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A QEEG Activation Methodology That Obtained 100% Accuracy in the Discrimination of Traumatic Brain Injured from Normal and Does the Learning Disabled Show the Brain Injury Pattern?

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Abstract

Previous research has focused on determining whether the quantitative EEG (QEEG) can discriminate a traumatic brain injury (TBI) participant from a normal individual. The research has differed with respect to the critical variables involved in the discrimination task. All the research has limited its approach to the collection of eyes-closed data and most confine themselves to less than 32 Hz. The present research employs four cognitive activation tasks, an eyes-closed task, 19 locations, Spectral Correlation Coefficient (SCC) and phase algorithms in the beta2 frequency range (32–64 Hz), and the relative power of beta2 in six frontal locations to obtain 100% correct identification in original discriminant analysis. In addition, 50 random misclassifications—involving different participants—across the five tasks in a group of 196 subjects were correctly identified as misclassifications. To determine if a learning disability would show a similar pattern to a TBI pattern, a preliminary analysis of a group of 94 normal and learning disability (LD) participants were examined for their QEEG differences. The pattern evident in the analysis for the LD group (decreased coherence and phase alpha) was not the pattern evident in the TBI group, while the TBI pattern of decreased coherence and phase beta2 was not dominant in the LD group.

Keywords: quantitative EEG; traumatic brain injury; discriminant analysis; TBI discriminant; cognitive activation QEEG

Background

Previous research which has addressed the issue of statistically discriminating traumatic brain injury participants from normal individuals include publications by Thatcher, Walker, Gerson, and Geisler (1989); Thatcher, Biver, McAlaster, and Salazar (1998); Hughes and John (1989); Tabano, Cameroni, and Gallozzi (1988); Trudeau et al., (1998); Barr, Prichep, Chabot, Powell, and McCrea (2012); Thornton (1997, 1999, 2000, 2003, 2014); and Thornton and Carmody (2009).

Tabano et al. (1988) investigated posterior activity of subjects (*N* = 18) at 3 and 10 days following a mild traumatic brain injury (MTBI) and found an increase in the mean power of the lower alpha range (8–10 Hz), a reduction in fast alpha (10.5–13.5 Hz) with an accompanying shift of 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. They did not conduct a discriminant analysis of traumatic brain injuries (TBI) vs. normals.

Thatcher et al. (1989) were the first to attempt to conduct a discriminant function analysis. They used the eyes-closed QEEG data to differentiate between 608 MTBI adult patients and 108 age-matched controls and obtained a discriminant accuracy rate of 90%. Moderate to severe cases were not included in the analysis, nor was the high frequency gamma band (32–64 Hz) or cognitive activation conditions. The useful QEEG measures included increased frontal theta coherence (Fp1–F3), decreased frontal beta (13–22 Hz) phase (Fp2–F4, F3–F4), increased coherence beta (T3–T5, C3–P3), and reduced posterior relative power alpha (P3, P4, T5, T6, O1, O2, T4). Three independent cross validations (reported within the original research) resulted in accuracy rates of 84%, 93%, and 90%.

Thatcher et al. (1998) were able to demonstrate a relationship between increased theta amplitudes and increased white matter T2 Magnetic Resonance Imaging (MRI) relaxation times (indicator of dysfunction) in a sample of mild TBI subjects. Decreased alpha and beta amplitudes were associated with lengthened gray matter T2 MRI relaxation times. The subjects were 10 days to 11 years post-injury. This study integrated MRI, QEEG with eyes closed, and neuropsychological measures in a sample of MTBI subjects. Thatcher et al. (2001) employed this method to develop a severity of brain injury value.

One review of the research in the TBI area indicated that numerous eyes-closed EEG and QEEG studies of severe head injury (Glascow Coma Scale [GCS] score of 4–8) and moderate injury (GCS score of 9–12) have agreed that increased theta and decreased alpha power (microvolts) and/or decreased coherence and symmetry deviations from normal groups often characterize such patients (Hughes & John, 1999). The authors asserted that changes in these measures provide the best predictors of long-term outcome. The Thatcher discriminant function (Thatcher et al., 1989) correctly identified 88% of the soldiers with a blast injury history and 75% with no blast injury history (Trudeau et al., 1998).

Other studies have reported that similar QEEG abnormalities are correlated with the numbers of bouts or knockouts in boxers (Ross, Cole, Thompson, & Kim, 1983) and with professional soccer players who frequently used their heads to affect the soccer ball's trajectory ("headers"; Tysvaer, Storli, & Bachen, 1989). Neither of these research reports attempted to develop a discriminant function analysis.

