

The electrophysiological effects of a brain injury on auditory memory functioning. The QEEG correlates of impaired memory

ArchClin Neuropsychol. 2003 May;18(4):363-78

ABSTRACT

The effect of a brain injury on the Quantitative EEG (QEEG) variables during an auditory memory activation condition was examined with 56 normal subjects and 85 mild traumatic brain injured (MTBI) subjects. An analysis was conducted on the different response patterns of the two groups, the variables which were correlated with memory performance in the brain injured group and the variables which predicted the memory score for the combined two groups (normal and brain injured). The three conditions included the input task, the immediate recall and delayed recall task. The consistent effect of a brain injury was a lowering of the connectivity patterns in the beta1 and beta2 frequencies (phase and coherences) and increases predominantly in the relative power of beta1 (13-32 Hz), which were correlated with the differences in recall. There is a subtle shift to right hemisphere/right temporal functioning and employment of the higher beta1 and beta2 frequencies (phase and coherence) in the response pattern of the MTBI subject. Memory functioning is predominantly positively correlated with connection activity (phase and coherence) and negatively correlated with beta activation at specific locations.

Key Words: QEEG, auditory memory, brain damage, memory, electrophysiology

Introduction

There have been several previous attempts to analyze the electrophysiological differences between the mild traumatic brain injured (MTBI) subject and a normative reference group under the eyes closed condition. There isn't any published literature which has examined all of the available electrophysiology differences between the normal and MTBI subject under auditory memory conditions to determine the specific electrophysiological correlates of memory functioning. This is the purpose of the present study. Previous research (Thatcher, 1989, 1998) has been able to demonstrate 1) a consistent difference between normals and MTBI subjects on specific QEEG variables and 2) a relationship between eyes closed QEEG variables and return to work and 3) between QEEG variables and neuropsychological functioning.

Prichep and John (1992) reported the first study to demonstrate the usefulness of the QEEG in discriminating between normals and MTBI subjects. The Thatcher, Walker, Gerson and Geisler (1989) study is the most comprehensive database to date (608 subjects). This study reported development of a discriminant function involving 264 MTBI patients and 83 age-matched controls for the eyes closed condition that obtained a successful classification accuracy rate of 94.8%. Two independent cross validations were conducted, obtaining in 1—a 96.2% correct classification of MTBI patients and 90.5% for normals and 2— a 77.8% (MTBI) and 92.3% (normals) correct classification. The specific discriminating variables included 1) an increased coherence and decreased phase in the frontal and frontal-temporal regions, 2) decreased power differences between anterior and posterior cortical regions and 3) reduced alpha power in posterior cortical regions.

The study evaluated subjects who experienced no loss of consciousness or loss of consciousness under 20 minutes, were over the age of 13, had a Glasgow coma scale between 13 and 15 and were within one year of the accident. The phase and coherence values were the most powerful variables in the prediction of return to work, thus providing a clue on how the QEEG variables might relate to cognitive functioning.

Randolph and Miller (1988) (N=20) examined brain injured (2–4 years post injury) and normal subjects during several cognitive tasks (T3, T4, O1, & O2 electrode placements). They found significantly poorer performance in the brain-injured subjects and specific differences between the groups with increased (in comparison to normals) EEG amplitudes and amplitude variances under task conditions (particularly in the beta band) but no significant differences in the relative power figure of the bands between the two groups. The inference from this study would be that the increased beta amplitudes and variances related to the poorer performance.

Hooshmand, Beckner and Radfar (1989) discussed the issue of TBM (topographic brain mapping) in a sample of 135 brain injuries (1–22 years post injury) and reported EEG abnormalities in 40 subjects, which consisted mostly of mild, nonspecific generalized slowing. Of the 135 patients, 75 (56%) had abnormal TBM's, with the temporo-frontal involved in 65% of the abnormal subjects. An additional 25% had abnormalities in the temporo-occipital regions. The authors found that the most common type of abnormality was in the absolute voltage asymmetry.

Tabano, Cameroni and Gallozzi (1988) investigated posterior activity of subjects (N=18) 3–10 days following a MTBI and found an increase in the mean power of the lower alpha range (8–10 Hz) and reduction in fast alpha (10.5–13.5 Hz) with an accompanying shift of the mean alpha frequency to lower values. They also reported a reduction in fast beta (20.5–36 Hz) activity.

In two studies (Thornton, 1999a, 1999b), addressing eyes closed and activation (auditory and visual attention, listening to paragraphs) conditions, exploratory analysis of the frequencies higher (32–64 Hz) than normally employed in discriminant analysis demonstrated encouraging results in distinguishing between normals and MTBI subjects. The results emphasized, as in the Thatcher study (1989), the importance of the phase and coherence values in obtaining successful discrimination between the groups.

