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Event Related Potential Changes In A Two-Stimulus Auditory Oddball Task In Concussed College Athletes: A Linguistic Component

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EVENT RELATED POTENTIAL CHANGES IN A TWO-STIMULUS AUDITORY
ODDBALL TASK IN CONCUSSED COLLEGE ATHLETES:
A LINGUISTIC COMPONENT

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by

Paola G. Sanchez

2013

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ODDBALL TASK IN CONCUSSED COLLEGE ATHLETES:
A LINGUISTIC COMPONENT

by

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Abstract

“Return to Play” decisions are done based on cognitive-communicative testing and clinical assessments; concussed athletes may benefit from electrophysiological testing for a more accurate representation of their recovery. The purpose of this study is to investigate the electrophysiological performance post-concussion analyzing the attentional differences using the traditional “oddball” paradigm with a CV linguistic component. Participants for this study were 6 male college athletes with a history of concussion and 10 participants with no history of concussion (controls). Athletes were evaluated using event-related potentials (ERPs) that were recorded during a consonant-vowel (CV) auditory oddball task. Both the P300a and P300b components were analyzed at the CPz, Cz, Pz and FCz central electrode sites. We hypothesized a significant difference in attentional ERP components of concussed individuals; the hypothesis was supported. There was a statistically significant difference between controls and concussed P300a latency at FCz. A statistically significant amplitude difference was also found at CPz between target stimuli detection vs. non-target stimuli detection in controls; no statistically significant difference was found for concussed athletes. Clinical Implications: Further research is necessary to clarify electrophysiological patterns post-concussion before implementation of ERP use in the clinical setting with individual participants.

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Chapter 1: Introduction

The annual incidence of sports-related concussion in the U.S, is estimated at 300,000, placing athletes at a 19 % likelihood of experiencing a concussion per season (ImPACT, Applications, Inc., Pittsburgh, PA, 2011). “Return to play” decisions are based on neurocognitive test results and clinical observation to account for individual differences in recovery. The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) is the neurocognitive test used internationally in concussion management of professional collegiate athletes. The ImPACT test results are based on behavioral performance but lack data based on the actual electrical activity of the brain. Although, neurocognitive testing provides accurate representation of cognitive recovery, implementation of additional instruments to detect electrophysiological changes is necessary.

Electroencephalograms (EEGs) have been used to investigate neural electrical activity associated with brain function with limited use in concussed individuals (Broglia, Pontifex, O'Connor, Hillman, 2009). This study proposes to use event-related potentials (ERPs) to examine the functional brain activity reflected in the electrical activity that is produced in the brain in response to unpredictable stimuli. The electrical activity is measured through the skull with electrodes that are attached to a skullcap. According to Handy (2005), ERPs provide real-time information in the millisecond range since it is time-locked to a specific stimulus event. The use of ERP is of vast significance since ERPs have a high temporal resolution that PET and fMRI lack. One of the simplest tasks used to record ERP components sensitive to cognitive variables is the “oddball” task, in which it is required to discriminate infrequent (target) stimuli from more frequent (non-target) stimuli (Rugg, Pickles, Potter, Doyle, Pentland & Roberts, 1993). As will be shown in the literature review, most of the studies on this topic have revealed

differences in a specific ERP component, the P300. The P300 component is evoked by infrequent but expected target stimuli and has been considered a marker of attention. Amplitude and temporal differences in the P300 component are characteristic of individuals who have suffered a concussion (Beaumont, Theoret, Mongeon, Messier, Leclerc, Tremblay, Ellemborg & Lassonde, 2009); such differences have been related to attention difficulties (Luck, 2005)

The current study aims to investigate the generality of electrophysiological changes post-concussion. Electrophysiological assessment would guide clinicians into a more exact return to play decision. Second, the study of the P300 wave would detect changes in attention, which is a fundamental process to higher-order cognitive processes such as memory, reaction time, and auditory comprehension. Cognitive processes such as attention should be studied in relative isolation using ERPs, before higher-order cognitive processes are evaluated using behavioral measures. The study of ERPs post-concussion and replication of findings will allow generality of the data becoming an important clinical tool in concussion management.

1.1 Concussion

A concussion or Mild Traumatic Brain injury has been defined as a “complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces” (McCrory, Meeuwisse, Johnston, Dyorak & Aubry, 2009, p. 341). A concussion may result in deficits of cognitive functioning, such as problems with concentration and memory, sleep disturbances and emotional changes. Most of the symptomatology resulting from a concussion generally resolves spontaneously within 7-10 days of the injury (McCrory et al., 2009). The majority of patients have completely recovered by 3 months, but a significant minority continues to have symptoms on a long-term basis (Potter et al., 2001). The persistent symptomatology resulting on chronic cognitive and neurobehavioral disturbances, is characteristic of the “Post-

Concussion Syndrome”, and such difficulties may be permanent (ImPACT, 2011). Receiving a second injury to the head before the athlete has fully recovered from the first injury may result in the “Second Impact Syndrome” (SIS) which can have catastrophic consequences and possible death. SIS has led to approximately 30-40 deaths in the past decade (ImPACT, 2011); emphasizing the need for additional recovery measures in concussion management. Behavioral measures have been used to assess recovery of cognitive function at different time points post-concussion. However, new developments, such as the use of EEGs, in sports related concussion management may also play an important role in the diagnosis and recovery processes.

1.2 ERP Component

EEGs provide important cognitive information through the functional interpretations of the ERP data. EEGs may be interpreted by analyzing ERP waveforms. An ERP waveform consists of a series of peaks and troughs; these voltage deflections reflect the sum of several relatively independent latent components (Handy, 2005). Thus, the sum of latent ERP components equals the ERP waveform. ERP components are measured in terms of latency and amplitude deflections locked to a specific stimulus event. Latency can be quantified with one of the following temporal measures: onset, peak latency, rise time, or duration (Handy, 2005). Amplitude implies the degree of engagement of an associated cognitive process. Therefore, a variation in amplitude is produced depending on the task demands imposed in the participant (Handy, 2005). The interpretation of an ERP waveform, by looking at the ERP components, is represented by a combination of a letter and a number. The letter is used as a label for amplitude polarity, with the “P” representing a positive-going deflection and a negative-going deflection represented by the letter “N”. The current study represents troughs and peaks accordingly. The letter is followed by a number that represents the temporal range in milliseconds (ms) after the

stimulus is detected by the brain. There are known ERP components that have been associated with specific cognitive processes such as the N400 (semantic wave), P300 (attention wave) and the P600 (syntactic wave).

Different ERP components are elicited after the presentation of either visual or auditory stimuli, and have been related to specific cognitive processes. Both the N400 and P 600 components, for example, are language–related components. The N400 is a negative-going wave that is typically elicited in response to a violation of a semantic expectation (Luck, 2005). Although a large N400 is elicited after a semantic violation, some N400 activity can be detected after the presentation of any content word. The P600 is a positive-going wave that is elicited by syntactic violations (Luck, 2005). When interested in looking at differences in language-related components in the semantic and syntactic domain, the N400 and P600 are important waves to analyze. The P300 wave, on the other hand, represents an attention component which is elicited by unexpected stimuli (Luck, 2005). The published P300 experiments conducted in concussed individuals demonstrate an amplitude decrease and a temporal delay during oddball task procedures. These P300 changes are thought to indicate a difference in attention which is a pre-requisite to successfully accomplish many other higher order cognitive processes. For the purpose of this study we will focus on the P300 component.

1.3 P300 ERP component

There are two subcomponents to the P300 wave elicited by an auditory stimulus; the P300a and the P300b (Luck, 2005; Squires, Squires, & Hillyard, 1975). Fusar-Poli et al., (2010), refers to the P300a as a “novelty detection” and the P300b as a “target detection”. According to Squires et al., (1975), the P300a is elicited by task irrelevant stimuli and has been considered to be a marker of involuntary orienting of attention and novelty. P300a changes are more noticeable

on the frontocentral area and typically occur around 280-350 ms (Luck, 2005). The P300b wave is a positive going wave which peaks at about 300-600 ms after the detection of infrequent targets embedded in a series of background stimuli (Handy, 2005). The amplitude of a P300 wave has been shown to be larger after the infrequent target stimulus, and as the target probability gets smaller (Duncan-Johnson & Donchin, 1977). Researchers have shown that the P300 amplitude is a manifestation of attentional allocation and stimulus probability (Duncan-Johnson & Donchin, 1977).

The P300b component is elicited by task-relevant stimuli (Luck, 2005) and has been associated with stimulus categorization (Donchin & Coles, 1988). Changes on the P300b are more noticeable on the central-parietal area of the brain and occur between 300-600 ms (Luck, 2005; Handy, 2005; Squires, Squires, & Hillyard, 1975). Opposed to the P300a, the P300b is evoked by an unpredictable but in some sense expected target stimulus (Luck, 2005). Thus, the participant must be attending to the task for the stimuli to evoke a P300b wave. Most researchers refer to the P300 meaning the P300b, which is important to consider when reviewing the literature. The current study will directly specify the subcomponent analyzed since it will be looking at both P300a and P300b for the specific focus on attention. The P300 component has been extensively studied in attention tasks where temporal and amplitude changes indicate activation of components of the attention network (Bassett, Jory & Barrett, 2001). The study of the P300 wave is of great significance to evaluate the attentional differences in auditory processing that occur after having a mild traumatic brain injury. Recent research on the P300 wave has shown amplitude decrease and latency delay in concussed individuals during auditory oddball paradigms.

1.3.1 P300 Amplitude and Latency

Differences in the P300 component amplitude and latency post-concussion may provide additional electrophysiological measures during the diagnostic procedure. According to McCarthy and Donchin, (1981), peak latency of the P300b component is understood to correlate with the time required to categorize a stimuli. However, latency is insensitive to factors such as motor preparation and stimulus response which affect reaction time by influencing response selection and execution. Therefore a latency delay would be an indicator of a delay in the processes involved in categorization. Amplitude reflects the degree of engagement of the associated cognitive process (Handy, 2005), in this case, attention. Other researchers suggest that the P300 amplitude may be influenced by the complexity of the task, probability and uncertainty (Luck, 2005). Therefore, both the P300 amplitude and latency, may be significant as measures of the changes in the degree of attention engagement and the time required to categorize the target stimuli, in individuals with a history of concussion.

