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NEUROPHYSIOLOGICAL ABNORMALITIES AFTER MILD TRAUMATIC BRAIN INJURY IN ATHLETES

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ABSTRACT

Mild traumatic brain injury (MTBI) is one of the most common injuries seen among athletes. More commonly known as concussions, these injuries are often overlooked and treated poorly due to misconceptions athletes and parents have. Because MTBI is difficult to diagnose in athletes, it is important to study why and how they occur. It is hypothesized that major significant neurophysiological abnormalities will be seen in both functional magnetic resonance imaging (fMRI) and electroencephalogram (EEG) after MTBI. This study consisted of forty-four collegiate rugby players participating in the EEG studies, where sixteen subjects were uninjured and used as a baseline control and where twenty-eight subjects were injured and received a MTBI. The study also consisted of thirty collegiate athletes participating in the fMRI study, fifteen subjects being uninjured and considered to be the control, while fifteen subjects were injured after suffering from a MTBI. According to the EEG results, no significant differences were found for TBI discriminant, TBI Severity, and TBI probability scores between baseline and MTBI subjects. However, when looking at the data, a general trend is seen of a lesser TBI discriminant score for baseline, and greater TBI Severity Index and TBI probability index for the MTBI subjects. According to the low resolution brain electromagnetic tomography (LORETA) analysis conducted, the most common areas affected by the brain injury in concussed patients are the parahippocampal gyrus in the limbic lobe and the middle temporal gyrus in the temporal lobe. According to the fMRI results, in all comparisons between conditions, the subjects suffering from a MTBI had significantly higher levels of activation in the brain when performing tasks compared to the control subjects. According to the results of this study, as well as others completed in the past, it is important to use a comprehensive approach in dealing with a MTBI obtained by an athlete in sport, which includes neuropsychological tests, EEG, and fMRI.

TABLE OF CONTENTS

Chapter 1 - Introduction

Background

Mild traumatic brain injury (MTBI) is one of the most common injuries that are seen among athletes. More commonly known as concussions, these injuries are often overlooked and treated poorly due to the misconceptions many athletes and parents have. These brain injuries are very serious and are not treated the way they should be. The definition of a concussion can vary greatly, showing the uncertainty seen in sports with recognizing and treating these injuries. The most general, appropriate, and widely used definition of a concussion would be, "a certain immediate disturbance of neurologic function due to mechanical forces causing the brain to move and collide with the skull" (Thompson, 2007). It is also known that as the strength of these mechanical forces to the head increase during an injury, the greater the severity of the concussion will be, leading to differences in the degree of symptoms (Gennarelli, 1986). This could lead to further difficulty in diagnosing brain injury among athletes.

Common symptoms that could be seen in a variety of degrees include headache, dizziness, nausea, vomiting, fatigue, and drowsiness. Further symptoms may be increased sensitivity to light or noise, loss of balance, and double vision (Piebes et al., 2009). Some symptoms, especially headache, may be evident for several days or even weeks before they begin to subside (Piebes et al., 2009). Most of the symptoms caused by MTBI reflect functional deficits including loss of memory, concentration, processing speed, reaction time, and coordination. These symptoms are not as evident on the field after the athlete receives the injury than the symptoms of non-brain injuries such as breaks or sprains (Piebes et al., 2009). Loss of consciousness can be a symptom seen during MTBI, but is in no way necessary in order to diagnose the injury. Loss of consciousness is actually a rare symptom to be seen, only occurring in about nine percent of concussion injuries that occur (Piebes et al., 2009). These symptoms that are seen due to brain injury are most commonly self-reported to athletic trainers or coaches after the injury had occurred. Because these symptoms are self-reported, it is even more difficult to diagnose MTBI due to athletes not reporting correctly or avoiding reporting symptoms in order to be able to still play the sport.

The symptoms that are seen in athletes after suffering from a MTBI, are termed the “postconcussion syndrome” (PCS) (Mendez et al., 2005). Symptoms of the PCS include persistent headache, irritability, inability to concentrate, memory impairment, generalized fatigue, dizziness, or a generalized loss of well-being, all which are most commonly resolved within six to eight weeks of injury (Mendez et al., 2005). Depending on the different symptoms that are reported by the athlete, PCS can be used in order to determine a scale to see how severe the concussion was that had occurred (Chen et al., 2007). PCS scores can then be compared to fMRI results, cognitive impairment, and brain physiology (Chen et al., 2007). PCS is experienced during recovery of a MTBI, where patients who are older or who have certain personality traits may experience these symptoms for a longer period of time (Nuwer et al., 2005).

Another serious consideration that must be made after an athlete has suffered a concussion is the chance of suffering from Second Impact Syndrome (SIS) (Thompson, 2007). This syndrome indicates that after one has received a MTBI, the likelihood of receiving a second one is significantly increased (Thompson, 2007). This syndrome occurs most often when an athlete who had received a concussion returns to play too early, before PCS is resolved and then suffers from another concussion (Thompson, 2007). It is hypothesized that due to the variety of symptoms and physiological effects to be resolved, an athlete may be vulnerable to SIS for several months after the first concussion was received (Thompson, 2007). SIS is a rare occurrence; however it does occur most commonly in adolescents (Thompson, 2007). After this second concussion had been received, the athlete may only appear dazed and can walk off the field on his or her own, but the affects are much more serious (Piebes et al., 2009). After this second concussion, the brain loses its ability to regulate blood flow which can lead to a dramatic increase in brain swelling, intracranial pressure, and sometimes death (Piebes et al., 2009). SIS is preventable as long as an athlete does not return to play too quickly. Because of this serious and sometimes fatal condition, it is extremely important for coaches and athletic trainers to be able to recognize the signs and severity of PCS. It is important to refrain from putting athletes back into the game too early even if an athlete may say that he or she is feeling better and are no longer symptomatic (Piebes et al., 2009).

The effects of MTBI in athletes are not only seen in their symptoms of behavior or feelings. Major effects could be seen from injuries within the brain itself using different procedures such electroencephalogram (EEG) and magnetic resonance imaging (MRI) (Schrader et al., 2009; Alves et al., 1993). An EEG is a measure of the neurophysiological electrical activity of the brain (Thompson, 2007). The signals are measured by placing a certain number of electrodes on the patient's scalp and the activity of post-synaptic potentials of the pyramidal cells of the upper cortex layers are recorded (Thompson, 2007). The two most important EEG waveforms have been identified as alpha and beta forms (Cao, 2009). Alpha activity has been found to be associated with activity in the cortical areas while beta activity has been found to be associated with inactivity in the cortical areas (Cao, 2009). The potentials of the pyramidal cells that the EEG measures are directly related to the sodium, potassium, and calcium ion pumps which are found at each neuron (Cao, 2009). MTBI in athletes lead to severe damage of these ionic channels which lead to differences in post-synaptic potentials in the cortex and differences in EEG recordings. Immediately after injury, there is an efflux of potassium ions out of cortical neurons and an influx of calcium ions into the neurons, due to the membranes of these cells becoming disrupted (Thompson, 2007). Due to this disruption, there are fewer ionic channels per neuron that are functional, leading to a reduced average current influx (Thompson, 2007). These neurophysiological effects could be seen in the recorded EEG as decreased alpha and beta frequency and power (Thompson, 2007).

Another procedure that is used to see the neurophysiological effects of MTBI in athletes is magnetic resonance imaging (MRI). The components of an MRI are very complex, consisting of magnetic fields and spins, radio pulses and relaxation times, and tissue contrasts. Traumatic lesions can be visually detectable within the brain of an athlete who had received a MTBI by using MRI (Schrader et al., 2009). A specific type of MRI that is commonly used in order for us to see objective neurophysiological effects of brain injuries is functional magnetic resonance imaging (fMRI) (Mendez et al., 2005). fMRI gives us information about neural function during task performance (Mendez et al., 2005). It is hypothesized that brain activation during task performance is more wide spread after an athlete suffers from a MTBI while performance from the task remains constant (Mendez et al., 2005). It is also hypothesized that mid-dorsolateral activation of the cortex, which is important with memory function, has less activation during a memory task in an athlete who had recently suffered from a concussion (Mendez et al., 2005).

Purpose

Because MTBI is so difficult to diagnose in athletes, it is important to study why and how they occur, especially due to the fact that they are so commonly seen. Data suggests that concussions account for about nine percent of all high school sport injuries, while nineteen percent of all high school athletes have experienced at least one concussion during their athletic career so far (Thompson, 2007; Piebes et al., 2009). It has also been estimated that in sports such as ice hockey, football, and soccer, about fifty percent of the athletes have suffered at least one concussion (Chen et al., 2007). However, even these estimations might be fairly low due to the diagnosis of MTBI in athletes being underestimated (Chen et al., 2007).

Along with the fact that MTBI is so common among athletes, one of the most concerning issues is that athletes tend to return to play much earlier than they should (Piebes et al., 2009). If athletes are not truthful with their subjective measures of symptoms or if athletic trainers and coaches are not careful, athletes may return to play too early and suffer more serious injury such as SIS (Thompson, 2007). According to the Consensus Statement on Concussion in Sport made during the International Conference on Concussion in Sport in 2008, a return-to-play protocol should be used in order to manage each individual concussion received by an athlete (McCrory et al., 2009). It was also determined that objective measures of symptoms, cognition, and balance should be used in order to determine when an athlete is ready to return to play (McCrory et al., 2009). In the recommended stepwise process, there are six stages that the athlete would progress through once asymptomatic in the previous stage (McCrory et al., 2009). If a process such as this were implemented by coaches and athletic trainers, the likelihood of returning to play too early and suffering SIS would be decreased.

Due to the prevalence of MTBI in sport and the danger and likelihood of returning to play too early, it is important to devise appropriate and effective neurophysiological testing for these injuries. With proper testing it will be easier for doctors, coaches, and athletic trainers to prevent returning athletes to play too early and avoid more serious injury such as SIS. Therefore, the purpose of this research is to learn more about the testing methods of EEG and fMRI and to use these methods in a comprehensive approach in order to determine if and how long affects are still lingering in the athlete's brain after they have received the concussion. It is hoped that the results from this research will limit returning to play too early after head injury.

