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Exploratory Investigation into Mild Brain Injury and Discriminant Analysis with High Frequency Bands (32-64 Hz)

Kirtley E. Thornton, Ph.D.
Center for Health Psychology, South Plainfield, N.J.

ABSTRACT

QEEG variables (5 activation, 2 relationship variables, 19 locations and 5 bands up to 64 Hertz) were collected under eyes closed condition (under both 32 Hertz and 64 Hertz conditions) on 91 subjects, consisting of 32 mild brain-injured subjects (no loss of consciousness greater than 20 minutes) and 52 normals over the age of 14. An additional 7 subjects who were unconscious greater than 20 minutes was available for analysis. Previous discriminant function analysis developed by Thatcher, R. W. et al. (7) was employed on the eyes closed 32 Hertz condition to ascertain its robustness for time periods greater than a year and for significant periods of unconsciousness. A separate discriminant for subjects was developed employing only frontal high frequency coherence figures.

The Thatcher Discriminant could reliably (79%) identify all subjects up to 43 years post accident. The high frequency discriminant effectively identified 87% of the brain injured across all time periods (without significant loss of consciousness) and 100% of subjects within 1 year of accident. The combination of the discriminants resulted in a 100% accuracy rate for the 39 brain injured subjects for which discriminant values were available.

Key Words: Discriminant Function, High Frequency Bands, Mild Brain Trauma, QEEG

Literature Review

There have been several previous attempts to analyze the electrophysiology of the mild brain trauma victim. The Thatcher, R.W. et al. (7) study is the most comprehensive in terms of its database of 608 subjects. This study was able to develop a discriminant function from 264 mild brain injured patients and 83 age-matched controls which was able to achieve a successful discriminant classification accuracy rate of 94.8%. Two independent cross validations were conducted which obtained a 96.2% correct classification of brain trauma patients and 90.5% for normals. A second cross validation obtained a 77.8% (brain injured) and 92.3% (normals) correct classification. The 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 Thatcher et al.(7) study evaluated subjects who experienced no loss of consciousness or loss of consciousness under 20 minutes, were over the age of 13 and had a Glasgow coma scale between 13 and 15.

Randolph, C. et al. (5) (N=20) examined brain injured and normal subjects during several cognitive tasks and employing T3, T4, O1, & O2 electrode placements. They found significantly worse performance in the brain-injured subjects and increased (in comparison to normals) EEG amplitudes and amplitude variances (task conditions), particularly in the beta band. The authors noted no significant differences in the relative power figure of the bands between the two groups. The subjects in this study were 2 to 4 years post injury.

Hooshmand, H. et al. (2) discussed the issue of TBM (topographic brain mapping) in a sample of 135 brain injuries 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. Hooshmand et. al. (1) Found that the most common type of abnormality was in the absolute voltage asymmetry. The subjects were 1 to 22 years post injury.

Tebano, M.T. et al (7) investigated posterior activity of subjects (N=18) 3-10 days following a minor brain trauma 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.

Thatcher, R.W. et al (8) 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 brain injured subjects. Decreased Alpha and Beta amplitudes were associated with lengthened gray matter T2 MRI relaxation times. Neuropsychological measures. These measures were correlated with decreased cognitive function. The subjects were 10 days to 11 years post injury.

METHOD

1-SUBJECTS

A total of 91 subjects underwent the experimental procedure. The following breakdown represents the demographics of the subjects involved. Subjects were paid $25 for their participation and signed an informed consent form as required in human research situations. The brain injured group consisted of 32 subjects, while the normal group consisted of 52 subjects. Inclusion in the brain injured group was based upon the subject hitting their head on part of the car during a car accident, with either no loss of consciousness of loss of consciousness less than two minutes. Only one of the 32 subjects reported that they did not hit their head during the accident (but did demonstrate deficits on Neuropsychological testing) and for two other subjects it was unclear whether their head hit an object. Six of the subjects had a history of a previous minor brain trauma. Only two of these subjects had underwent any Neuropsychological testing to document cognitive problems as a result of these previous accident. Twenty three of the subjects underwent Neuropsychological testing following the traumatic brain event and all of these evidenced deficits on cognitive testing. On the basis of the clinical interview, thirteen of the subjects received the diagnosis of Post Traumatic Stress Disorder, five subjects received a separate or additional diagnosis of depression and one subject a manic-depressive diagnosis.