1.4 Oddball Paradigm

The “oddball” paradigm has been used to assess the neurological reactions to unpredictable but recognizable stimuli. “The task used in most studies is a simple target detection (oddball) task, in which an infrequent target tone is intermixed with frequent nontarget tones” (Bruder, Kayser, Tenke, Amandor, Friedman, Sharif & Gorman, 1999, p. 267). Most developmental studies conducted to date have used a standard oddball paradigm on which two or more stimuli are presented repeatedly, but with different frequencies (Handy, 2005). Attention (P300) ERPs in the centro-parietal area have been specifically investigated to examine cognitive processes. P300 ERP amplitude attenuation (decrease) has been found in concussed patients, using the auditory oddball paradigm, even after neurocognitive testing results demonstrate

recovery (Theriault, De Beaumont, Gosselin, Filipinni & Lassonde, 2009).

1.4.1 Visual Oddball Paradigm

A number of studies have been conducted finding significant differences in ERPs recorded under visual oddball paradigms. Broglio, Pontifex, O'Connor, and Hillman (2009) found persistent decrease in P300 amplitude 3 years post-concussion recorded in a visual oddball task, although neurocognitive results showed recovery. Also, long term electrophysiological changes were found in multi-concussed athletes compared to single concussed athletes who had no wave changes when tested two years and seven months post-concussion (Beaumont, Brisson, Lassonde & Jolicoeur, 2007). This means either that athletes with a history of a single concussion have shown recovery in P300 amplitude or ERPs are not sensitive enough to detect changes during single concussions.

1.4.2 Auditory Oddball Paradigm

In agreement to visual oddball paradigms, both a P300 amplitude attenuation and latency delay has been found after a concussion. Recent investigation recorded under an auditory oddball task, found persistent P300a and P300b amplitude attenuation and latency delay even in athletes who sustained their last concussion 30 years prior to testing (Beaumont et al., 2009). Consistently, latency delays are also reported in closed head injury patients who sustained their last concussion 6 months prior to testing (Rugg, Pickles, Potter, Doyle, Pentland & Roberts, 1992). Of equal importance, a reduction in amplitude and latency delay of P300 waves has been noted in both symptomatic and asymptomatic athletes when compared to controls (Gosselin, Theriault, Leclerc, Montplaisir & Lassonde, 2006). These results show that although the patients were not symptomatic, their brain potentials were still affected. Although most of the studies do

not control for symptoms reported, the literature indicates that it would not be a contributing factor to inconsistency in findings.

However, contradicting findings have been reported when studying the electrophysiological changes post-concussion. Although most of the studies report a P300 amplitude attenuation, temporal differences are inconsistent across studies. Rugg, Cowan, Menagy, Milner, Jacobson and Brooks (1988), found smaller P300 amplitude but its latency was not significantly different from the control group. Additionally, inconsistent amplitude findings have also been reported. Potter, Bassett, Jory and Barrett (2001) reported no significant differences in the amplitude and latency of both P300a and P300b components. It has also been argued that oddball ERPs may not be sensitive enough to detect neuropsychological changes in MTBI, in an attempt to explain the similarity of P300 amplitude and latency between controls and individuals with concussion (Sivak, Kurca, Hladka, Zelenak, Turcanova-Koprusakova & Michalik 2008).

Findings in the recovery of the P300 are also unclear. Pratap-Chand, Sinniah, and Salem (1988), reported a P300 amplitude reduction and delay as soon as four days after the injury. However they reported return to normal P300 values 30 days after the injury. A recovery of the P300 component was also found 2 months post-injury, when studying individuals who received concussion feedback during the assessment period (Bierbrauer & Weissenborn, 1998). Although some researchers argue that the P300 wave continues to be affected as long as 30 years post injury, some studies report a normalization of the P300 value at 30 days or two months post-concussion. These differences may be related to the variations such as history of concussions for individuals considered for the study.

Although ERPs of individuals with a history of multiple concussions do not appear to show a *full* recovery, the literature indicates that there is electrophysiological recovery to some extent. However, the recovery pattern is unknown. This study attempted to fill this gap in the literature. Research on electrophysiological recovery using the auditory oddball task is limited, thus this study intended to investigate the changes in the P300 component at 3-7 days, 2 weeks, 1 month and 3 months post-concussion to establish a time frame where changes occur (a recovery pattern). However, due to time constraints and participants attrition after the first testing session, the recovery pattern could not be followed. The review of the literature clearly demonstrates significant variability among P300 amplitude and latency findings indicating that further research is required to clarify the electrophysiological changes post-concussion.

1.4.3 Variation of Traditional Oddball Paradigm

Further research noted that N2 waves were larger in amplitude and its peak latency was delayed related to stimulus categorization (Rugg et al. 1988). They suggested that the latency of the N200 wave may be a more sensitive measure of information-processing. ERPs of healthy participants have shown a right ear advantage for perceiving dichotic CV syllables, which was associated with a left lateralized N2 amplitudes in temporoparietal sites (Bruder, Kayser, Tenke, Amador, Friedman, Sharif & Gorman, 1999). Left lateralization that occurs after the syllable onset is due to the location of the main areas for language processing which are in the left hemisphere. Furthermore, the P300 component has been analyzed using CV syllable sounds during a continuous performance task (Shucard, Abara, McCabe, Benedict & Shucard, 2004). Shucard and colleagues (2004) reported greater P300 amplitudes on target sounds than non-target sounds when providing a motor response vs. non-motor (covert attention). Results indicate that adding a linguistic component does not interfere with the “oddball task paradigm”.

Following this premise a variation of the traditional auditory oddball task (tonal task) will be used with an added linguistic component.

To incorporate the detection of speech sounds which are acquired in early auditory development specific consonant sounds were selected. The acquisition of stop consonants is a natural process that results from auditory experience without the use of linguistic structure knowledge (Seebach, Intrator, Lieberman & Cooper, 1994). Research shows that prenatal auditory environment in addition to a model of neural modification caused by environmental exposure accounts for the acquisition of basic speech contrasts (Seebach et al., 1994). The phonetic features distinguishing English stop plosive consonants are voicing and place of articulation. This study will use stop plosive sounds differing by one phonetic feature; the place of articulation. The /ta/ and /ka/ syllables are both voiceless and stop plosive consonants and differ by place of articulation which is alveolar and velar placement respectively.

1.5 Purpose of Study

Based on the literature reviewed, the electrophysiological changes post-concussion using an auditory oddball task are not clear. There is great variability in P300 findings across studies. Although most of the findings indicate a decrease in the P300 amplitude, temporal changes are inconsistent. Furthermore, other studies have indicated no significant electrophysiological differences post-concussion. The review of the literature led us to believe that there is a need for further research on this area as well replication of studies to clarify the electrophysiological changes and promote generality.

The present study aims to answer the following research question. Is there a statistically significant difference on temporal and amplitude components of the P300a and P300b waves between concussed and non-concussed athletes across central electrode sites using an auditory

oddball task with a linguistic component? We hypothesize a significant difference on electrophysiological measures between controls and individuals with history of concussion.

Chapter 2: Methods

2.1 Participants

Eighteen college level males participated in the study. Participants' ages ranged from 18 years to 25 years with an average age of 22 years (see Table 2.1). Participants were male university students practicing sports (concussed group) and non-athlete students (control group) who attended to the University of Texas at El Paso. A sample of convenience was used to select the participants for this study. All participants included in the study were native English speakers, reported no history of psychiatric disease prior to the concussion, and passed the hearing screening at 500, 1000, 2000 and 4000 HZ at 30 dB HL. The first group was composed of 10 male, non-athlete participants with no history of concussion who served as controls. Non-athlete students were selected as controls to avoid biased results secondary to undiagnosed, unrecognized or non-reported history of concussions.

Table 2.1: Descriptive statistics on participant's characteristics

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Age	16	18.00	25.00	22.6250	2.30579
Time since injury in months	6	.00	108.00	40.0000	48.39835
History of Concussions	6	1.00	7.00	2.5000	2.34521
Valid N (listwise)	6				

The experimental group was composed of 8 male athletes with a history of single or multiple concussions who sustained their last concussion within a time range of 0-9 years prior to testing. Athletes who participated in this study were referred to the Concussion Management Clinic at the University of Texas at El Paso by their athletic trainer or physician. Specific details on the characteristics of participants with concussion are given in Table 2.2. Participants who

suffered a concussion were involved in one of the following sports: football (n=4), hockey (n=2) and/or soccer (n=2). A prospective participant failed the hearing screening and was not considered for the study. Two participants from the concussed group were excluded from the study; a history of meningitis and ADD/ADHD diagnosis were reported in the medical questionnaire.

History of seizures, 6 months after birth, was reported by one participant from the concussed group. However, the seizures ceased within a year post-birth; therefore, his data was included in the study. Another participant reported being diagnosed with “generalized anxiety disorder” after the concussion; his data was also included in the study. Two participants required hospitalization and underwent a Computed Tomography (CT) after experiencing their injuries; the CT scans were read normal. Total number of participants considered for the data analysis includes 10 controls and 6 athletes with a history of concussion. The two groups compared did not differ in terms of gender, age and education level. Participants were informed about the study purpose, risks and voluntary participation and gave consent to participate.