Thatcher, Biver, McAlaster, Camacho and Salazar (1998) were able to demonstrate a relationship between increased theta amplitudes and increased white matter T2 MRI relaxation times (indicator of dysfunction) in a sample of MTBI subjects. Decreased alpha and beta amplitudes were associated with lengthened gray matter T2 MRI relaxation times. These measures were correlated with neuropsychological measures, which indicated decreased cognitive function. The subjects were 10 days to 11 years post injury. This study integrated MRI, QEEG (eyes closed) and neuropsychological measures in a sample of MTBI subjects. Despite these encouraging results the value of the QEEG in MTBI patients has received criticism in the literature by some (Nuwer, 1997) but support by others (Hughes and John, 1999).

This study was undertaken to discover the specific electrophysiological correlates of the impaired auditory memory ability of the MTBI subject. The frequency range was extended to 64 Hertz to evaluate the possible contribution of the 32–64 Hertz range to memory functioning.

METHOD

Subjects. A total of 56 normal subjects (no history of psychiatric problems, brain injury, neurological problems or learning disability and over the age of thirteen, right and left handed) were obtained for the normative reference sample by advertising. Eighty-five individuals who were mostly referred to the author's clinic (by doctors, lawyers, etc.) for examination of the possible effects of a MTBI (defined as loss of consciousness under 20 minutes) underwent the experimental procedure. Some of the MTBI subjects had volunteered to be part of the normative database but were placed in the MTBI group when they informed the investigator of a previous MTBI. All the referred MTBI subjects underwent neuropsychological testing and had demonstrated difficulties in memory functioning on either the California Verbal Learning Test, Logical Memory test of the Wechsler Memory Scale or the Luria-Nebraska neuropsychological battery or a combination of the measures. The average time between accident and testing date was 3.1 years (minimum of 17 days to maximum of 27 years). Twenty-seven of the MTBI group were on medication (anti-seizure, anti-depressants, blood pressure, for pain, methadone) and nine of the normal group were on medication (anti-depressant, blood pressure). Depression was clinically evident enough in 10 of the MTBI subjects to require medication, although none had been hospitalized. This group of 143 was part of a larger group of 202 subjects (consisting of head injured, learning disabled, psychiatric, Lymes patient, multiple sclerosis patient and children under the age of thirteen) who underwent a procedure lasting about one and one-half hours, during which eighteen cognitive tasks were administered. Table 1 represents the demographics of the 143 subjects involved in this research. The subjects chosen out of the total sample were either classified normal or MTBI. One hundred and twenty five were right-handed and eleven were left-handed. The figures indicate lower sample sizes than indicated in the table, as each condition employed the relative power of delta under 45 at the Fp1 site as a criterion for inclusion in the analysis. The table presents the data on all the subjects who were available prior any selection criteria. Subjects were paid \$25 for their participation and their parents (when subjects were under the age of eighteen) signed an informed consent form as required in human research situations.

TABLE 1

Descriptive Data on Subject Population

	Brain Injured	Normal	P level
Number	85	56	
Age (Yrs.)	40.6(13.4)	36(16.2)	.06
Education	13.5(3.4)	13.6(3.2)	.76
Shipley Scale			
Raw Verbal	27.3(6.6)	32.2(4.9)	.0000*
Raw Abstraction	22.3(10)	31.3(5)	.0000*
Verbal IQ**	103.3(12.4)	113.7(6.5)	.0000*
Abstraction IQ	101(18.3)	107(11)	.0013*
Short Term Memory	28.9(10.7)	42.6(11)	.0000*
Long Term Memory	10.8(8.7)	20.1(11.3)	.0000*

Savings	.36(.24)	.46(.22)	.011*
Total Memory	39.7(17.2)	62.7(19.7)	.0000*
Males	37	28	
Females	48	28	

P level of t-test indicated in right column.

**Employed Paulson, M. J. and Lin, T. (1970) formulas in estimation of IQ for subjects age 15 and over as formulas developed for subjects over age 15.

Standard Deviations noted in parenthesis

Apparatus. While the subjects underwent the experiment, they were videotaped and recorded. The recording device combines a computer, video, audio recording equipment and allows an experimental recording session to be saved to a hi-8 mm tape with all pertinent information. The videotape, which is saved, is a split-screen videotape, with the left side reflecting the EEG recording with the appropriate epoch number and the right side of the screen showing the subject during the experiment. The epoch number refers to a one-second period of time. Thus, epoch number one is the first one-second period of the recording and epoch number sixty is the sixtieth second of the recording. This device enables the experimenter to review the tape to check and confirm the scoring of the subject's responses during the experiment.

The EEG recording equipment of Lexicor Medical Technology, Inc. (NRS-24) was employed. The sampling rate was set to 256 to allow for examination of up to the 64-Hertz range with a 60-Hertz notch filter. In the system employed in this study, filtering is accomplished in the software. The signals passed are between .5 and 64 Hz (3dB points). The signals, which pass, are then subjected to a Fast Fourier Transform (FT) using Cosine-tapered windows which output spectral magnitude in microvolts as a function of frequency. The bandwidths were divided according to the following division: delta: .5-3.5 Hertz, theta: 4-7.5 Hertz, alpha: 8-12.5 Hertz, beta1: 13-31.5 Hertz, beta2: 32-63.5 Hertz. This equipment provides for the collection of data in the standard 10-20 system (ear linked references) format of EEG data collection. Impedances below 5 Ω (and within 1.5 Ω of each other) were obtained on all locations. Gain was set to 32000 and the high pass filter was set to off. The earlobes and forehead were prepped with rubbing alcohol and NuPrep. An Electro-cap was employed and spaces filled with Electro-gel. The data was visually analyzed and marked for deletion when artifact was evident.