Barr et al. (2012) took EEG recordings from five frontal locations (F7, Fp1, Fp2, F8, and a location below Fz) immediately post-concussion and 8 and 45 days after. They examined the frequency range up to 45 Hz on measures of absolute power, relative power, mean frequency, coherence, symmetry, and a fractal measure. Using a brain injury algorithm, abnormal features of brain electrical activity were detected in athletes with concussion at the time of injury, which persisted beyond the point of recovery on clinical measures. Features that contributed most to the discriminant applied in this study included

- relative power increase in slow waves (delta and theta frequency bands) in frontal;
- relative power decreases in alpha 1 and alpha 2 in frontal regions;
- power asymmetries in theta and total power between lateral and midline frontal regions;
- incoherence in slow waves between fronto-polar regions;
- decrease in mean frequency of the total spectrum composited across frontal regions; and
- abnormalities in other measures of connectivity, including mutual information and entropy.

A resulting discriminant score was employed to distinguish between the TBI and normal group. If the discriminant score was above 65, there was a 95% probability that the individual had experienced a TBI. The average discriminant score changed from the immediate post-concussion score of 75 to a score of 55, 45 days later; thus rendering its ability to discriminate 45 days after the original concussion not as useful as would be desired. The TBI's cognitive status, as assessed with neuropsychological measures, had returned to the "normal" range at day 45, although brain abnormalities were still present (TBI n = 59). The researchers did not internally attempt to replicate the findings within the sample that they had obtained.

Leon-Carrion, Martin-Rodriguez, Damas-Lopez, Martin, and Dominguez-Morales (2008) documented the discriminant ability of the QEEG to accurately classify brain injury in 100% of the "training set sample" (n = 48) and obtained a 75% correct classification in "an external cross-validation sample" of 33. The average time between the QEEG evaluation and incident (TBI, CVA) was 22 months. The authors noted that "coherence measures were the most numerous variables in the function," employing the frequency range of 1–30 Hz.

Previous research by Thornton (1997, 1999, 2000) focused on the damage to the Spectral Correlation Coefficients (SCC; based upon the Lexicor algorithms) and phase values in the beta2 (gamma; 32–64 Hertz) range when comparing the traumatic brain injured subject to the normal group during eyes-closed and different cognitive activation tasks. The TBI sample size ranged from 22 to 32 with 52 normal participants in the 1999 and 2000 studies. Lexicor Medical Technology (Boulder, CO) company developed their own algorithms for coherence and phase. The coherence measure algorithms were not the same as employed in the Barr et al. (2012) study.

The Thornton results (1997, 1999, 2000) did not indicate any deficits in the amplitudes or relative power of delta, theta, or alpha. In the Thornton (2003) article addressing auditory memory, the alpha level was set to .02 due to high number of significant findings in the beta2 SCC and phase values predominantly in the values involving the frontal lobe. The TBI group showed lower beta2 coherence (SCC) values. The article studied the relations between the QEEG variables and memory performance in 85 TBI patients and 56 normal subjects.

Thornton and Carmody (2009) and Thornton (2014) investigated the use of frontal beta and delta activity as well as coherence (SCC) and phase relations within the frontal locations to distinguish between TBI and normal participants. The Thornton (2014) chapter obtained a 97.5% to 100% accuracy rate in the discrimination analysis.

Methods

The participants underwent a cognitive QEEG evaluation, which consisted of an eyes-closed condition (300 seconds), auditory attention task (200 seconds), visual attention task (200 seconds), four auditory memory tasks (200 seconds), one reading task (100 seconds) in addition to a problem-solving (Ravens matrices) task. The auditory attention task consisted of the participant listening to the sound of a pen tapping on a table while their eyes were closed, and raising their right index finger when they heard the sound. The visual attention task required the participant to look at a page of upside down Spanish text. The participant was asked to raise their right index finger when a laser light was flashed on the text. The auditory memory tasks required the participant to listen to four individually administered stories with their eyes closed, quietly recall the story, and then repeat the story back to the examiner. The reading task required the subject to read a story presented on a laminated sheet for 100 seconds, quietly recall the story while their eyes are closed, and then recall the story to the examiner. During all of these tasks QEEG data was collected. The data for the eyes-closed condition and four cognitive activation tasks (auditory and visual attention, listening, reading) were employed for the discriminant analysis.