Table 2.2: Participants with history of concussion details

Age	Sex	TSI (years)	Nature of Injury	HOC	Persistent Symptoms
18	M	0	SRC-Soccer	1	No
22	M	1	SRC-Football	3	No
25	M	9	SRC-Hockey	7	No
25	M	8	SRC-Football	1	No
22	M	1	SRC-Soccer	2	No
25	M	1	SRC-Football	1	No

a. TSI: time since injury; HOC: History of Concussion; SRC: sports related concussion

2.2 Experimental Settings and Procedure

Male college participants provided a written informed consent form prior to testing. Procedures, benefits and risks related to the research project were comprehensively explained to each participant. The participants were informed about their voluntary participation in this study. Their rights not to participate or withdraw from the study at any time point were explained. A concussion history questionnaire form was administered to obtain detailed information about the number of previous concussions, date of concussions, description of the accident and symptoms after the injuries. A health questionnaire was administered to determine the participants that met the inclusion criteria, including screenings for lifestyle or medical conditions that are known to influence brain function. The questionnaire included questions on any psychiatric and neurological illnesses experienced, history of drug abuse, as well as current medications. More specifically, participants were asked to report any history of hospitalization, medical problems, seizures, hearing problems, tobacco or drug use, asthma, lung problems, heart disease, diabetes, hypertension and learning, reading or attention disorders (ADD or ADHD). Each participant's hearing was tested to exclude those with a hearing loss.

Following the hearing screening, athletes underwent electrophysiological testing. The electroencephalogram was recorded from a 64 active Ag/AgCl electrodes (Biosemi Active Two system) under an auditory "oddball" paradigm procedure. The patient was seated comfortably in a 6 X 6 soundproof room. The participant was asked to visually fixate to the white square in the middle of the black screen and to listen with attention to the auditory stimuli presented. No motor response from the participant was required to isolate the electrical activation from motor involvement and activation from attention components. Motor involvement was controlled to avoid the larger amplitude effects occurring during motor attention conditions vs. covert

attention (mental count) conditions (Shucard, Abara, McCabe, Benedict & Shucard, 2004). Participants were asked to complete a mental count of the target sounds to ensure attention maintenance throughout the test. A two consonant-vowel (CV) syllable auditory oddball task was used to assess the stimuli-locked electrophysiological changes.

2.2.1 The auditory oddball task

The auditory oddball task consisted of two English CV syllables, spoken in a male voice, binaurally presented one at the time to the participants in a soundproof room. The syllables that were used for this experiment were /ta/ and /ka/. Superlab (Superlab Pro, Cedrus Corp) software was used to present the auditory stimuli. Two blocks of 200 stimuli were presented to the participant; first, 160 non-target tones (/ta/) and 40 target tones (/ka/) at a frequency of 1000 Hz in a random sequence. The second block was inverted to control for any electrophysiological differences associated to detection of different phonetic components of the CV sounds. An 80-20 percent paradigm was utilized to control the frequency of stimuli presentation. The auditory CV sounds were presented at 80 dB. Subjects were instructed to keep their eyes open and maintain a mental count of each time they heard the target sound. Most of the participants reported a perfect count of target sounds (total=80). Only two participants reported minimal errors in the total count (76 & 79); confusion during block inversion was reported. A mental count was required to ensure the participants maintained attention throughout the task; results indicated sustained attention. An interstimulus interval (ISI) of 1000 ms was used (Shucard et al., 2004; Sivak et al., 2008). ERP data was high pass filtered at 35 Hz and low pass filtered at 0.0510 Hz. Testing was completed at one point in time, in individuals who suffered a concussion within a time range of 0-9 years.

2.3 Assessment Instruments

The Electroencephalogram (EEG) is a non-invasive technique used to assess neural activity. An elastic cap with 64 electrodes symmetrically distributed across the parietal, frontal, temporal and occipital areas of the scalp, was used to measure voltage fluctuations (electrical activity) in the brain. Administration of the EEG took approximately 60 minutes. Participants reported fatigue after completion of task; however, all participants completed the study. ERP's were recorded with respect to the mastoid reference from the midline scalp sites. Eye-blink artifact correction procedure was used in all participants. The CPz, Cz, Pz, and FCz central electrode sites were included when analyzing the P300 component.

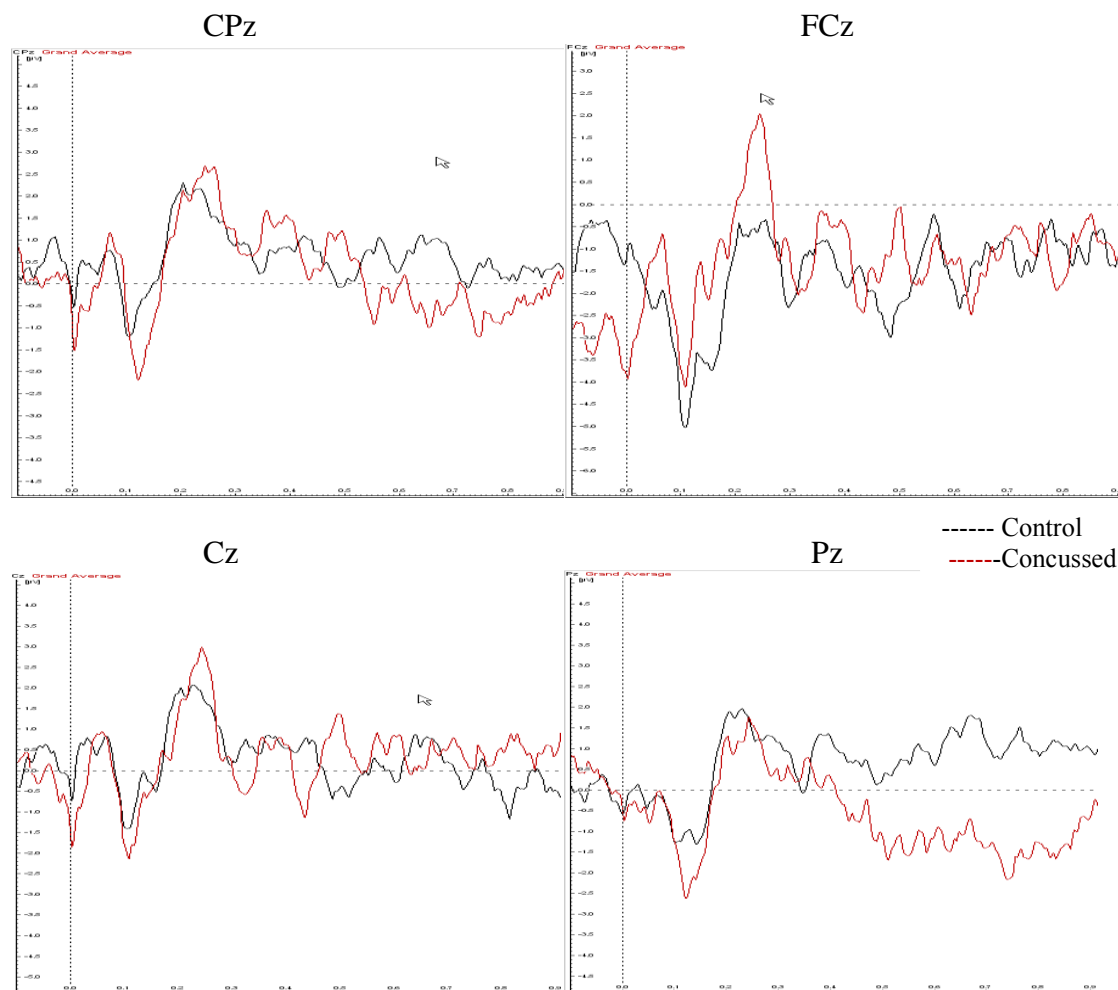
2.4 Experimental design and statistical analysis

EEG data from the auditory oddball task, and demographic information obtained from the testing session and recordings was analyzed. This study is a between subject design with two groups of participants and it was conducted using descriptive statistics and t-test to compare between group differences. Independent samples t-test were completed when comparing individual peak amplitude and latency at the CPz,Cz, Pz, and FCz electrode sites. Grand average P300a and P300b comparison was completed by visual inspection with high inter-rater reliability. A comparison between P300b elicitation during trigger #1 (non-target sound) and trigger #3 (target sound) of the oddball task was completed (CPz electrode) as a reliability measure. Trigger #3 elicited a P300, as expected following the oddball paradigm, indicating reliability of the procedure completed. Grand averages were completed by Vision Analyzer software and were compared by visual inspection to find between group differences.

Chapter 3: Results

3.1 Grand Averaged Waveforms

Figure 3.1 depicts the grand averaged waveforms showing the P300a and P300b components at CPz, Cz, Pz and FCz. Additionally, figure1 provides the peak amplitudes and latencies measured from the Grand Averaged waveforms. Central electrode sites, selected to compute the analysis, most accurately reflect where the component of interest P300a (FCz) and P300b (CPz, Cz and Pz) manifests its maximum amplitude during an auditory oddball paradigm (Luck, 2005; Handy, 2005; Squires, Squires, & Hillyard, 1975; Beaumont et al., 2009; Comerchero and Plich, 1999). A peak amplitude measure was utilized to analyze the waveforms with an operational definition of 280-350 ms for the P300a and 350-600ms for the P300b component. Grand averaged waveforms comparing control and concussed group were measured by visual inspection. Results show significant differences between controls and concussed participants. At the CPz electrode site, P300a and P300b larger amplitudes and earlier latencies were found in MTBI participants. At FCz, both P300a and P300b components were also larger and with earlier latencies. The Cz electrode site shows a P300a amplitude attenuation and an earlier latency than controls. However, P300b shows a larger amplitude and latency delay. Finally, a P300a and P300b amplitude attenuation was recorded at Pz. Latencies were different for both P300a and P300b at Pz, as there was latency delay and an earlier latency respectively.



CPz		Cz		Pz		FCz		
Controls								
	Lat	Amp	Lat	Amp	Lat	Amp	Lat	Amp
P300a	303	0.948	324	0.75	287	1.313	338	-1.042
P300b	424	1.092	363	0.859	396	1.372	563	-0.208
Concussed								
P300a	287	1.295	293	0.355	318	0.602	289	-0.774
P300b	355	1.652	500	1.367	355	0.785	500	-0.061

Figure 3.1. Overlaid ERP grand averages for controls and concussed participants in the two stimulus oddball task at CPz, Cz, FCz & Pz. Controls are represented as a black trace; concussed individuals are represented with the red trace.