Hypothesis

Based on previous research projects completed (Thompson, 2007; Mendez et al., 2005), it is hypothesized that major significant neurophysiological abnormalities will be seen in both fMRI and EEG testing after MTBI. The EEG and fMRI testing will show abnormalities throughout follow-up appointments weeks after the concussion, indicating that the brain is still affected by the injury well after the athlete says he or she is feeling better. It is also hypothesized that the abnormalities seen would show an increase in activity in the brain to abnormal level during testing indicating that damage has been done to the athlete's brain, therefore it must work harder in order to complete the tasks asked of them.

Chapter 2 – Review of Literature

Review of EEG Literature

A significant number of athletes who receive MTBI report persistent post-concussive symptoms weeks, months, or even years after they have received the injury (Duff, 2004). The subjective nature of reporting the symptoms of this particular injury makes it difficult to properly diagnose and determine the severity of the injury. EEG has been a very helpful technique in order to help physicians, coaches, and athletic trainers prevent athletes from sustaining any further injury.

According to one research study completed by Thompson, neuropsychological testing such as EEG is a very effective technique within the first twenty four hours of receiving a concussion where the affects are able to be seen (Thompson, 2007). After the first week, neuropsychological deficits began to normalize (Thompson, 2007). During this study, about 60 athletes from a university were tested either as normal or concussed subjects. The EEG was completed in a variety of positions and the data was analyzed by using Neuroguide and LORETA software programs (Thompson, 2007).

Before EEG was used, neuropsychological tests such as The Trails B test, Symbol Digit Substitution test, and the Symptom Rating Scale were administered. These three tests are taken with paper and pencil and each test for different psychological impairments that may have occurred due to the MTBI. The Trails B test is used specifically to assess processing speed and scanning ability. The Symbol Digit Substitution test is used to assess processing speed and working memory in athletes who have received head injury (Randolph et al., 2005). Finally, the Symptom Rating Scale is used to help determine the severity of the symptoms affecting the athlete. Although these neuropsychological tests are often used in helping see the effects caused by concussions in athletes, the reliability of them are not fully accepted. There is not enough evidence found in order to support the use of these tests, therefore they are not currently recommended to be used as a primary means of assessing the affects of MTBI on athletes. (Hinton-Bayre & Geffen, 2002)

After using both neuropsychological tests and EEG on athletes after receiving a head injury, Thompson analyzed the results and compared the two different types of means of assessing affects of concussion (Thompson, 2007). According to the results found after using the neuropsychological tests, the only test that showed significant differences between concussed and non-concussed athletes was the Symptoms Rating Scale, which only showed significant results within twenty four hours of the time of injury (Thompson, 2007). The Trails B and Symbol Digit Substitution tests did not show significant differences in the results between the injured and normal athletes, which has also seen in a number of other studies completed (Thompson, 2007; Killam et al. 2005). The results that were obtained from the EEG testing were much more informative. EEG was found to be sensitive enough that negative affects in the brain after injury could be seen even after one week had passed from the time of injury (Thompson, 2007). It was found that injured subjects had a significant reduction in EEG power compared to the normal, control subjects (Thompson, 2007). Although the injured athletes were only found 83 percent of the time, the EEG was able to detect ample differences that neuropsychological tests could not detect as well (Thompson, 2007).

Due to the results that were found in this study completed by Thompson and other related studies, there is significantly lower cortical power found in the posterior part of the brain, including the postcentral gyrus (Thompson, 2007). In another study, it was also found that lower power in the alpha band and a significant decrease in power of the beta band was evident in patients suffering from MTBI (Tebano et al., 1988). In yet another study, it was found that there was a reduced alpha band power in the posterior cortical region even up to eight years after the injury was induced (Thatcher et al, 1989). After comparing results from several of the previous studies, consistent analyses were found between results ranging from within 24 hours of injury up until eight years after injury. All studies agree that there is reduced power noted from the EEG results after receiving a MTBI, commonly found in the posterior regions of the brain. Due to the consistent findings between the studies and also throughout a long time-period, one could confirm that using EEG in order to determine the results of brain injury in athletes is an effective technique and should be used more often in sports so athletes do not return to play earlier than necessary.

Review of fMRI Literature

EEG has been found in a significant number of studies to be an effective tool to use in order to see the effects of MTBI in athletes. However, another tool that has been commonly used in order to see the damage head injury has caused on the brain of an athlete is functional magnetic resonance imaging (fMRI).

According to an article by Chen et al., assessment of a concussion involves the characteristics of the post-concussive symptoms that were being experienced by the athlete (Chen et al., 2007). The technique of fMRI was used in this study in order to try to assess these post-concussive symptoms in male athletes (Chen et al., 2007). fMRI is a technique which involves performing different tasks, in this case relating to memory, while a complete MRI of the brain is being conducted (Chen et al., 2007).

During this experiment, the athletes first completed a questionnaire that told the researchers what post-concussive symptoms that were being experienced at that time. Next, a cognitive battery test was administered which further acquired post-concussive symptom information from the athletes (Chen et al., 2007). The fMRI task that was completed in this study included completing a verbal and a non-verbal working memory task in which the athletes must keep track of a presentation of several items and recognize an item from this group after a delay (Chen et al., 2007).

In order for the researchers to analyze the fMRI results, blood oxygenation level dependent (BOLD) contrast was used. BOLD contrast depends on the balance between the oxygen supply in the brain and consumption by the neural tissues (Attwell et al, 2002). Deoxyhemoglobin in the brain is paramagnetic, leading to a strong unaligned magnetic field in the MRI (Attwell et al, 2002). As the proportion of this deoxyhemoglobin decreases in the brain, the MRI signal, which is referred to the BOLD signal, increases due to the decrease in un-alignment (Attwell et al, 2002). In an athlete with MTBI, the brain must work harder in order to complete certain tasks such as memory, leading to an increase in blood flow, decreasing deoxyhemoglobin and increasing oxyhemoglobin. This finally leads to an increase in a diamagnetic field and increase in BOLD signal (Attwell et al, 2002).

According to the results of the experiment completed by Chen et al., the cognitive battery tests which involved testing reaction time and matching skills held significantly lower results in individuals suffering from a high number of post-concussive symptoms than individuals suffering from a low number of post-concussive symptoms (Chen et al., 2007). According to the results of the fMRI testing, the control group and the individuals with low post-concussive symptoms performed significantly better on verbal working memory and the verbal and visual control tasks than the individuals who suffered from high post-concussive symptoms (Chen et al., 2007). The fMRI also showed that activation patterns in the dorsolateral prefrontal cortex for both groups suffering from low and moderate levels of post-concussive symptoms were significantly reduced (Chen et al., 2007). The final conclusion made from this particular study was that athletes suffering from post-concussive symptoms at any severity had significant levels of cerebral haemodynamic abnormality and mild cognitive impairment. Therefore, fMRI was found to be sensitive enough to detect these results and should be further used in the comprehensive approach of detecting and treating head injury in athletes (Chen et al., 2007).

Another study focusing on using fMRI to look at affects of MTBI on athletes completed by Slobounov et al., found abnormal results similar to the article described above when testing for memory impairments. After completing an fMRI procedure, the participants who had suffered from MTBI had larger activation patterns in the left parietal cortex and cerebellum (Slobounov et al., 2009). Abnormalities were also found in the hippocampus where significant increased BOLD activity was found in the right hippocampal area (Slobounov et al., 2009). Having abnormal levels of activity in both the parietal cortex and hippocampal cortex, one could see the effects of a MTBI due to these areas being important in the function of spatial navigation tasks which this specific fMRI procedure tested for (Slobounov et al., 2009).

According to the literature on EEG and fMRI, both procedures are found to be effective ways in order to determine the effects that MTBI have on the brains of athletes. Due to the fact that EEG, fMRI, and neuropsychological tests may all be used to give us information on these serious brain injuries, they could all be used together in a comprehensive approach to treating athletes. MTBI is one of the most common injuries seen in athletes and also the most difficult to diagnose. Because of these two facts and also because they are such serious injuries, it is important to find as much information as possible on the effects of MTBI in order to treat the athletes and keep them from returning to play too early and receiving an even more serious injury. A comprehensive approach including EEG, fMRI, and neuropsychological testing procedures will give us the most information on these serious injuries so we could begin to prevent them.

Chapter 3 - Methods

Neuropsychological Tests and EEG

Subjects

Forty-four athletes participated in this experiment. The subjects were male and female collegiate athletes from The Pennsylvania State University. The athletes consisted of rugby players currently participating in the University's collegiate season. The subjects were split into two groups, one containing baseline, non-injured athletes and one containing concussed, injured athletes. There were sixteen baseline subjects used as a control and twenty-eight concussed subjects who had received a mild traumatic brain injury (MTBI). The mean age of the baseline subjects was 19.73 years and the mean age of the concussed subjects was 19.8 years (Table 1). Baseline tests were performed on the rugby athletes. Initial assessment of an athlete's MTBI was completed on the field or in practice by medical personnel. We then set up an initial assessment and two follow up tests with the injured athlete after a MTBI was obtained.

Table 1: Demographics of Baseline subjects

Sex	Age
Male	19
Male	21
Female	20
Female	22
Female	20
Male	19
Female	20
Male	18
Female	19
Male	20
Male	20
Male	19
Female	19
Male	19
Male	Not given
Female	21
	AVG: 19.7

Table 2: Demographics of Concussed Subjects

Sex	**Age**
Female	18
Male	21
Male	18
Female	20
Female	20
Female	17
Female	18
Female	21
Male	19
Male	20
Female	21
Male	19
Female	19
Female	20
Male	23
Male	16
Male	20
Male	20
Female	20
Female	21
Male	20
Male	20
Male	20
Female	19
Male	20
Female	21
Male	23
Male	21
	AVG: 19.8

Experimental Procedures

Subjects from The Pennsylvania State male and female rugby teams were required throughout the season to come into our lab and complete a baseline test. To begin, the subject would come into the lab, sit at a desk and read and sign the consent form. Subjects were then asked to provide demographic information including sex, birthdate, and medical and concussion history. After providing the relevant background information that we needed, neuropsychological tests were administered including The Trails B test, Symbol Digit Substitution test, and the Symptom Rating Scale. The subject was asked to complete the first two tests as quickly as possible. The Trails B test is a pencil and paper test which tests for processing speed and scanning ability. The next pencil and paper test, the Symbol Digit Substitution test, tests for processing speed and working memory. Finally, the Symptom Rating Scale was used to determine the severity of the different symptoms that were being experienced by the athlete at that specific time or the time immediately following the injury.

