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CHANGES IN CENTER OF PRESSURE, ALPHA DEPRESSION, AND TRAUMATIC BRAIN INJURY DISCRIMINANT SCORES BEFORE AND AFTER A SPORTS-RELATED CONCUSSION

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ABBSTRACT

Determining when an athlete is safe to return to play after a sports-related concussion is one of the most controversial yet important sports medicine topics being researched. Recently, neuropsychological testing has been named as one of the best ways to track the brain's healing process post-concussion, and determine when the athlete is safe to return to play. This study measured percent changes between center of pressure (COP) standing eyes closed and standing eyes open, percent changes between alpha power electroencephalography (EEG) values from sitting eyes closed to standing eyes closed (alpha depression), and the changes in Traumatic Brain Injury discriminant scores pre and post-concussion. All subjects were student-athletes at The Pennsylvania State University, and participated in one baseline test pre concussion and three follow-up tests post concussion. It was found that within the first 20 days post-concussion; the percent difference in center of pressure (COP) from standing eyes closed to standing eyes open decreased from baseline value in 71% (5/7) of the subjects, alpha depression from sitting eyes closed to standing eyes closed decreased from baseline value in 71% (5/7) of the subjects, and TBI discriminant scores decreased from baseline value in 57% (4/7) of the subjects. After 30 days post-concussion, alpha depression was decreased from baseline in 71% (5/7) of the subjects, COP percent difference was increased from baseline in 57 (4/7) of the subjects and 57% (4/7) of the subjects had a decrease in their TBI discriminant score from baseline value.

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Chapter One

Introduction

1.1 Statement of the Problem

Sport-related concussions have become a well-known injury in the athletics world. Sports commentators, coaches, fans, trainers and players alike are aware of the prevalence of concussions in competitive sports. At the forefront of sports-related concussion research is no longer the methodology of a concussion (though that is still being continuously studied), it is the question of how to determine when a concussed athlete can safely return to play after a suffering a concussion[8] – to eliminate the risk of Second Impact Syndrome. Second Impact Syndrome (SIS) occurs when an athlete with a concussion returns to play before that injury has fully healed, and receives a second blow to the head.[1] SIS is rare yet deadly, and is often overlooked. When concussions were first reported and studied, it was believed that once symptoms subsided, the brain had fully healed. Today, neurological imaging and neuropsychological testing are proving that the brain may still be impaired even after outward symptoms have ceased.[2,3]

Outward symptoms of a concussion include, but are not limited to: nausea, confusion/disorientation, temporary loss of consciousness at onset of injury, headaches, impaired cognition, dizziness, fatigue, irritability and impaired balance.[1,4,7,8,9,10] Neuropsychological testing can reveal small changes in brain activity and functioning that outward symptoms cannot, and allows for the comparison of brain functioning pre- and post-concussion.[5] Due to its broad range of assessment and ability to detect small abnormalities in neurocognitive functioning, neuropsychological testing has been named the “cornerstone” of concussion diagnosis and recovery assessment.[5,6] There are numerous neuropsychological tests available that test cognitive skills such as recall, orientation, verbal memory, attention span, visual scanning, and coordination.[7] These neuropsychological assessments are most recently being used in assessment of short and long-term concussion symptoms, as well as measuring baseline values to compare with post-concussion values to monitor the brain's recover post-concussion.[3]

During the 2009-2010 school year, Meehan et al[6] surveyed high schools using the High School Reporting Information Online (HS RIO) injury surveillance system on their methods of diagnosing and tracking concussions in their athletes. The high schools surveyed employed a certified athletic trainer, and it was found that 40% of those U.S. high schools use computerized neurocognitive tests when managing sport-related concussions. 100% of the schools that offered computerized neurocognitive testing to their athletes report that these scores were used in making return-to-play decisions post-concussion. Schools that offered computerized testing were slightly more likely to have a medical professional return an athlete with a concussion to play than schools that did not offer testing. Those schools were also less likely to return athletes with concussions back to play within 10 days of their injury as opposed to the schools that did not offer testing. In the 2009-2010 academic year, 41.2% of concussions were monitored using computerized neurocognitive testing; an increase from 25.7% in the 2008-2009 school year, and it is expected for this number to continue rising as more schools gain access to the new technology and its importance continues to be proven.[6]

In this study, Electroencephalography (EEG) was used as the primary tool for baseline and post-concussion testing. In a review of Electroencephalography (EEG) testing and concussions, Arciniegas highlighted both the benefits and downfalls of using EEG for baseline and recovery concussion assessment.[5] It is known EEGs should not be used alone when assessing concussions – it should be used in conjunction with extensive symptom questioning and other neuropsychological testing methods by trained professionals in order for proper interpretation to happen.[5,6] EEGs have the ability to demonstrate abnormalities in neurocognitive functioning during the early post-injury period,[5] however, as the brain heals these abnormalities become so subtle that they may not be visible on an EEG – this is why other assessment methods must be used in order to confirm the total healing of a sport-related concussion.

On an EEG reading, there are four main brain waves that are analyzed: alpha, beta, delta, and theta. In this study, the power of the alpha waves was examined in athletes pre-and post-concussion. Alpha waves are best seen during relaxation, and are known to be increased in those who practice meditation.[12] In order to best measure alpha waves in the athletes, the EEG was conducted in a quiet, dark room and they were instructed to relax all muscles in their face and to "zone-out." In concussed subjects, the change in alpha power (known as alpha depression or the percent change) from sitting with the eyes closed to standing with the eyes closed should increase when compared to baseline difference. Increased alpha depression from sitting to standing indicates an abnormally high change in brain activity when standing with the eyes closed when compared to sitting with the eyes closed, which is a warning sign of a traumatic brain injury (TBI).

Center of pressure (COP) was also measured and analyzed as an indicator of balance in the subjects for this study. Center of pressure is the point of balance that an individual uses when standing – measured using a force plate that detects their center of weight, and reported in cm^2 (the area around which this point moved during the trial). If a person has poor balance, their center of pressure will be larger (a higher value) than someone with good balance, who will have a smaller center of pressure. When using COP as a measure of TBIs and concussion recovery, a value greater than $2cm^2$ indicates problematic or abnormal balance and is a warning sign that

that person may have a TBI. Center of pressure should be within normal for a healthy (non-TBI) athlete, should increase above their baseline value post-concussion, and should decrease back towards baseline as their brain heals over time.

TBI discriminant scores are compiled from EEG recordings and are one way of diagnosing a person with a TBI. Normal TBI discriminant scores range from -6 to about -1, and TBI-indicative scores range from about -1 to 4. These scores are a quick way to diagnose a person as having a TBI or not, however since the range of values overlap (see **Figure 1**), they are not a strong indicator of TBI when used on their own.

As technology continues to advance, neuropsychological testing is becoming more accessible and invaluable to athletic programs across the country when it comes to screening and monitoring athletes with concussions. The DSM has deemed neuropsychological testing as necessary to establish a concussion diagnosis,[11] furthermore establishing the exciting importance of this equipment as we continue to learn more about sport-related concussions and establish return-to-play guidelines. In the future, neuropsychological testing should be able to clarify ambiguities in diagnostic measures and return-to-play protocols for sport-related concussions.

1.2 Objectives

This study was designed to examine three neuropsychological variables in athletes pre- and post-concussion over a period of time in order to discover a pattern or timeline to aid in determining when an athlete is able to return to play without being at risk for Second Impact Syndrome (SIS). The three variables tracked were: alpha depression (from EEG) values sitting eyes closed and standing eyes closed, center of pressure (COP) standing eyes closed and standing eyes open, and Traumatic Brain Injury (TBI) discriminant scores. Through neuroimaging techniques and postural measures, the aim was to track the minute changes in the recovery of an athlete's brain after a concussion. The minute changes were tracked using percent differences between the two conditions for center of pressure and alpha depression, and plotting the TBI discriminant scores against days after concussion to try and find a recovery pattern for athletes post-concussion.

1.3 Preliminary Aims

1. Measure changes in center of pressure from standing eyes open to standing eyes closed.
2. Measure changes in alpha depression from sitting eyes closed to standing eyes closed.
3. Measure changes in Traumatic Brain Injury discriminant scores pre and post-concussion.

1.4 Specific Aims

1. Track the changes in percent difference of center of pressure from standing eyes open to standing eyes closed from baseline (pre concussion) to first, second, and third follow-ups post concussion.

2. Track the changes in alpha depression (percent difference) from sitting eyes closed to standing eyes closed from baseline (pre concussion) to first, second, and third follow-ups post-concussion.

3. Track the changes in Traumatic Brain Injury discriminant scores pre and post-concussion (three follow-ups) to establish a preliminary timeline for return to play guidelines.

1.5 Hypotheses

1. Center of pressure percent difference between StandEC to StandEO should increase from baseline post-concussion due to the increased difficulty of balancing with eyes closed after a concussion.

2. Alpha epression (percent difference) from StandEC and SitEC should increase from baseline to post-concussion due to increased brain activity while balancing with the eyes closed in a standing position vs. a relaxed sitting position. Balance is decreased post-concussion and therefore the brain must work harder to maintain a standing posture with the eyes closed.
3. TBI discriminant score should increase from baseline to post-concussion – indicating a TBI or mTBI and should decrease back to baseline over the course of recovery after a concussion.

Chapter Two

Methods

2.1 Subjects

All subjects used for this study were Pennsylvania State University student athletes. The seven subjects were athletes, ranging in age from 18-21 years. In order for the data to qualify for this study, each subject must have had a baseline assessment (pre-concussion), and three follow-up assessments post-concussion. Time in between each follow up was recommended at two weeks, but was not consistent between subjects.

2.2 Collecting Electroencephalography (EEG) Data

Continuous EEG activity was collected from the scalp at 19 sites: FP1, FP2, FZ, F3, F4, F7, F8, CZ, C3, C4, T3, T4, T7, T8, PZ, P3, P4, O1, O2 according to the international 10-20 system.[13] The ground electrode was located 10% anterior to FZ, linked earlobes served as references and electrode impedances were below 10 kΩ. The Ag/AgCl electrodes mounted in a Quickcap Electrode helmet (Neuroscan, Inc., El Paso, TX) were used in this study. EEG signals were recorded using a programmable dc coupled broadband SynAmps amplifier (NeuroScan, Inc., El Paso, TX). EEG signals were amplified (gain 1000, range set for ±55 mV) and bandpass filtered in the dc to 70 Hz frequency range. The EEG data were sampled at 250 Hz, using a separate 16-bit analog-to-digital converter for each channel. Data were collected using NeuroScan's Scan 4.2 software package and written to and stored on a Dell Precision 530 computer running an Intel XEON processor.