The mean number of months since injury was 64.9 months or 5.34 years. Twelve subjects were within one year of the injury and an additional seven subjects were within ten years of the accident. The longest period of time since the accident was for one subject who was 43 years post injury. All the subjects (in the no loss of consciousness group) reported that they were conscious and at least somewhat alert immediately following the accident. There were no Glasgow coma scale ratings available.

There were an additional 7 brain injured subjects available for analysis who were not included because their reported duration of unconsciousness was greater than 20 minutes. T-test comparisons revealed a different pattern of significant differences between the groups. However, as the sample size was small, the results will not be presented. Twenty-eight of the thirty-two brain injured subjects reported hitting their head. The one subject who was 43 years post accident was only included in the Thatcher Discriminant Analysis results and demographic information and not in any of the high frequency analysis. His pattern of results was that of a statistical outlier. He is a successful computer entrepreneur.

Table #1

Demographics	Head Inj.	Normals	T-Value	P-Level
Age (Yrs.)	**41**	**37**	**1.21**	**.23**
Handedness				
Right	**29**	**41**		
Left	**3**	**11**	**-1.31**	**.16**
Sex				
Female	**21**	**28**		
Male	**11**	**24**	**-1.34**	**.29**
Education	**13**	**14**	**-.99**	**.34**
Shipley*				
Raw Verbal	**28.6**	**32.8**	**-3.33**	**.0013****
Raw Abstraction	**24.2**	**31.4**	**-3.94**	**.00017****
Verbal IQ	**105.6**	**114.7**	**-1.15**	**.00008****
Abstraction IQ	**99.2**	**105.4**	**-1.76**	**.08**

As indicated in Table #1 there were no significant differences between the group in terms of age, handedness, sex, level of education or Abstraction IQ. Significant differences, however, were present in terms of Raw Verbal and Abstraction scores on the Shipley and Verbal IQ. The demographics information covers only subjects with no significant loss of consciousness.

**-significant differences

*-IQ obtained from Shipley Institute of Living Scores and employed the Paulson, M.J. & Lin, L. (1970) formula. The formula was averaged across all age groups. As formulas were developed on subjects age 15 and above, the average IQ cell also indicates the number of subjects that were above age 15 and the formula could be applied.

2-APPARATUS

The EEG recording equipment of Lexicor Medical Technologies was employed. The sampling rate was set to 256 to allow for examination of up to the 64-Hertz range. The bandwidths were divided according to the following division: Delta: 0-4 Hertz, Theta: 4-8 Hertz, Alpha: 8-13 Hertz, Beta1: 13-32 Hertz & Beta2: 32-64 Hertz.

All available measurements available through the software provided by Lexicor Medical Technologies were employed. These included the following for each bandwidth:

3-MEASURES

ACTIVATION MEASURES

Absolute Magnitude-the absolute magnitude (as defined in microvolt) 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 peak amplitude of band at location #1 divided by peak amplitude of band at location #2

CONNECTION MEASURES

Coherence-the average similarity between the wave forms 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 at location #1 is matched in location #2.

Roland (6) discusses the issues of connectivity of the brain in terms of the anatomical organization of the neocortex, which contains six layers (with layer I being closest to the scalp) and is approximately 3 mm thick. The pyramidal cells (excitatory) in layer II and the upper part of layer III send their axons to the cortex in the same hemisphere while the pyramidal neurons in the lower part of layer III send their axons to the other hemisphere or over longer distances intercortically. Thus, apart from other subcortical considerations, these are the physiological foundations of the coherence and phase figures.

The total number of activation variables resulting from 19 locations, 5 bandwidths and 4 parameters (excluding symmetry) is 380. The symmetry measures produce 855 variables. The total number of connection measures resulting from 19 locations, 5 bandwidths and two parameters is 1710. The resulting total number of variables under consideration is 2945. For each of the 85 subjects the resulting 250 epochs (1 second duration) were visually analyzed for artifacts and marked for deletion if they appeared to be significantly affected by artifact issues (eye movements, muscles activity).

4-PROCEDURE

The eyes closed data was collected as part of a larger experiment during which subjects underwent approximately 1 to 1 ½ hours of testing during which a total of 28 cognitive tasks were administered. The eyes closed condition was the first task which was undertaken in a series of cognitive challenge tasks.