All measurements available through the software provided by Lexicor Medical Technology, Inc. were employed. These included the following for each bandwidth and employed the peak-to-peak method.

Activation Measures.

Absolute Magnitude: the average absolute magnitude (as defined in microvolts) of a band over the entire epoch (one second)

Relative Magnitude: the relative magnitude of a band (absolute magnitude of the particular band divided by the total microvolt generated at a particular location by all bands)

Peak Amplitude: the peak amplitude of a band during an epoch (defined in microvolts)

Peak Frequency: the peak frequency of a band during an epoch (defined in frequency)

Symmetry: the peak amplitude symmetry between two locations in a particular bandwidth– i.e. defined as $(A-B)/(A+B)$ where A and B are different locations.

Connectivity Measures.

Coherence: the average similarity between the waveforms of a particular band in two locations over the one–second period of time. Conceptualized as the strength/number of connections between two positions.

Phase: the time lag between two locations of a particular band as defined by how soon after the beginning of an epoch a particular waveform amplitude in a particular frequency at location #1 is matched in location #2. The propriety Lexicor software matches the amplitudes, calculates the time delay (in milleseconds) and generates a number between 0 and 100 to reflect the phase delay. The higher the number the less the delay.

PROCEDURE

The subjects were read the four stories (one at a time) from the Rivermead Behavioral Memory Test (1991) while their eyes were closed. They were instructed at the end of each story (when the examiner said “end”) to start recalling the story in as much detail as possible, silently to themselves. At the end of a thirty–second period, the examiner placed the recording on pause and asked the subject to open their eyes and repeat outloud the entire story they recalled during the quiet thirty–second period. Following the reading and recalling of the first story, the second story was read under the same conditions, then the third, etc. Following about forty–five minutes of other demanding cognitive tasks, the subjects were asked to close their eyes and silently recall anything they could recall from all of the four stories for thirty seconds. At the end of the thirty seconds, the recording was paused and the subject was asked to recall the stories out loud. Scoring for the stories followed the recommendations of the Rivermead manual, but added the possibility of half points for partial answers. Scores are based upon the method presented in the following example where the concept/words between the forward slash marks represent a score of 1.

Fireman / and volunteers/ worked all day/ yesterday/ putting out a bush fire/ six miles / south / of San Diego/ in Southern California./

The four listening periods were treated as one group as well as the four quiet recall periods. This procedure was employed to obtain as many epochs as possible to increase the statistical validity of the mean, which was what was used in the correlational analysis.

Data Analysis.

The raw data was analyzed for artifact, appropriately marked and then analyzed with the Exporter program available from Lexicor Medical Technology. The visual analysis for artifact focused on muscle activity in temporal locations and delta activity in frontal locations. The software does not include deleted epochs in its reporting on the values of all variables for all individual epochs. The Exporter software solves the cumbersome time problem of obtaining the required figures from the raw data file. The program generates the values for the variables under consideration from the raw data file

and generates ASCII, comma delimited files, which can then be imported into Excel or CSS Statistica. Every epoch of the spreadsheet was labeled according to the experimental condition, which was occurring at the time. One Excel spreadsheet was generated for each subject containing the 1-values of the variables for each of the tasks and 2-the degree of activation of the variable from a relevant condition (i.e. auditory attention versus listening to paragraphs). The subject's values were then exported into two CSS files. For example, in the immediate recall of paragraphs, one file would contain the absolute levels of the condition, another file would contain the degree of activation values from the relevant comparison condition (eyes closed). The degree of activation variables were analyzed for the three conditions (listening, immediate and delayed recall).

Description of Figures.

The blackened circles represent the areas activated (magnitude, relative power, peak frequency, and amplitude asymmetry) to a significant level according to the discussion of significance in the statistical consideration section. The lines represent the phase and coherence generators which were significant, with the filled in circles indicating the assumed origin of the signal. The positive and negative correlations are noted on the top of each set of figures. Each head figure is labeled on top with the parameter under consideration, according to the following nomenclature. Each figure presents the sample size which was available for analysis after the selection criteria of Fp1 relative power of delta under 45 was employed. For each figure the relevant nomenclature is listed below the figure and verbal descriptions of the labels provided.

T: theta A: alpha B1: beta1 B2: beta2

M: Absolute Magnitude RP: Relative Magnitude PKA: Peak Amplitude

PKF: Peak Frequency Sym: Symmetry

P: Phase C: Coherence

The following examples are provided for clarification.

PA: reflects phase alpha.

CT: reflects coherence theta.