EEG data was collected at two minute intervals under the following four conditions:

sitting eyes closed (SitEC), sitting eyes open (SitEO), standing eyes closed (StandEC) and standing eyes open (StandEO). EEG data used were the alpha power values for SitEC an StandEC. Alpha depression was calculated as the change in alpha power from SitEC to StandEC. The EEG was conducted in a quiet, dark room and subjects were instructed to relax all muscles in their face and to "zone-out" while the EEG was being taken to allow for best electrical readings. Alpha depression values were calculated as percent difference between the sitting and standing values, and were calculated using the formula:

$$\text{Percent Difference} = \frac{|\text{Value 1} - \text{Value 2}|}{\text{Average of Two Values}} \times 100$$

2.3 Center of Pressure Measurement

Center of pressure (COP) was recorded with the subject in a bipedal stance, feet shoulder-width apart, on an AMTI force plate. Average COP area was computed in square centimeters using MATLAB R2009b version 7.9.0 (The MathWorks, Inc., Natick, MA). COP data was measured under two standing conditions: eyes closed and eyes open, and subjects were placed in a safety harness during the recordings. COP area greater than 1 was reported as problematic. Percent difference between the eyes closed and eyes open COP areas were calculated using the following formula:

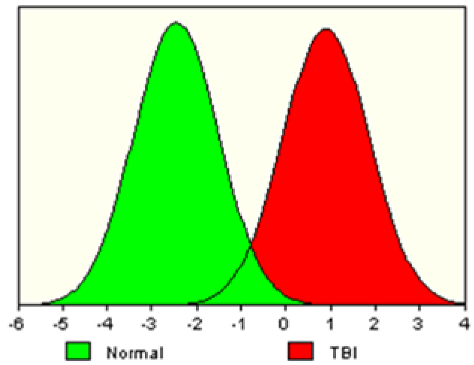
$$\text{Percent Difference} = \frac{|\text{Value 1} - \text{Value 2}|}{\text{Average of Two Values}} \times 100$$

2.4 TBI (Traumatic Brain Injury) Discriminant Score Calculation

TBI discriminant scores were generated in the Neuroguide Report using the subjects' EEG recordings on to the Neuroguide Deluxe 2.5.2 software (Applied Neuroscience, Inc., St.

Petersburg, FL). For this study, normal TBI discriminant scores were in the range from -6 to 0.5, and discriminant scores classifying a subject as having a TBI were evaluated in the range from 0.5 to 4. A TBI discriminant score in the overlap area from about -2 to 0.5 is classified as a warning sign for the presence of TBI – this area can be described as an "either-or" area. The subject may or may not have a TBI, and further testing should be done to determine their status (**Figure 1**). The farther a subject's TBI discriminant score is from the mean, the more probable their condition of normal or having a TBI is.

Figure 1: TBI Discriminant Score Range



Chapter Three

Results

3.1 Center of Pressure (COP) Results

Within the first 20 days post-concussion, 71% (5/7) of the subjects had a decrease in percent difference of COP from StandEC to StandEO from their baseline value (**Figure 2**). The change in percent difference averaged at -43.7901, ranging from -9.4867 to -98.1904. The earliest recorded decrease in percent difference from baseline was at 10 days post-concussion, and the latest recorded decrease in percent difference from baseline was at 66 days post-concussion.

After 30 days post-concussion, COP percent difference from StandEC to StandEO was increased from baseline in 57% (4/7) of the subjects (**Figure 3**). The increase in percent difference averaged at 41.03, ranging from 18.02 to 73.19. The earliest recorded increase in COP percent difference from baseline was at 13 days post-concussion, and the latest recorded increase in COP percent difference from baseline was at 124 days post-concussion.

Of the subjects that experienced the decrease in percent difference in COP from StandEC to StandEO within the first 20 days post-concussion, and those that experienced the increase in percent difference in COP from StandEC to StandEO after 30 days post-concussion, two subjects experienced both those patterns (**Figure 4**). COP data for all subjects can be found in Appendices A and B.

Figure 2: Decrease in COP Percent Difference from Baseline Within the First 20 Days Post-Concussion (Subjects 1,2,3,4,6)

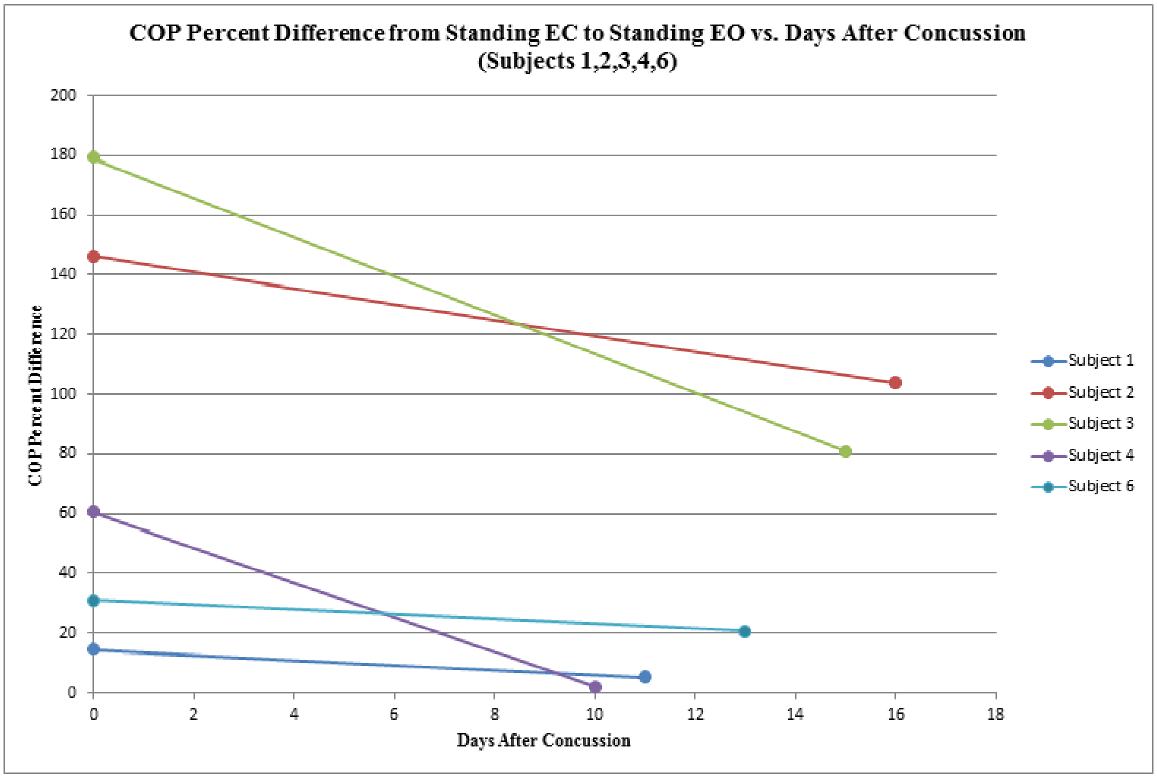


Figure 3: Increase in COP Percent Difference from Baseline After 30 Days Post-Concussion (Subjects 1,5,6,7)