Next, the subjects completed the EEG test. The subjects sat in a chair while their scalp and earlobes were cleaned with a rubbing alcohol prep pad. A cap containing 19 leads (Electro-Cap International, Inc) was placed on the subjects head and electrodes were clipped onto their earlobes. Electro-gel (Electro-Cap International, Inc) was placed inside each of the 19 leads with a blunt-end syringe in order to receive conduction of the brain waves from the scalp to the electrodes. The EEG of the subjects were then recorded in 5 different positions including eyes closed sitting, eyes open sitting, eyes closed standing, eyes open standing, and eyes closed standing on a foam surface (thickness 45cm$_2$ x 13 cm, density 60 kg/m$_3$). Two minute intervals were recorded in each of these 5 positions. Subjects were instructed to keep their face relaxed especially in the temporal area muscles and to minimize eye blinks. This was to avoid muscle artifact in the EEG record. After the EEG recordings were completed, the cap was removed and the scalp was cleaned of the electro-gel using a rubbing alcohol prep pad.

After baseline EEG testing was completed for the rugby athletes, we did not need to see them again unless they had received a MTBI. If one did happen to become injured, they were sent into our lab to complete another EEG test as close to the time of injury as possible, ideally within 24 hours. After the initial assessment of the injured athlete, the subject came into the lab for two additional follow-up appointments for EEG testing. Therefore, if an athlete suffered from a MTBI, they would have completed four EEG tests; one baseline, and three tests following the injury.

Equipment

The EEG was recorded using Ag/AgCl electrodes mounted in a 19-channel spandex Electro-cap (Electro-cap International Inc., Eaton, OH). The 19 different channels included sites FP1, FP2, FZ, F3, F4, F7, F8, CZ, C3, C4, T3, T4, T7, T8, PZ, P3, P4, O1, and O2. The ground electrode is located anterior to the FZ channel and all impedances were kept below 5 Kohms. The EEG tests were recorded using a DC coupled broadband SynAmps amplifier (NeuroScan, Inc., El Paso, TX). The data was collected using NeuroScan's Scan 4.2 software package and stored on a computer.

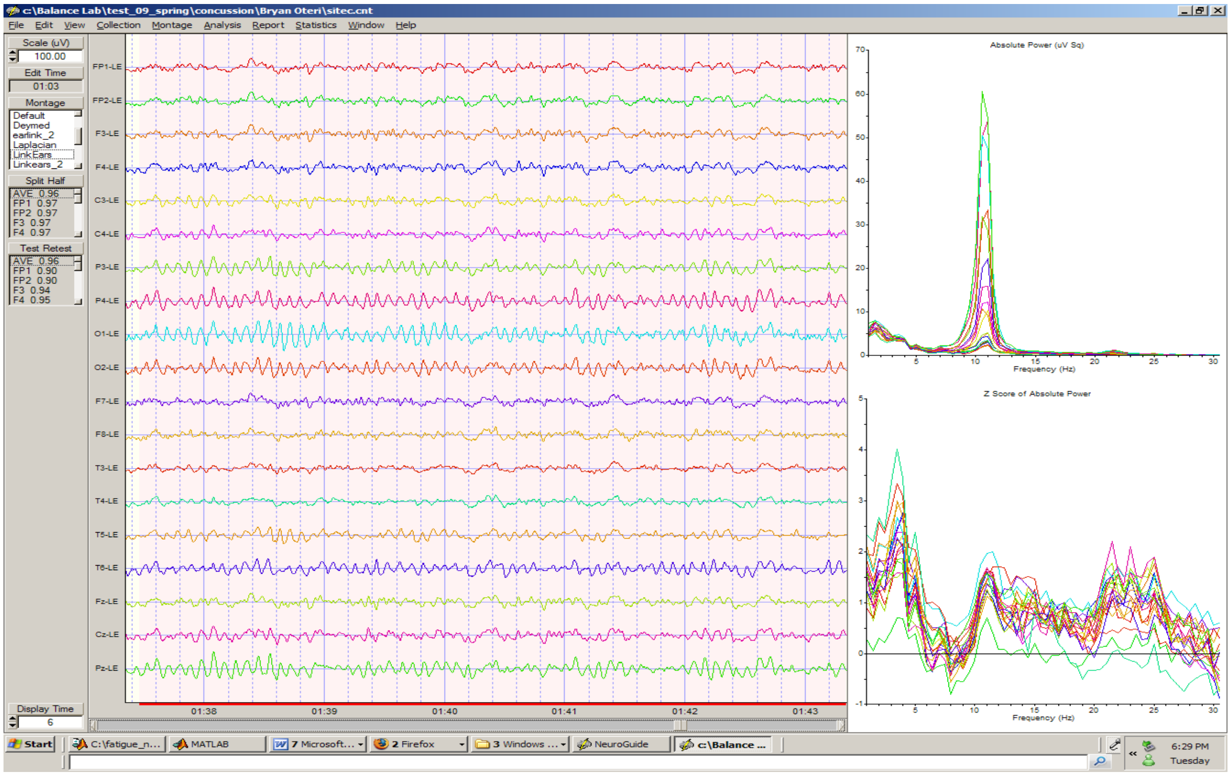
Analysis

To begin, the neuropsychological tests were analyzed for results. In order to analyze the Trails-B tests, the number of seconds it took to complete the test was recorded. If it took more than 50 seconds in order to complete the test, it was said to be abnormal. In order to analyze the

Symbol Digit Substitution test, the number of correct substitutions within a minute and half was recorded. If fewer than 40 substitutions were made within the minute and a half, it was said to be abnormal. The Symptom Rating Scale was analyzed by adding the ratings (0 – no change to 6 – severe symptom) of the 21 different symptoms that were asked for. Any rating above zero was considered to by abnormal.

The EEG recordings were analyzed by using Neuroguide's 2.3.5 software (Applied Neuroscience Inc., St. Petersburg, Fl.). In this specific experiment, the position analyzed was only the sitting eyes closed position. To begin, at least a minute of EEG recording was selected, eliminating the noise and any muscle activity that was detected. Neuroguide's software created bandwidths divided into the different waveforms, theta (4-7.5 Hz), alpha (8-12 Hz), beta1 (12-15 Hz), beta2 (15-17.5 Hz) and beta3 (18-25Hz). Reports were written up for each athlete's results using the Neuroguide 2.3.7 software combined with the Key Institute's low resolution brain electromagnetic tomography (LORETA) software program (Pasqual-Marqui, 2002) in order to determine the effects of the Brodmann areas of the cortex of the brain. An ear-linked montage was used where each channel represents the difference between a certain electrode and the average of electrodes attached to both earlobes (Figure 1). ANOVA and t-tests were statistical tools used in order to compare results between concussed and baseline athletes.

Figure 1: Ear-link montage of EEG recordings



fMRI

Subjects

Thirty athletes participated in this experiment. The subjects were male and female collegiate athletes from The Pennsylvania State University. The athletes consisted of rugby and ice hockey players currently participating. The subjects were split into two groups, one containing baseline, non-injured athletes and one containing concussed, injured athletes. There were 15 concussed subjects with a mean age of 20.8 years and 15 baseline subjects with a mean age of 21.3 years. The initial assessment of an athlete's mild traumatic brain injury was completed on the field or in practice by medical personnel and then we then set up an fMRI testing with the athlete within thirty days of injury.

Experimental Procedures

Athletes from The Pennsylvania State University were brought into the lab and completed several fMRI tasks involving a virtual environment. The tasks involved showing the subject that they are in a virtual hallway, being given a navigation route to encode (EN), having them navigate randomly through the hallway with a joystick (RN), and then having them navigate through the hallway to retrieve a specific target (RE). While the subjects were lying on their backs watching the scenes, the MRI completed its scanning. To begin, the subjects were able to practice using the joystick and got used to the program by navigating through a scene different from what was actually used during the testing. The test then began and the subject was shown four different routes in the virtual environment to a target room, with each route having a different difficult and number of turns. Next, the subject was given the joystick and they navigated through this hallway, mimicking these four pathways to the desired target room. Then, the subject was asked to freely navigate throughout the hallways in the virtual environment. Finally, the subject was asked to do a baseline test and use the joystick to follow a white cross on a black background (BL).

Equipment

In order for the subjects to see the virtual environment, a mirror was mounted on the head coil that enabled the tasks to be seen. The virtual environment was generated by a VTC Open GL developing kit (InnovativeVR, Inc, USA). The magnetic resonance images were created by a 3.0 Tesla Siemens Trio whole-body scanner (Siemens, Erlangen,Germany) with a 12 channel head coil.

Analysis

The anatomical images were acquired in the axial plane parallel with the anterior and posterior commissure axes covering the whole brain. Two-dimensional BOLD fMRI images were then obtained for the experimental tasks. The functional and structural images were then compared. Image processing was conducted with Statistical Parameter Mapping (Friston et al. 1995) version 8 (2008, Wellcome Department of Cognitive Neurology, London UK). Contrasts were created for the subjects for each specific task they had completed and then these contrasts were used to create contrasts between the baseline and the concussed subjects. Region of interest was also analyzed using the SPM 2 toolbox: PickAtlas (Maldjian et al. 2003) and Mars-BaR (Brett et al. 2002) for the activated clusters seen in the contrasts (Figures 6-9).

Chapter 4 - Results

Neuropsychological Tests and EEG

The results from the the Trails B test and Symbol Digit Substitution tests were compared between the concussed and baseline athletes using statistical ANOVA and t-tests. The results from baseline, concussion, first follow up and second follow up tests are shown below (Tables 3-6). The averages and standard deviations of data are also shown.