RPB2: reflects relative power of beta2

MB1: reflects magnitude of beta1

PKAA: reflects peak amplitude of alpha

PFKB2: reflects peak frequency of beta2

SymB1*: would reflect Asymmetry of beta1 band

* Symmetry measures employ the combination method. A particular location's symmetry measure is calculated in reference to all other positions and is calculated only for the beta bands. The formula for symmetry is $(A-B)/(A+B)$, where A and B represent different locations.

Statistical Considerations.

The Bonferroni correction was not considered appropriate for the analysis as it fails to take into account the different categories of information. Setting the alpha level to .05 would result in one hundred and forty-seven significant findings (of the 2,945 variables under consideration) by chance alone. To reduce this statistical problem to manageable levels, the following considerations were taken into account.

Epochs with minor delta activity (defined as between 40-70 microvolts) were included in the data analysis for two reasons: (1) Eye movement (the predominant delta activity artifactual concern) may relate to cognitive functioning as rightward eye

movements activate the left posterior and vice-versa and (2) the need to obtain as many epochs of a short thirty-second period of time as possible to increase statistical power. However, the delta band itself from these epochs was not included in the analysis for two reasons: (1) the inclusion of delta activity could be misleading as to the nature of the underlying brain activity as the activity could include artifact data and (2) the effective QEEG parameters were focused in the higher bandwidths, thus minimizing the probability that delta activity is an effective cognitive measure. The exclusion of delta activity is a limitation of the research design, as the probable negative influence of delta on cognitive function cannot be documented in this data.

Critical values for statistical significance were adapted to each variable under consideration so as to minimize both type I and type II errors. For example, in one of the activation measures (relative power, etc.) there are nineteen locations and four bands (eliminating delta), resulting in seventy-six possible significant findings. An alpha level of .05 would produce approximately 3.8 significant findings by chance alone. Significant activations are reported if there are: (1) two or more in adjacent positions, (2) involve different bands or types of activations in the same location or (3) significant phase and coherence activity at that location. The total number of activation variables resulting from nineteen locations, four bandwidths and four parameters (excluding symmetry) is three hundred and four. The symmetry measures produce six hundred and seventy-four variables. The total number of connection measures resulting from nineteen locations, four bandwidths and two parameters is 1,368. The resulting total number of variables (after elimination of delta activity) under consideration was 1,672. If an alpha level of .05 were employed with the relationship variables (coherence and phase), there would be thirty-four significant findings by chance alone (for each relationship variable).

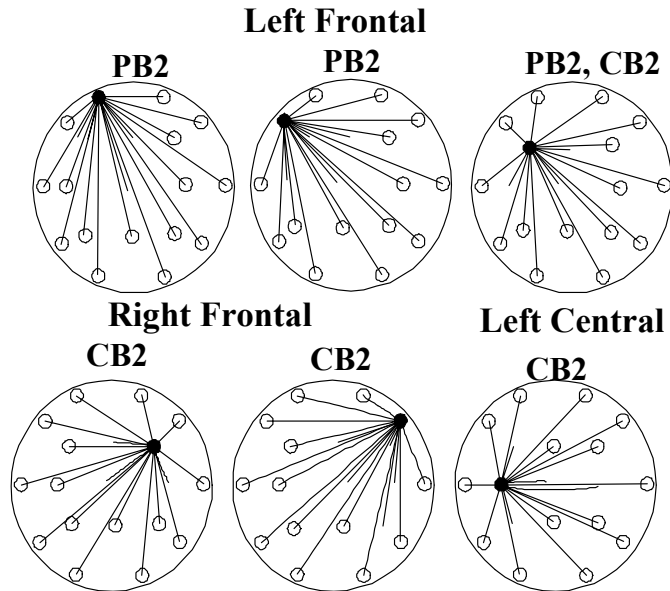
The connection measures (phase and coherence) were reduced by examination of the four frequencies emanating from each location to all other locations. Conceptually this is equivalent to considering that a location is capable of "generator capacities" in the different frequencies. The concept of generators has been employed previously in EEG research (Moran, Tepley, Jacobson & Barkley, 1993). For example, the phase alpha value from F7 to all 18 other locations was summed. This method of data reduction was conducted for all four frequencies (theta to beta2), both connection variables (phase, coherence) and all locations. Thus, each location would have eight possible significant relationships (phase alpha, coherence alpha, etc.). Any significant relationship from a location (alpha set at .05) would be above chance levels.

Results

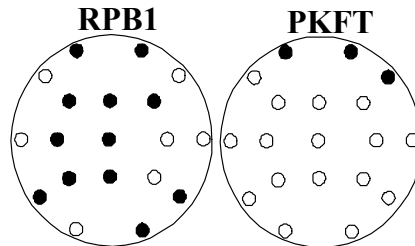
The figures present several levels of analyses of each condition. Each of the three conditions (input, immediate recall, delayed recall) were examined from two points of view. The initial figure presents the differences (the absolute level of the variable) between the MTBI group and the normal group on the variables which are correlated with memory performance. The figure, thus, addresses the question of what are the correlates of the MTBI individual's impaired memory. The third figure presents the results for how memory functions within the MTBI group for the individual conditions. The question of how does the MTBI individual recall information is addressed. Degree of activation differences between the groups (from relevant tasks) are discussed but not presented in the figures.