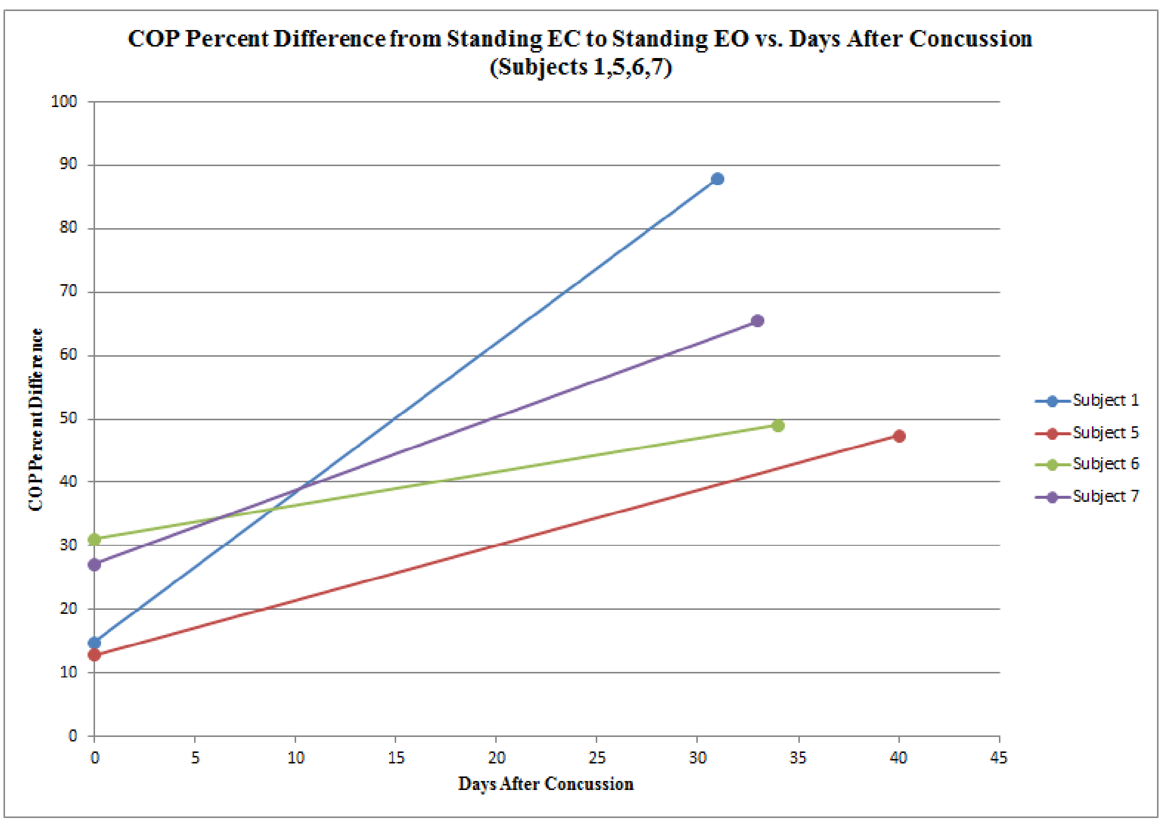
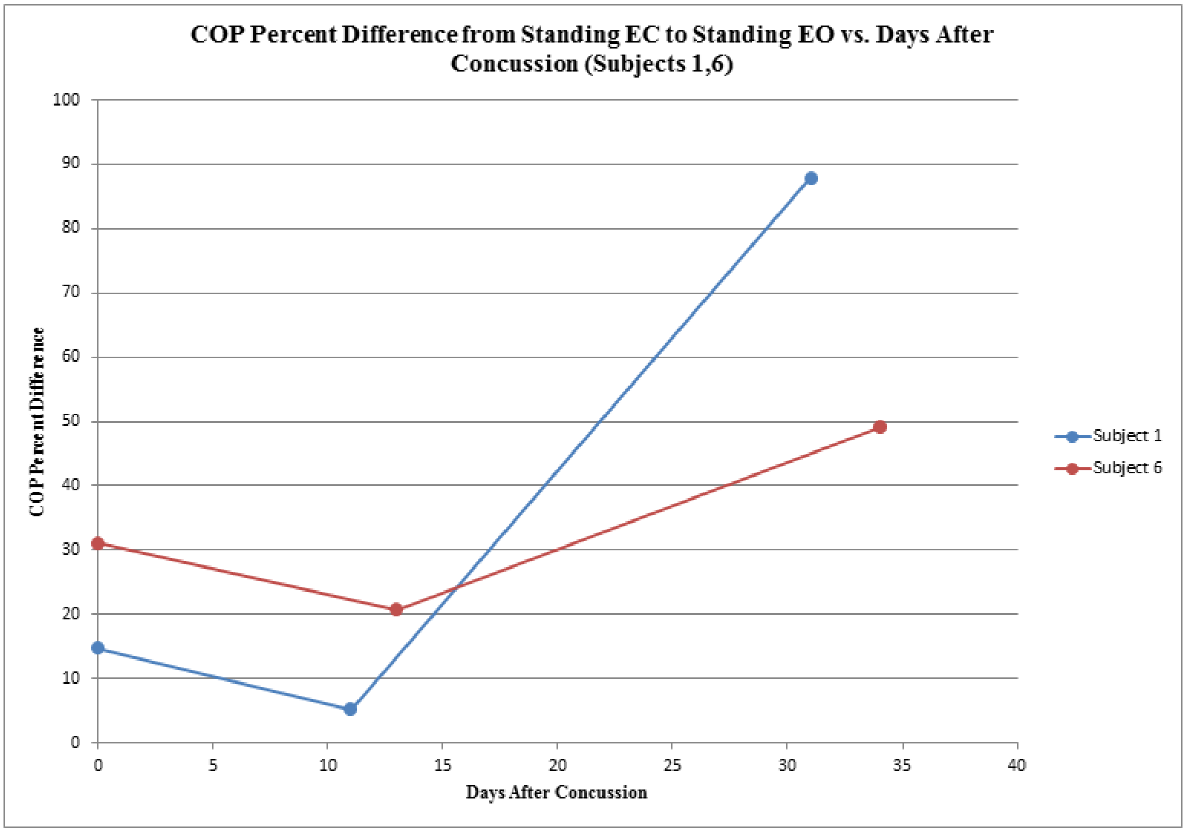


Figure 4: Decrease in COP Percent Difference from Baseline within 20 days Post-Concussion and Increase in COP Percent Difference from Baseline After 30 Days Post-Concussion



3.2 Alpha Depression Results

Within the first 20 days post-concussion, 71% (5/7) of the subjects had a decrease in alpha depression percent difference from SitEC to StandEC from baseline (**Figure 5**). The change in percent difference averaged at -15.63, ranging from -4.49 to -46.67.

After 30 days post-concussion, alpha depression percent difference from SitEC to StandEC was decreased from baseline in 71% (5/7) of the subjects (**Figure 6**). This change in percent difference averaged at -22.68, ranging from -14.17 to -43.05.

The earliest decrease in percent difference was recorded at 10 days post-concussion, and the latest decrease in percent difference was recorded at 124 days post-concussion. All five subjects that experienced a decrease in alpha depression percent difference from baseline within the first 20 days post-concussion also experienced a decrease in alpha depression percent difference from baseline after 30 days post-concussion (**Figure 7**). For three of those five subjects (subjects 2,5,7), the decrease from baseline after 30 days post-concussion was a further decrease from the decrease within 20 days post-concussion (see **Figure 7**). For the other two subjects (subjects 4,6), the decrease from baseline after 30 days post-concussion was an increase from the value taken within 20 days post-concussion (see **Figure 7**). Alpha power and alpha depression data for all subjects can be found in Appendices A and B.

Figure 5: Decrease in Alpha Depression Percent Difference from Baseline Within the First 20 Days Post-Concussion (Subjects 2,4,5,6,7)

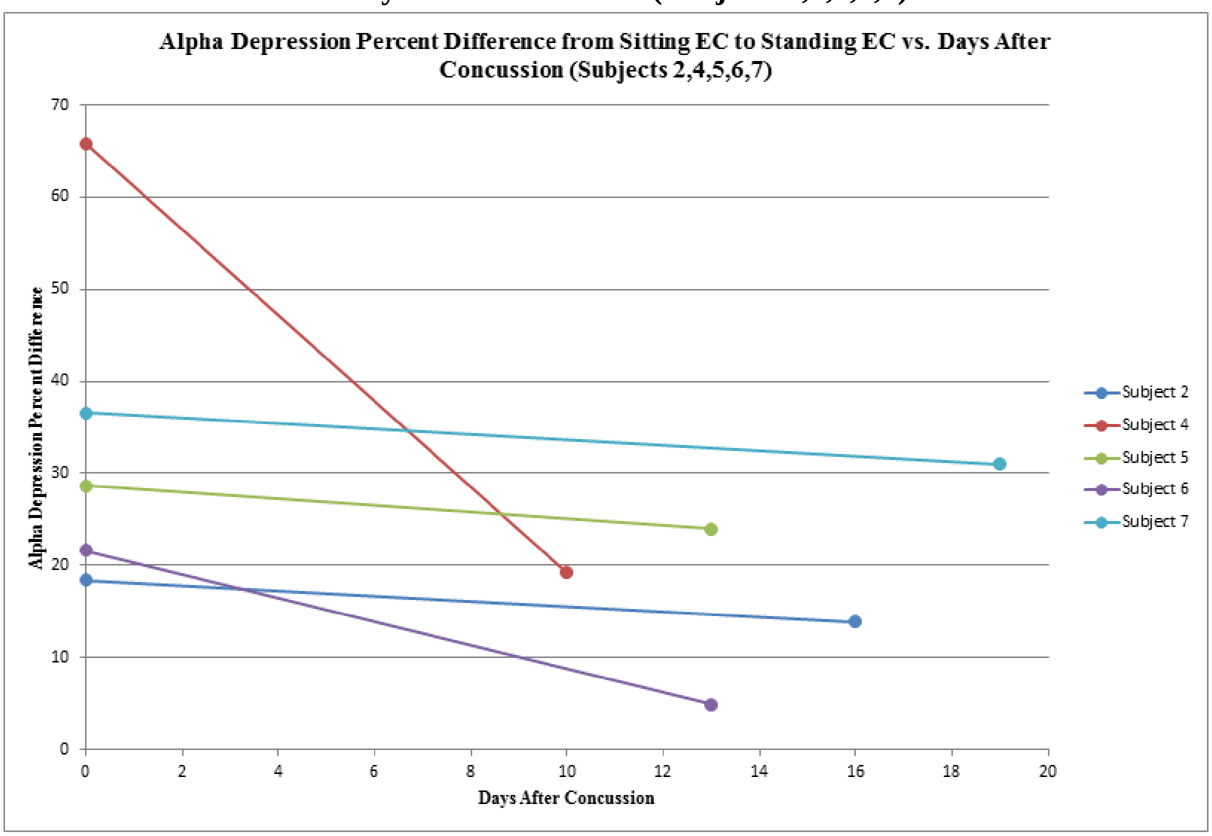


Figure 6: Decrease in Alpha Depression Percent Difference from Baseline After 30 Days Post-Concussion (Subjects 2,4,5,6,7)

