When using NFT, the qEEG data for a patient with a MHI may be collected, compared to a normative database, and differences from the normative database presented in terms of power and coherence. In previous studies using NFT, the focus has been on changes in relative power, and the training electrode placement has usually been set at Cz, C3, or C4. The only publication in which the coherence approach has been reported is that of Thornton (2000). In this study, two brain injured subjects improved by 85% and 168% on an auditory recall task after training to normalize coherence. Normal subjects also improved with this approach.

As an alternative to measuring power, coherence provides measures of functional linkages between different areas of the brain based on frequency. According to Thatcher (1992), coherence reflects the number of synaptic connections between recording sites and the strength of this relationship. Shaw (1981), using a non-mathematical description, explained that coherence can be considered a measure of the degree to which two signals at a given frequency maintain a phase-locked relation over time. As Shaw points out, coherence is independent of the amplitude of the signals over the epochs considered and is dependent on their pattern of fluctuations. Coherence is defined as "a measure of 'phase synchrony' or shared activity between spatially distant generators" (Thatcher, Biver, McAlaster, & Salazar, 1998, p. 308). Thatcher et al., (1998) reported that qEEGs done with MHI individuals commonly showed increased and/or decreased coherence in the frontal and frontal-temporal regions. A good mathematical discussion of coherence can be found in this paper.

The purpose of this study was to examine the effectiveness of qEEG-guided NFT training in MHI patients who report persistent PTS for three or more months. The PTS had significantly interfered with the patient's ability to work and/or to carry out daily activities. The NFT focused on normalizing coherence abnormalities, which had resulted from the MHI. Coherence was trained up if reduced on qEEG and was down-trained if elevated on qEEG. Initial training involved the qEEG electrode pair which had the most significant positive or negative coherence abnormality. The next protocol attempted to correct the second most significant coherence abnormality. This procedure continued until the impact of the PTS was reduced or eliminated, or when 40 NFT sessions had been given. Five sessions of eyes open training were done for each coherence abnormality. Preliminary studies had shown that five sessions were usually sufficient to normalize a coherence abnormality at an electrode pair. Effectiveness was measured by the extent to which the impact of the PTS was reduced or eliminated and the patient was able to return to work, if employment existed prior to the MHI.

METHOD

Patients. Thirty-six consecutive patients diagnosed as having a MHI had been referred to the first author because PTS had continued for three months or more. Each patient indicated how PTS interfered with daily activities including employment, and was offered NFT as a treatment alternative for the PTS. Of the 36 original patients, four were not interested in NFT, and six began but withdrew before treatment had been completed. Of the 26 who completed treatment, 12 were males and 14 were females. The mean age of the group was 39 years (range = 25 to 65 years). The mean time since the injury was 12.7 months (range = 3 to 70 months). Each patient reported more than one PTS. The PTS reported by the 26 patients can be seen in Table 2.

Procedure. A patient history was taken, including the basis for the diagnosis of the MHI, and for the PTS that had continued since the MHI occurred. Also noted was the manner in which the PTS had significantly

TABLE 2. Percentage of Post-Traumatic Symptoms Reported by Patients (N = 26)

Symptom	***Percentage***
Headache	84
Memory	72
Depression	44
Concentration	44
Vision	20
Anxiety	16
Dizziness	12
Fatigue	12
Neck Pain	12
Sleep Disturbance	12
Confusion	8

interfered with the ability of the patient to resume life activity levels present prior to the accident (i.e., work, social and/or leisure activities). Each of the 26 patients had a qEEG administered where data was collected using the eyes closed condition. EEG activity was recorded at the 19 standard sites using a Cadwell Spectrum® Digital EEG machine. Electrode placement followed the 10-20 International System. EEG activity was sampled at a rate of 200 Hz with filters set at 0.5 Hz for the low frequency filter and at 70 Hz for the high frequency filter. The raw EEG was visually artifacted by the same person. The first author scanned the raw EEG to determine the presence of any EEG abnormalities. The artificated EEG data were digitized, converted to Z-scores, and were then compared to the Cadwell Neurosearch® database (John, Prichep, Friedman, & Easton, 1988). The Neurosearch® program provided inter- and intra-hemispheric coherence scores. Coherence values were calculated at the sites in Table 3 using the Neurosearch® database.