Input Stage

**Figure 1 - Listening to Paragraphs MTBI=80 N=49
Generators Positively related to Total Recall Score
and significantly lower in MTBI subjects: Alpha set at .02**



**Negatively correlated with total memory
and higher in MTBI subjects: Alpha at .05**



CB2-Coherence Beta2 PB2-Phase Beta2 RPB1-Relative Power Beta1 PKFT-Peak Frequency of Theta

Figure 1 presents the results of the analysis which compared the MTBI injured QEEG response pattern to the normal response pattern. Due to the many generators which were significantly different at the .05 level, the figure presents only those generators which were significant at the .02 alpha level. Figure 1 is the only figure which employed the .02 alpha level. The generators which were significant at the .05 (and were positively correlated to the total memory (short plus delayed recall) included coherence beta2 (Fp1, Fp2, F7, F3, Fz, F4, F8, C3, C4), phase beta1 (F3) and phase beta2 (Fp1, F3, Fz, F4, F8, C3, Cz, C4, P3). The MTBI group's value for the F2 coherence theta generator was higher than the value for the normal group and was negatively correlated with memory. The amount of time since the accident did not correlate in any direction with any of the variables which distinguished the groups, indicating that spontaneous recovery does not improve these values. The variables which negatively related to memory and were higher in the MTBI group include the relative power of beta1 values

(at Fp1, Fp2, F3, Fz, F4, C3, Cz, P3, Pz, O2 & T5) and the peak frequency of theta at Fp1, Fp2 and F8.

TABLE 2
Listening to Paragraphs - Generator Differences between Normals and Brain Injured

	Coherence		Phase	
	BI>N	N>BI	BI>N	N>BI
Theta	2/18			
Alpha				
Beta1				3/18
Beta2		16/18		15/18

BI=brain injured N=normal > indicates greater than

Table 2 presents an analysis of the number of coherence and phase variables which were significant. As the table indicates the effects of a MTBI are significant for almost all of the beta2 generators (coherence and phase). The frontal lobe generators are therefore particularly sensitive to the effects of a MTBI.

The degree of activation results indicated that the MTBI group activated the T4 coherence beta1 generator to a greater degree than the normal group, as well as the peak frequency of alpha (Fp1, T3, T5, P3, P4, O1, O2) while the normal group increased the relative power of theta (Fp1, Fp2, F7 and F8) and increased magnitudes of theta at Fp1 & Fp2 with respect to the MTBI group.

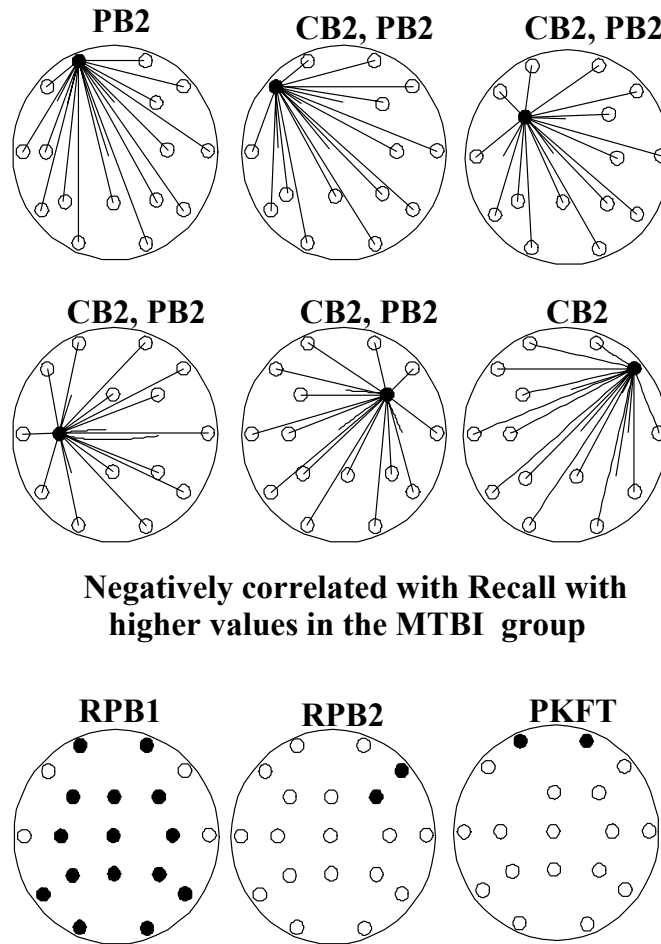
Figure 4 presents what generators, within the MTBI group, predict success and indicates that the F7 phase beta2 and T4 phase beta1 generators are positively correlated with subsequent recall as well as the peak frequency of beta2 at C3 & Cz. Negatively related variables includes frontal peak amplitude of alpha (Fp1, Fp2, F3, F4, C3 & C4), frontal magnitudes of alpha (F3 & Fz) and peak amplitude of beta1 (Fp1, F3 & Fz). This is in sharp contrast to the results for normal subjects which indicated that the T3 coherence and phase alpha generator pattern and F7 coherence alpha pattern are positively correlated with recall (Thornton, 2001c).