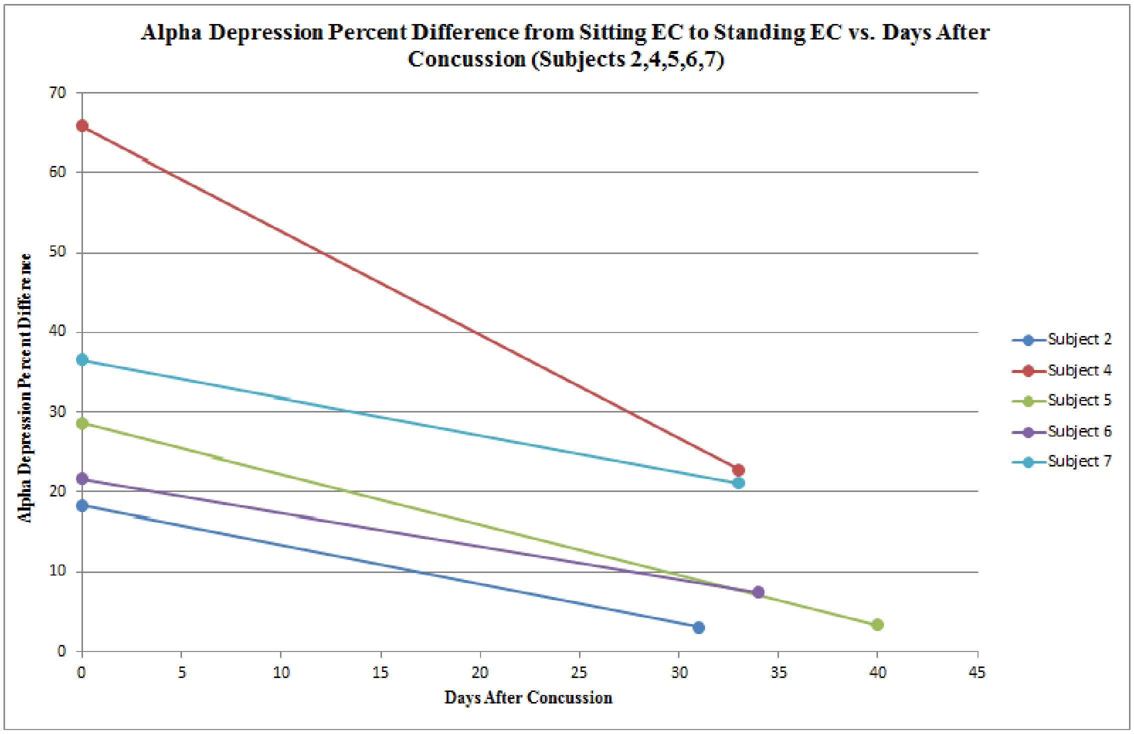
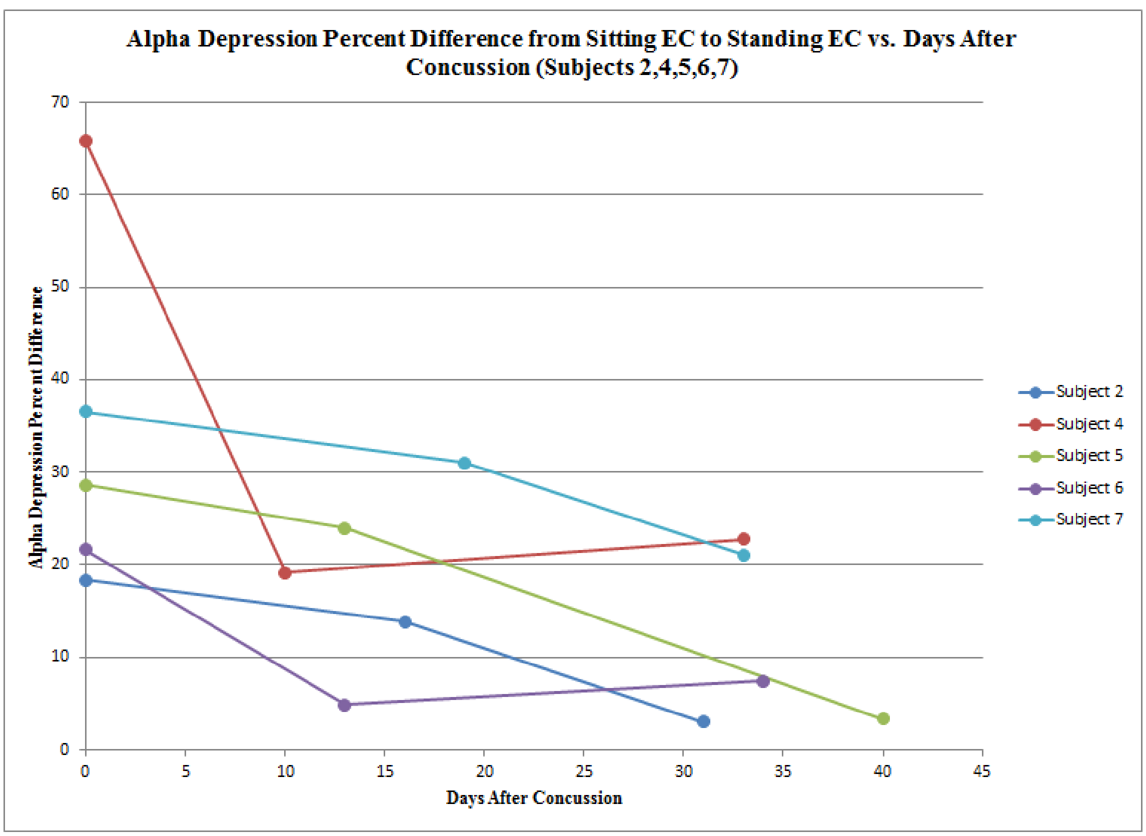


Figure 7: Decreases in Alpha Depression Percent Difference from Baseline Within 20 Days Post-Concussion and after 30 days Post-Concussion (Subjects 2,4,5,6,7)



3.3 Traumatic Brain Injury (TBI) Discriminant Score Results

Within the first 20 days post-concussion, 57% (4/7) of the subjects had a decrease in their TBI discriminant score from baseline (**Figure 8**). This decrease averaged at 7.60, ranging from 0.11 to 24.62 lower than baseline.

After the first 30 days post-concussion, 57% (4/7) of the subjects had a decrease in their TBI discriminant score from baseline (**Figure 9**). This decrease averaged at 1.59, ranging from 0.42 to 3.22 lower than baseline. Three of the subjects who experienced a decrease from baseline value within the first 20 days post-concussion also experienced a decrease from baseline after 30 days. Of those three subjects, two of the subjects' TBI discriminant scores from after 30 days post-concussion were lower than their TBI discriminant score recorded within 20 days post-concussion (**Figure 10**).

The earliest recorded decrease in TBI discriminant score from baseline was recorded at 10 days post-concussion, and the latest recorded decrease in TBI discriminant score from baseline was recorded at 124 days post-concussion. At baseline, according to their TBI discriminant scores, four subjects were normal (1,2,5,6), one subject was classified as having a mild TBI (3), and two subjects were classified as having TBIs (4,7). Within 20 days post-concussion, four subjects had TBI discriminant scores still indicating normality (1,2,6,7), and three subjects had TBI discriminant scores indicating a TBI (3,4,5). After 30 days post-concussion, two subjects had TBI discriminant scores still indicating normality (2,6), there subjects had TBI discriminant scores indicating a mild TBI (3,4,5), and two subjects had TBI discriminant scores indicating a TBI (1,7). TBI discriminant scores for all subjects can be found in Appendices A and B.

Figure 8: Decrease in TBI Discriminant Score from Baseline to Within 20 Days Post-Concussion

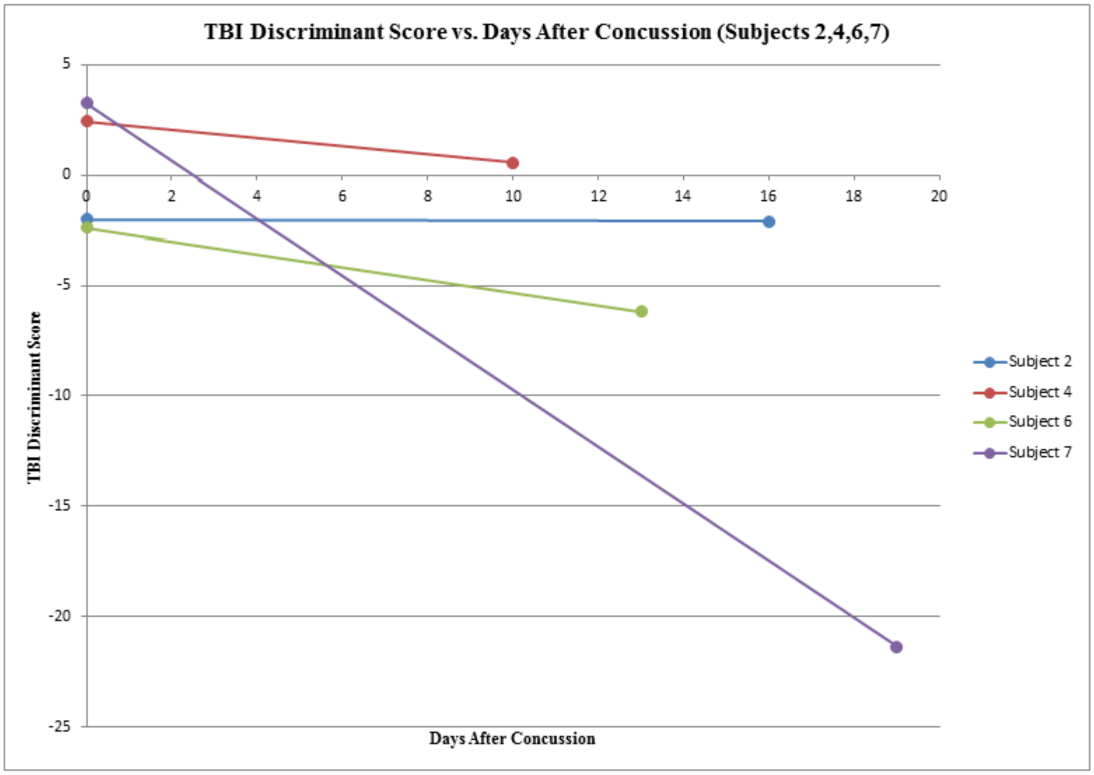


Figure 9: Decrease in TBI Discriminant Score from Baseline to After 30 Days Post-Concussion

