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DO CENTER OF PRESSURE MEASURES DERIVED FROM FORCE PLATFORMS CORRELATE TO ALPHA % CHANGES DERIVED FROM EEG MEASURES IN ATHLETES SUFFERING FROM CONCUSSIONS?

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ABSTRACT

The medical field currently lacks a "gold standard" when it comes to sideline assessment tools capable of diagnosing concussions. In an effort to come closer to finding a definitive sideline assessment tool to diagnose concussion injuries, the use of a force platform was researched in comparison to EEG results. EEGs are currently used as an acceptable tool for diagnosing concussion injuries. Force platform center of pressure (COP) values, which are indicative of balance, were compared to EEG alpha % change values, which is an accepted indicators of brain function. Twenty-one concussed collegiate athletes were tested on measures of balance (COP) and EEG indicators of brain function. When comparing the force platform data at the subgroup level (COP EC and COP EO results) clear trends were present, however they were not statistically significant due to the small subject group. It can be seen that the alpha % change clearly decreased and the COP data clearly increased in both concussed subject groups when compared to the baseline subjects. This suggests that both the force platform and EEG measures are sensitive to the recovery of balance following a concussion injury in both the acute and chronic phase of recovery.

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Chapter 1

Introduction

When a player leaves the field with a torn ACL or dislocated collarbone the crowd cringes, but when a player exits the field after a hard hit and a concussion is suspected it seems to go unnoticed. Sadly it has taken the high profile cases of professional athletes such as Muhammad Ali and numerous NFL players to bring attention to the serious negative long-term effects of concussions. It has been difficult to get organizations like the NFL and NCAA to take concussions more seriously and acknowledge the long-term negative effects that concussions are responsible for including chronic traumatic encephalopathy, early onset dementia and emotional issues. Current research, such as that in a study done at the University of North Carolina, found that NFL players are at a 37% greater risk for Alzheimer's disease than other males their same age due to the negative effects of concussions. As a result the NFL is getting more involved in concussion research, as evidenced by the NFL's recent donation of one million dollars to Boston University to aid in the continuing research on the long-term impacts of concussions (Schwarz 2009).

Although the exact wording used to define a concussion varies, overall it has been agreed upon that a concussion is an injury to the brain due to an external force that causes a decrease in brain function. In an article written by a healthcare professional, it was discussed how concussions tend to be "hidden injuries" because they are often not accompanied by visible symptoms (McBride,2012). A person can be suffering from a serious brain injury but because it cannot be easily seen people are not forced to acknowledge the injury the same way a broken bone forces us to seek treatment. Concussion symptoms are non-tangible and include things like dizziness, nausea, confusion, memory gaps, and headaches that rely on one to self-report, verses tangible, visible symptoms like swelling, bruising or protruding bones (Neumann, 2011). A study involving a minor league hockey association in Canada concluded that the "hidden injury" nature of concussions allowed players to get away with not seeking medical treatment even when asked to do so (Cameron, 2011).

According to the Center for Disease Control and Prevention approximately 300,000 people in the United States suffer from sports related brain injuries annually. Additionally, out of those 300,000 an estimated 100,000 never seek assistance from a medical professional and approximately 500 die from the injury (CDC, 2005). Although the immediate effects of concussions such as dizziness, balance/coordination problems, and concentration may not appear severe or life threatening, the long-term effects of concussions can be deadly. According to a study done at the University of Iowa, those who had suffered from Traumatic Brain Injuries (TBI), affectionately known as concussions, had a three times greater risk of dying early. The study also found that those who suffered from multiple concussion injuries were at greater risk for depression, suicide, and motor-skill issues (Healthday, 2014).

Suffering from just one concussion makes an individual four times more likely to suffer from another concussion than someone who has never encountered a TBI (Adesso, 2006). An article by Neumann in The Sport Journal talks about how the seriousness of concussions has been brought to light in the upper levels of sport by the NFL and the

NCAA but that at the high school level, where so many children are affected, there is little emphasis on the seriousness of a concussion injury. High school children are actually more likely to suffer from concussions due to the lack of brain maturity, yet only three states have even addressed the issue of concussions and set any sort of guidelines to aid in protecting society's youth (Theye & Mueller, 2004). While Oregon, Washington and Texas have taken action it has been limited to a single rule, which precludes a player from returning to the game on the same day as the injury occurred. Not only is this rule hard to enforce but it has also been proven that it can take anywhere from weeks to months to recover from a concussion. As a result, staying out of a sport for twenty-four hours is not an adequate way to protect young athletes (Moss 2005).