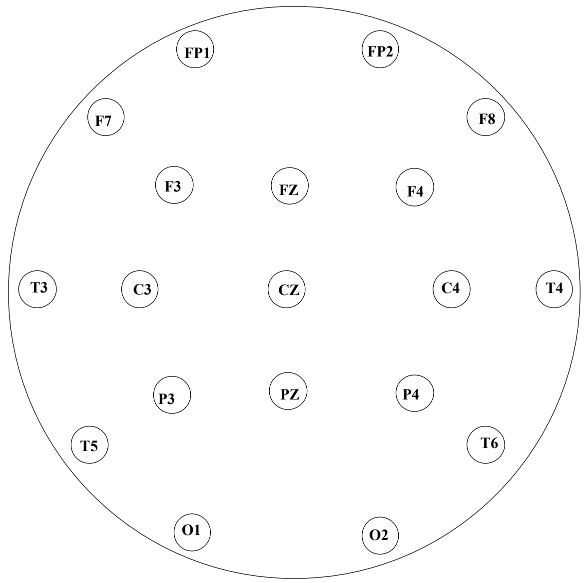
5-DATA ANALYSIS

The raw data, once artifacted, was analyzed with the Exporter program available from Lexicor Medical Technologies. The Exporter software program was commissioned by the experimenter to solve the cumbersome time problem of obtaining the required figures from the raw data file. The Exporter program was written by the programmer of Lexicor, under guidance by the experimenter. 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. The Exporter program was employed with all the subjects to generate the raw values for the variables.

With 2945 variables available for inspection, significance by chance alone becomes a significant problem. The following analysis was employed to determine significance. Setting the alpha level to .05 would result in 147 significant findings (of the 2945 variables under consideration) by chance alone. To reduce this statistical problem to manageable levels the following considerations were taken into account. Statistical significance was considered in view of the parameter under consideration. For example, in terms of one of the activation measures (relative power, etc.) there are 19 locations and 5 bands, resulting in 95 possible significant findings. An alpha level of .05 would produce approximately 5 significant findings by chance alone. The experimenter decided that at least two adjacent locations are activated in the same bandwidth before a result could be considered significant. Additional criteria included if a location was significant across different activation measures or if there were three locations, which were significant in a particular activation measure. If it assumed that the 5 chance findings are randomly distributed, then they would be distributed equally among the five bands. To require that two locations be activated in the same band and require an additional proximity of location lowers the chance factor significantly. The probability of a second significant finding in close proximity to the first is determined in part by the location of the first. For example, T3 has 5 locations (of the 18 remaining) which would be considered close enough, while Cz has 8 locations. Thus the probability for T3 is .05*.27 or .0146 All the additional activation measures are handled in a similar manner.

In terms of the relationship variables (coherence and phase) the problem is similar. Each band generates 171 relationships between all locations (for phase and coherence separately). For the 5 bands under consideration there are a resulting 1710 variables (all bands, phase and coherence separately or 5*2*171). With an alpha level of .05, there would be 85.5 significant findings by chance alone. Thus among the 10 categories (5 bands and 2 relationship variables) it is expected by chance that each category (band-relationship, i.e. phase beta1) would have about 8.5 significant relationships. The probability of one relationship being significant by chance alone is .049 (given 171 choices). The probability of a second significant relationship in the same band from the same location is .049*.044 or .002. The probability of a third significant relationship from the same location in the same band is .049*.044*.038 or .00008. The experimenter required three significant relationships at the .05 alpha level for a relationship to be considered significant.

Figure I-
Standard Nomenclature for Positions in 10-20 System



RESULTS

EXPLANATION OF FIGURES

The figures presented indicate the 19 locations of the 10-20 EEG system. Figure #1 presents the standard 10-20 system and the standard labeling of positions. Figure #2 presents the variables for which t-tests indicated significant differences as discussed in the data analysis section. Certain positions were eliminated to allow a clearer presentation of the results. The filled circles represent the areas activated (in terms of magnitude, relative power, peak frequency, and amplitude asymmetry) to a significant level according to the previous discussion of significance. The lines represent the significant levels of the respective phase and coherence levels. Each head figure is labeled on top with the parameter under consideration. Only the following variables require identification for figures #1 and #2.