Table 3: Results from Trails B and Symbol Digit Substitution tests for Baseline subjects

Trails B Test	**Symbol Digit Substitution**
53	64
64	58
41	61
39	66
50	71
55	54
33	67
45	50
40	87
50	62
28	82
81	48
40	62
39	70
48	55
56	51
AVG: 47.6	**AVG: 63.0**
STDEV: 12.8	**STDEV: 10.9**

Table 4: Results from Trails B and Symbol Digit Substitution tests for 1st test of MTBI subjects

Trails B Test	**Symbol Digit Substitution**
52	67
62	59
52	80
52	50
40	60
59	60
37	67
59	63
33	75
33	65
41	73
31	110
32	72
28	81
41	73
36	69
44	68
57	85
67	67
39	71
72	65
25	70
41	68
56	60
61	59
50	74
47	81
47	68
AVG: 46.2	**AVG: 70.0**
STDEV: 12.4	**STDEV:11.1**

Table 5: Results from Trails B and Symbol Digit Substitution tests for 1st follow-up of MTBI subjects

Trails B Test	Symbol Digit Substitution
40	74
94	65
52	79
40	81
37	7
33	85
36	70
42	43
22	79
34	75
33	82
31	71
40	102
41	58
39	81
AVG: 40.9	**AVG: 70.1**
STDEV: 16.1	**STDEV: 21.9**

Table 6: Results from Trails B and Symbol Digit Substitution tests for 2nd follow-up of MTBI subjects

Trails B Test	Symbol Digit Substitution
25	77
48	71
41	85
33	79
32	90
25	80
30	100
30	83
33	87
55	69
41	69
AVG: 35.7	**AVG: 80.9**
STDEV: 9.50	**STDEV: 9.52**

First, ANOVA tests were conducted for the Trails B test between all four groups (Table 8). The significance between the four groups was 0.072 (non-significant). Although it was found that the time it took for baseline and concussed subjects were not significant, it could be seen that the time it took the subjects to complete the test from concussion through their second follow-up test decreased (Table 7).

Table 7: Comparison of Trails B test results

Group	Number of Subjects	Mean	Standard Deviation
Baseline	16	47.625	12.81
Concussed	28	46.2	12.4
1st Follow up	15	40.93	16.07
2nd Follow up	11	35.73	9.5

Table 8: Results of ANOVA test for Trails B Test between groups

	Sum of Squares	Df	Mean Square	Fisher F-value	Significance (*p*)
Between Groups:	1,235.13	3	411.71	2.441	0.072
Within Groups:	11,130.89	66	168.65		
Total:	12,366.02	69			

A paired T-test was then completed between baseline subjects and each of the other groups in order to determine if there was significant difference between these groups during the Trails B Test (Tables 9-11). Results from the Trails B neuropsychological test is close to significant and might be found to be significant with a few more subjects used in the study.

Table 9: T-test results for Trails B Test between baseline and concussed subjects

T score:	0.3587523
Degree of Freedom:	42
Mean A:	47.625
Mean B:	46.21
p-value:	0.7215

Table 10: T-test results for Trails B Test between baseline and 1st follow up subjects

T score:	1.286
Degree of Freedom:	29
Mean A:	47.625
Mean B:	40.933
p-value:	0.2086

Table 11: T-test results for Trails B Test between baseline and 2nd follow up subjects

T score:	2.618
Degree of Freedom:	25
Mean A:	47.625
Mean B:	35.7272
p-value:	0.01478

Next, ANOVA analysis was completed for the results of the Symbol Digit Substitution Test (Table 13). All four groups were compared. There is a significant difference found between all four groups (p=.017) and between baseline and 2nd follow up subjects (p=.014), however no significance was found between other conditions. Although there are no significant differences seen between the other conditions, it could be seen that the number of substitutions increased from time of concussion to subjects' second follow-up tests (Table 12).

Table 12: Comparison of Symbol Digit Substitution test results

Group	Number of Subjects	Mean	Standard Deviation
Baseline	16	63	10.92
Concussed	28	70	11.075
1st Follow up	15	70.1	21.885
2nd Follow up	11	80.91	9.523

Table 13: Results of ANONA test for Symbol Digit Substitution Test

	Sum of Squares	Df	Mean Square	Fisher F-value	Significance (*p*)
Between Groups:	2,092.17	3	697.389	3.621	0.017
Within Groups:	12,712.62	66	192.615		
Total:	14,804.79	69			

A paired T-test was then conducted between baseline subjects and each of the other groups for the Symbol Digit Substitution test (Tables 14-16). Significant differences were found between baseline and concussed subjects (p=.017) and baseline and 2nd follow up subjects in the Symbol Digit Substitution Test (p=.000175). However, results did not show baseline subjects having greater results than the injured subjects.

Table 14: T-test results for Symbol Digits Test between baseline and concussed subjects

T score:	-2.0265
Degree of Freedom:	42
Mean A:	63
Mean B:	70
p-value:	0.049

Table 15: T-test results for Symbol Digits Test between baseline and 1st follow up subjects

T score:	-1.1596
Degree of Freedom:	29
Mean A:	63
Mean B:	70.133
p-value:	0.255

Table 16: T-test results for Symbol Digits Test between baseline and 2nd follow up subjects

T score:	-4.402
Degree of Freedom:	25
Mean A:	63
Mean B:	80.909
p-value:	.000175

Symptom rating scale results were then compared between baseline and the concussed subjects using paired-t test (Table 17). The results were very significant (p=0.000264), showing a dramatic increase in symptoms in concussed patients.

Table 17: T-test results for Symptom Rating Scale between baseline and concussed subjects

T score:	-3.98
Degree of Freedom:	42
Mean A:	5.125
Maen B:	31.107
p-value:	.000264

Next, the results from the NeuroScan analysis were compared between baseline and concussed subjects. A representation of the abnormalities seen in MTBI subjects by using NeuroScan is shown in Figure 2. Three factors were examined which include the TBI discriminant score, TBI probability index and the TBI severity index (Figure 3). TBI discriminant score and TBI probability index shows the subject's probability of membership in the mild traumatic brain injury population. TBI Severity Index will show an index of an estimate of the neurological severity of injury. The report generated by the Neuroscan takes several scans of power of the brain (Figure 2) and uses this information to generate these three different factors. They are given on a final page of the report (Figure 3). Paired T-tests were used to compare TBI discriminant score, TBI Probability Index, and TBI Severity Index between the baseline and concussed athletes (Tables 18-20). No significant p-values were found, however there was a definite trend showing greater TBI discriminant, TBI Probability, and TBI Severity scores in the concussed athletes compared to the baseline subjects.

Figure 2: Relative Power of a concussed subject given by NeuroScan

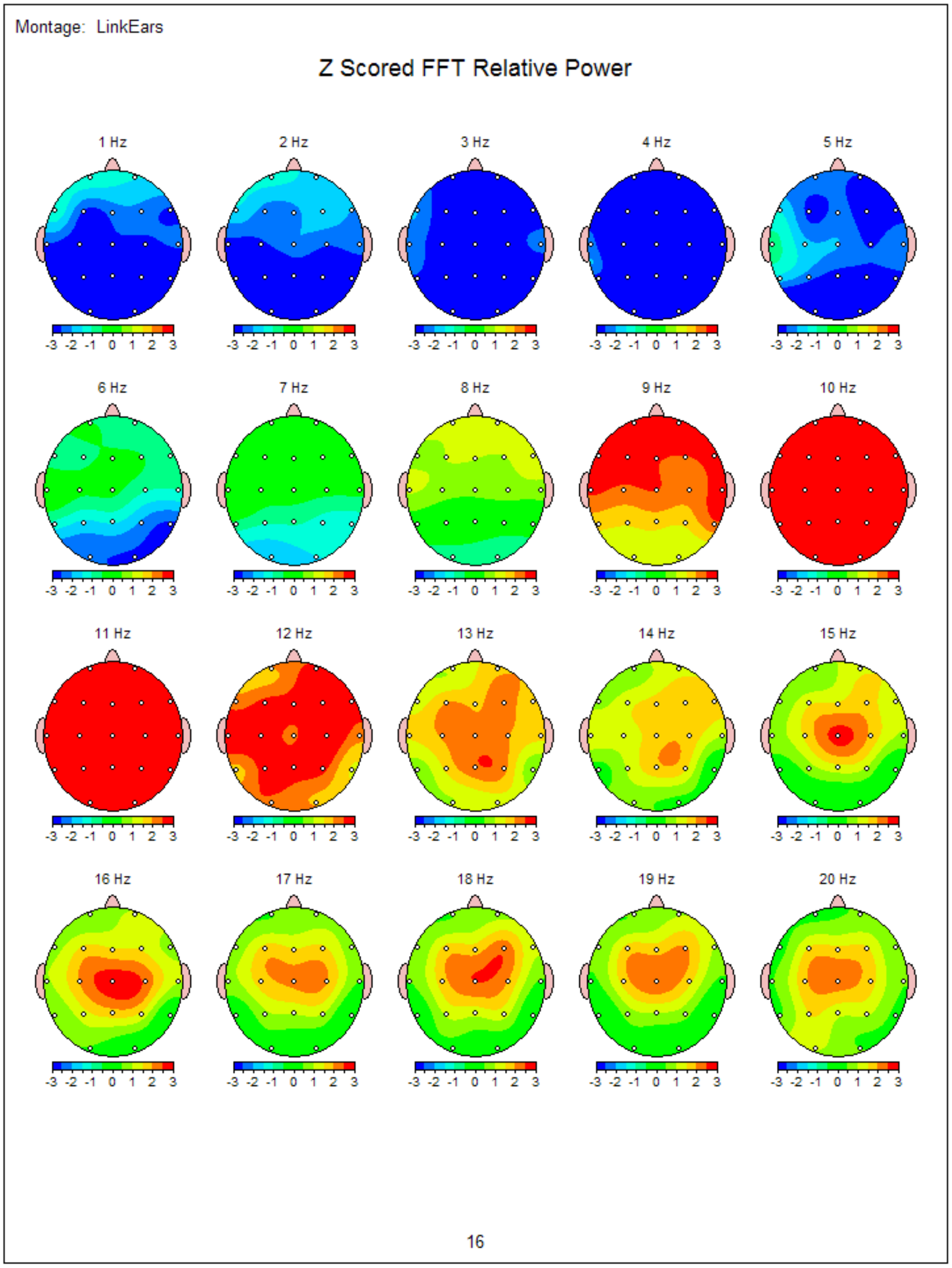


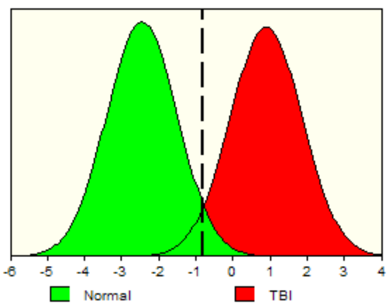
Figure 3: Final page of NeuroScan report including TBI Discriminant Score, Probability Index, and Severity Index