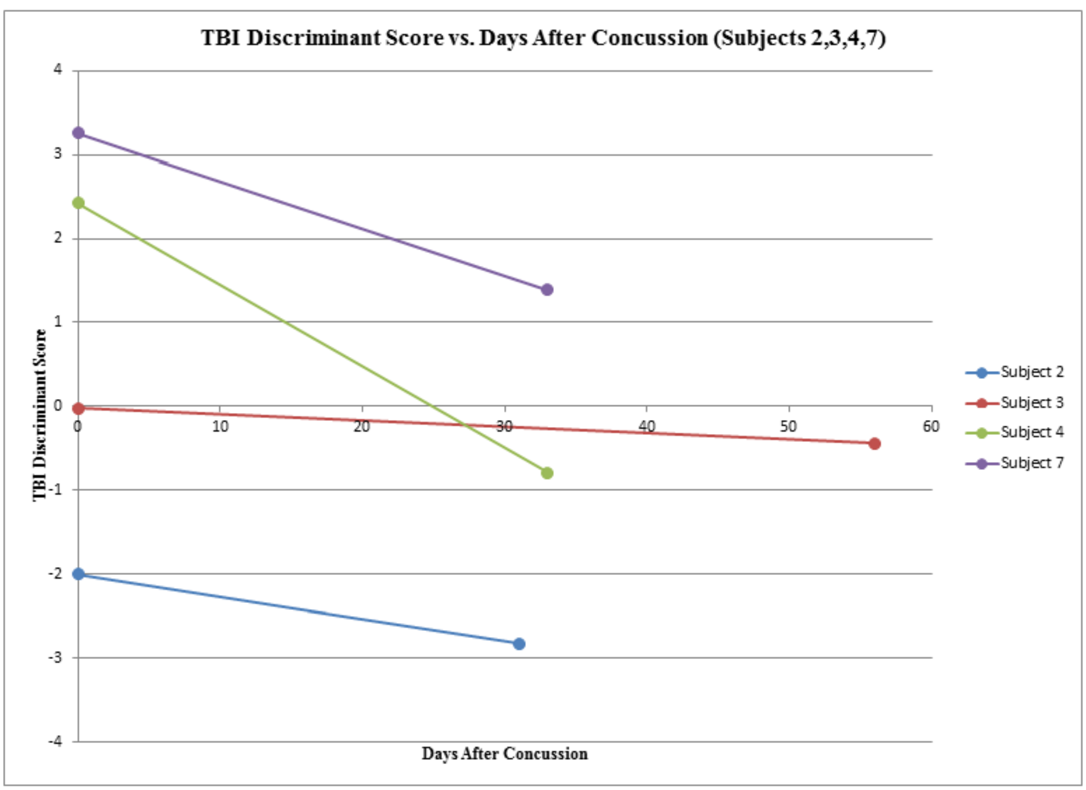
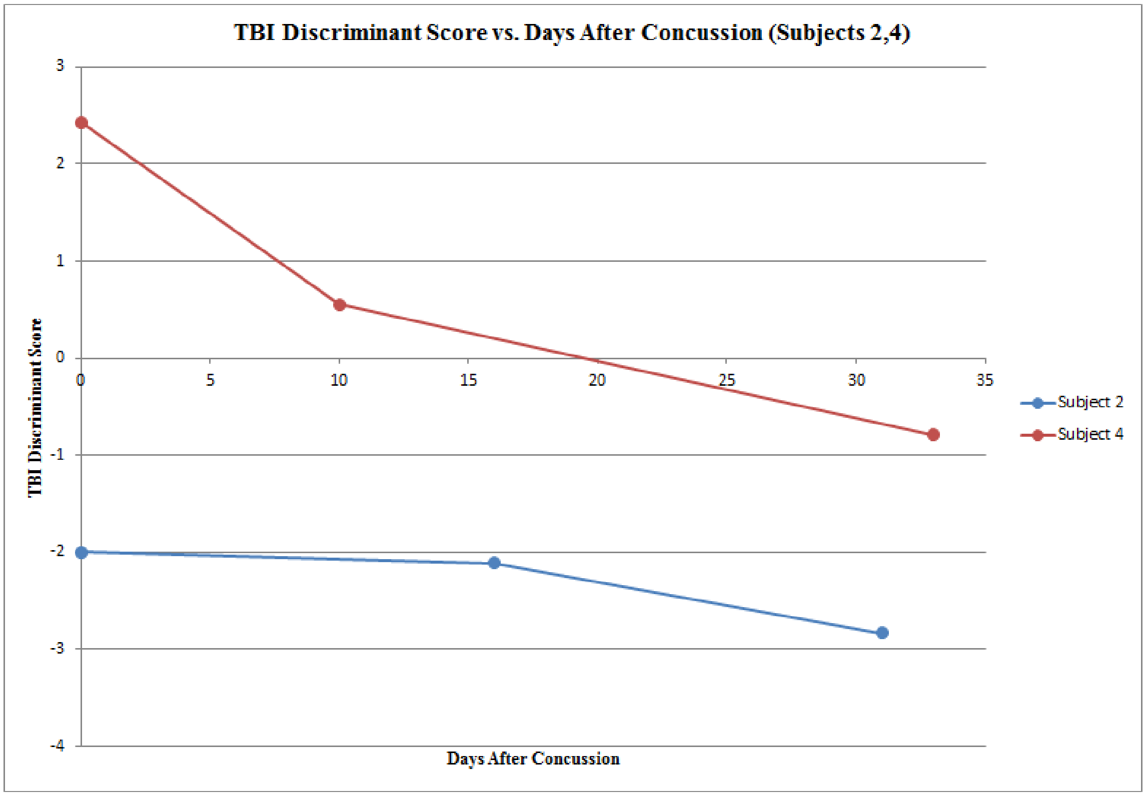


Figure 10: Decrease in TBI Discriminant Score from Baseline to Within 20 Days Post-Concussion and After 30 Days Post-Concussion



Chapter Four

Discussion

4.1 Summary and Analysis of Results

The first hypothesis stated that the subjects should experience an increase in COP percent difference from StandEC to StandEO post-concussion when compared to baseline. They should experience an increase in percent difference because the task of standing with eyes closed becomes more difficult post-concussion. However, 5/7 of the subjects experienced a *decrease* in COP percent difference between StandEC to StandEO from baseline within the first 20 days post-concussion. This could be due to a number of factors. When looking back at the baseline data of COP StandEO and StandEC when compared to the values within the first 20 days post-concussion (**Appendix A**), five of the subjects had an increase in their COP Stand EO from baseline to post-concussion, and a similar change within the COP StandEC values as well. This changes the value that the COP StandEC would be compared to and thus explains why these subjects had the unexpected decrease in percent change. COP is a measure of balance, which can also be affected by extraneous variables that may not be associated with concussion such as fatigue or sickness (increased fluid in the ears can cause an abnormal decrease in balance ability). COP can also be influenced by whether or not the athlete is having a “good” or “bad” concussion symptom day. It is common for concussion symptoms to fluctuate during recovery and therefore if the subject was testing on a good day, their balance may have been better than the day before or day after – explaining the decrease in percent difference between StandEC and StandEO post-concussion.

After 30 days post-concussion, five subjects did experience the expected increase in COP percent difference from StandEO to StandEC when compared to baseline. The fact that the majority of the subjects did not experience this increase until 30 days post-concussion could mean multiple things. This could mean that: it takes balance impairment symptoms longer to resolve than other symptoms, balance impairment can fluctuate throughout the recovery process post-concussion (as stated above, for multiple reasons), and that measuring COP may not be the best indicator of concussion recovery. Since the hypothesized change in COP percent difference was not seen in the majority of the subjects until after 30 days post-concussion, this also means that neuropsychological tests needs to be continued at least one month after a concussion because symptoms may not have resolved fully until then. Center of Pressure is a very sensitive measurement and can detect minute changes in balance – so even if the athlete may not report having difficulty balancing during practice or play, they still may not be back to baseline as indicated by their COP.

The second hypothesis stated that alpha depression percent difference from SitEC to StandEC should also increase from baseline post-concussion due to increased brain activity (alpha power) when performing a task with the eyes closed post-concussion. However, the alpha depression percent change decreased within 20 days post-concussion *and* after 30 days post-concussion in the majority of the subjects. There are a couple explanations for this phenomenon. Like COP, each individual's alpha waves are different and have a different baseline and they are rarely consistent in their presence or activity due to extrinsic factors. Thus, these atypical results could be because the subject took their baseline on a day or during a point in their day, when their alpha waves were abnormally active or inactive. Then, when they went in for their follow-ups, their recordings weren't being compared to a true baseline, producing the aforementioned results. Looking at the individual data for alpha depression during SitEC and StandEC

(**Appendix A**), there is no clear pattern from baseline and through the follow-ups – further explaining why the percent differences decreased, opposing the second hypothesis.

Just over half of the subjects experienced a decrease in their TBI discriminant score from baseline within 20 days post-concussion and after 30 days-post concussion. This opposes the third hypothesis of this study; however the opposition is not very strong since four of the subjects showed this decrease, while three showed the hypothesized increase. The TBI discriminant scores were hypothesized to increase because TBI scores are higher than normal scores on the TBI discriminant score scale. The TBI discriminant scores were generated by the NeuroGuide program using the recorded EEG values. However, since they only take into account brain activity, they are not reliable scores when used alone in diagnosing a TBI.

One overarching explanation for the unexpected trends in all three variables is the unknown concussion history of the athletes. If an athlete has had multiple concussions, then it becomes difficult to know what their "real" baseline is, or if they even have one. There are two components to this explanation. First, the long-term effects of multiple concussions (especially four or more) are cumulative: the more concussions someone suffers, the more damage occurs to their brains and the more susceptible they become to subsequent concussions. Thus, to say that these baseline values are really "baseline" for these subjects may be false – they may have had concussions previously, therefore affecting what their "baseline" might be. Second, recent studies have detected the possibility of the brain adapting to the effects of a concussion – much like it adapts to repeated substance use or abuse. The brain might be adapting to the effects of multiple concussions by deviating from baseline values less and less as the number of concussions a person has increases. Pertaining to this data, this may mean that some of these subjects could have been experiencing their first or sixth concussion – and will therefore have different healing times, increasing the difficulty of standardizing any sort of "timeline" for recovery post-concussion.

4.2 Limitations

In this study, there were many limitations, including: a small subject size, variability of individual healing processes, the difficulty of isolating concussions as single incidents, and the inconsistency of each of the variables measured.

For this study, the main and most important limitation to note is the extremely small sample size. In any study, a small subject pool compromises the data and questions its value. Since there were a limited number of subjects, it was difficult to establish major patterns in their recovery processes, and deciding whether or not that pattern was typical, atypical, significant or insignificant. For this study, each subject had to have a baseline plus three follow-up tests in order to qualify. As mentioned below, it is difficult to emphasize the importance of neuropsychological testing to athletes who have packed schedules, and it is even more difficult to convince them they still need to be tested after they have been cleared to return to play. However, in a research field as young as that of sport-related concussions, any data, and any patterns found within that data, can be useful.

In the world of sports especially, it is difficult to isolate a concussion as a single incident in other words, while the athlete was supposed to be recovering, there might have been other situations in which they could have exacerbated their injury instead of allowing it to heal, which could explain many of the results trending away from expected patterns. Concussions are also polyetiological[5] – they can happen (and symptoms can be exacerbated) in many different ways. In this study, each subject followed different pathways of recovery – reflecting the complexity of assessing concussion recovery.

Every brain is built differently, and so every brain will heal differently. When trying to establish a timeline of the recovery process post-concussion, it is almost impossible to establish one that will apply to all athletes. Concussions that are more severe may take more time to heal when compared to concussions that are more mild and athletes who have had multiple concussions may also have a longer healing time than athletes with only one or two concussions. Lifestyle variables are also known to have an influence on neuropsychological testing – including stress, fatigue, patient history, and conscious or unconscious elaboration of symptoms or actions.[5]

Along with confounding variables that can influence EEG recordings, the minute changes in brain activity that occur during concussion recovery are not always detected by electroencephalography. This study also used center of pressure (balance) measurements to track the recovery of concussed athletes, however in order for return-to-play decisions to be completely solid, multiple neuropsychological tests need to be performed on the athlete.