CT – coherence Theta: CA-coherence Alpha: PT-phase Theta: PB1-phase Beta1

RPB1 – relative power of Beta1: PKAB1-peak amplitude Beta1: PKAB2: Peak Amplitude Beta2: MB1-magnitude Beta1: MB2-magnitude Beta2

RESULTS OF DISCRIMINANT ANALYSIS

To determine if the upper frequency bands were relevant to the brain injured situation an analysis of the significant differences between the mild brain injured and normals was conducted for those subjects who were within one year post accident and with no significant loss of consciousness. The results were in line with the variables employed in the Thatcher discriminant, in that there was a decrease in the relative power of alpha activity predominantly in the posterior portion of the brain and diffuse, broad decreases in the Alpha coherence values (both long and short range connections). There was also a significant decrease in the phase Beta1 activity originating from the T5 position to almost all frontal and central positions. As the Thatcher discriminant was based upon a much larger sample, it is clearly superior in identifying the pattern indicative of a mild brain trauma. Employing the relative power and coherence values (Alpha) obtained with the 14 subjects did not result in a useful discriminant result.

To ascertain the usefulness of the higher frequencies, a discriminant analysis, which consisted of 31 variables, was conducted. Variables which had been useful in differentiating between all brain injured (including those who were greater than one year post accident, without significant loss of consciousness) and normals were employed. Only the high frequency differences were employed. Table #2 presents those results. Twenty seven of the 31 variables involved the frontal lobe positions. Variables were chosen on the basis of Figure #2. Figure #2 presents those variables where there was a significant difference (.05 level) between the brain injured (no significant loss of consciousness) and normal subjects across the entire time range.

Table #2
High Frequency Discriminate, Subjects within 1 Year of Accident

Group	% Correct	Head Injured	Normals
Head Injured	100	14	0
Normals	100	0	52
Total	100	14	52

Rows: Observed Classifications
Columns: Predicted Classifications

When the same variables were employed to assess their discriminating ability with all brain injured subjects across all time periods (no significant unconscious period), the variables produced the following table (#3) of hits and misses.

Table #3
High Frequency Discriminate across all time periods

Group	% Correct	Head Injured	Normals
Head Injured	87.1	27	4
Normals	96.15	2	50
Total	92.77	29	54

Rows: Observed Classifications
Columns: Predicted Classifications

When the subjects were split in half on an alternating random basis into groups A and B, the following results were obtained. Group A (N=15) achieved a 100% hit rate for discriminating between brain injured and normals and the discriminant result for group B was 64% for the brain injured group (N=14) and 96% for the normals (N=52). Thus the high frequency ranges are useful in differentiating between normals and brain injured subjects. Introducing the unconscious subjects into the discriminant significantly reduced the power of the variables to differentiate (hit rate of 58% for brain injured subjects).

Twenty seven of the subjects underwent a standard (sampling up to 32 Hertz) eyes closed condition which evaluated the subjects with the Thatcher database. The Traumatic Brain Injury Discriminant function was employed for all subjects. Of the 39 subjects (including both with (N=7) and without (N=32) a significant period of unconsciousness), the discriminant correctly identified 26 of 32 subjects (81%) (no significant unconscious period) as brain injured and 5 of the 7 subjects (71%) with significant periods of unconsciousness. A significant period of unconsciousness is defined as a period of unconsciousness greater than 20 minutes. If the subject was within one year of accident, the discriminant correctly identified 93% of the brain injured subjects. Table #4 presents the analysis of the time since injury and the correct identification of a brain injury with the Thatcher Discriminant. The criteria for identification with the Thatcher discriminant was either of the two samples taken which indicated a greater than 50% probability that the subject had experienced a traumatic brain injury. When a cell has two numbers in it, it is representing those subjects without a significant period of unconsciousness (first number) and those with a significant period of unconsciousness (second number, marked with a u).

Table #4

Effectiveness of Thatcher Discriminate across all subjects

Hit/Miss	<1 Yr.	1-3 Yrs.	3-10 Yrs.	10-20 Yrs	20-43 Yrs	Total
Hit	**14**	**5-1u**	**4-2u**	**1**	**2-2u**	**31**
Miss	**1**	**2**	**1-1u**	**2**	**0-1u**	**8**
Total	**15**	**8**	**8**	**3**	**5**	**39**

< means under

Of the 52 normal subjects involved in the analysis, 40 subjects had the MTBI discriminant function conducted. The discriminant function had a false hit rate of 52%. When an additional 23 subjects (19 normals, ages 13-14, and 4 learning disabled subjects) were included the false hit rate dropped to 33%.