Annually, an estimated 33% of high school students will suffer a concussion but sadly a majority of those concussions will go undiagnosed or mistreated (Moss 2005). In a journal by the American Academy of Physician Assistants it is noted that although the only treatment for a concussion is rest, it is still important to seek a medical diagnosis and regulate one's recovery (Martineau, 2007). Suffering a concussion on top of an existing concussion that has not yet healed can lead to a coma and or death. Monitoring the recovery process with a health care professional can keep an athlete from returning to activities before they are fully recovered. This would greatly reduce the risk of further injury that could damage a young person's long-term health and wellbeing.

In an effort to better protect the health of athletes the medical field needs to make advances in sideline assessment tools to diagnose concussions immediately to prevent injured players from returning to play and furthering brain injuries. In hopes of furthering the process of diagnosing concussions this study looks at the potential of using force platforms to diagnose concussions by evaluating if they correlate with brain function results from EEG tests. The benefit of exploring a tool that correlates balance to brain function is that it does not rely on athletes to self-report their symptoms and it could potentially give immediate sideline insight to the current function of one's brain. I hypothesize that center of pressure (COP) balance values derived from a force platform will correlate with alpha % change values derived from EEG analysis.

Chapter 2

Literature Review

In order to identify a modality to better diagnose concussions quickly and more accurately it is first important to research what is currently being used in the medical field to evaluate concussion injuries. Currently there is no "gold standard" when it comes to the tools used to diagnose concussions however, when it comes to evaluating concussions, there are currently two main categories that concussion tests fall into which are: sideline assessments and cognitive testing (Davis & Makdissi, 2012). The most common sideline assessment tool is the Sport Concussion Assessment Tool 2 (SCAT2) and the most common cognitive testing tool is an exam administered by the computer program known as ImPACT, which stands for Immediate Post-Concussion Assessment and Cognitive Testing (Borich et al., 2013).

The SCAT2 evaluates subjects by scoring them on self-reported symptoms, physical signs, coordination, balance, orientation, immediate memory, delayed recall, concentration and their Glasgow coma score (Clinical Journal of Sports Medicine 2009). The SCAT2 is the most up to date sideline concussion evaluation tool, however there are still many flaws with the assessment that push researchers to look for a better tool. The main issues with the SCAT2 revolve around the fact that it is a time consuming test, and certain sections of the examination are subjective or easily influenced by other factors. The test takes approximately 15-20 minutes to complete which potentially removes an athlete from an entire period of play in many sports. The symptoms portion of the examination is frequently criticized for reliability because it relies on subjects to self-report their symptoms. An example of this flaw is included within a study done by the University of Pennsylvania that found that 54% of contact athletes would be unlikely to report a concussion during a game. The balance portion of the exam, which is done via the Balance Error Scoring System known as BESS, was also not found to be very reliable, identifying only approximately 36% of concussed subjects. In addition, it was found to be heavily influenced by other variables such as the type of sport, fatigue levels, and history of ankle injuries. The BESS exam is done by evaluating how well a subject maintains their balance in three different positions on both a hard and soft surface. The BESS exam is scored by tallying how often a subject commits an "error". Errors include lifting one's hands off their hips, opening their eyes, stepping, stumbling, falling, moving their hips more than thirty degrees, lifting the toes or heel, or not standing in the indicated position for more than five seconds (Dziemianowicz et al., 2012).

Other sideline assessment tools include the Head Impact Telemetry System (HITS), Standardized Assessment of Concussion (SAC), and the King-Devick (K-D) Test.

The HITS system is a method in which accelerometers are placed inside of a helmet that record the linear and angular head accelerations. The two main issues with the HITS system are that there has not been found to be any correlation between the impact values and the head injury severity and the fact that this technology can only be used in sports where helmets are worn. This technology cannot be used to diagnose a concussion and is still currently undergoing research (Beckwith, 2011).