As demonstrated by the results, center of pressure, alpha waves, and TBI discriminant scores are all variables that are inconsistent even in healthy individuals. Trying to compare post-concussion values to baseline values for these variables was difficult due to their baseline inconsistency. These results and limitations emphasize the importance of using multiple methods of survey and neuropsychological testing when diagnosing and monitoring an athlete with a concussion.

4.3 Future Research

Sport-related concussions will most likely continue to be at the forefront of sport-injury research in the coming years. These results, all of which opposed the three original hypotheses, strongly indicate the need for future research on these variables and their changes post-concussion in athletes.

The number one correction to this study for future research is to recruit more subjects. This can be done by expanding to multiple teams, universities, and emphasizing to the athletes that neuropsychological testing is crucial for making informed return-to-play decisions post-concussion. The more subjects that can participate in a study of this type will only strengthen the results and clear-up possible recovery patterns picked up by neuropsychological testing. The more subjects that demonstrate particular patterns will help to distinguish typical vs. atypical recovery post-concussion, and what constitutes a "recovered" athlete.

The time between concussion, and each of the follow-ups should be standardized in future studies of this type. Meaningful patterns of change were hard to discern when subjects' were not completing follow-ups at the same intervals. The first follow-up should happen within the first ten days post-concussion, and each follow-up after that should be done at ten-day intervals (or otherwise specified by a physician if needed). Consistency within the time post-concussion will help yield better results and display a better timeline of recovery as seen through the variables studied. In order for these intervals between tests to stay consistent it is, again, crucial to emphasize the importance of neuropsychological testing to the athlete (or concussed patient) and encourage them to stay loyal to their appointments. They should recognize how these tests are immensely helpful in their diagnosis, recovery, and decision to return-to-play (by a physician or certified clinician), and their role in minimizing the athlete's risk for the life-threatening Second Impact Syndrome (SIS).

Further research that compares neuropsychological variables pre- and post-concussion in athletes is at an all-time high, and the better we can refine the methods, variables, and results – the more we can educate athletes, coaches, and athletic trainers on monitoring a concussion and making return-to-play decisions.

4.4 Conclusion

Sport-related concussions are a young and rapidly expanding topic of research in sports medicine. Neuropsychological testing has emerged at the forefront of this research, and is proving to be an invaluable tool in diagnosing and tracking the recovery of concussions in athletes.

In this study, three variables were measured pre- and post-concussion in seven Penn State University athletes: center of pressure percent change from StandEC to StandEO, alpha depression percent change from SitEC to StandEC, and TBI discriminant scores. All three variables were hypothesized to increase post-concussion , however not all of them followed the expected pattern. COP percent change decreased from baseline in 5/7 subjects within 20 days post-concussion, and increased from baseline in 5/7 subjects after 30 days post-concussion. Alpha depression percent change decreased in 5/7 subjects both within 20 days post-concussion and after 30 days post-concussion. TBI discriminant scores decreased in 4/7 subjects both within 20 days post-concussion and after 30 days post-concussion. These results can be attributed to many factors such as the inconsistency of each variable both in normal and concussed subjects, outside variables such as stress or fatigue, and also due to the small amount of subjects used in the study. Future research on this topic involves increasing sample size, controlling for outside variables, monitoring inconsistencies within the measured variables, and standardizing time between follow-up tests post-concussion.

The results of this study further emphasize the growing need for sport-related concussion research and monitoring and exhibit the importance of using neuropsychological testing in diagnosing and monitoring concussions in athletes. In our society, when kids at the age of four are thrown into the dangerous sport of football, we need to continue to emphasize the dangers of concussions – especially at a young age – and develop ways to carefully monitor concussions in sport. The dangers of returning a concussed athlete to play too early are potentially life threatening (SIS) and need not to be taken lightly. Neuropsychological testing and research is crucial to eliminating the risk for SIS in young athletes and has the potential to save many lives.

APPENDIX A: TOTAL SUBJECT DATA

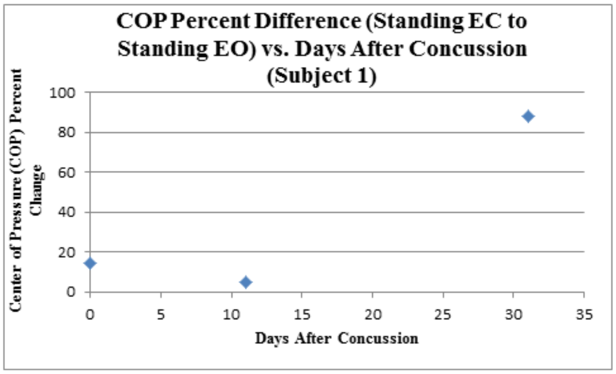
Subject/Test	COP Stand EC	COP Stand EO	COP Percent Difference	Alpha Power Sitting EC	Alpha Power Standing EC	Alpha Depression Percent Difference	TBI Discriminant Score
1: Baseline	1.6628	1.4349	14.7141	30.392	25.6915	16.7625	-3.02
FU-1	13.8234	13.1192	5.2274	39.937	27.752	36.0029	-2.66
FU-2	NO DATA	0.6087	NO DATA	18.781	32.0905	52.326	-0.64
FU-3	1.2399	3.1845	87.9034	15.0155	49.675	107.1548	2.30
2: Baseline	3.35	0.5202	146.2353	125.8345	151.291	18.3718	-2.00
FU-1	1.5476	0.4892	103.9277	99.4625	86.5505	13.8829	-2.11
FU-2	0.8909	0.7397	18.5453	119.895	123.59	3.0351	-2.83
FU-3	1.4564	0.7164	68.1149	110.353	111.6275	1.1483	-1.81
3: Baseline	0.1	0.05	179.1667	8.2255	8.8082	1.7599	-0.02
FU-1	1.275	0.5401	80.9763	16.3688	6.749	8.3211	2.31
FU-2	3.096	1.5448	66.8505	8.916	8.5345	4.3724	-0.44
FU-3	1.9392	1.6728	14.7508	10.6475	70.118	147.2671	1.20
4: Baseline	2.8462	1.5196	60.7224	58.89	29.7135	65.8586	2.43
FU-1	4.5858	4.4917	2.0733	43.138	35.5835	19.193	0.55
FU-2	1.0368	0.9506	8.6747	4.582	4.247	7.5886	2.41
FU-3	1.8031	1.5983	12.0421	43.8415	34.867	22.8044	-0.79
5: Baseline	1.3037	1.4822	12.8145	5.0045	3.75	28.6595	-1.86
FU-1	10.2162	1.9917	134.7406	2.3745	1.8665	23.9566	2.51
FU-2	2.2238	3.605	47.3923	4.55	4.704	3.3283	-0.30
FU-3	7.112	1.3247	137.1935	6.577	6.6255	0.7347	1.67
6: Baseline	1.5787	2.1592	31.0602	124.492	154.671	21.6211	-2.4
FU-1	2.2576	2.7801	20.7436	204.896	245.179	4.8758	-6.18
FU-2	2.5778	1.1985	73.0503	286.4525	281.9065	1.5997	0.16
FU-3	3.6716	2.2247	49.0782	277.2285	298.684	7.451	-1.47
7: Baseline	2.7493	3.613	27.1506	143.6516	207.952	36.5755	3.26
FU-1	5.2322	2.1031	85.3162	49.0615	67.056	30.9936	-21.36
FU-2	5.5203	2.7968	65.4916	76.9095	62.244	21.0782	1.39
FU-3	1.2284	0.7709	45.766	49.4195	43.487	12.7709	2.93

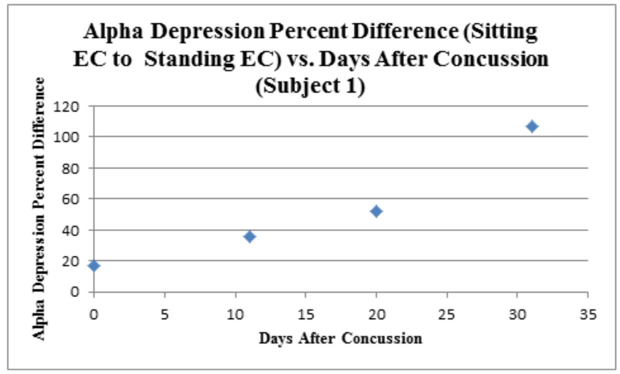
FU=Follow-Up Test (Post-Concussion) **COP**=Center of Pressure **EC**=Eyes Closed **EO**=Eyes Open **TBI**=Traumatic Brain Injury

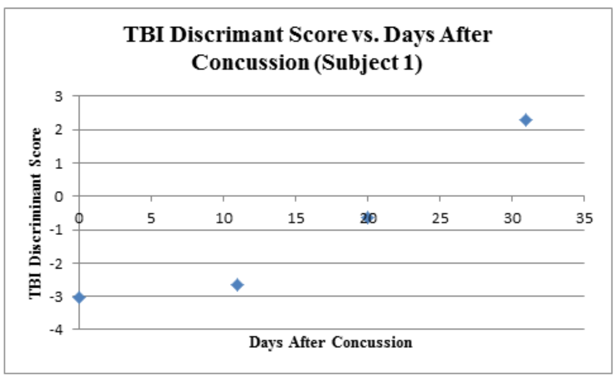
APPENDIX B: INDIVIDUAL SUBJECT DATA

NOTE: The value at "0" days after injury is the baseline pre-concussion value. All other values are post-concussion, and correspond with the days after concussion along the x-axis.