Montage: LinkEars

Traumatic Brain Injury Discriminant Analysis*

TBI DISCRIMINANT SCORE = -0.87   TBI PROBABILITY INDEX = 70.0%

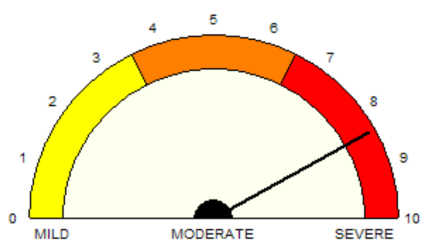
The TBI Probability Index is the subject's probability of membership in the mild traumatic brain injury population. (see Thatcher et al, EEG and Clin. Neurophysiol., 73: 93-106, 1989.)



			RAW	Z
FP1-F3	COH	Theta	89.90	1.33
T3-T5	COH	Beta	61.88	0.93
C3-P3	COH	Beta	75.04	0.56
FP2-F4	PHA	Beta	-0.31	-0.65
F3-F4	PHA	Beta	0.15	-1.18
F4-T6	AMP	Alpha	-112.26	-1.12
F8-T6	AMP	Alpha	-143.76	-0.92
F4-T6	AMP	Beta	-32.57	-0.52
F8-T6	AMP	Beta	-71.28	-0.23
F3-O1	AMP	Alpha	-154.78	-1.07
F4-O2	AMP	Alpha	-135.41	-0.68
F7-O1	AMP	Alpha	169.65	0.82
F4-O2	AMP	Beta	-52.72	-0.16
P3	RP	Alpha	66.37	1.03
P4	RP	Alpha	70.79	1.25
O1	RP	Alpha	72.29	0.88
O2	RP	Alpha	66.93	0.58
T4	RP	Alpha	34.00	0.01
T5	RP	Alpha	50.50	0.17
T6	RP	Alpha	55.36	0.32

TBI SEVERITY INDEX = 8.35

This severity score places the patient in the SEVERE range of severity.



			RAW	Z
FP1-C3	COH	Delta	76.25	2.14
FP1-FP2	COH	Theta	94.24	1.46
O1-F7	COH	Alpha	39.92	0.42
O2-T6	COH	Alpha	88.09	0.64
P3-O1	COH	Beta	82.22	1.12
FP1-T3	PHA	Theta	0.87	-1.17
T3-T4	PHA	Theta	-0.27	-2.33
O1-F7	PHA	Alpha	31.59	0.16
F7-F8	PHA	Alpha	0.15	-1.50
T5-T6	PHA	Beta	4.83	0.45
C3-F7	AMP	Delta	-27.83	-2.83
FP2-F4	AMP	Delta	49.03	2.00
C4-F8	AMP	Delta	-1.08	-1.86
O1-O2	AMP	Theta	15.65	0.90
P3-F7	AMP	Alpha	151.16	0.60
FP2-P4	AMP	Alpha	-163.32	-1.25

The TBI Severity Index is an estimate of the neurological severity of injury. (see Thatcher et al, J. Neuropsychiatry and Clinical Neuroscience, 13(1): 77-87, 2001.)

***Statement of Indications of Use:**

The Discriminant Analysis and Severity Index are to be used by experienced and qualified professionals for the post-hoc statistical evaluation of the human electroencephalogram (EEG). The Discriminant Analysis and Severity Index are to be viewed as an adjunct to the evaluation of the patient, and they do not serve as a primary basis for a diagnosis. Warning: Inclusion criteria of a history of traumatic brain injury and greater than 13 years of age must be adhered to.

29

Table 18: Results of T-test of TBI discriminant score between baseline and concussed subjects

T score:	-1.4808
Degree of Freedom:	42
Mean A:	-2.197
Mean B:	-0.072
p-value:	0.146

Table 19: Results of t-test of TBI Severity Index between baseline and concussed subjects

T score:	-1.097
Degree of Freedom:	42
Mean A:	2.159
Mean B:	3.15
p-value:	0.278

Table 20: Results of TBI Probability Index between baseline and concussed subjects

T score:	-0.265
Degree of Freedom:	42
Mean A:	45.68
Mean B:	49.52
p-value:	0.7922

Next, the LORETA results were analyzed to find the region of interest where most head injury occurred and where the MTBI was most affecting. The most common areas of injury are shown below with percentages of instances out of all concussed patients (Table 21). These areas are also shown below using pictorial representations (Figures 4-5).

Table 21: Most common affected areas of the brain from MTBI subjects

Parahippocampal gyrus, limbic lobe	25.60%
Middle temporal gyrus, temporal lobe	15.38%

Figure 4: Abnormal LORETA results in parahippocampal gyrus from concussed subject

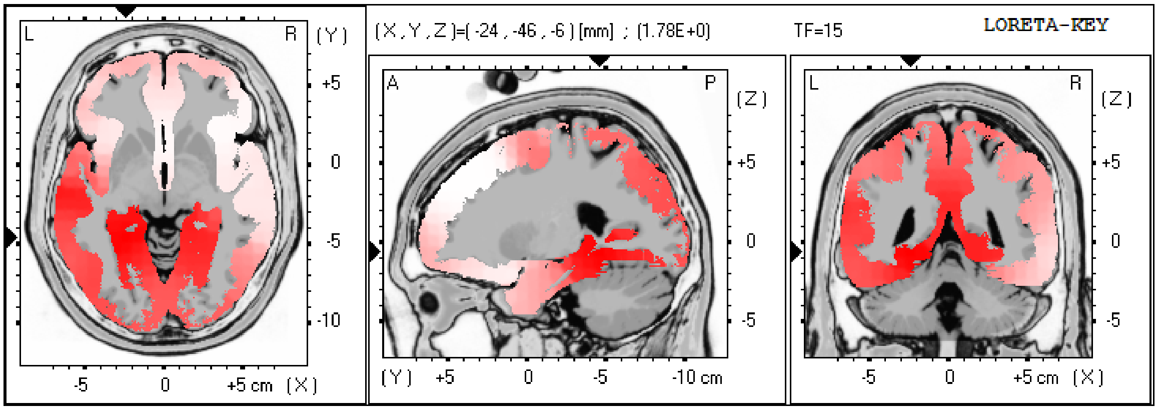
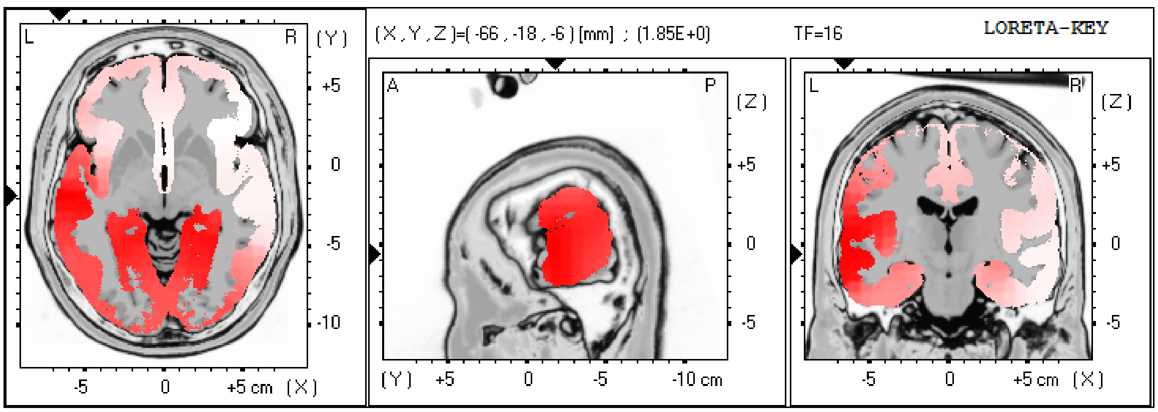


Figure 5: Abnormal LORETA results in middle temporal gyrus from concussed subject



fMRI

Encoding (EN), retrieval (RE), random navigation (RN), and baseline (BL) conditions were compared. Clusters of activities of comparisons between these groups were observed. All values were found to be significant. Results are shown in Table 22. Clusters of activation between conditions are also shown using pictorial representations (Figures 6-9).