The SAC is an assessment that evaluates a player's mental state in five to ten minutes by analyzing orientation, immediate memory, neurological functions, concentration, and delayed recall. The SAC alone cannot diagnose a concussion and is not a comprehensive test because it does not assess whether there has been any impact on the brainstem or cerebellum like the SCAT does by analyzing one's coordination and balance (Greenwich, 2014).

The K-D test is a newer assessment tool that has subjects read single digit numbers displayed on a card or iPad and if the time it takes them to read the numbers is longer than their previously established baseline time then it is suggested that the athlete should be seen by a medical professional to evaluate the possibility of a concussion. The K-D test science relies on the fact that impaired eye movements correlate with decreased brain function. The K-D test is still very new and so the data is limited and as a result considered less reliable (Galetta, 2011).

Based on the research of the tools listed above, it can be concluded that the sports medicine field is lacking a "gold standard" sideline assessment tool for diagnosing concussion injuries.

ImPACT is a cognitive exam administered on the computer and is the most common concussion management tool. It is mainly used to track the severity and progress of concussion injuries. ImPACT measures an array of brain functions including attention span, working memory, sustained and selective attention time, response variability and non-verbal problem solving. The ImPACT exam is given on a computer and takes around twenty-five minutes to complete. The exam consists of five sections that include collecting demographic information and health history, current concussion symptoms and conditions, baseline and post-injury neurocognitive tests, and lastly a graphic display of ImPACT test scores. It is important to do baseline testing for the ImPACT exam because without baseline scores the results are essentially meaningless since everyone's baseline cognitive scores are different. The scores an athlete receives is based on the twenty-two symptoms known for concussion injuries and the higher the score, the more impaired an athlete is thought to be. Out of all of the areas analyzed in the exam studies done by ImPACT they have found that verbal memory, visual memory, processing speed, reaction time and the symptom scores are the best determinants in evaluating a concussion injury. On the down side, the ImPACT test produces a significant amount of false-positive results. One test found that 20-40% of athletes who were not currently suffering from concussions were found to have cognitive impairments and 17% of concussed athletes weren't found to have any cognitive impairment. Although an athlete's performance on the ImPACT test can be compared to their baseline scores in an effort to assess their cognitive functions after a concussion, no measures have been found that can diagnose an athlete as "concussed" or "clear" solely from the ImPACT examination scores (Dziemianozicz et al., 2012).

Other concussion management tools that have been researched or used include computerized tomography and conventional magnetic resonance imaging (CT & MRI), diffusion tension imaging (DTI), functional magnetic resonance imaging (fMRI), magnetic resonance spectroscopy (MRS), positron emission tomography (PET), and electroencephalography (EEG).

MRI and CT exams have been tested to see if they would be applicable tools for diagnosing concussions. Unfortunately these instruments show physical damage where a concussion is caused by chemical damage to the brain and thus not necessarily visible in these tests. MRIs are commonly used to examine soft tissues such as ligaments and tendons where CTs are commonly used to examine bones, the thoracic cavity, and detect cancers. MRIs and CTs are not appropriate tools for diagnosing or monitoring a concussion (Diffen, 2014).

Diffusion Tensor Imaging is a variation of the traditional MRI that is based on the diffusion rate of water within tissues. It is most commonly used to diagnose brain abnormalities. It is noninvasive, does not require additional equipment, contrast or chemical tracers. Basically it involves disturbing water molecules with electromagnetic radiation and then documenting their movement within a structure. There has been found to be some correlation between DTI results and neurocognitive performance due to the high sensitivity of the instrument, however DTI has not yet been accepted as a routine way to diagnose TBI injuries. In addition, DTI is expensive and time- consuming (Alexander et al., 2007).

fMRIs detect changes in brain blood flow based on neural activation. This tool utilizes the fact that when different parts of the brain are activated for use that blood flow in those regions of the brain increases. fMRIs use blood oxygen-level dependent imaging known as BOLD-imaging to assess which areas of the brain are active at different times. In a study done at the Medical University of Wisconsin concussed individuals were found to have decreased activity in regions of the right brain that corresponded with their poor cognitive performance. fMRI results however have to be taken with caution because there is a significant amount of variability in the BOLD results from different subjects. Along with the high amount of variability fMRIs are also a very expensive test to perform (Raemaekers et al., 2012).