The NFT was done in sets of five sessions. At the end of each set, the patient was asked to report a global improvement score (GIS). The first set focused NFT at the statistically most aberrant coherence pair, ignoring the positive or negative change. If improvement was not noted, the next significantly aberrant coherence pair was targeted. The procedure continued until success was achieved or until it was evident that no progress was occurring (40 trials). Neurofeedback training was carried out using EEG Spectrum® Neurocybernetics 3.1 equipment (Othmer & Othmer, 1995). Each patient was given positive feedback for increasing coherence when there was a decrease in coherence, or was given positive feedback for decreasing coherence when there was abnormally in-

TABLE 3. Electrode Placement for Coherence Scores

Intrahemispheric	***Interhemispheric***
Fp1/F3	Fp1/Fp2
Fp2/F4	F3/F4
T3/T5	F7/F8
T4/T6	C3/C4
C4/P4	T5/T6
F3/O1	P3/P4
F4/O2	O1/O2

creased coherence. The equipment did not allow amplitude free coherence training, but did allow a modified form of coherence training (S. Othmer, "poor man's coherence training" [unpublished]). The electrode setups for training to increase or decrease coherence are seen in Figure 1 and Figure 2, respectively. Reward was given for increasing the amplitude for the increase or decrease set-up.

FIGURE 1. Montage used for increasing coherence at C3 and C4.

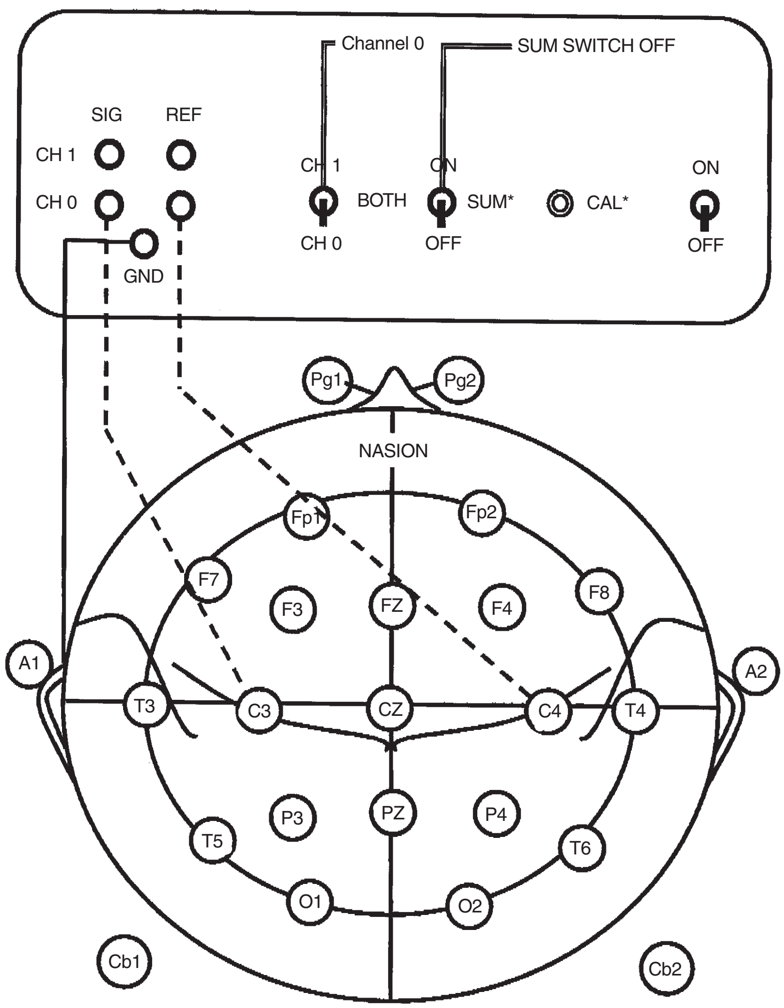
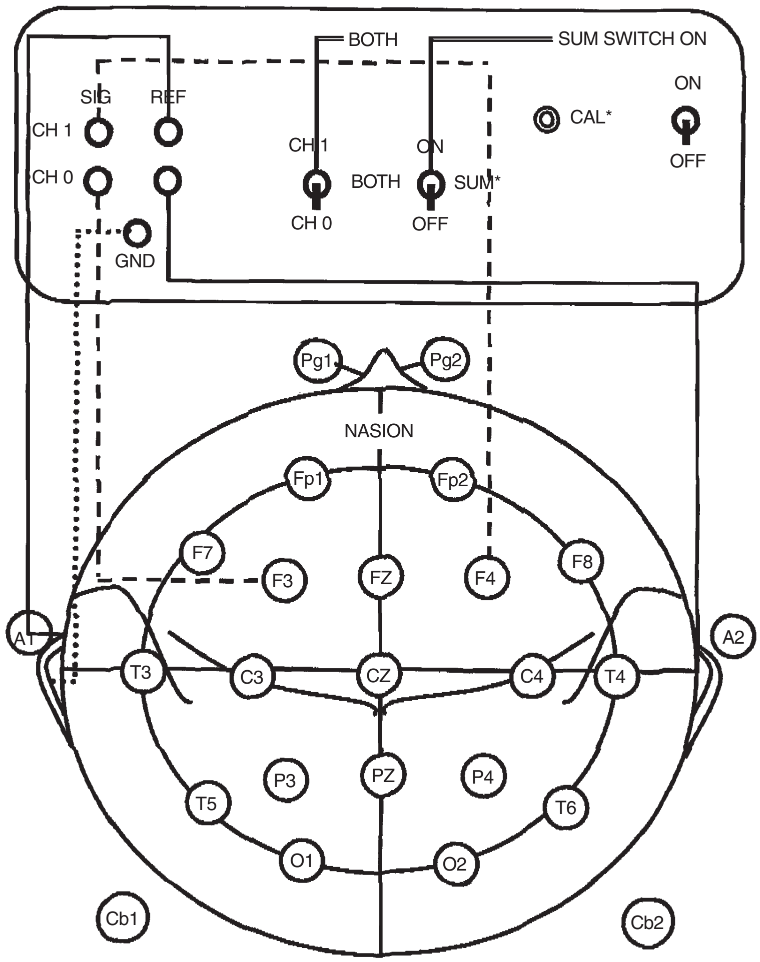