Participants

A different number of participants were available for the different tasks. There was a range of 162–197 subjects involved in the different conditions. The listening task had the largest number of participants. The average age of the total sample (listening task data) was 37 with a range between 9.4 years to 72.42 years. There were 95 males and 102 females in the listening task group (N = 197). There were 88 participants classified as TBI and 109 participants classified as normal. The time between the date of the head injury and evaluation ranged from 12 days to 30 years. The child group consisted of 49 normal children (average age = 10.6) and 45 children (average age = 10.6) who could be classified as having a learning disability (LD). There were 63 males and 31 females in the child sample. Thirty-seven of the 45 LD group were males, not an untypical finding. The subjects were protected and the data was collected in accordance with the Declaration of Helsinki.

Quantitative EEG (QEEG) Measures

Activation / Arousal Measures

RP: Relative Magnitude/Microvolt or Relative Power: the relative magnitude of a band defined as the absolute microvolt of the particular band divided by the total microvolt generated at a particular location across all bands

Connectivity Measures

C: Coherence or Spectral Correlation Coefficients (SCC): the average similarity between the waveforms of a particular band in two locations over the epoch (one second). The SCC variable is conceptualized as the strength or number of connections between two locations and is a correlation of the magnitudes.

P: 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.

Results

Figure 1 presents the relations that were significantly below the normative reference group (*p* < .05) for the SCC and phase values. The blackened circle is the indication that the location is the origin of a metaphorical flashlight, which is sending out a beam to three other locations. The flashlight locations were chosen according to the number of significant relations emanating from that location. In deciding if whether the source of a connection between two locations (A and B) is A or B, the location with the higher number of other significant relations was determined to be the source. It is of interest to note that the deficit patterns were distributed throughout the 19 locations and were not primarily focused on frontal locations, contrary to a commonly held belief that a head injury's primary location of injury is the frontal lobes. The most affected locations evident in Figure 1 appear to be the T4 location and posterior locations (T5, O1, O2, T6) for the SCC relations. There is also a pattern, mostly emanating from frontal locations, of the effect occurring across the hemispheres for more distant locations, while posterior flashlights involved mostly shorter connections. Figure 2 presents summary figures of all the significant relations (coherence and phase) as well as the frontal RPB2 locations. As the figures indicate, the effect is broad and diffusely located.

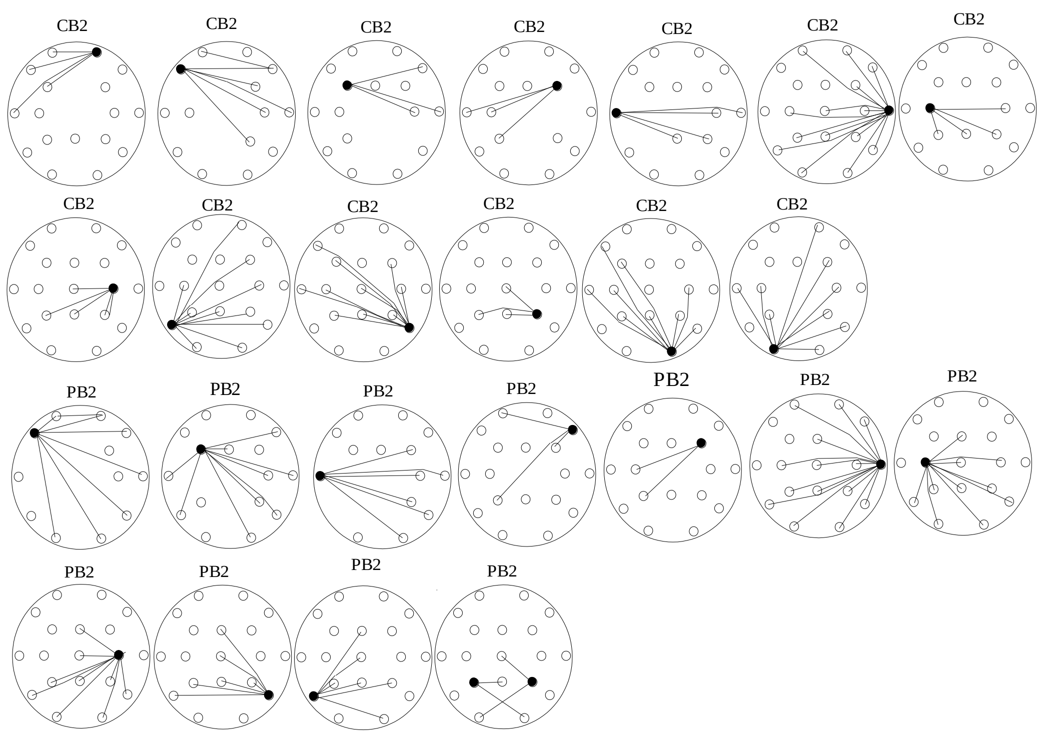

Figure 1. Significant SCC and phase deficits in the TBI participant. CB2 = Coherence (SCC) Beta2; PB2 = Phase Beta2.