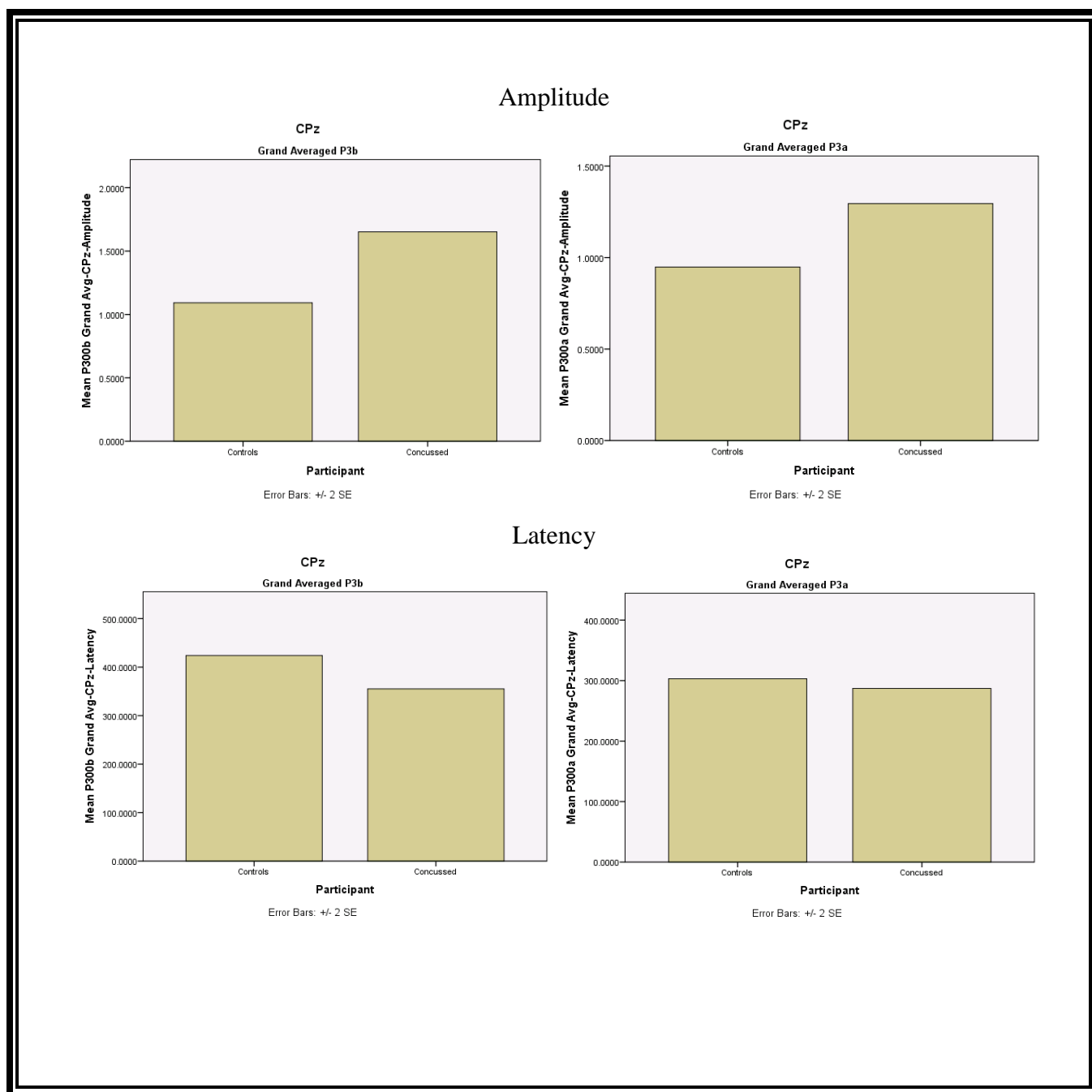


Figure 3.1.2: Graphed grand averages for P300a and P300b amplitude and latency at the CPz electrode site. Grand Avg. shows an increase in amplitude and earlier latency for both P300a and P300b components.

3.2 Statistical Analysis Results

Independent samples t-test were conducted to compare the individual latency and amplitude differences between controls and individuals with a history of concussion. Table 3.2 presents the independent samples t-test results on P300a and P300b latency and amplitude at CPz, CZ,Pz and FCz. A significant difference was found at the FCz electrode site (P300a latency); however, no significant differences were found on neither P300a nor P300b at CPz,Cz, and Pz.

Table 3.2: *Electrophysiological measures; P300a & P300b amplitudes and latencies at CPz, Cz, FCz, and Pz electrode sites.*

Mean	P300	Amplitude			Latency		
Site	Measure	Controls Mean (SD)	Concussed Mean(SD)	P value	Controls Mean (SD)	Concussed Mean(SD)	P value
CPz	P300a	1.89 (2.80)	1.57 (3.01)	.832	311 (20.26)	316 (16.99)	.576
	P300b	3.13 (2.57)	3.72 (2.16)	.646	495 (86.53)	431 (103.16)	.206
Cz	P300a	1.53 (3.64)	0.68 (2.32)	.618	315 (21.24)	307 (10.84)	.425
	P300b	3.49(2.70)	3.30 (1.55)	.874	496(91.12)	428(105.45)	.196
FCz	P300a	-0.059 (3.15)	-0.037 (2.36)	.988	331 (16.65)	310(22.89)	.049*
	P300b	2.66 (3.30)	2.23 (2.09)	.782	461(99.5)	467 (112)	.907
Pz	P300b	2.78 (3.06)	1.97 (2.07)	.325	479 (93.11)	428 (105.87)	.578

** Statistically significant difference

Both P300a and P300b component's latency and amplitude were measured at FCz for each participant from the target sound condition (trigger #3=odd sound condition) averages. There was a statistically significant difference in P300a latency between the control group (M=331, SD=16.6) and the concussed group (M=310,SD=22.8) ; $t(14)=2.15$, $p=0.049$, at the FCz

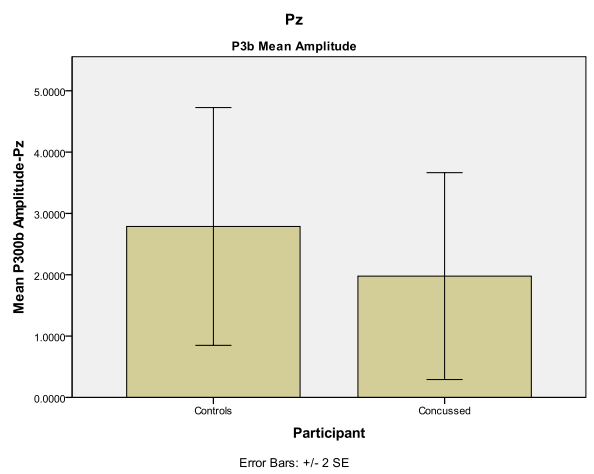
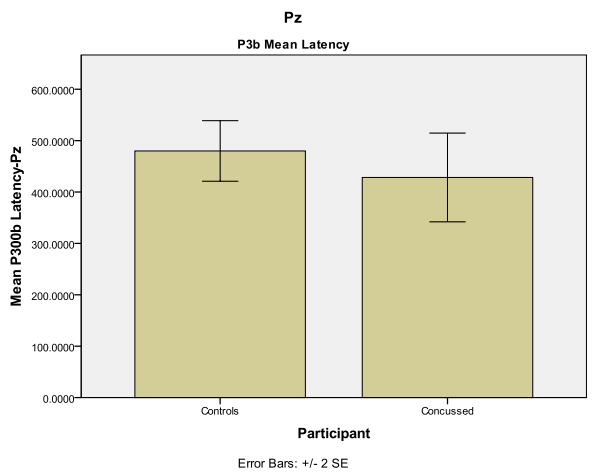
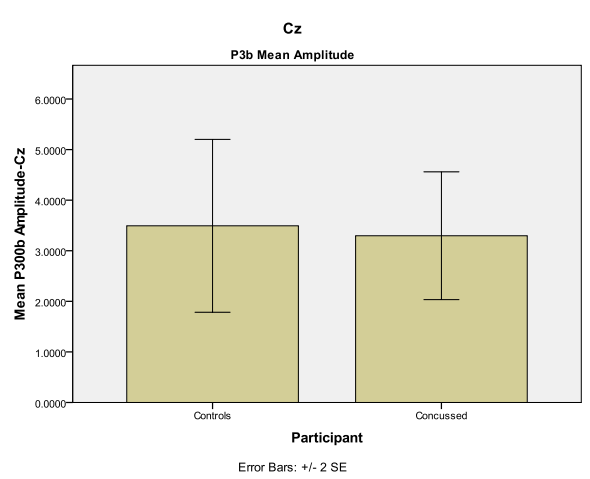
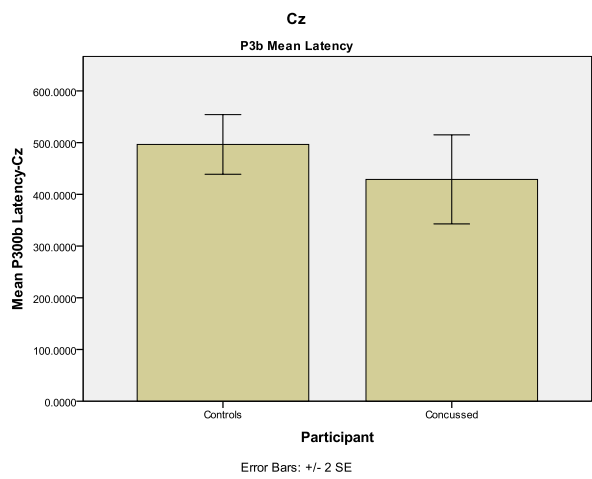
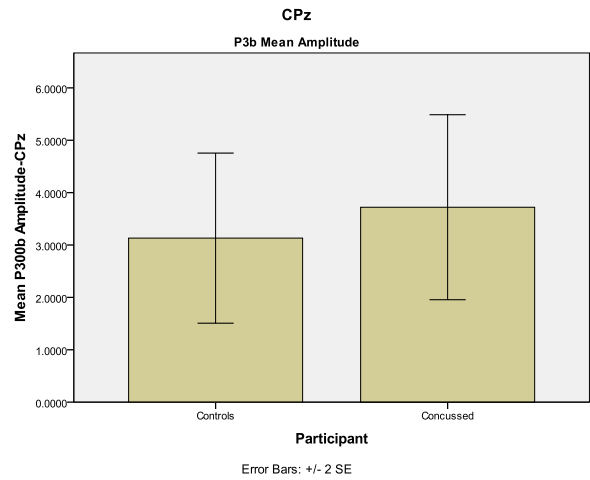
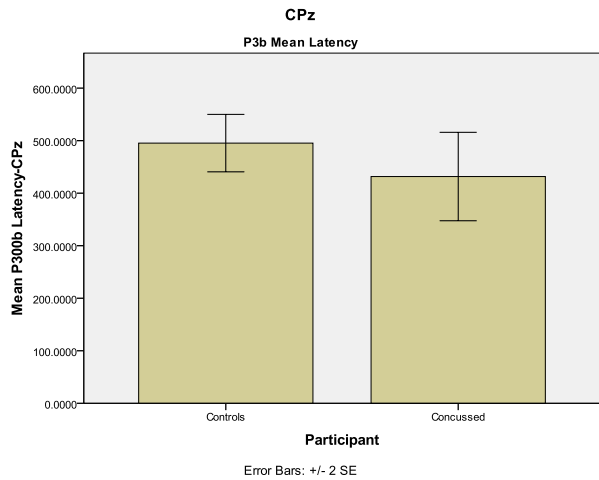
electrode site. Athletes with a history of concussion showed P300a latency recorded earlier than the control group. No statistically significant difference was found on the P300a amplitude of athletes with a history of concussion (controls=-.059 μ V, SD=3.14; MTBI=-.037 μ V, SD=2.36) ; $t(14)=-.015$, $p=.988$. However, controls demonstrated decreased FCz P300a amplitudes compared to results reported in the literature; P300a amplitudes in controls tend to be larger. Conversely, there was no evidence of statistical significance on P300b latency (controls=461ms, SD=99.54; MTBI=467ms, SD=112) ; $t(14)=-.120$, $p=.907$, or amplitude (controls=2.66 μ V, SD=3.30; MTBI=2.23 μ V, SD=2.10) ; $t(14)=0.283$, $p=0.78$) differences . However, a slight non-significant P300b amplitude attenuation was observed (see figure 3.2).