Immediate Recall

Figure 2 presents the difference between the normals and MTBI subject for the immediate recall period with alpha set to .05. As in the study condition, the frontal generator pattern in the high frequencies (32–64 Hz) distinguish between the groups and are positively correlated with total recall ability. The coherence beta2 generators (alpha set at .05) which were significantly lower in the MTBI group and positively correlated to

total recall included F7, F3, F4, F8, C3 while the phase beta2 results indicated Fp1, F7, F3, F4 and C3 as significantly lower in the MTBI group and positively correlated with total recall.

**Figure 2 Recalling Paragraphs MTBI=77 N=52
Generators Positively related to Total Recall Score
and significantly lower in MTBI subjects**



CB2-Coherence Beta2 **PB2**-Phase Beta2 **RPB1**-Relative Power Beta1 **RPB2**-Relative Power Beta2
PKFT-Peak Frequency Theta

The increased relative power of beta1 (at Fp1, Fp2, F3, Fz, F4, C3, Cz, C4, T5, P3, Pz, P4, T6, O1 and O2), right frontal relative power of beta2 (F8 & F4) and frontal polar peak frequency of theta (Fp1, Fp2) are higher in the MTBI group and negatively correlated with memory ability. The relative power of beta1 results are similar to the study condition.

The degree of activation analysis indicated a significant difference between normals and MTBI response pattern, with the normal group increasing (in comparison to the MTBI group) coherence theta generators from predominantly frontal locations (Fp1, Fp2, F7, F4, P3 and P4), phase theta generators (Fp2, F4 and P3) and phase alpha (P3)

and increasing coherence alpha from occipital locations (O1 and O2). In addition, the normal group increased frontal amplitudes of theta (Fp1, Fp2, F7 and F8), magnitudes of theta (Fp1, Fp2, F7) while the MTBI group increased peak frequency of alpha (T3, T5, P3, Pz, P4, O1, O2). The MTBI group also increased right frontal/temporal beta2 activity (relative power, peak amplitude, magnitude of beta2 at F4 and T4), symmetry of beta1 at F4, F3 (peak amplitude of beta2), and T3 beta activity (magnitude of beta1 and beta2, symmetry beta1). Thus the MTBI group increased right frontal/temporal beta2 activity while the normal group increased frontal connectivity patterns in the lower frequency ranges (theta and alpha) and absolute levels of frontal theta activity.

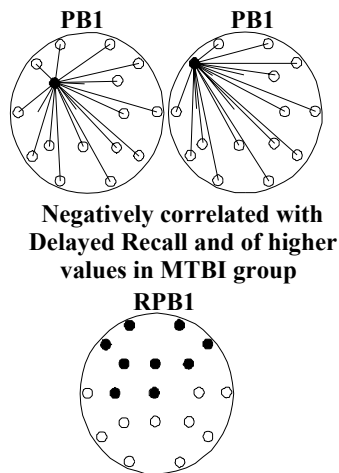
Figure 5 presents the within MTBI group analysis. The results indicated only the negatively related (to total recall) variables which involved frontal and temporal beta1 activity (relative power, peak amplitude and magnitude of beta1), right temporal (T4) peak amplitude and magnitude of beta2, frontal alpha (magnitudes, peak amplitudes) and right frontal theta (peak frequency).

Delayed Recall

Figure 3 presents the relationships which are relevant to the delayed memory score in the delayed recall situation and which have been affected in the MTBI group. The frontal beta1 generators (F7 & F3-phase beta1) were higher in the normal group and positively correlated with the recall score at the time of delayed assessment (not total memory). Frontal relative power of beta1 figures in predominantly frontal locations (Fp1, Fp2, F7, F3, Fz, F4, F8, C3 & Cz) were higher in the MTBI group and was negatively correlated with memory, again similar to the study and immediate recall condition.

The degree of activation analysis indicated that the MTBI group did not activate any of the generators more than the normal group, but did activate C4 (relative power, magnitude and symmetry of beta2) more than the normal group. A normal group's response pattern (Thornton, 2001c) employs the T3 and F7 generator to obtain success in the delayed recall situation. As in the study condition, the MTBI subject employs the higher frequencies and the right temporal location to aid in successful recall.