Table 22: Comparison of EN, RE, RN, and BL fMRI results

EN VS BL			
	Normal Control	TBI	TBI-NC
p-value	2.19E-06	2.18E-06	6.715e-oo5
T	6.47	6.47	4.83
df	18	18	18
area of cluster	right cerebrum-temporal lobe-sub-gyral white matter	right cerebrum-frontal lobe-middle frontal gyrus	right cerebrum-temporal lobe-superior temporal gyrus
EN VS RE			
	Normal Control	TBI	
p-value	N/A	0.00015	
T	N/A	4.45	
df	N/A	18	
area of cluster	N/A	left cerebrum pareital lobe-superior parietal lobule	
EN VS RN			
	Normal Control	TBI	TBI-NC
p-value	3.50E-05	3.58E-05	6.72E-05
T	6.48	6.48	5.99
df	10	10	10
area of cluster	right cerebrum - parietal lobe - inferior parietal lobule	left cerebrum -frontal lobe-sub-gyral	right cerebrum-limbic lobe-anterior cingulate
RE VS BL			
	Normal Control	TBI	
p-value	6.71E-05	6.71E-05	
T	4.83	4.83	
df	18	18	
area of cluster	left cerebrum-parietal lobe-superior parietal lobule	left cerebrum-parietal lobe-superior parietal lobule	
RE VS RN			
	Normal Control	TBI	
p-value	N/A	2.53E-05	
T	N/A	6.75	
df	N/A	10	
area of cluster	N/A	right cerebrum-sub-lobar	

Figure 6: Clusters seen in RE VS BL (Normal Control)

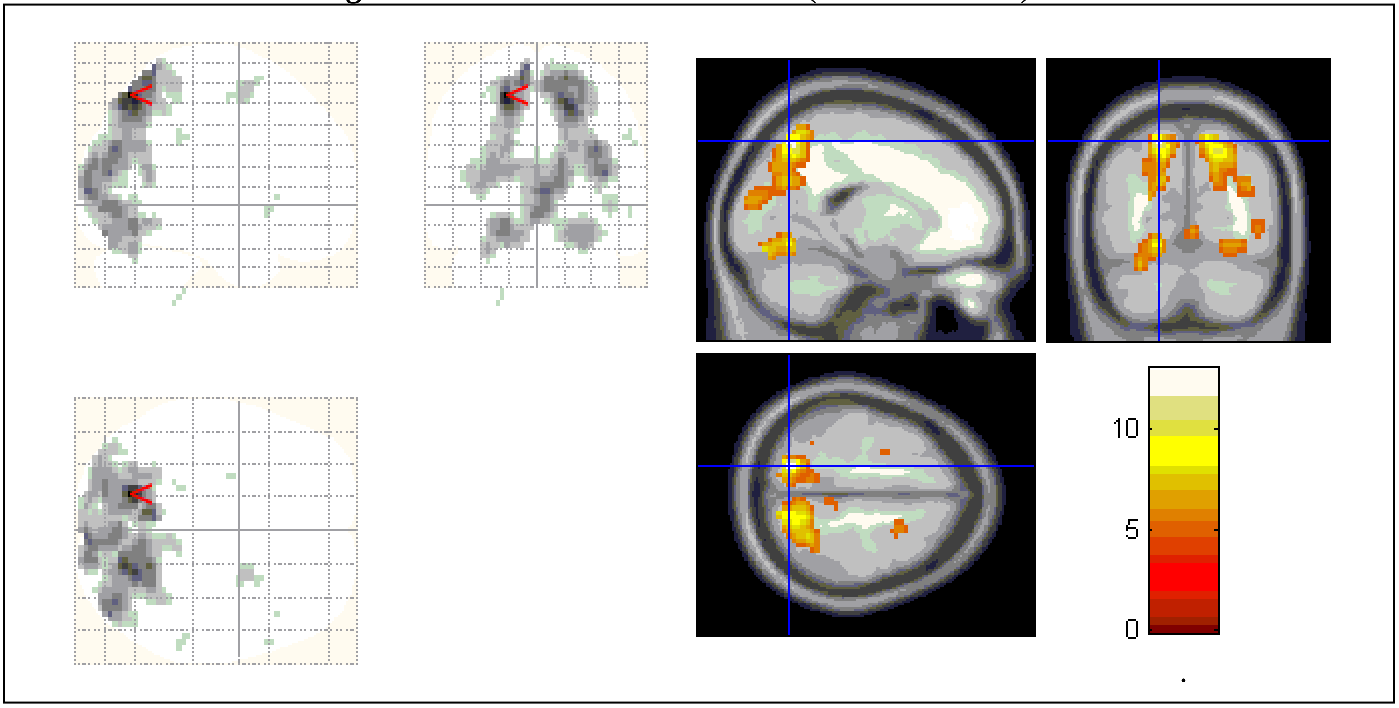


Figure 7: Clusters seen in RE VS BL (TBI)

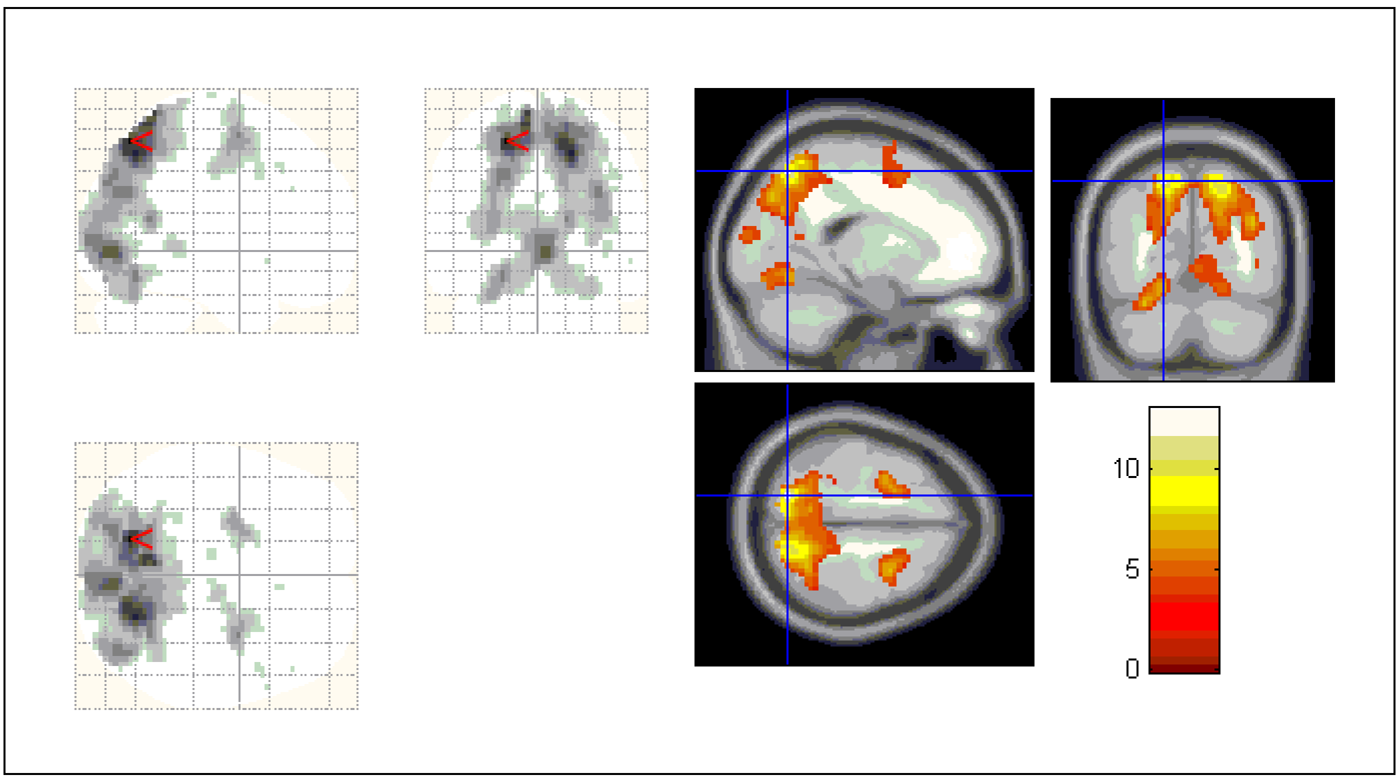


Figure 8: Clusters seen in EN VS BL (Normal Control)