P300a and P300b latency and amplitude was then measured at CPz for each participant from the target sound condition (trigger#3) averages. Although there was no statistically significant difference in P300a latency (controls=311ms, SD=20.26; MTBI=316ms, SD=16.99) ; $t(14)=-.57$, $p=.576$, there was a non-significant P300a latency delay present. Furthermore, a non-statistically significant P300a attenuation was found (controls=1.89 μ V, SD=2.80; MTBI=1.57 μ V, SD=3.01); $t(14)=-.57$, $p=.58$, at CPz. Similar non-significant P300b recordings were found at CPz. There was no statistically significant difference on P300b latency (controls=495ms, SD=86.53; MTBI=431ms, SD=103.2) ; $t(14)=1.32$, $p=0.206$, or amplitude (controls=3.13 μ V, SD=2.57; MTBI=3.72 μ V, SD=2.16); $t(14)=-.47$, $p=.65$) . Although there was no statistical significance, the P300b component at the CPz recorded a slight increase in amplitude and earlier latency in concussed individuals (see figure 3.2).

P300a and P300b components latencies and amplitudes were also determined at Cz for individual participants from the target condition (trigger #3) averages. Although P300a latencies did not differ (controls=315ms, SD=21.24; MTBI=307ms, SD=10.83) ; $t(14)=0.82$, $p=0.43$, there

was a non-significant P300a amplitude attenuation (controls=1.53 μ V, SD=3.64; MTBI=0.68 μ V, SD=2.32); $t(14)=0.51$, $p=.62$. A similar pattern was observed when analyzing the P300b component at the Cz electrode site; there was no evidence of group differences in latency (controls=496 ms, SD=91.12; MTBI=428 ms, SD=105.45); $t(14)=1.36$, $p=0.196$ or amplitude (controls=3.49 μ V, SD=2.70; MTBI=3.30 μ V, SD=1.55); $t(14)=0.16$, $p=.87$. However, there was a non-significant P300b amplitude attenuation as well as an earlier latency in concussed individuals (see figure 3.2). (Look P300a results at FCz for discussion section)

Only target P300b latencies and amplitudes were analyzed at the Pz electrode site. P300a component was not analyzed at this site since the literature indicates the P300a maximal amplitude is frontally distributed. Although no statistically significant difference was found on neither P300b latency (controls=479 ms, SD=93.11; MTBI=428 ms, SD=105.87) ; $t(14)=1.02$, $p=0.33$ nor amplitude (controls=2.79 μ V, SD=3.06; MTBI=1.98 μ V, SD=2.07); $t(14)=0.57$, $p=.58$, there was a non-significant earlier P300b latency and amplitude attenuation in the concussed group (see figure 3.2).



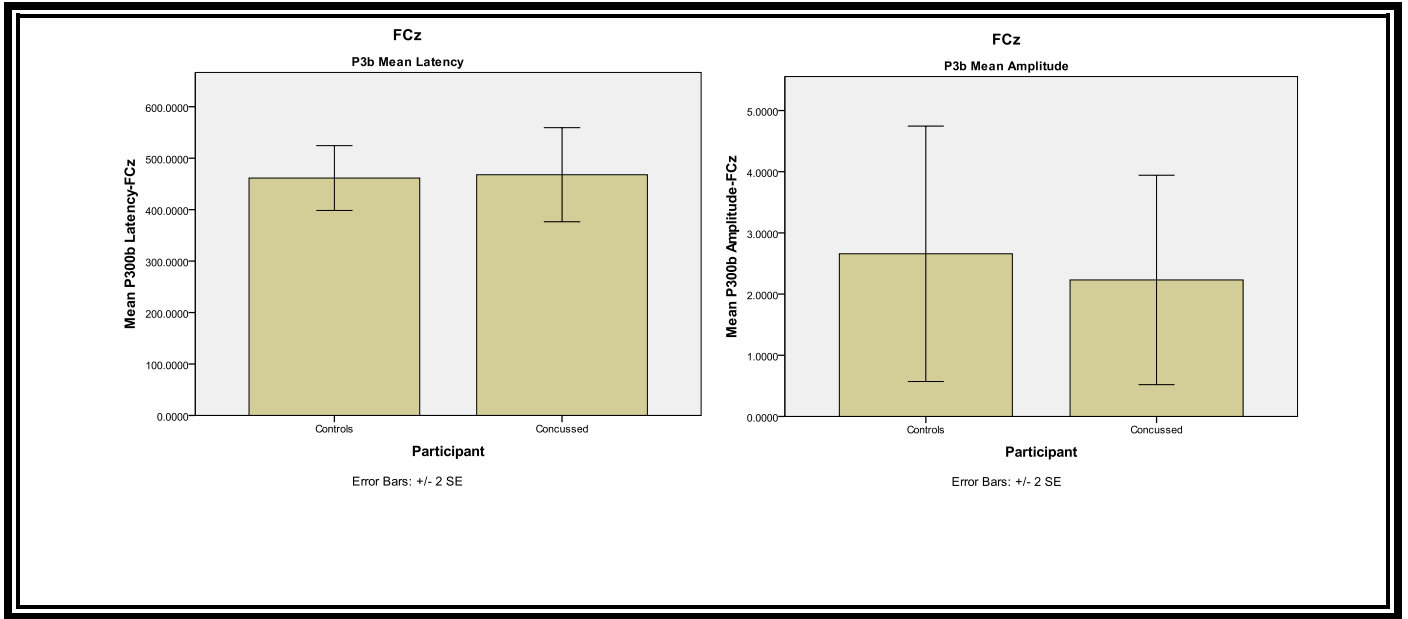


Figure 3.2 Graphed mean P300b differences and standard error at CPz, Cz, FCz, Pz electrode sites showing non-significant differences. Although non-significant, similar amplitude patterns to the one reported in the literature are observed at Cz, Pz, FCz. However, CPz shows a non-significant increase in amplitude. An overall earlier latency is observed across central electrode sites.

3.2.1 T1 vs.T3 Statistical Comparison

A statistical comparison was completed between Trigger #1 (non-target sound condition) and Trigger #3 (target/infrequent sound condition) as a reliability measure for the variation of the traditional “oddball” task paradigm utilized in the current study. Also, this comparison determines differences between the electrophysiological reaction to novel/infrequent target stimuli between controls and individuals with a history of concussion. Table 3.2.1 presents the statistical analysis results of trigger 1(T1) and trigger 3 (T3) at CPz for both groups. There was a statistically significant difference between T1 ($M=1.69 \mu V$, $SD=1.58$) and T3 ($M=3.31 \mu V$, $SD=2.50$); $t(9)=2.387, p=0.041$, in the control group. However, the concussed group showed no evidence of statistical significance on P300b amplitude measures when comparing T1 ($M=2.15 \mu V$, $SD=1.8$) and T3 ($M=3.78 \mu V$, $SD=2.15$); $t(5)=1.89, p=0.117$. Although a P300b was elicited, demonstrated by the mean difference, the difference was not significant.

Table 3.2.1: Statistical analysis results of P300b T1 vs T3 comparisons at the CPz electrode site.