MRS also known as Nuclear Magnetic Resonance (NMR) analyzes brain metabolism by looking at the changes in concentrations of certain brain chemicals. The chemicals analyzed that have shown to be affected by traumatic brain injuries (TBI) include N-acetylaspartate, creatine, choline, and lactate. By analyzing brain metabolism researchers have been able to track brain recovery following a concussion. Studies have shown recovery usually takes around thirty days. However, MRS is time consuming, expensive and there is currently not enough evidence for the tool to be accepted to solely monitor concussions (Brooks, 2001).

PET scans produce three-dimensional images of body processes that, with the help of a tracer, measure the rate of glucose metabolism. In a study done on subjects suffering from mild traumatic brain injuries (mTBI), also known as a concussion, the subjects showed decreased glucose metabolism in the cerebellum, which is responsible for balance, as well as the temporal cortex, which deals with visual memory and processing sensory input. Although PET scans are effective at measuring glucose metabolism it is important to also analyze the subjects brain structure using a CT or MRI to make sure that there aren't other causes for the results. PET scans are also expensive and time consuming (Dziemianozicz et al., 2012).

An EEG uses electrodes to measure the electrical activity of the brain. A person's TBI discriminant score, which quantifies the severity of the brain injury, is then derived based on the electrical activity of the brain using the Neuroguide software. The Neuroguide software takes into account personal information based on power frequency, brain asymmetry and multiple discriminant variables. The Neuroguide software awards a discriminant score based on how many standard deviations a subject scores from normal. The greater the number of standard deviations from normal a subject scores the more serious the brain injury. The Neuroguide formulas were derived after testing over ten thousand subjects. One of the measures that the TBI discriminant score takes into account is power frequencies. An EEG evaluates one's electrical activity in the brain by looking at its rhythmic activity. The rhythmic activity is evaluated based on six different power bands, one of them being the alpha power band that indicates one's level of concentration and is thought to be a good indicator of brain function (Slobounov, 2008).

Although EEG tests are a good tool for monitoring one's recovery process by evaluating their brain activity, it is far from a solid sideline assessment tool. In an effort to correlate EEG results with a sideline assessment tool that can be used to make return to play (RTP) decisions this study will compare EEG results with force platform results. This study will look to see if there is a correlation between the center of pressure results on a force platform and EEG alpha band % change. In addition to comparing the EEG results with the force platform, the study will also analyze within each subject group for statistically significant relationships.

Chapter 3

Method

Participants: Concussed collegiate athletes (n=21) and non-concussed baseline collegiate athletes (n=16). Age Range: 18-21 years old.

Demographics-

	Baseline	Within 7 days Post-Concussion	< 30 Days Post Concussion*
N	16	8	13
Gender	Boys = 6 Girls = 10	Male = 1 Female = 7	Male = 8 Female = 5
Days Post Concussion	N/A	0-7	8-22

* Note: Subject injuries are greater than 7 days but less than 30 days post concussion. The < 30 day subjects do not include the within 7 day subject group.

Procedure-

All tests took place in 019 Recreation Hall at Pennsylvania State University.

<u>Force Platform:</u> Subjects were asked to stand as still as possible with their feet shoulder-width apart on an AMTI force platform for one minute with their eyes open and one minute with their eyes closed. A specialized matlab code-then determined one's center of pressure (COP) scores based on the total area covered by the subject's COP displacement on the force platform with their body movements. A larger area indicates poorer balance as it indicates the subject moved more.

EEG: Before an EEG test can be run the experimenter must prepare the subject. Subjects were seated in a chair and their scalp, forehead and earlobes were cleaned with alcohol swabs to reduce impedance of the electrical signal from dead skin cells and bodily oils. Next an EEG cap was placed on their head and plugged into the computer. After the EEG cap had been placed on the subject's head, blunted-tip needles were used to insert conducing gel into each electrode in order to produce the strongest electrical signal possible. Once the computer indicated an adequate electrical signal had been detected the EEG tests could be run. Subjects underwent both a sitting and standing EEG analysis. Data was recorded for approximately ninety seconds with their eyes open and two minutes with their eyes closed during both the sitting and standing EEG tests.

Data Analysis-

After completion of the EEG and force platform protocols, computer software quantified the subjects' performance, enabling inter-subject comparison.