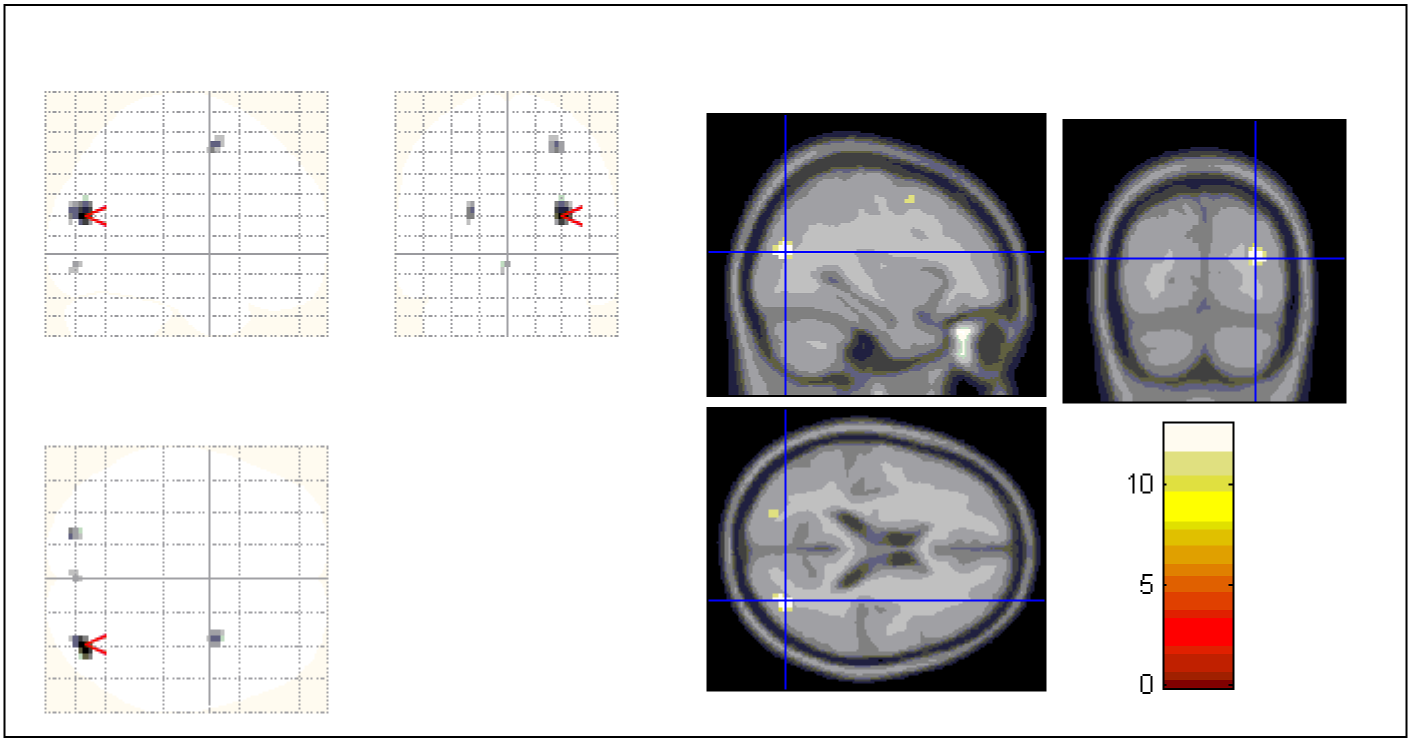
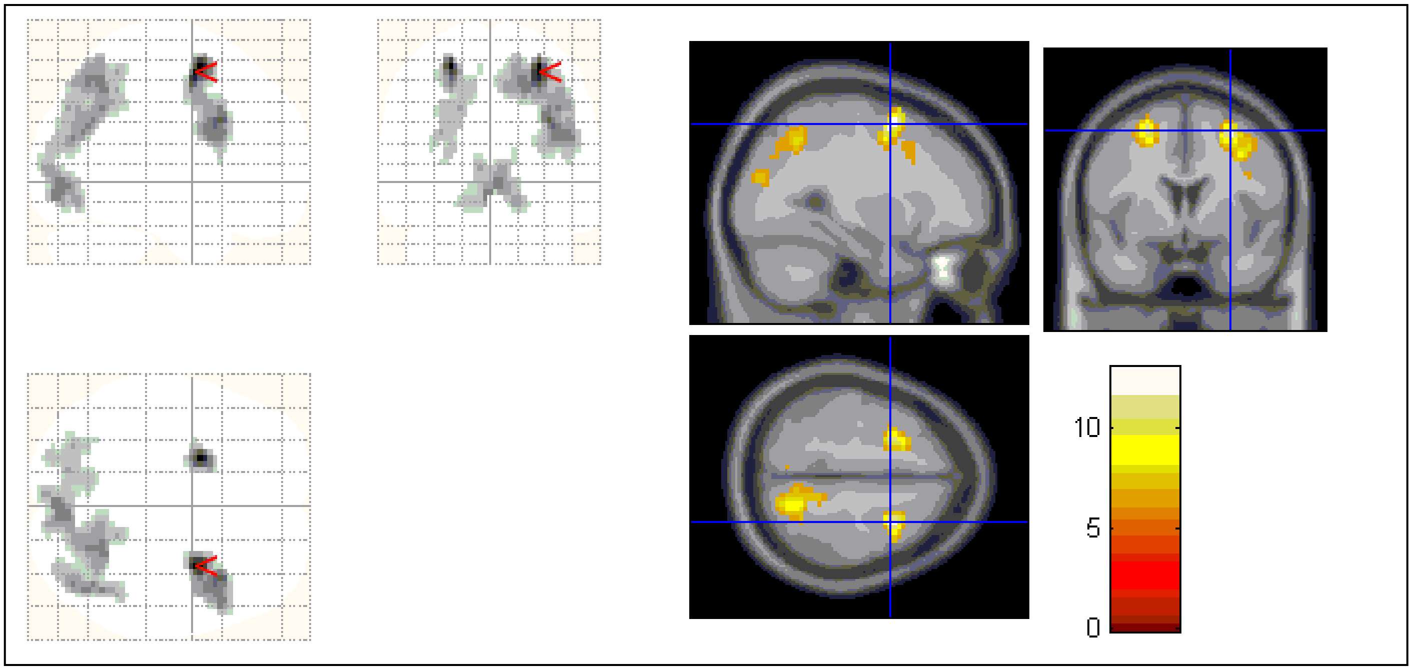


Figure 9: Clusters seen in EN VS BL (TBI)



Chapter 5 - Discussion

This study consisted of forty-four collegiate rugby players participating in the EEG studies, where sixteen subjects were un-injured and used as a baseline control and where twenty-eight subjects were injured and received a mild traumatic brain injury. The study also consisted of thirty collegiate athletes participating in the fMRI study, fifteen subjects being uninjured and considered to be the control, while fifteen subjects were injured after suffering from a MTBI. One aim of the study was to use several different measures including neuropsychological testing, EEG, and fMRI to determine the effects that MTBI has on an athlete's brain. It was hypothesized that all three of these methods would help show the negative effects MTBI has on the brain and that these effects are present even weeks after the injury is obtained. According to all of the results that were gathered throughout the past year, it was evident that injury can be seen by all three tests, however each may not be reliable on its own due to the complicated nature of the head injury. Therefore, one can use all three tests as a comprehensive approach in determining severity and treatment of MTBI in athletes.

Neuropsychological testing is commonly used as the initial assessment of MTBI in athletes, used both on and off the field (Mendez et al., 2005). This testing is used in several professional areas of athletics including the National Football League (NFL), the National Hockey League (NHL), and National Association for Stock Car Auto Racing (NASCAR) (Mendez et al., 2005). Neuropsychological tests can test for a variety of impairments due to brain injury including cognitive skills, immediate and delayed recall, orientation, attention span, verbal memory, visual scanning, coordination, and word fluency (Mendez et al., 2005). For these tests to be most beneficial to determining severity of a MTBI, the test given at the time of injury should be able to be compared to a test that was given at baseline, before the injury was obtained (Mendez et al., 2005). This is why it is important to test athletes at the beginning of a season so this information is accessible to trainers and physician's if an injury is obtained further into the season. However, a common limitation to these neuropsychological tests is that both practice and learning effects can be confounding factors in the interpretation of the test scores (Thompson, 2007). One can also see problems with difficulty of the tests being different for each individual athlete. To some athletes who may have seen such a test before, it may come very easily to them, having it appear that the athlete is functioning properly neuropsychologically, but further testing in a more physical environment and conditions may show mental impairment due to the injury (Thompson, 2007).

In this study we used three specific types of neuropsychological testing including The Trails B test, Symbol Digit Substitution test, and the Symptom Rating Scale. The Trails B test is used specifically to assess processing speed and scanning ability. The Symbol Digit Substitution test is used to assess processing speed and working memory in athletes who have received head injury (Randolph et al., 2005). Finally, the Symptom Rating Scale is used to help determine the severity of the symptoms affecting the athlete. According to the results found after these three tests were administered in our study, no significant effects were found for The Trails B test and the Symbol Digit Substitution test, however a significant effect was found for the Symptom Rating Scale between baseline and MTBI subjects. Although there was no significant effect was found for the first two tests administered, one can see a positive trend from the test administered to the MTBI subjects the first time through their second follow-up test. The results from these two tests began to improve with time following injury, showing an increase in healing of the brain. Significant results were found from the Symptom Rating Scale showing a dramatic increase in symptoms which included dizziness, headache, nausea, irritability, difficulty concentrating or remembering, balance problems, and sensitivity to light or noise for MTBI subjects compared to baseline. We can see from this that the subjects who had received injury, were feeling the affects, many even through their second follow-up testing. Due to the results that were found from the three neuropsychological tests used in this study, one could conclude that they could be helpful in determining the severity and cognitive effects the concussion is having on the athlete as long as you have a baseline test in order to compare the injured tests to. However, it should be used with other measures as well, since it cannot be fully reliable on its own.

Electroencephalogram (EEG) measures the neurophysiological electrical activity of the brain and has been found to be extremely useful in the detection and treatment of MTBI in athletes (Thompson, 2007). The recorded brain waves shows the temporal and spatial summed activity of the excitatory and inhibitory post-synaptic potentials from the pyramidal cells in the upper layer of the brain's cortex (Kandel et al., 2000). Since the EEG records the brain waves from the extracellular space of the cortex, it is able to detect the signals of numerous amounts of pyramidal cells in the brain at one time (Thompson, 2007). The EEG is a direct measure of cerebral functioning and shows the level of the subject's arousal of the brain (Thompson, 2007). It is said that the changes in brain waves seen in the EEG of MTBI patients, are very similar to those brain waves seen in patients with congenital or acquired brain disorders (Nuwer et al., 2005). In several studies, EEG patterns in MTBI were shown to have reduced mean alpha frequency, reduced mean alpha power, and decreased beta power compared to uninjured subjects (Thompson, 2007). Low Resolution Electromagnetic Tomography (LORETA) can be used with EEG and can create a three-dimensional picture showing the distribution of active neurons in the brain. This tool is helpful in determining which areas of the brain are most commonly affected by MTBI. In another study, researchers observed the effects of EEG patterns during postural tasks in injured athletes even up to 90 days after the MTBI was obtained. It was found that all EEG bandwidths had reduced power and suggests reduced functional capabilities and postural instability in athletes with brain injury even several weeks after the time of injury (Mendez, 2005). It is also noted that during the initial months following a head injury, EEG testing shows abnormality in athletes more often than a simple physical examination (Nuwer et al., 2005)

In this study, we recorded brain waves using EEG of normal and MTBI subjects in a rested, sitting position. We then inputted this data into NeuroScan software which gave us TBI discriminant score, TBI probability index and the TBI severity index for each subject tested. The TBI discriminant score and the TBI probability index show the subject's probability of membership in the mild traumatic brain injury population while the TBI Severity Index shows an index of an estimate of the neurological severity of injury. According to the results that were compiled, no significant differences were found for any three of these scores between baseline and MTBI subjects. However, when looking at the data, a general trend is seen of a lesser TBI discriminant score for baseline, and greater TBI Severity Index and TBI probability index for the MTBI subjects.

According to the LORETA analysis conducted, the most common areas affected by the brain injury in concussed patients are the parahippocampal gyrus in the limbic lobe and the middle temporal gyrus in the temporal lobe. Medial temporal lobe structures, including the hippocampus and surrounding parahippocampal cortices are essential for the formation of new declarative memories (Chai et al., 2010). More importantly, certain areas in the parahippocampal cortex are known to dramatically grow in size from youth to adulthood, with growth correlating with recognition memory (Chai et al., 2010). With this information, it is even more important to try to prevent serious head injuries in athlete's, especially in their earlier years where it can lead to problems with development.