Paired Samples Statistics					
Controls		Mean	N	Std. Deviation	P value
Pair 1	Amplitude Trigger 3(target)	3.3107	10	2.50444	.041**
	Amplitude Trigger 1	1.6932	10	1.57500	
Pair 2	Latency Trigger 3-(target)	487.1000	10	99.84705	.366
	Latency Trigger 1	449.2000	10	103.02945	

Paired Samples Statistics					
Concussed		Mean	N	Std. Deviation	P value
Pair 1	Latency Trigger 3-(target)	423.5000	6	110.76958	.400
	Latency Trigger 1	402.5000	6	83.71320	
Pair 2	Amplitude Trigger 3(target)	3.7807	6	2.14887	.117
	Amplitude Trigger 1	2.1462	6	1.80215	

**Statistically significant difference

3.3 Cortical Activation Patterns

Cortical activation was measured at both P300a and P300 b components at the central electrode sites. Figure 3.3 shows the cortical activation maps at CPz, Cz &Pz electrode sites during the target stimuli condition (trigger 3), when the P300 is elicited, for controls and concussed groups. Topographic maps are codified from no cortical activation (blue), reduced cortical activation (green), moderate cortical activation (yellow) to adequate or increased cortical activation (red). Topographic maps of grand averages from the current study show a clear pattern of decreased cortical activation throughout the cerebral cortex represented by the blue coloration indicating reduced micro voltage at most electrode sites. Activation in the frontal areas is still present in concussed cortical maps; however, frontal activation is also diminished. Additionally, cortical activation of controls show a more focal activation in the frontal lobe, when the P300 is

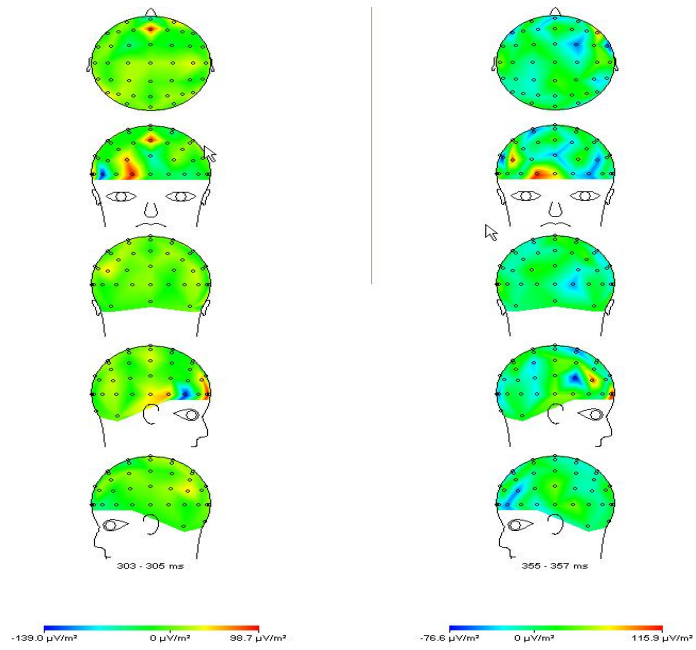
elicited. Conversely, the Cz electrode site shows increased scalp voltage distribution throughout the cerebral lobes. An increase in cortical activation in a language related area (Broca's area) was also noted in individuals with a history of a concussion at P300b; results show a different activation pattern than controls.