B.1: Subject 1 Data







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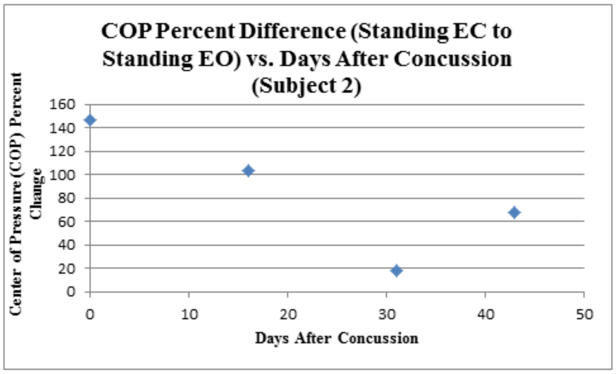

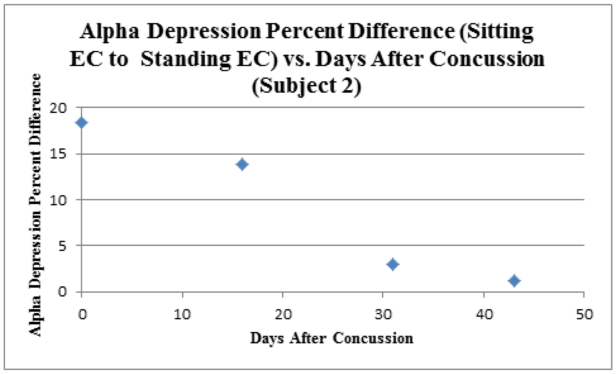

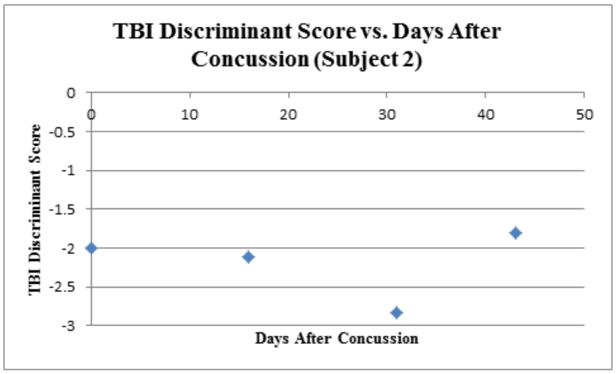

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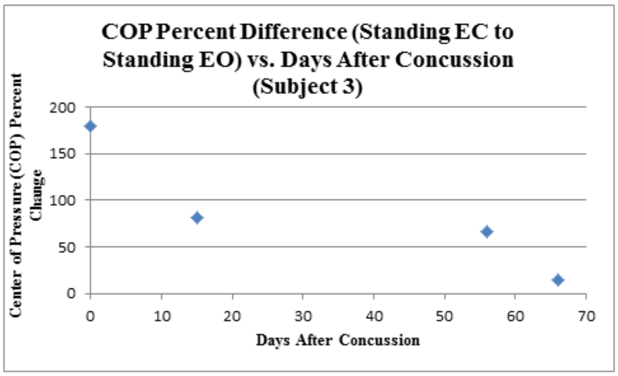

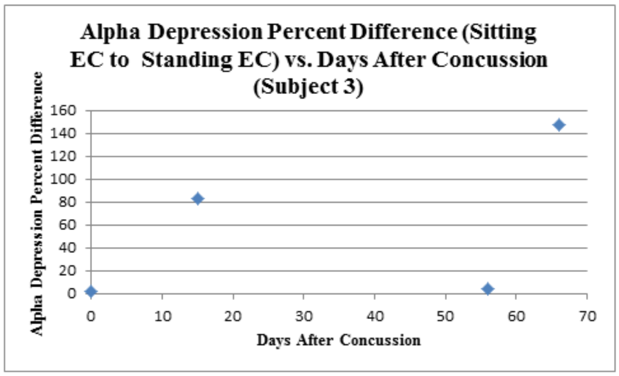

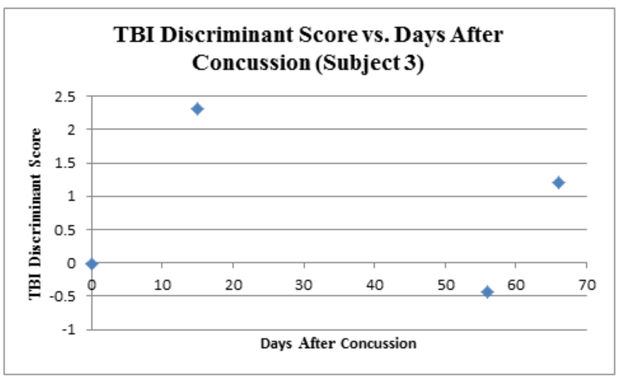

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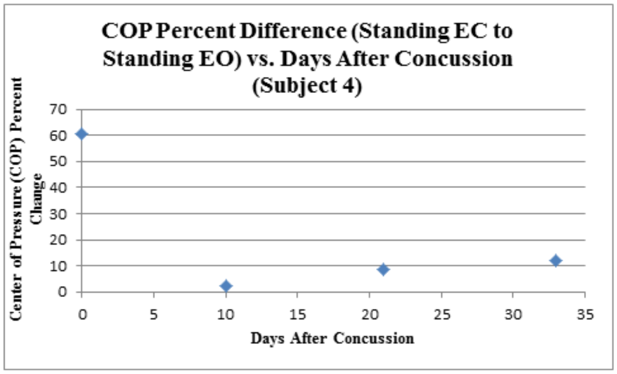

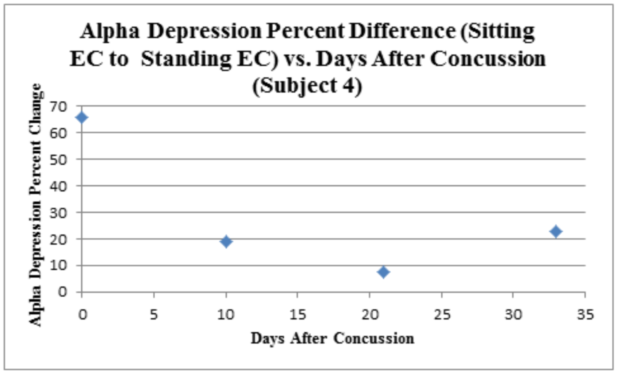

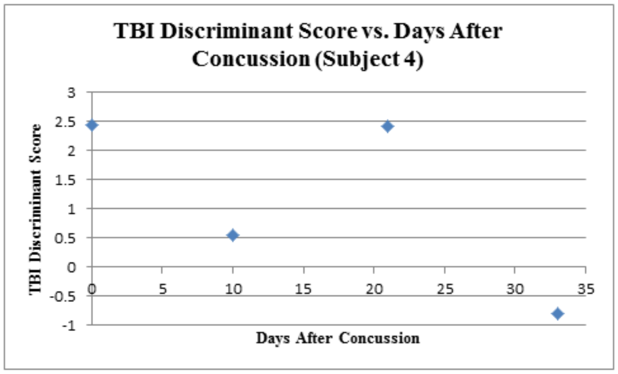

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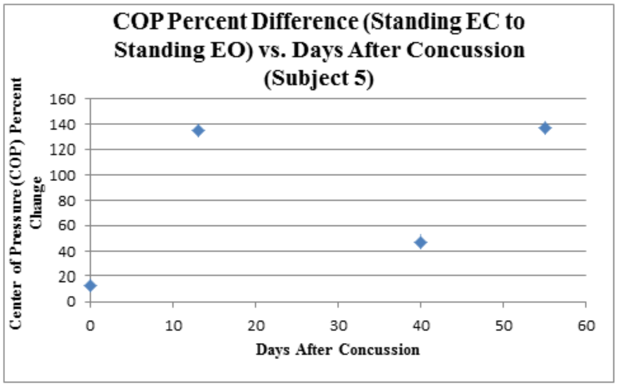

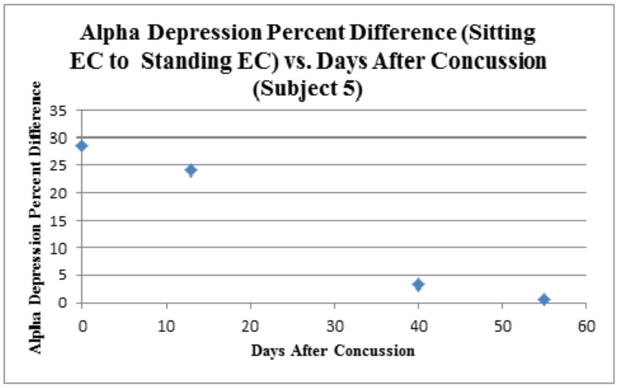

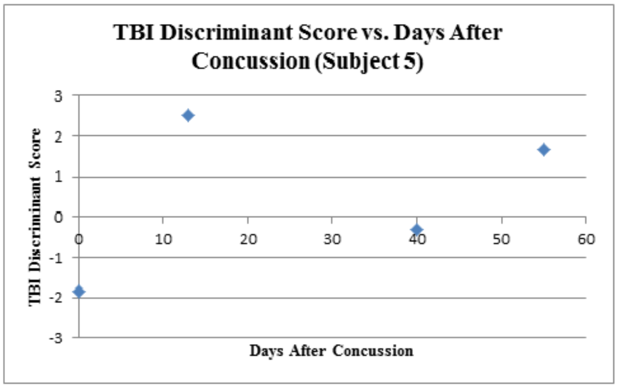

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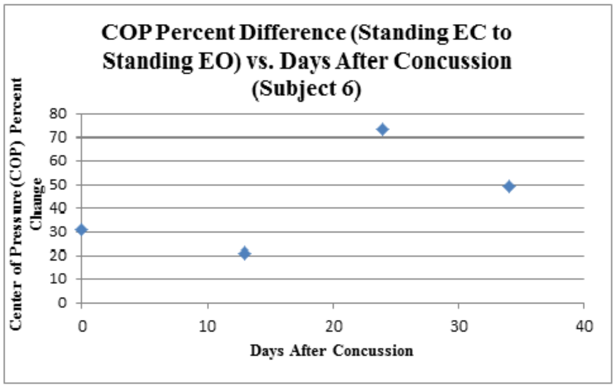