To evaluate whether time had a healing function on the problems caused by a brain injury, a correlational analysis was conducted between the variables which were significant in discriminating between normals and brain injured subjects (Figure #2) and the time since the accident. A positive significant relationship would indicate that the greater the time since the accident the higher the value of the variable. This could indicate that time had a healing/improving effect on the connections which were affected by the brain injury. None of the values correlated positive with the time variable, reflecting no healing effect of time with these variables.

To determine if the variance between the groups was a significant factor in the analysis, an analysis of variance was conducted on the variables in question. Employing the raw values and Levene's Test for Homogeneity of Variances on the variables (Figure #2) which indicated significant differences, 12 of the 64 variables showed significant differences (.05 alpha) in the variances, 10 of these variables involved the FP1 position (relative power, coherence theta, coherence and phase Beta2). Six of these variables were involved in the discriminant functions (which involved 31 variables). As it becomes an important clinical question to be able to separate out the effects of a previous brain injury upon a more recent one, a correlational analysis was conducted to discern if there was a pattern of change between the subjects who were under one year post accident and those subjects greater than a year post accident (no significant loss of consciousness). A discriminant analysis was conducted employing the log10 values of the resulting variables which were shown to be significant (as displayed in Figure #3). The results are presented in Table #5. There were nine variables which constituted the discriminant.

Table #5
Effects of time on Recovery

Group	% Correct	< 1 Yr.	> 1 Yr.
< 1 Yr.	85.71	12	2
> 1 Yr.	94.12	1	16
Total	90.32	13	18

< means under : > means greater than
Rows: Observed Classifications
Columns: Predicted Classifications

Of note in Figure #2 is an improvement in the connections and a decrease in amplitudes, magnitudes and relative power. This result mirrors the Randolph, C. et al. (5) results which indicated increased amplitudes in the posterior region (O1, O2) under activation conditions. His subjects were within 2-4 years of the accident.

Discussion

This research was part of a larger research project to understand how QEEG parameters relate to cognitive functioning in normals and brain injured subjects. Previous attempts to uncover differences between normals and brain injured subjects has focused on the eyes closed condition and frequency ranges under 32 Hertz. This research attempted to extend the frequency range (up to 64 Hertz) as well as the type of parameters under consideration in order to include peak frequencies and peak amplitudes. The analysis of the results indicated that the high frequency range (32 to 64 Hertz) can offer significant information in terms of differentiating between mild brain injury and normals. A discriminant function based solely on the high frequency range obtained a 100% correct classification of normals and mild brain injured (subjects within one year post accident) and 87% across all years.

The Thatcher discriminant, although based upon subjects within one year of accident, proved useful is distinguishing subjects up to 43 years post accident. The discriminant was also able to correctly identify (71%, 5 of 7 subjects) subjects who were rendered unconscious as a result of the accident (even though this group was not studied in the original research).

Combining the Thatcher discriminant with the high frequency discriminant resulted in a 100% correct classification among 39 brain injured subjects (across all time periods and including significant periods of unconsciousness) for which data was available. It appears that a mild brain injury will have significant effects on the ability of the frontal lobes to communicate within the frontal lobes and to the posterior portions of the brain in terms of the high frequency Hertz ranges. The predominant effect is on the long distance cortico-cortico connections. Of particular note is that the connections are predominantly inter-hemispheric connections (across hemispheres). Ignoring the Fz-Cz-Pz positions, there are 41 inter-hemispheric connections and 23 intra-hemispheric connections involved in the discriminant, yet only the Fp1-Fp2 and F7-F8 of the inter-hemispheric connections involved homologous connections.