CPz

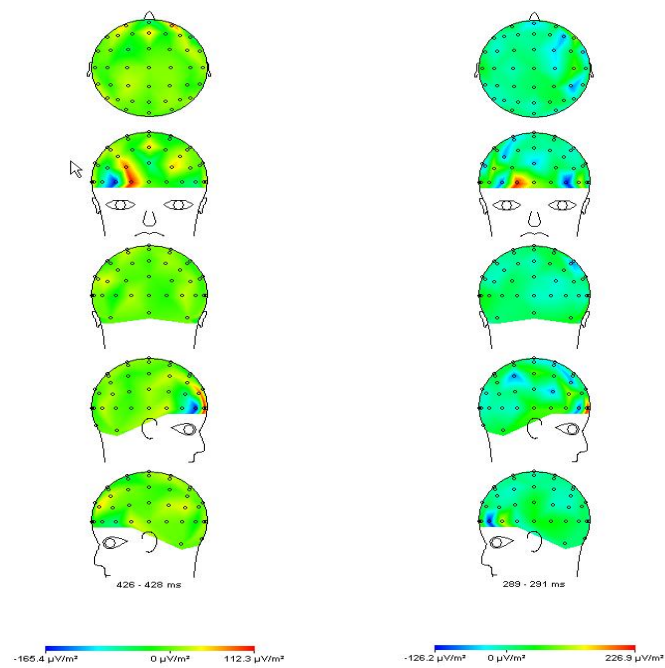
Controls

Concussed

P300a



P300b

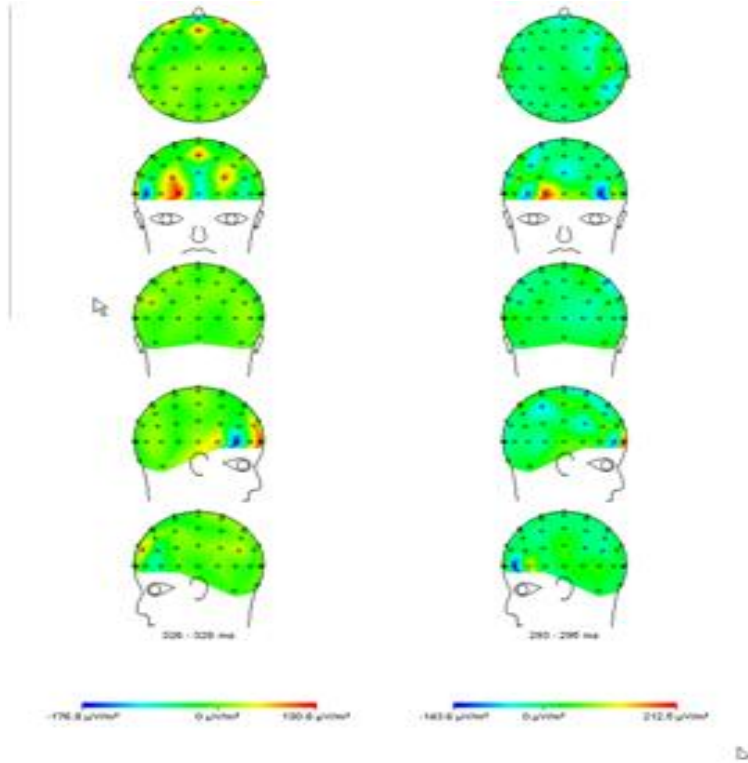


Cz

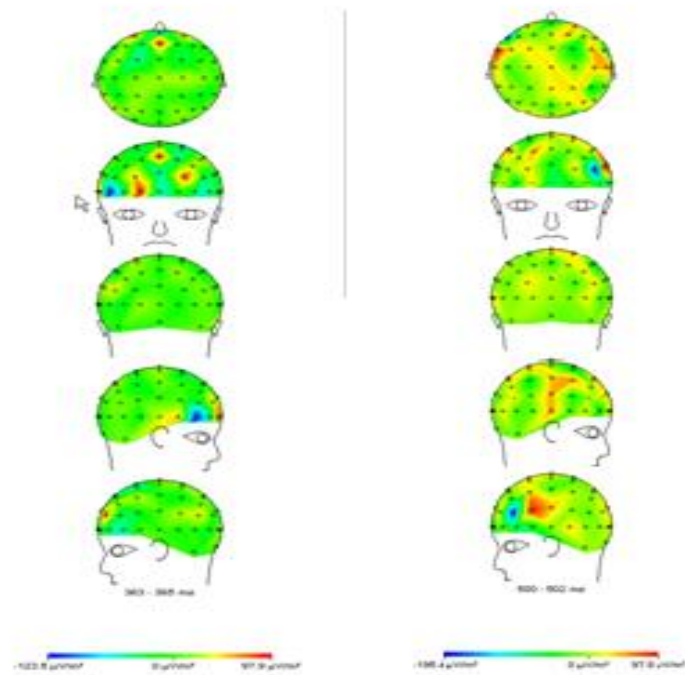
P300a

Controls

Concussed



P300b

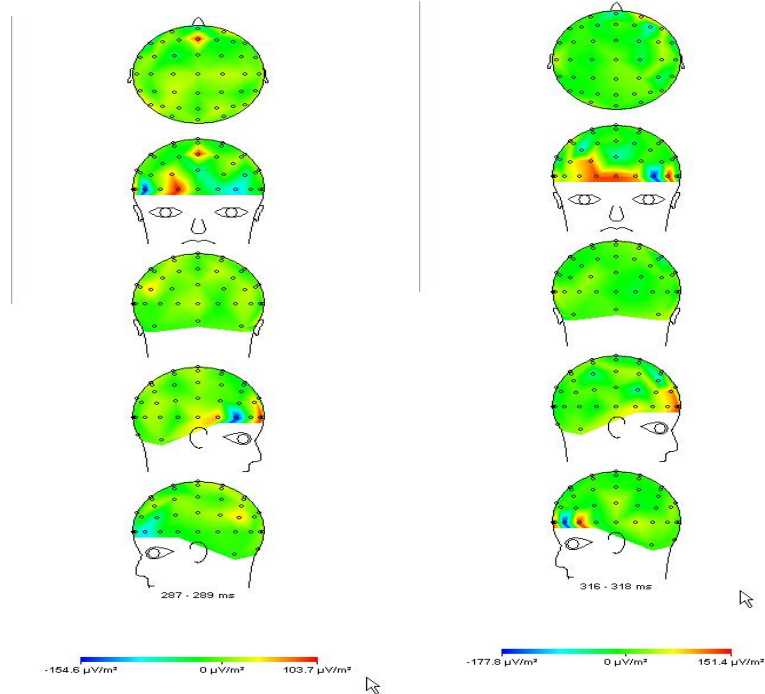


Pz

Controls

Concussed

P300a



P300b

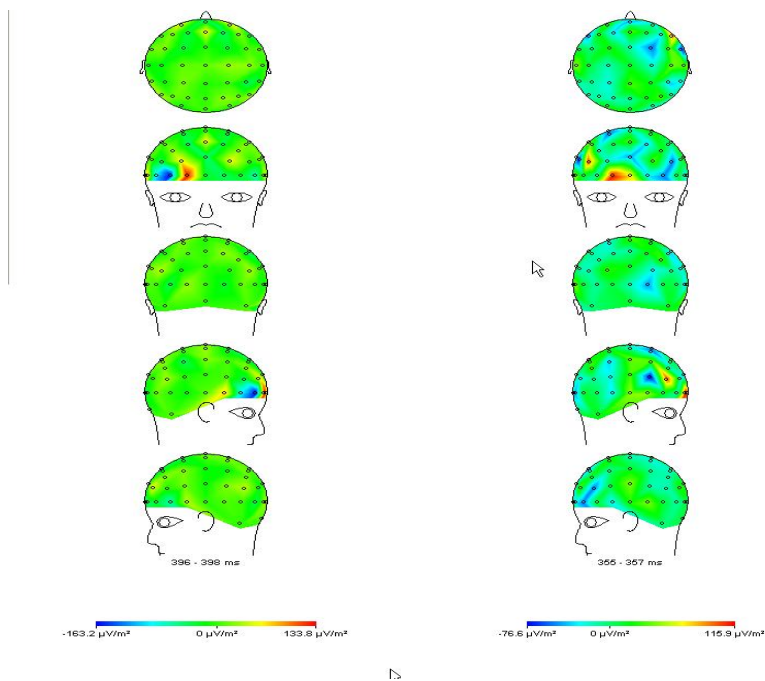


Figure 3.3: Topographic maps

Chapter 4: Discussion

4.1 Supporting and Contradicting Data

The results of the electrophysiological measures indicate that there is a statistically significant difference on temporal and amplitude components of the P300a and P300b waves, between concussed and non-concussed athletes across two central electrode sites (FCz &CPz) using an auditory oddball task with a linguistic component. It was hypothesized a significant difference on electrophysiological measures between controls and individuals with history of concussion. The hypothesis was supported, as there was a significant difference on P300a latency at the FCz electrode site between controls and individuals with a history of concussion. In addition, differences in attentional components were found when comparing controls and concussed in their electrophysiological reaction to the target and non-target sound at the CPz. grand averaged waveforms and topographic maps of cortical activation measured from the grand averaged waveform at the P300a and P300b also demonstrated electrophysiological differences in concussed athletes.

A statistically significant difference was found in latency measures of the P300a component; however, no significant amplitude differences were found. There was a P300a latency significant difference between controls and concussed at the FCz electrode site. However, results are not consistent with the literature; most researchers report a latency delay (Beaumont et al. 2009; Rugg et al. 1992; Gosselin et al. 2006) or no significant difference between groups (Potter et al. 2001; Sivak et al. 2008).The current study found an earlier latency in the concussed group which may indicate a faster detection of the target sound. Results may be associated with increased attention during completion of the experimental task since athletes who had suffered a concussion had an increased intrinsic motivation to return to play, therefore, to

perform well on the task. The concussion management clinic where participants were recruited contributes to return to play decisions. Participants may have been concerned about returning to play which may have increased their effort and attention to the task. Additionally, concussed individuals demonstrated more interest in the outcome of the data, for self awareness of recovery. Controls did not have an intrinsic motivation to participate in the experiment.

Results indicate that there was no P300a amplitude significant difference at any of the central electrode sites analyzed. However, non-statistically significant mean differences indicate a slight decrease in P300a amplitude at the Cz electrode site. Results suggest that there is variability in mean differences across electrode sites; no clear pattern may be predicted. Lack of significance may be associated with confounding factors such as small number of participants, and/or variation of oddball task used, which are further explained in the limitations section.

A statistically significant difference was not found on latency and amplitude of the P300b component at any central electrode site between controls and concussed participants. However, non-significant P300b amplitude attenuation was found at Pz/Cz and amplitude increase at CPz suggesting that, although not significant, there are mean electrophysiological differences in concussed individuals. Amplitude attenuations in MTBI patients are consistent with the literature. Further research is necessary to clarify the results.

Statistical analysis revealed a P300b amplitude difference between that elicited by the target/infrequent(T3) stimuli and non-target/frequent (T1) stimuli at CPz in the control group indicating that adequate P300 measures were utilized. This is consistent with previous research on the oddball paradigm which demonstrates that a P300 wave is elicited during the target stimuli presentation under an auditory oddball task (Shucard et al. 2004; Potter et al. 2001; Rugg et al. 1988; Beaumont et al. 2007). Results represent reliability of the P300 oddball paradigm

used in the current study. The variation of the traditional oddball task which added a linguistic component by presenting CV syllables instead of single sounds of different frequencies, successfully served the purpose of eliciting a P300 component. Of equal importance this measure served as an additional control for the current study since it compared P300 differences within participants.

On the contrary, the results of athletes with a history of a concussion did not show similar results. Individuals with a history of concussion did not show significantly larger P300 amplitudes elicited by target stimuli when compared to the non-target condition. A non-statistically significant difference found in the concussed group indicates failure to elicit a P300 ERP when the target sound is presented. These differences may have occurred as a consequence of the concussion. These results suggest that although, concussed athletes detect the target sound, their electrophysiological reactions are affected, as demonstrated by the different pattern found compared to the control group. It may be concluded that attentional components are affected and abnormal in concussed athletes.

Although, most studies report a significant decrease in P300 amplitude and latency delay in concussed individuals, the current study did not find similar results. However, variability has been reported in the P300 amplitude and latency results when using an auditory oddball task. A significant number of studies report non-statistically significant difference in neither P300a (Potter et al.1999) or P300b components at any electrode site (Potter et al. 2001; Sivak et al. 2008. Sivak and colleagues (2008) argue that EEGs may not be sensitive enough measures for MTBI. They reported using 1 sec ISI, similar to the current study, which may be a contributing factor to similarity in results (lack of significance). Longer ISIs are utilized by the majority of the literature reviewed (2-3 sec ISI); however the number of trials is significantly smaller. Another

study also reported larger P300 amplitudes in individuals with severe TBI (Kaipio, Cheour, Ceponiene, Ohman, Alku & Naatanen, 2000). The literature indicates that most of the studies, looking at electrophysiological changes in individuals with brain injury have been conducted with more severe cases of TBI. Additionally, this study was conducted with athletes who had suffered a MTBI, and severe cases of TBI were not considered for the study. Severe TBI patients are not evaluated in the concussion management clinic where participant recruitment was completed. Furthermore, the current study aimed to look at electrophysiological changes in MTBI. However, severity may be a contributing factor to variability in results.

In addition, research conducted on individuals with multiple concussions has shown stronger P300 differences when compared to individuals with a single concussion (Beaumont et al. 2007). This may also indicate that EEG measures may not be sensitive enough to detect electrophysiological changes in individuals with a history of a single concussion. Repeated concussions may result in greater electrophysiological abnormality which as a result will be more clearly shown in ERP results. Or it may indicate that individuals with a history of a single concussion may show electrophysiological recovery. This may be an additional contributing factor to lack of significance found in the current study, since inclusion criteria integrated athletes with single and multiple concussions.

Grand averaged waveforms from both controls and concussed participants showed similar patterns across CPz and FCz electrode sites. Both P300a and P300b components demonstrated an amplitude increase and earlier latency than controls. Results measured by visual inspection in the topographic maps indicate increased cortical distribution of activation during attention tasks, as opposed to focal activation in the frontal lobe. Level of engagement may be higher in an attempt to overcome increased distractibility or lack of inhibitory processes as a

result of the concussion. Conversely, both Cz and Pz recorded a latency delay and amplitude attenuation (excluding P300b at Cz). Overall, most of the components analyzed showed an increase in amplitude, taking into consideration that CPz and FCz, were the main focus of this investigation due to maximal peak of components of interest reported at these sites.

Topographic cortical activation maps provided important insights to attention differences in concussed individuals. A decrease of generalized scalp voltage activity was present at CPz and Cz, indicating decreased activity throughout the cerebral cortex while performing attention tasks. Also a reduction in focal activation in the frontal lobe was found in participants with a history of concussion. Although concussed participants did show activation in the frontal lobes, this activation was diminished indicating disturbed attention. Disturbed attention is also indicated by scalp voltage distribution throughout the cortex shown in the Pz electrode since healthy participants tend to show a more focal activation pattern. This increased generalized distribution of activation may be associated with an attempt to compensate with attention difficulties by accessing all the available cortical resources. Although, it may occur as compensation, another explanation may be associated with lack of inhibitory processes as a consequence of the concussion. A predominant frontal lobe function related to attention is the inhibition of irrelevant external and internal stimulation (distracters) to be able to focus attention to one stimulus or task. These inhibitory processes may be disrupted in individuals as a result of the concussion which is represented as increased scalp voltage distribution in a failure to inhibit distracters (eg. background noise, internal distracters). Although, no motor response was required from the participants to maintain count of the target sounds, participants were required to keep a mental count to ensure sustained attention. A clear pattern was noted in the cortical activation of individuals with a history of a concussion when compared to controls. Cortical activation was

shown in the left hemisphere, in a language related cortical area (Broca's area) when listening to the target sound. This difference may indicate that concussed individuals may be engaging in subvocal count of the target sounds. Whereas controls, did not engage in similar behavior, they maintained a mental count with no need to subvocally produce the target sounds. These cortical activations patterns may also indicate an attempt to compensate for difficulties in categorization of the target sound, which may be associated to the Oddball-CV linguistic component.

4.2 Limitations

The lack of significant difference of P300a and P300b at CPz, Cz, and Pz may be associated with the previously mentioned factors. One of the main limitations of the current study is that this study did not control for history of concussions (single vs. multiple). Both individuals with a history of a single concussion and individuals with multiple concussions were included in the same group. Although these differences were acknowledged, due to time constraints and a low availability of pathological population during data collection period, these two groups could not be divided. Additionally, the small number of participants may also be a contributing factor to variability in results. Most studies reviewed in the literature had a larger number of participants. This study would have benefited from a larger sample to increase the signal to noise ratio. However, a large number of trials was used to overcome this limitation.