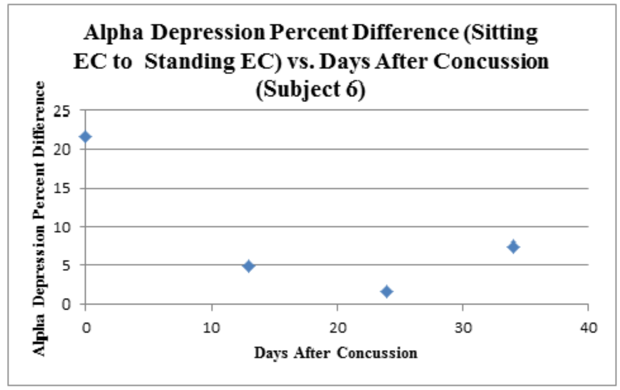

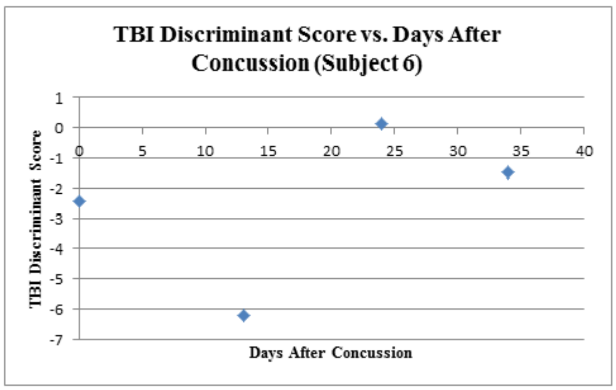

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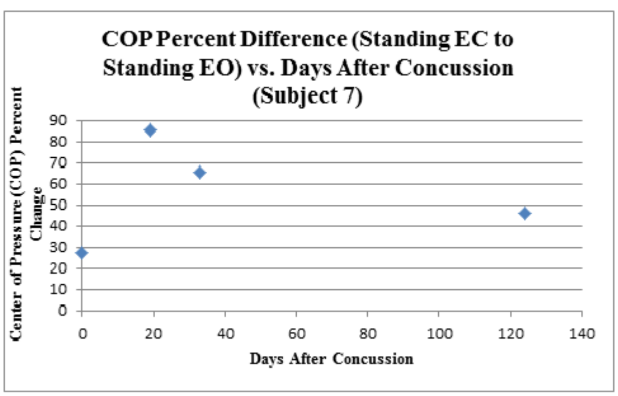

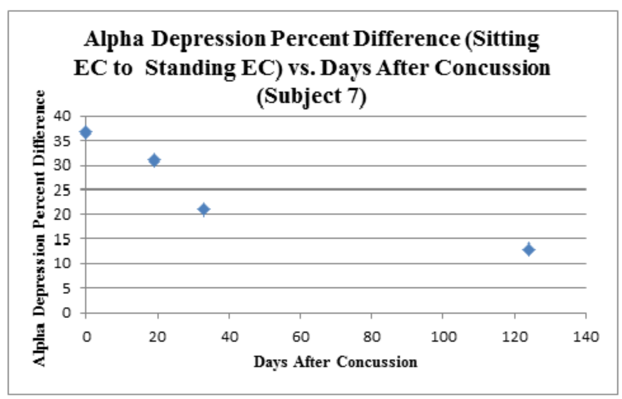

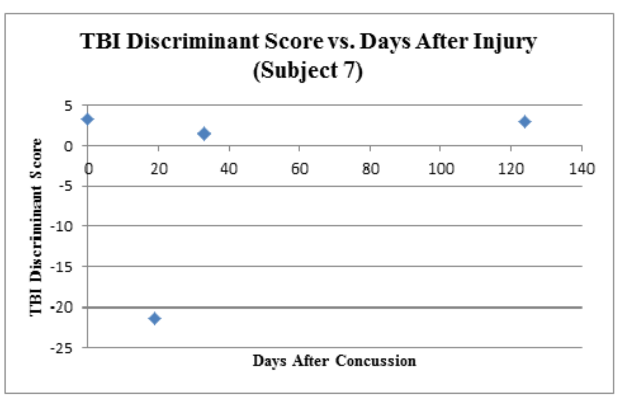

APPENDIX C: IRB CONSENT FORM

PENNSTATE

ORP OFFICE USE ONLY:
DO NOT REMOVE OR MODIFY
IRB#26266 Doc #1
The Pennsylvania State University
Institutional Review Board
Office for Research Protections
Approval Date: 06/27//2011 DWM
Expiration Date: 06/26/2012 DWM

Informed Consent Form for Biomedical Research
The Pennsylvania State University

Title of Project: The Effects of Mild Traumatic Brain Injury on Neuropsychological Test Scores, Postural Stability and General Brain Function

Principal Investigator: **Dr. Slobounov**
Department of Kinesiology, Penn State University
19 Recreation Building, University Park, PA 16801
Phone: 814 863 3883 (lab); 814 865 3146 (office)
Email: sms18@psu.edu;

Other Investigator(s): **Dr. Sebastianelli; Dr. Newell, Dr. Arnett; Dr. Thompson; Dr. Ray**

1. **Purpose of the study:** The purpose of this research is to more accurately measure an athlete's readiness for return to play following a concussion, while examining the relationship between balance, cognitive (memory & attention), and basic brain functions and symptoms of concussion in athletes. This experiment is novel in that it will use combination of procedures using pre- and post-concussion testing of the same subjects.

2. **Procedures to be followed:** The project will be divided into several parts, as outlined below:

BASELINE TEST

EEG (Electroencephalogram):

Upon arrival to the lab, you will be asked to remove your shoes and sit in a chair as the EEG electrodes are applied to your scalp. Your scalp will be cleaned with rubbing alcohol; this is done to remove any residue on the scalp. An elastic cap containing 32 evenly spaced sensors will then be place on the head. A blunt-ended syringe (absolutely NO injections are made) will then be filled with gel and used to place the gel between the sensors on the cap and the scalp; this will help insure the researchers collect data that will be useful. Two sensors will be placed, one on each ear. Standard EEG recordings will be taken under the following conditions: eyes open and eyes closed while *standing*; eyes open and eyes closed while *maintaining normal posture*; eyes open and eyes closed while *seated*; and during a task that will require *thinking skills* (math) and/or a task that requires you to *do more than one activity* (standing up and holding a dynamometer [a small handheld device that measures mechanical force or power]).

'Flock of Birds' Vest:

Following the EEG, you will be asked to put on a vest that contains several sensors. The vest is a light-weight and padded (an adjustable personal floatation device purchased from Wal-Mart) with a strip of Velcro down the back. You will be asked to stand on the force platform (measures balance) directly in front of the screen and will be given 3-D glasses for viewing the screening.

You will be asked to remain as stable as possible with your hands at your sides, feet flat on the force platform and eyes looking straight ahead. The screen will display five black and white striped walls (ceiling, floor, left wall, right wall and back wall) that will move in various directions and at various speeds. You will be asked to perform six trials of 25 seconds in duration with a 10 second break between each trial.

Next, a test consisting of 3 postures held for 20 seconds each will be conducted and performed two times (total of 6 postures held for 20 seconds each). Balance is assessed based on the cumulative scores acquired during this test.

Additional Tests:

The tests, given via computer and paper and pencil, examine the relationship between the nervous system [especially the brain] and mental functions such as language, memory, and perception. The tests consist of memory tests and attention based on word and number sequences. Reaction time tests are a timed response to a visual signal presented on a computer screen.

- ***If you DO NOT experience a concussion:***
  - No further testing will be needed

- ***If you DO experience a concussion:***
  - One (1) post-concussion measure (Baseline Test) will be done within 7 days following the encounter;
  - One (1) post-concussion measure (Baseline Test) will be done after a physician has cleared you for return to play; and
  - One (1) post-concussion measure (Baseline Test) will be done approximately 30 days from the injury.

3. **Discomforts and risks:** Risks to you while participating in this experiment are minimal. There is a chance of dizziness, especially if you have experienced a concussion. Spotters will be used to aid you if you feel dizzy or begin to fall. The experiment will be terminated immediately at your request and/or if viewed as unsafe.

4. **Benefits:** The benefits to you include detailed baseline assessment. Should a concussion occu the results from this study will be considered complementary information for the physician regarding return-to-sport participation decisions. The benefits to society include better understanding the mechanisms, symptoms and symptoms resolution associated with concussion.

5. **Duration/time of the procedures and study:** Research activities, as outlined above, will take about 90 minutes (one baseline testing session). Data collection for all measures will terminate within one month of the completion of the 2008/2009 competitive season.

6. ***Statement of confidentiality:*** *The participant records and data obtained from this research will be held confidentially, properly coded, secured and stored at a specially designated locked and password protected computer. The assess to the records and data obtained from this research will be available to Dr. Slobounov, PI and Dr. Sebastianelli, MD, Director of Athletic Medicine.*

The following may review and copy records related to this research: The Office of Human Research Protections in the U.S. Department of Health and Human Services, the Institutional Review Board and the PSU Office for Research Protections. In the event of any publication resulting from the research, no personally identifiable information will be disclosed.

7. **Right to ask questions:** Please contact Dr. Slobounov at 814-863-3883 or Dr. Sebastianelli at 814-235 2747 with questions, complaints or concerns about the research. Please contact the Office for Research Protections (ORP) at (814) 865-1775 with questions, complaints or concerns about your rights as a research participant, if you feel this study has harmed you, or if you would like to offer input. The ORP cannot answer questions about research procedures. All questions about research procedures can only be answered by the research team.

8. Payment for participation: ***NO* payment for participation will be provided to participants.**

9. **Cost of participating:** *NO* cost will be incurred from participation in this research

10. **Voluntary participation:** Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this study will involve no penalty or loss of benefits you would receive otherwise.

11. **Injury Clause:** In the unlikely event you become injured as a result of your participation in this study, medical care is available. It is the policy of this institution to provide neither financial compensation nor free medical treatment for research-related injury. By signing this document, you are not waiving any rights that you have against The Pennsylvania State University for injury resulting from negligence of the University or its investigators.

You must be 18 years of age or older to take part in this research study.

If you agree to take part in this research study and the information outlined above, please sign your name and indicate the date below.

By signing this consent, you are giving us the permission to use information obtained in this study for research purposes. You will be given a copy of this signed and dated consent form for your records.

____ ____________________
Participant Signature Date

____ ____________________
Person Obtaining Consent Date

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Academic Vita
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Education

Bachelor of Science in Kinesiology, Penn State University, Spring 2012
Honors in Kinesiology
Thesis Title: Changes in Center of Pressure, Alpha Depression, and Traumatic Brain Injury Discriminant Scores Before and After a Sports-Related Concussion
Thesis Supervisor: Dr. Semyon Slobonouv
Minor in Dance
Studied Abroad in Dublin, Ireland, Summer 2011

Honors and Awards

- Thomas W. and Jane Mason Tewksbury Trustee Scholarship, Pennsylvania State University Department of Kinesiology, 2010-2011, 2011-2012
- Schumacher Honors Scholarship, Schreyer Honors College, Pennsylvania State University, 2010-2011, 2011-2012
- State of Delaware Scholarship, 2010-2011, 2011-2012
- Dean's List
- Phi Eta Sigma National Honors Society

Activities

Penn State University Dance Company
Tapestry Dance Company, THON Chair
Penn State Homecoming 2011 – OPPerations Captain
Penn State Dance Alliance