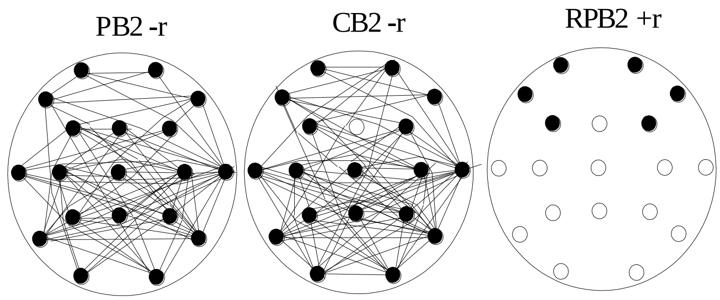

Figure 2. Summary head figures. CB2 = Coherence (SCC) Beta2; PB2 = Phase Beta2; RPB2 = Relative Power Beta2.

The average standard deviation (*SD*) difference between the normal and TBI group for the SCC variable was .47, and .44 for the phase variables for all the variables, which is significant at the .05 alpha level. The frontal relative power values of beta2 indicated a similar average *SD* value difference of .47 between the TBI and normal group.

Tables 1–5 present the resulting discriminant analysis for the five tasks. As the tables indicate, the discriminant analysis was 100% effective in distinguishing between the TBI and normal participants. The variables employed were the SCC and phase values in the 32–64 Hz range and the RPB2 values for the six frontal locations indicated in Figure 2.

Table 1
Classification Matrix (EC) – Eyes Closed

	EC	**TBI**	**Normal**
	Correct	p = .56	p = .44
TBI	100	102	0
Normal	100	0	81
Total	100	102	81

Table 2
Classification Matrix (AA) – Auditory Attention

	AA	**TBI**	**Normal**
	Correct	p = .51	p = .49
TBI	100	90	0
Normal	100	0	86
Total	100	90	86

Table 3
Classification Matrix (VA) – Visual Attention

	EC	**TBI**	**Normal**
	Correct	*p* = .52	*p* = .48
TBI	100	87	0
Normal	100	0	81
Total	100	87	81

Table 4
Classification Matrix (Listen) – Auditory Memory

	EC	**TBI**	**Normal**
	Correct	*p* = .45	*p* = .55
TBI	100	88	0
Normal	100	0	109
Total	100	88	109

Table 5
Classification Matrix (RS) – Reading

	EC	**TBI**	**Normal**
	Correct	*p* = .46	*p* = .54
TBI	100	75	0
Normal	100	0	87
Total	100	75	87

To determine if the discriminant algorithm could accurately indicate a misclassification, five TBI subjects and five normal subjects were misclassified for each task as to their status and the discriminant analysis was recalculated to determine if the inaccurate classification was identified. Ten different subjects were selected for each task for a total of 50 misclassifications. The discriminant reanalysis was 100% correct in the identification of all of the misclassifications.

Could a Learning Disabled Participant Be Identified as Brain Injured?

A potential diagnostic problem would be the presence of a pre-existing learning problem, which could show a similar pattern to a TBI. A preliminary investigation of this problem was undertaken by the author with the clinical data available. Two problems were initially evident. One is a lack of sufficient adult learning disabled (LD) to compare to adult TBI group. The second problem is the presence of a strong developmental pattern showing increases in almost all coherence and phase relations. This developmental pattern would negate the use of comparing the values of children to normal adults or TBI adults, as the child's numbers would be lower strictly due to development patterns. Thus, the only viable method to assess for the diagnostic problem would be to compare children with LD to the normal control group and determine if the LD child deviant patterns from the normative reference group would be similar to the adult TBI patterns from a corresponding adult normative reference group. The reasonable assumption is that a child's TBI pattern would be the same as an adult's TBI pattern. Figure 3 presents the results of this analysis for a group of 49 normal children and 45 children who pursued EEG biofeedback treatment for cognitive/learning problems. To allow the reader to see the more dominant patterns, the circles were blackened for locations that contained three significant relations.