**Figure 3 Delayed Recall of Paragraphs MTBI=77 N=46
Generators Positively related to Total Recall Score and significantly lower in TBI subjects**



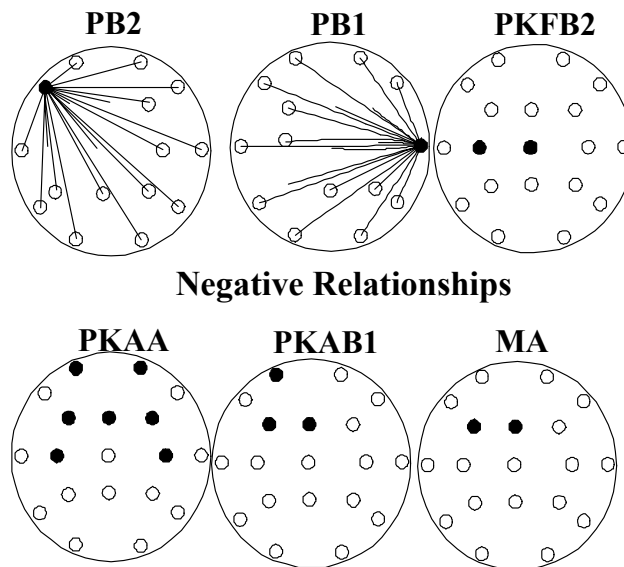
PB1-Phase Beta1 RPB1-Relative Power Beta1

Discussion

There are five main findings of this research.

- 1) The electrophysiological effects of a MTBI are substantially greater than previously presented in the literature and are clearly evident under activation conditions. The effects consistently involve, across the three conditions, a decrease in the phase and coherence beta2 generators (which were positively correlated with recall) and an increase in the relative power of beta1 and beta2 activity (which were negatively related to recall) predominantly in the frontal regions (Figures 1, 2 and 3). This finding is consistent with previous research implicating the frontal lobes in MTBI cases.
- 2) There is a subtle shift to right temporal functioning (Figure 4 and 6) in the MTBI individual in the beta1 and beta2 frequencies (phase and coherence), which was not evident in the normal group. As the MTBI increase beta generator activity in the right temporal location (T4) their memory improved. Increases in left temporal (T3) alpha generator activity (Thornton, 2001c), which positively correlated with recall in the normal group, did not correlate with improved recall in MTBI group. The inference drawn from this result is that the information is being “stored” in the right temporal location for the MTBI group, thus a shift to a right temporal location. This shift, as well as other response changes, does not correlate with improved memory functioning (total recall score of 40 for MTBI vs 63 for normals).
- 3) Memory functioning is predominantly positively correlated with connection activity (phase and coherence) in the beta1 and beta2 frequencies and negatively correlated with beta1 and beta2 activity (i.e. relative power, magnitudes, etc.) levels at specific locations. This pattern is indicated in Figures 1, 2, 3, 4, 5 and 6.

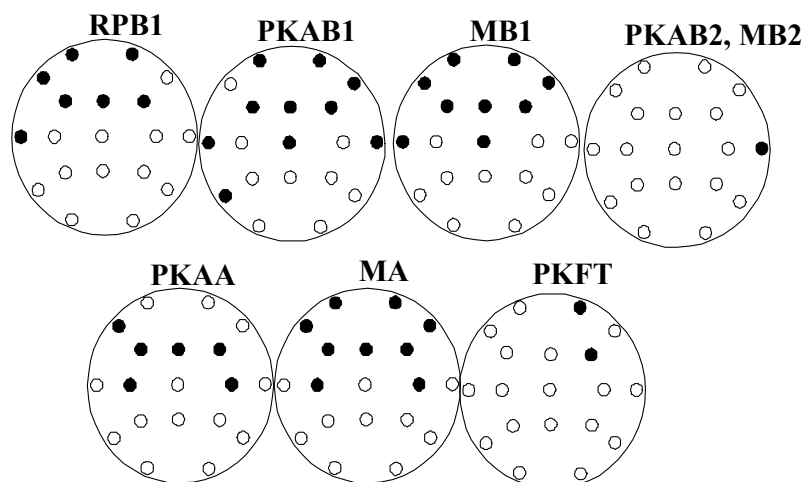
**Figure 4 - Listening to Paragraphs N=80
Positive Relationships to Total Recall - Within MTBI group**



**PB1-Phase Beta1 PB2-Phase Beta2 PKFB2-Peak Frequency Beta2 PKAA-Peak Amplitude Alpha
PKAB1-Peak Amplitude Beta1 MA-Magnitude Alpha**

Figure 5 - Recalling Paragraphs N=77

**Variables Negatively Correlated
with Total Recall within MTBI Group**



RPBI-Relative Power Beta1 **PKAA**-Peak Amplitude Alpha **PKAB1**-Peak Amplitude Beta1
PKAB2-Peak Amplitude Beta2 **MA**-Magnitude Alpha **MB1**-Magnitude Beta1 **MB2**-Magnitude Beta2
PKAA-Peak Amplitude Alpha **MA**-Magnitude Alpha **PKFT**-Peak Frequency Theta

The Randolph (1988) finding of no differences in relative power of beta figures was strongly disconfirmed in the present research, nor was the increased amplitude variances in the beta frequency in the MTBI group confirmed. However, the increased amplitudes of beta activity was confirmed in Figure 5 and was negatively related to memory. The Tebano (1988) finding of decreased alpha peak frequency in the brain damaged group was not confirmed. The Thatcher et al. (1989) finding of decreased phase relationships in MTBI subjects was maintained, but not increased coherences. The relationship between cognitive abilities (return to work in the Thatcher (1989) article) and memory performance in this article) and the phase and coherence values were substantiated.