Although the CV syllable oddball task successfully elicited a P300 component in healthy individuals, the variation in results may also be related to the use of syllables instead of pure tones to elicit the P300 wave since it increases the complexity of the task. Increase in complexity may pose higher cognitive demands on concussed individuals to complete the task which may increase the degree of engagement demonstrated in larger amplitudes; therefore, not showing significant differences when compared to controls.

4.3 Conclusions

Electrophysiological differences are present between controls and athletes with a history of concussion. Differences found at both CPz and FCz electrode sites indicate disturbed attentional components at the level of involuntary orienting of attention and stimulus categorization cognitive processes. Additionally topographic maps showed increased cortical activation distribution compared to controls who demonstrated more focal activation during the auditory oddball task. However, variability in results was found indicating a need for further research to clarify electrophysiological patterns post-concussion.

4.4 Clinical Implications

Participants benefited from this study by knowing the outcome of their performance using event related potentials. This study led to the establishment of an additional measure for attention studies using a variation of the traditional oddball task with a linguistic component. In addition, it may be concluded that attentional components are affected post-concussion. ERP measures may be useful during the evaluation process before higher order cognitive processes are tested using cognitive communicative tests. However, further research is necessary to clarify the P300 changes post-concussion and replication of studies is needed for generality of results.

4.5 Future Research

Future research should focus on the establishment of an electrophysiological recovery pattern post-concussion for its application in clinical practice. Concussed patients have not been examined, *early* post-concussion (3-7days, 2weeks, 1month and 3 months post-concussion). Also, additional research is needed which controls for history of concussion. Isolating individuals with a history of a single or multiple concussions would account for differences of repeated trauma.

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Appendix

A

INFORMED CONSENT

**University of Texas at El Paso (UTEP) Institutional Review Board
Informed Consent Form for Research Involving Human Subjects (Ages 18-Adult)**

Protocol Title: Electrophysiological and neuropsychological recovery patterns in athletes with a history of concussion

Principal Investigator: Paola Sanchez, B.S. Graduate Student Clinician

Supervisor: Dr. Anthony P. Salvatore, CCC-SLP, Chair of the Rehabilitation Sciences Department, Director of the Speech-Language Pathology Department

Thesis Committee Members: Samuel C. Riccillo, Ph. D., Director Biosemiotic Research Laboratory, Adjunct Faculty College of Health Sciences; Bess Fjordbak, Ph. D. Assistant Professor Department of Speech-Language Pathology.

**UTEP College of Health Sciences: Speech-Language Pathology Masters Program-Brain
Voice and Language Laboratory**

1. Introduction

You are being asked to take part voluntarily in the research project described below. Please take your time making a decision and feel free to discuss it with your friends and family. Before agreeing to take part in this research study, it is important that you read the consent form that describes the study. Please ask the study researcher or the study staff to explain any words or information that you do not clearly understand.

2. PURPOSE OF THE STUDY

You have been asked to take part in a research study that uses event related potentials (EEG) to compare brain activity in non-brain damaged and mild concussed participants when listening to spoken consonant-vowel syllable sounds. College level athletes from the El Paso area will be participating in this study.

The rationale: This study will provide a post-concussion management program to athletes who have suffered a concussion, to help with their recovery process. A concussion may result in deficits of cognitive functioning, such as problems with concentration and memory, sleep

disturbances and emotional changes. Most of the symptoms resulting from a concussion generally resolve spontaneously within 7-10 days of the injury. The majority of patients have completely recovered by 3 months, but a significant minority continues to have symptoms on a long-term basis. "Return to play" decisions are based on behavioral test results and clinical observation. However, additional instruments to assess changes in brain activity are necessary. For that reason, we need to have a better understanding of the functional processes involved in the recovery of a concussion. Research will focus on finding an effective means of assessing a concussion.

Approximately, 20 subjects (10 individuals who sustained a concussion and 10 healthy individuals) will be enrolling in this study at UTEP.

You are being asked to be in the study because you (1) suffered a single concussion (2) multiple concussions or (3) will serve as a healthy control subject for the purpose of comparison. If you decide to enroll in this study, your involvement will be required for approximately four 1-hour sessions on four separate days (3-7 days, 2 weeks, 1 month and 3 months post-concussion).

3. Procedure

If you agree to take part in this study, you will be provided with an explanation regarding the use of event related potentials. Also during your first visit, you will be asked to fill out the self-report medical and concussion history questionnaires. In addition, your hearing will be tested with a hearing screening.

You will begin by taking a 15-20 minute ImPACT test. This test will assess memory, reaction time, speed and concentration. It is not an IQ test. To do this you will sit in front of a computer monitor. There is a separate information sheet regarding this test that you will read and sign following this form.

Following this computer test the principal investigator will take head measurements and apply the electrode cap according to the Biosemi procedure of conduction gel and amplified electrodes. You will then be seated comfortably in a 6 X 6 soundproof room in front of a computer touch monitor to complete the experimental task. The experimental task required that the participant listen with attention to the auditory stimuli presented. No motor response will be required from you part.

4. Risks, Discomforts and Benefits

There are no known risks associated with this research. However, you may experience slight fatigue during the testing conditions. If you feel fatigued, you will be given the opportunity to rest.

5. What will happen if I am injured in this study?

The University of Texas at El Paso and its affiliates do not offer to pay for or cover the cost of medical treatment for research related illness or injury. No funds have been set aside to pay or reimburse you in the event of such injury or illness. You will not give up any of your legal rights by signing this consent form. You should report any such injury to Paola Sanchez at (915) 487-7028 and to the UTEP Institutional Review Board (IRB) at (915-747-8841) or rb.orsp@utep.edu.

6. Benefits

There will be no direct benefits to you for taking part in this study. However, you may benefit from this study by knowing the outcome of your performance using event related potentials. This research may lead to better understanding of the functional processes involved in the recovery of a concussion and this in turn may assist in the provision of a more accurate diagnosis, prognosis and “return to play” decisions.

7. Options

You have the option not to take part in this study. There will be no penalties involved if you choose not to take part in this study.

8. Funding

Internal Funding:

Funding for this study is provided by UTEP Department of Speech Pathology.

9. COSTS

There are no direct costs to you. However, you will be responsible for travel to and from the research site and any other incidental expenses.

10. COMPENSATION

There is no monetary compensation for taking part in this research study.

11. Refusal or Withdrawal

Taking part in this study is voluntary. You have the right to choose not to take part in this study. If you do not take part in the study, there will be no penalty. If you choose to take part, you have

the right to stop at any time. However, we encourage you to talk to a member of the research group so that they know why you are leaving the study. If there are any new findings during the study that may affect whether you want to continue to take part, you will be told about them.

The researcher may decide to stop your participation without your permission, if he or she thinks that being in the study may cause you harm, and/or there is not sufficient effort on your part to complete the testing.

12. Contact Information

You may ask any questions you have now. If you have questions later, you may call Paola Sanchez at (915) 487-7028 or pgsanchez3@miners.utep.edu. You may also contact the principal investigator's advisor, Dr. Anthony P. Salvatore at (915) 747-7265 or at asalvatore@utep.edu. If you have questions or concerns about your participation as a research subject, please contact the UTEP Institutional Review Board (IRB) at (915-747-8841) or irb.orsp@utep.edu.

13. Confidentiality

Your part in this study is confidential therefore, all information collected in this study will remain confidential. Only the principal investigator (Paola Sanchez) and her research advisor (Dr. Anthony Salvatore) will have access to this information. In addition, none of the information will identify you by name. Instead, identification numbers will be used. All records will be stored in a locked cabinet in the Brain, Voice and Language Lab at the UTEP Speech Clinic (1101 N. Campbell, El Paso, Tx. 79902). For further protection, only the principal investigator and her advisor will have access to the locked cabinet. Computer information will be stored in the lab computers and password secured. Only the principal investigator and her advisor will have access to the password. The results of this research study may be presented at meetings or in publications; however, your identity will not be disclosed in those presentations.

14. Mandatory Reporting

If information is revealed about abuse or neglect to the elderly or disabled, the law requires that this information be reported to the proper authorities.

15. Authorization Statement

I have read each page of this paper about the study (or it was read to me). I know that being in this study is voluntary and I choose to be in this study. I know I can stop being in this study without penalty. I will get a copy of this consent form now and can get information on results of the study later if I wish.

Participant Name: _____ Date: _____

Participant Signature: _____ Time: _____

Consent form explained/witnessed by: _____

Printed name: _____ Signature

Date: _____ Time: _____

Curriculum Vita

Paola Sanchez was born in El Paso, Texas, and raised Mexico. She completed her education prior to college in Mexico and initiated her undergraduate education in El Paso in 2005. With the support of her parents Dolores Calleros and Victor Sanchez, she completed her Bachelor of Science degree in Psychology at the University of Texas at El Paso in 2010. She continued her graduate studies and is currently pursuing her Master of Science degree in Speech Language Pathology with an expected graduation date of May 2013. Ms. Sanchez worked as a research assistant from 2008-2011 in a neuroscience laboratory at the University of Texas at El Paso. She conducted research focusing on investigating the changes in locomotor activity in hemiparkinsonian rats during dopamine-depleted conditions, to clarify the dysfunctional or compensatory status of the Basal Ganglia dopamine. She also worked as a research assistant in the Concussion Management Clinic from 2010-2013, where she developed her interest in Event Related Potentials (ERP). Her research interest and experience in concussion management led her to complete a thesis on the electrophysiological changes in athletes with a history of concussion using an auditory “oddball” task. The study focus was on attention differences in post-concussion measures.

The research she conducted during her Master’s program was presented at the Texas Speech-Language Hearing Association convention held in 2012. She was also part of the Research Initiative for Scientific Enhancement (RISE) program from 2009-2011.

Education

B.S., Psychology, University of Texas at El Paso, Texas, 2010

M.S., Speech Language Pathology, University of Texas at El Paso, Texas, anticipated completion: 2013

Permanent address: 3424 Richmond

El Paso Tx, 79930

This thesis was typed by Paola G. Sanchez.