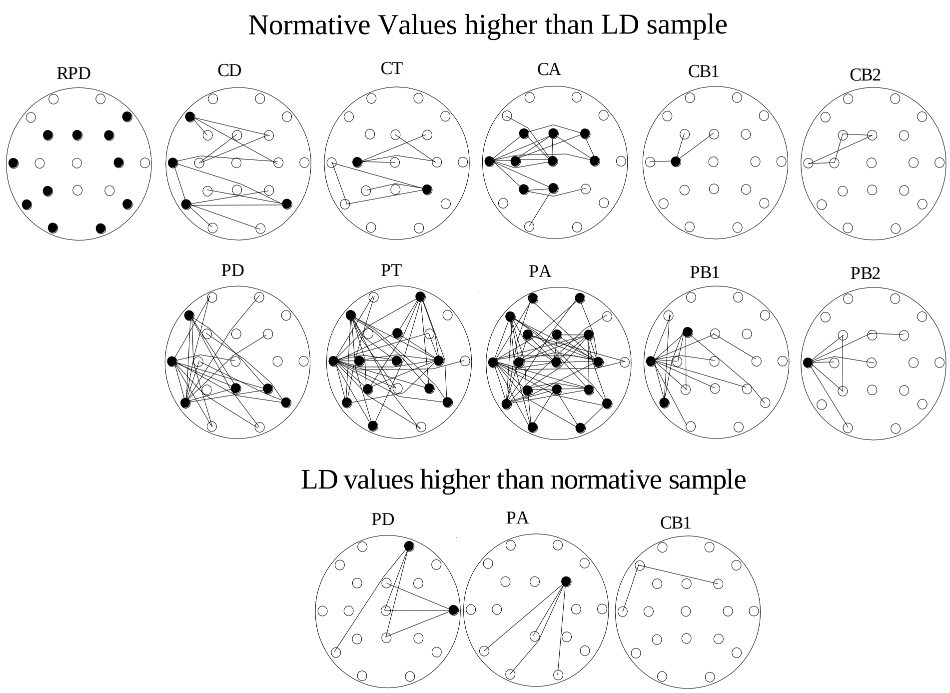

Figure 3. LD vs normal patterns during reading task. CD = Coherence Delta; CT = Coherence Theta; CA = Coherence Alpha; CB1 = Coherence Beta1; CB2 = Coherence Beta2; PD = Phase Delta; PT = Phase Theta; PA = Phase Alpha; PB1 = Phase Beta1; PB2 = Phase Beta2; RPD = Relative Power Delta.

As Figure 3 indicates, the LD pattern shows deficit patterns predominantly in the phase theta and alpha variables from the F7, T3, and T5 locations. The coherence and phase beta2 variables do not appear strongly involved in the deficit patterns. While preliminary, it is encouraging that this diagnostic potential problem may not present a real problem. Other cognitive tasks underwent a similar analysis. While the patterns differed, there was no strong evidence of an overwhelming deficit in the coherence or phase beta2 values in the LD group, which was evident in the TBI group. Correspondingly, in the TBI group the pattern of overwhelming decreased values in the lower frequencies was not evident. However, there are several qualifications with this data. The diagnostic issues with the LD group were not validated with standardized psycho-educational or neuropsychological batteries. In addition, there were uncertain issues with respect to a history of head injury in the LD sample, which confuses the diagnostic issue. What, however, is also evident in the data is that the LD sample does not show the standard pattern of ADD or ADHD as there were no elevations in theta or alpha relative power.

Discussion

A method that can obtain 100% accuracy is a valuable aide in the diagnosis of a traumatic brain injury and is a valuable asset to the medical personnel in charge of rendering the diagnosis. It is important, however, that the method and results be further replicated for confirmation. Nevertheless, in the case of a pre-existing concussion the software would not be accurate in the determination of a present concussion. In the sports arena, this problem could be addressed by a baseline evaluation prior to the athletic season. The concern of a pre-existing learning problem appearing as a TBI does not appear to be an issue, according to some preliminary data analysis the author has available. However, the data analysis involved children and the conclusion extrapolated to adults. A sounder basis for the conclusion would be obtained with adolescent and adult learning disabled and an adolescent and adult TBI group.

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