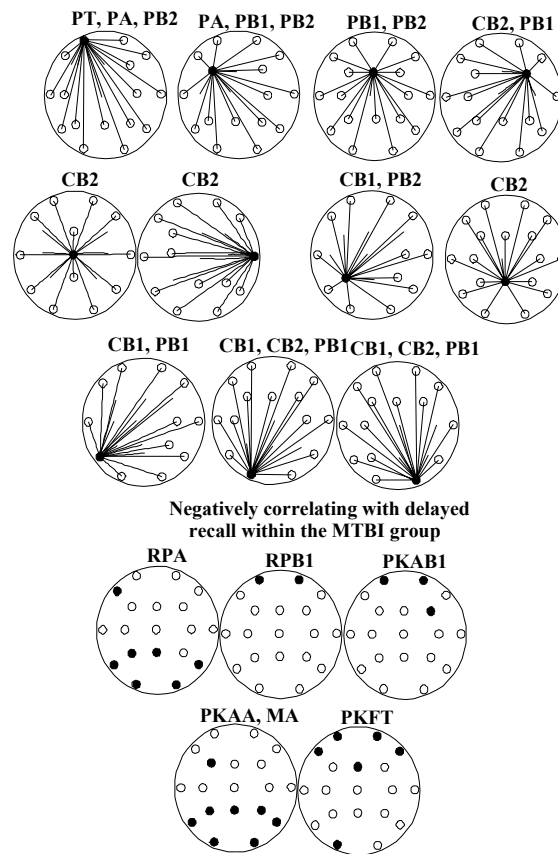
The questions raised, but unanswered by this research, concern:

- 1) Why does the brain switch to a right temporal location and employ a higher frequency (than the normal group) to address/solve the problem of auditory memory?
- 2) Why does beta1 and beta2 activation negatively relate to memory performance while coherence and phase generators positively relate to recall?

An additional factor which requires consideration is the effect of the emotional differences between the groups. Many of the MTBI subjects had been involved in auto accidents and were experiencing post-traumatic stress disorder in addition to depression, as previously indicated. Hughes & John (1999) note (eyes closed condition) that depression (unipolar) is marked by increases in alpha and theta, asymmetry and hypocohereance in anterior regions. Bipolar depressed patients are marked by decreased alpha and increased beta activity. Hughes and John (1999) have noted that consistent

patterns in other psychiatric disorders (anxiety, obsessive-compulsive and eating disorders) have not been discerned by the research at this point in time. While none of the theta, alpha and beta findings were evident in these results, the anterior hypocoherence was evident in Figures 1, 2 & 3. However, the effect was predominantly in the 32–64 Hertz frequency, a frequency range not employed in the cited studies. The effect was not evident in the other frequencies for locations in the anterior positions, thus eliminating the possibility of depression affecting the results.

**Figure 6 Delayed Recall of Paragraphs - N=77
Positive Relationships to Delayed Recall - Within MTBI group**



CB1-Coherence Beta1 **CB2**-Coherence Beta2 **PT**-Phase Theta **PA**-Phase Alpha **PB1**-Phase Beta1 **PB2**-Phase Beta2
RPA-Relative Power Alpha **RPB1**-Relative Power Beta1 **PKAA**-Peak Amplitude Alpha
MA-Magnitude Alpha **PKFT**-Peak Frequency Theta

The problem of possible EMG artifact affecting the data receives some support from the observation that (Figure 1) the MTBI group has higher relative power figures of beta1 in frontal positions, which could be a contributing factor to the lowered coherence and phase values emanating from those locations (in the beta2 frequency). However, the finding that the higher frequency (coherence and phase) values are related to memory functioning is a strong argument, by itself, against the EMG hypothesis (if the higher frequencies are considered manifestations of EMG activity). Additionally, it would be

expected that the amplitudes and magnitudes would increase under the EMG hypothesis and not solely relative power in a frequency different than the affected phase and coherence values (beta1 vs beta2). Thirdly, the pattern of intercorrelations between the relative power and coherence and phase figures did not demonstrate a consistent significant pattern of increases in relative power figures (beta2) negatively related to decreased phase and coherence values from the particular location and in some instances were positively related. Fourthly, if the relative power of beta1 reflect "mental effort" which decreases coherence and phase values in the higher frequency, this effect should be for both the normal and MTBI groups. The effect was not evident in the normal group.

Nuwer's (1997) conclusion regarding the lack of usefulness of the QEEG in the MTBI situation has challenged by Hughes & John (1999) conclusion that there is high consistency of findings in the mild to moderate brain injury subjects, in sports related head impact injuries and in patients with severe brain injury as they recover. These findings indicated increased focal or diffuse theta, decreased alpha, decreased coherences and increased asymmetry issues. The results of this study are in agreement with the general findings noted by Hughes & John (1999) most recent and most extensive review of the literature to date for decreased coherences.

In conclusion, the effect of a MTBI on an individual's electrophysiological functioning shows a consistent pattern of changes which can be correlated with memory abilities, a key ability to job functioning. The next research step is to ascertain if remediation efforts directed towards these problems can effectively change the cognitive ability.

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