- The force platform produced the COP data for eyes open and eyes closed by totaling the area a subject covered while attempting to stand still.
- The alpha % change for each subject was calculated by comparing the difference in the subject's alpha stimulation between their sitting and standing EEG. Alpha % change is usually significantly lower following a concussion, and, therefore is a reliable indicator of the injury.

In order to find out if the results from the experiments produced any significant findings statistical analysis was used. Two different types of statistical analysis were used which include Pearson Correlation, an Independent Samples T-Test. Minitab 16 statistical software was used for all calculations.

1. A Pearson Correlation analysis produces a correlation coefficient, R, and a p-value. The correlations coefficient tells you if there is a relationship between two variables and if there is, how strong it is. A R closer to +/- 1 presents a strong relationship where a R closer to 0 presents a weaker relationship. P-value indicates the statistical significance of this relationship.

2. An independent two-sample t-test can be used to compare the means of two different samples. The two-sample t-test produces a p-value to determine if there is a significant difference between the two means. In this case a two-tailed t-test was used to test for a significant difference in the means in either direction.

Chapter 4

Results

Abbreviations:	
EO - Eyes Opened Group	EC - Eyes Closed Group
COP – Center Of Pressure	

All Concussed Subjects vs. Baseline Subjects Alpha % Change Correlation

P-value: < 0.001

Alpha % Change means are significantly different between the concussed and baseline groups with a p-value less than. 0.005.

Independent Sample T-Tests

Table 1: Group Statistics for Baseline & Within Seven Days Post Concussion

	Subject Group	N	Mean	Std. Deviation	Std. Error Mean
Alpha % Change	Within 7 Days	8	.2175	.17368	.06140
	Baseline	16	.2338	.14135	.03534
COP EO	Within 7 Days	8	2.3703	1.72059	.60832
	Baseline	16	1.6319	1.45991	.36498
COP EC	Within 7 Days	8	3.4956	3.12008	1.10312
	Baseline	16	2.3281	1.45695	.36424

The t-test indicates, as seen in Table 1a, that there are no overall statistically significant differences between the non-concussed (baseline) and concussed within seven days groups on alpha % change (t_{22}= -.247, p = 0.807), COP EO (t_{22}= 1.102, p = 0.282), or COP EC (t_{22}= 1.265, p = 0.219). (Refer to means and standard deviations in Table 1.) However it should be noted that there is a clear trend displaying a decrease in alpha % change and an increase in COP means in concussed subjects but the sample size was not large enough to display statistically significant results.

Table 1a: T-Test analyzing Baseline vs. Within Seven Days Post-Concussion

	t	Df	Sig. (2-tailed)
Alpha % Change	-0.247	22	0.807
COP EO	1.102	22	0.282
COP EC	1.265	22	0.219

Table 2: Group Statistics for Baseline & Less Than Thirty Days Post Concussion

	Subject Group	N	Mean	Std. Deviation	Std. Error Mean
Alpha % Change	Less Than 30	13	.1738	.12319	.03417
	Baseline	16	.2338	.14135	.03534
COP EO	Less Than 30	13	3.2576	3.57663	.99198
	Baseline	16	1.6319	1.45991	.36498
COP EC	Less Than 30	13	7.2668	13.38384	3.71201
	Baseline	16	2.3281	1.45695	.36424

The t-test indicates, as seen in Table 2a, that there are no statistically significant differences between the non-concussed (baseline) and concussed within thirty days groups on alpha % change (t_{27}= -1.202, p = 0.240), COP EO (t_{27}= 1.661, p = 0.108), or COP EC (t_{27}= 1.472, p = 0.153). (Refer to means and standard deviations in Table 2.) Again it should be noted that there is a clear trend displaying a decrease in alpha % change and an increase in COP means in concussed subjects but the sample size was not large enough to display statistically significant results.