There is an appearance of inconsistency in the results between the Thatcher discriminant and the values obtained in this study which require comment. The predominant effect of a brain injury (in the Thatcher database) on the coherence values of Alpha was an increased value of coherence. The present study found decreased phase values in the upper Beta bands and increased values in the Theta band. The band definitions were not exactly the same, as Alpha was defined as 7-13 Hertz in the Thatcher study and 8-13 Hertz in the present study. Although the exact specifications of the bands appears different in terms of the increased values, the general power of increased coherence values in the lower frequency ranges and decreased connectivity patterns in the upper bands is maintained. An additional problem in this study is the subject to variable ratio. With only 84 subjects in the discriminant, and given a normally acceptable ratio of 10 subjects to 1 variable, there could be only 8 variables allowed for analysis. Because of this limitation, the results of this study can only be considered preliminary and not definitive.

In terms of Roland's (6) analysis of the cytoarchitecture of the cortical layer the effect of the mild brain injury is either a disturbance of the pyramidal neurons in layer II or III, as the significant differences reside both in inter and intra cortical connections, a disturbance in the myelinated fibers which connect the regions, or possibly an increase in the Gaba activity (responsible for inhibition of activity).

A more discouraging result was obtained when the time difference from the accident and the evaluation was analyzed. The analysis was conducted to ascertain if "time heals". The results indicated that time does not heal in terms of the high frequency variables. This result is a mild contradiction to the Thatcher result, who found slight improvement (within one year) in the values employed for the discriminant Figure #2, however, does indicate that there is improvement in terms of decreased activation levels and increased connectivity. The discouraging result is echoed in the ability of the Thatcher discriminant function to correctly identify subjects as brain injured even though there has been 20-43 years since the accident. A longitudinal design would provide a more definitive answer, however, to this question.

From a clinical point of view this finding represents a double edged sword. It allows the clinician to go further back in time in terms of the usefulness of the Thatcher discriminant and allows subjects with significant periods of unconsciousness to be evaluated with the discriminant. However, to discriminant the effect of old injuries requires further analysis. Although the sample size is small, the analysis conducted does present the encouraging possibility that this discriminating ability is available.

A related and important theoretical question with significant practical applications is how do these parameters affect cognitive functioning. This question and others will be the focus of the future analysis of the data obtained with 151 subjects involved in numerous cognitive challenges.

There were other possible approaches to the analysis of the data such as development of discriminant with a subgroup and confirmation with the second group. However, this research is an exploratory analysis as clinical usefulness requires greater sample size and independently developed and validated discriminant analysis.

The effect of other variables (emotional status, intelligence level, previous brain injuries) into this analysis requires notation. Table #1 shows the differences between the groups in terms of Shipley IQ scores. It is certainly the case that head injury will generally affect problem solving ability (hence the Abstraction score). Verbal skills, however, are generally considered the least affected. The statistically significant difference between the brain injured group and normals in terms of both the Verbal and Abstraction Raw scores belies a possible preexisting difference in the groups.

An additional factor is the effect of emotional differences between the groups. Twenty-three of the 32 brain injured subjects had received a diagnosis of Post Traumatic Stress disorder and 5 an overlapping or separate diagnosis of depression. Hughes and John (3) note that depression (unipolar) is marked by increases in alpha and theta, asymmetry and hypocoherence in anterior regions. Bipolar depressed patients are marked by decreased alpha and increased beta activity. Hughes and John (3) 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. This pattern of results for depression is not totally consistent with the results of this study, and thus cannot fully explain the results. Previous research has not addressed the effect of a previous brain trauma. Six of the subjects in this research had a history of a previous head trauma.

The limitations of discriminant function analysis in delineating between clinical groups has been discussed by Duffy et al (1) and in the brain injured situation in specific by Nuwer, M. (4). One of the primary problems with this approach is the requirement of uncontaminated group membership. To differentiate between clinical groups, the groups must not have overlapping membership in different clinical conditions. As this research included head injured with Post Traumatic Stress disorder, the results are potentially contaminated by this overlapping diagnosis. Nuwer's conclusion regarding the lack of usefulness of the QEEG in the brain injured situation has challenged by Hughes and John's (3) 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 and John's (3) most recent and most extensive review of the literature to date in terms of decreased alpha activity and decreased coherences.

The value of the results of this study reside not only in their potential discriminating power, but in their ability to direct rehabilitation efforts. The field of Neurotherapy (EEG biofeedback) has been growing rapidly for the past several years and has been demonstrating its effectiveness in a number of clinical and cognitive conditions. This results of this research can direct the interventions in a very specific manner.

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