FIGURE 2. Montage for decreasing coherence at F3 and F4.



RESULTS

At the end of NFT sessions, each patient was asked to indicate a self-reported GIS by the percentage of change from 0 to100% since the beginning of the NFT. For the self-reported GIS, the mean = 72.7; median = 79.9; mode = 100; (range = 0 to 100%). The mean number of sessions was 19 (range = 5 to 41). The data for the 26 patients are presented in Table 4.

TABLE 4. Mean and Range for Age, Time Since MHI, Number of Sessions and Global Improvement

Factor	***Mean ± Standard Deviation***	***Range***
Age (yrs)	38.6 ± 13.5	15-55
Time Since MHI (months)	12.7 ± 18.5	3-70
Number of Sessions	19.1 ± 9.7	5-40
Global Improvement	72.7 ± 27.6	0-100

To investigate a possible relationship among the four variables presented in Table 4, correlation coefficients were calculated for age, length of time since the injury, GIS, and number of training sessions. None of the correlation coefficients reached a significance level of $p \leq 0.05$. Therefore, a successful outcome was likely, regardless of the age of the patient or the time since the head injury.

DISCUSSION

This study focused on the use of NFT for the treatment of PTS in patients with MHI. To be included in this study, the patient had to have had PTS for at least three months. Further, the PTS symptoms had to interfere significantly in the lives of the patients.

It appears that qEEG-guided NFT was an effective treatment. Eighty-eight percent of the patients reported GIS of 50% or greater. Not only was there improvement, but the positive changes occurred most frequently for headaches and memory loss or confusion, two of the most debilitating PTS. For a few of the patients, the qEEG-guided NFT was not very effective and such patients might have benefited from additional coherence training or even power training. The distribution of global scores was unusual, with the mode, the most frequent score, being 100%.

A three month or longer time criteria since the MHI before training was required to avoid the confounding effect of natural or spontaneous recovery. However, in our opinion, if a patient is suffering PTS which interfere with daily activities, treatment should probably be initiated with a shorter wait time.

The correlation coefficients were calculated to determine whether any of the variables such as age, time since MHI or number of training sessions influenced the determination of the GIS. Since none of the correlation coefficients was significant, it would appear that neither age, time since MHI, nor the number of training sessions significantly affected the benefit of training.

Not only were the PTS significantly reduced by the NFT, the positive changes resulted in a return to work for all patients who were employed prior to the accident, including those for whom a limited global improvement was reported. We recommend that other NFT centers pursue training aberrant coherence and collect data that will help evaluate the reproducibility of our results.

A weakness of current databases is that coherence is only measured for a fraction of all the coherence pairs. In the Neurosearch® database used in this study, eight intrahemispheric coherence pairs (Fp1/F3, Fp2/F4, T3/T5, T4/T6, C3/P3, C4/P4, F3/O1, F4/O2) and eight interhemispheric coherence pairs (Fp1/Fp2, F3/F4, C3/P3, C4/P4, O1/O2, F7/F8, T3/T4, T5/T6) were measured, out of 360 possible coherence pairs. Further investigation into other coherence pairs is recommended since it is currently unknown if those pairs included in this study are the most important coherence pairs to measure.

In addition, future studies in this area should be done with as many coherence measurements as possible, with pre- and post-qEEG measurements, as well as pre- and post-standardized self-report scales.

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SUBMITTED: 03/06/01
REVISED: 10/09/01
ACCEPTED: 12/11/01