Table 2a: T-Test analyzing Baseline vs. Less Than Thirty Days Post-Concussion

	t	Df	Sig. (2-tailed)
Alpha % Change	-1.202	27	0.240
COP EO	1.661	27	0.108
COP EC	1.472	27	0.153

Table 3: Group Statistics for Within Seven Days Post Concussion & Less Than Thirty Days Post Concussion

	Subject Group	N	Mean	Std. Deviation	Std. Error Mean
Alpha % Change	Within 7 Days	8	.2175	.17368	.06140
	Less Than 30	13	.1738	.12319	.03417
COP EO	Within 7 Days	8	2.3703	1.72059	.60832
	Less Than 30	13	3.2576	3.57663	.99198
COP EC	Within 7 Days	8	3.4956	3.12008	1.10312
	Less Than 30	13	7.2668	13.38384	3.71201

The t-test indicates, as seen in Table 3a, that there are no statistically significant differences between the within seven days post concussion and less than thirty days post concussion groups on alpha % change (t_{19}= 0.675, p = 0.508), COP EO (t_{19}= -0.52, p = 0.522), or COP EC (t_{19}= -0.777, p = 0.447). (Refer to means and standard deviations in Table 3.)

Table 3a: T-Test analyzing Within Seven Days Post Concussion vs. Less Than Thirty Days Post-Concussion

	t	Df	Sig. (2-tailed)
Alpha % Change	0.675	19	0.508
COP EO	-0.52	19	0.522
COP EC	-0.777	19	0.447

Pearson Correlations

Table 4 analyzes within baseline subject data. The only significant correlations found when the alpha % change, COP EO and COP EC data were cross-analyzed was between the COP EC and COP EO data (r_{18}= 0.727, p-value = 0.001).

Table 4: Baseline Correlations

		Alpha % Change	COP EO	COP EC
Alpha % Change	Pearson Correlation	1	-.440	-.364
	Sig. (2-tailed)		.088	.166
	N	16	16	16
COP EO	Pearson Correlation	-.440	1	.727**
	Sig. (2-tailed)	.088		.001
	N	16	16	16
COP EC	Pearson Correlation	-.364	.727**	1
	Sig. (2-tailed)	.166	.001	
	N	16	16	16

**. Correlation is significant at the 0.01 level (2-tailed).

Table 5 analyzes within seven days post-concussion subject data. The only significant correlations found when the alpha % change, COP EO and COP EC data were cross-analyzed was between the COP EC and COP EO data (r_{10}= 0.805, p-value = 0.016).

Table 5: Within Seven Days Post Concussion Correlations

		Alpha % Change	COP EO	COP EC
Alpha % Change	Pearson Correlation	1	.463	.323
	Sig. (2-tailed)		.248	.435
	N	8	8	8
COP EO	Pearson Correlation	.463	1	.805*
	Sig. (2-tailed)	.248		.016
	N	8	8	8
COP EC	Pearson Correlation	.323	.805*	1
	Sig. (2-tailed)	.435	.016	
	N	8	8	8

*. Correlation is significant at the 0.05 level (2-tailed).

Table 6 analyzes less than thirty days post-concussion subject data. The only significant correlations found when the alpha % change, COP EO and COP EC data were cross-analyzed was between the COP EC and COP EO data (r_{15}= 0.883, p-value = 0.000).

Table 6: Less Than Thirty Days Post Concussion Correlations

		Alpha % Change	COP EO	COP EC
Alpha % Change	Pearson Correlation	1	.309	.294
	Sig. (2-tailed)		.304	.329
	N	13	13	13
COP EO	Pearson Correlation	.309	1	.883**
	Sig. (2-tailed)	.304		.000
	N	13	13	13
COP EC	Pearson Correlation	.294	.883**	1
	Sig. (2-tailed)	.329	.000	
	N	13	13	13

**. Correlation is significant at the 0.01 level (2-tailed).

Chapter 5

Discussion

The purpose of this study was to investigate the relationship between force platform measures of balance (COP displacement) and EEG analysis measures (alpha % change). Specifically, to investigate the sideline diagnostic capacity of COP displacement as determined by its relationship to one of the known EEG indicators of concussion, alpha % change. There is currently a need for a sideline diagnostic method that can definitively evaluate cognitive functions, does not rely on self-reporting symptoms, is quick to administer, and portable. Concussions are serious, silent injuries and the medical field currently lacks a "gold standard" sideline assessment tool. EEG test results have been proven to accurately identify concussion injuries by analyzing the electrical activity of the brain. In an effort to analyze the capability of force platforms in diagnosing concussion injuries, COP displacement was compared to EEG results to see if a correlation existed. In order to quantify the diagnostic capacity of force platform measures of balance, the data collected was analyzed for statistical relationships and significance.