Due to the results that were found in this experiment, one can conclude that EEG could be beneficial in determining the severity and area affected from MTBI in athletes, however it is not sufficient to be used as the sole means in treating head injury, since it cannot be fully reliable on its own. Several problems have been found with testing MTBI patients with EEG. One is that drowsiness, pain, anxiety and other factors could also lead to reduced alpha waves shown in the recording (Nuwer et al., 2005). Injury, illness, or developmental problems, which subjects may have coming into the lab which is beyond our scope to test for, may also lead to the same EEG results (Nuwer et al., 2005). Therefore, it is important to be careful if EEG is the only technique being used to examine the brain waves of MTBI patients. One tip that should be considered in performing EEG tests with these subjects is that if the EEG is unchanged throughout the entire post-traumatic period, from first test after injury through several follow-ups, the results are probably not related to the trauma, but some other underlying factor (Nuwer et al., 2005). Because of the results found in this study and others in the past, EEG should be used in a comprehensive attempt with includes other forms of testing for head injuries such as neuropsychological and fMRI tests.

Functional Magnetic Resonance Imaging (fMRI) is the newest technique being used today in MTBI research, but has been gaining much popularity with its reliable objective results that are being found. fMRI is noninvasive and provides information regarding the neural function of the brain during task performance (Mendez et al., 2005). Brain activation during fMRI is measured by using blood oxygenation level dependent (BOLD) analysis (Chen et al., 2007). BOLD contrast depends on the balance between the oxygen supply in the brain and consumption by the neural tissues (Attwell et al, 2002). Deoxyhemoglobin in the brain is paramagnetic, leading to a strong unaligned magnetic field in the MRI (Attwell et al, 2002). As the proportion of this deoxyhemoglobin decreases in the brain, the MRI signal, which is referred to the BOLD signal, increases due to the decrease in un-alignment (Attwell et al, 2002). In an athlete with MTBI, the brain must work harder in order to complete certain tasks such as memory. This leads to an increase in blood flow, decreasing deoxyhemoglobin and increasing oxyhemoglobin. Finally, this leads to an increase in a diamagnetic field and increase in the MRI signal or rather the BOLD signal being measured (Attwell et al, 2002).

Several studies that have been conducted using fMRI have found consistent results. In a previous study looking at memory tasks performed by baseline and concussed athletes, it was found that while the two groups had no differences in accuracy and success rate, there was significant increase in activation of certain brain regions during these tasks for the MTBI subjects (Slobounov et al., 2009). This shows that the brain of the injured athlete is working harder to complete the task and the blood flow to the brain increases dramatically. Further studies using verbal working memory, verbal control, and visual control tasks found significant task related BOLD signal increases in MTBI subjects compared to normal, uninjured subjects (Chen et al., 2007).

In this study, significant results were found between the baseline and MTBI subjects for several conditions. Two conditions were compared to each other and a picture was given showing the difference in activation clusters between these two conditions. This comparison was done with normal control subjects and subjects with mild traumatic brain injury. The most significant differences found between the normal control and brain injury subjects were in encoding versus baseline and encoding versus random navigation conditions. In these two comparisons, we were then able to create contrasts subtracting the normal control clusters from the brain injury clusters, finally showing just the difference of these clusters on the brain image. Significant differences were also found in the results between normal control and brain injury subjects in encoding versus retrieval and retrieval versus random navigation conditions. In all of these comparisons between conditions, the subjects suffering from a MTBI had significantly higher levels of activation in the brain when performing the tasks compared to the normal control subjects.

During encoding compared to the baseline condition, when the subject was required to remember a certain pathway to complete later in the test, there were significantly higher levels of activation in the right cerebrum, specifically the middle frontal gyrus in the frontal lobe and superior temporal gyrus in the temporal lobe of the brain. The middle frontal gyrus has been associated with storage and processing components of working memory in the human brain (Leung et al., 2002) and the superior temporal gyrus has been associating with visual search and spatial perception (Gharabaghi et al., 2006). One can see how much harder the brain is working in individuals suffering from brain injury when trying to understand and encode this pathway into their memory than the normal control subjects. It is also found that processing more complex scenes will likely result in greater activations sin scene-selective regions in the parahippocampal gyrus, a major structure seen to be affected during MTBI by EEG research (Chai et al., 2010). According to all of the results collected from the fMRI study, one can conclude that this technique is a very useful tool for physician's to use in order to determine the affects MTBI has on an athlete. Unfortunately, in order to complete any MRI, physicians, coaches, or athletic trainers must have the financial means to pay for a test since it can become very expensive. It is also necessary for the athlete to have a decent amount of time and patience, since he or she will be asked to lay as still as possible in the MRI machine for a great deal of time. However, it is important to include fMRI, if resources are available, to a comprehensive approach along with neuropsychological tests and EEG, to determine how MTBI affects athletes and how they should be treated.

Mild traumatic brain injuries, or also known as concussions, are one of the most common injuries seen today in sports. It is said that concussions account for about 8.9% of all high school sports injuries obtained each year (Piebes, 2009). It is also said that about one-third of the population is expected to suffer from a MTBI sometime during their life (Nuwer, 2005). These brain injuries are also one of the most difficult injuries to diagnose and treat due to the great variability in definitions seen for what a concussion is classified as. These injuries are often overlooked and treated poorly due to the misconceptions many athletes and parents have. Concussions are much more serious than how they are commonly treated. Even three months after a MTBI had been received, some patients still experience significant symptoms including headache, irritability, anxiety, dizziness, fatigue, and impaired concentration (Nuwer, 2005).

Due to the fact that in many cases after an athlete receives a blow to the head, coaches and athletic trainers rely on only subjective measures to determine if a MTBI was obtained, many athletes return to play too early, before they are completely healed from their injury. This is a very serious problem that must be considered due to the occurrence of Second Impact Syndrome (SIS) when athletes return to play after obtaining a concussion. SIS occurs when an athlete receives another head injury before the first injury had time to completely heal and is still experiencing some symptoms (Piebes, 2009). This second injury to the brain can lead to a decrease in the brain's ability to auto-regulate blood flow leading to vascular engorgement, brain swelling, and increases in intracranial pressure (Piebes, 2009). In cases such as this, athletes may collapse and then experience a coma or even death. These second head injuries dramatically increase the risk for neurological dysfunction even if the second injury occurs within a few days after the first (Nuwer, 2005).

Since the prevalence of MTBI in sport is so high, the specific tools used to diagnose, treat, and understand MTBIs are not well known, the high occurrence of returning to play too early before a MTBI is healed, and the severity of SIS is so great, one can see the extreme importance of learning more about MTBI to prevent these events from happening. Physicians, coaches, athletic trainers, as well as the athletes themselves, must become educated on how serious MTBI can be in sport. It is also important to find the most effective techniques that can be used in order to diagnose, determine the severity, and treat these serious head injuries. According to the results found in this study, as well as others completed in the past, it is important to use a comprehensive approach in dealing with a MTBI obtained by an athlete in sport, which includes neuropsychological tests, EEG, and fMRI. All of these tests have been found to be beneficial tools in giving us information about MTBI.

Beneficial and significant results were found during this study after completing the three different types of tests commonly seen in dealing with MTBI in athletes. However, several limitations were found. One limitation was that sometimes it was difficult to get the athletes into the lab for testing as soon as possible. A member of the lab was in touch with the subjects, setting up tests according to the subject's schedule. For concussion subjects, we would have liked the first test to be within 24 hours of when the injury was obtained, however in some cases this was not possible due to scheduling conflicts. Another limitation was the EEG cap not being fully functional. In some cases, a certain electrode would not be working or stop working halfway through the test, giving us inappropriate results. At times, it was also difficult to obtain proper EEG results due to the subjects not being to relax as much as we would have liked them to and not being able to reduce the noise given to us by muscle activity. Finally, since the process of fMRI is based off of magnetic principles, results from subjects who had metal in their mouths, such dental braces or permanent fixtures, were not able to be used due to this metal causing perturbations in the magnetic field and leading to inappropriate activation areas and levels shown in the brain.

This study, as well as others performed in the past, has given us the basic framework of techniques we are able to use to see the affects MTBI has on the brains of athletes. Using this information, further tests should be conducted in order to determine long-term effects of these injuries and introduce a proper treatment method to keep athletes safe from events such as Second Impact Syndrome. It is also important to further educate coaches, athletic trainers, athletes, and parents about the serious effects of these head injuries and to try to prevent them in the first place. Hopefully with the results from current and previous research, returning to play too early after head injury can be prevented and the prevalence of these serious injuries can be decreased.

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EDUCATION: **The Pennsylvania State University**, University Park, PA
Expected Graduation Date (May, 2010)
Major: Kinesiology: Movement Science Option

HONORS

August 2007 – present	Member of The Schreyer Honors College
September 2007 – present	Member of The Health and Human Development Honor Society

ACTIVITIES

January 2008 – present — *Research Assistant* in EEG and fMRI laboratory

September 2007 – present — *Member of Orchesis Dance Company*

- 2008-2009 Position: Chair for Penn State Dance Marathon, the nation's largest student-run philanthropy
- 2009-2010 Position: Treasurer

WORK EXPERIENCE

June 2009 – present	*Peri-Operative Surgical Assistant*, Good Samaritan Hospital Medical Center (W. Islip, NY)
January 2008- December 2009	*Note-taker*, Nittany Notes (State College, PA)

SERVICE ACTIVITIES

November 2008	14 hours shadowing Dr. Stephen U. Harris MD, Good Samaritan Hospital Medical Center (W. Islip, NY)
June 2008 – August 2008	48 hours volunteering in physical therapy department, Good Samaritan Hospital Medical Center (W. Islip, NY)
July 2008 – August 2008	21 hours shadowing Mr. Kevin Niles RPA-C, Good Samaritan Hospital Medical Center (W. Islip, NY)
March 2008	Volunteer to run Kinesiology information booth at Health Fair, Park Forest Middle School (State College, PA)
Spring 2007 – present	Fundraiser for The Penn State Dance Marathon, The Pennsylvania State University (University Park, PA)

SKILLS

- CPR/AED certified through American Heart Association BLS Healthcare Provider Course
- Familiar with Neuroguide, Neuroscan, and MATLAB softwares