Research has shown that balance deficits following a concussion injury are usually resolved prior to cognitive deficits. Typically, by the fifth day post-injury balance, deficits have been resolved (McCrea et al., 2003). In order to make sure that the force platform correlation results were not being skewed by recovery time, the data was analyzed in two different subgroups. The groups that subjects were divided into included: within than a week post-injury and less than a month post-injury. It was important to break the data into these two groups because "spontaneous clinical recovery" is usually seen in subjects between 7-10 days post injury. "Spontaneous clinical recovery" refers to the concept that concussion symptoms tend to disappear rapidly and suddenly even though the brain is still suffering from the injury (IRB, 2011). Once the subjects were separated by recovery time, the data was analyzed for statistically significant differences in the mean results (alpha % change, COP EO, COP EC) when comparing the three different subject groups against each other (baseline vs. within 7 days post concussion, baseline vs. less than 30 days post concussion, and within 7 days post concussion vs. less than 30 days post concussion).

When comparing the force platform data at the subgroup level (COP EC and COP EO results) clear trends were present, however they were not statistically significant due to the small subject group. It can be seen that the alpha % change clearly decreased and the COP data clearly increased in both concussed subject groups when compared to the baseline subjects. This suggests that both the force platform and EEG measures are sensitive to the recovery of balance following a concussion injury in both the acute and chronic phase of recovery. This could greatly enhance a clinician's ability to make informed and safe decisions about an athlete's return to play.

Making accurate return to play decisions is crucial, because suffering from another concussion before a current concussion injury has healed can lead to serious and sometimes deadly brain injuries. This concept of suffering from another concussion injury while currently injured is known as "second-impact syndrome" and is the main concern considered when making sideline return to play decisions (Healthday, 2011).

Given the results of this study, future research should explore COP correlations with alpha % change in larger subject groups. Additionally studies could be done that explore EEG relationships with other concussion symptoms. These may include, but are not limited to; memory, concentration, and eye tracking.

It should be noted that the conclusions based on this study are subject to several limitations. One of the main limitations of this study was the small subject pool, which consisted of only twenty-one concussed and sixteen baseline athletes. Drawing conclusions upon only twenty-one subjects is not ideal, so in the future studies should be conducted with a much larger subject pool, in order to see significance in trends. In addition the baseline and two different concussed sub-groups consisted of different subject pools so in the future studies should be done that track the same subject group. Every subject's baseline results are personal so the fact that this was a cross-sectional study, instead of a longitudinal study, could have skewed the results.

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ACADEMIC VITA

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Academic
Penn State University Schreyer Honors College (Graduation: May 2014)
Major: Kinesiology (Movement Science Option)

Certifications
CPR, AED & First Aid Certified

HEALTHCARE EXPERIENCE

Gap Medics- Chiang Mai, Thailand June 2014- Aug. 2014
(International Student)
Shadowed doctors in seven different departments of a Chiang Mai hospital.

- While in Thailand I spent a week learning in each the following departments: anesthesiology, radiology, orthopedics, emergency medicine, alternative medicine, neurology, and obstetrics/gynecology.
- While shadowing doctors taught and allowed me to mix serums, cast patients, unscrew bolts from patient's legs and assist in x-raying patients.

Mount Nittany Medical Center- State College, PA Sept. 2011- April 2013
(Volunteer)
Emergency Department

- Transfer patients to and from CAT scans, MRIs and Ultra Sound
- Move patients from the Emergency Room to permanent rooms
- Help doctors manage their time by checking on patients

PROFESSIONAL EXPERIENCE

Virtual Reality/ TBI Laboratory- University Park, PASept. 2012- May 2014
(Undergraduate Research Assistant)
Work to help run concussion tests on individuals.

- Set up and run electroencephalography (EEG) tests on subjects
- Monitor virtual reality tests on subjects.

Life Link- University Park, PA Jan. 2013- May 2014
(Mentor)
Help aid in making it possible for intellectually disabled students to attend college.

- Mentor students in their daily activities in order to enable them to participate in the college experience such as attending class with the students and working on homework with them.