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QUANTIFYING SUB-CONCUSSIVE IMPACTS OF DIVISION I FOOTBALL PLAYERS: A COMPARISON OF THE BODITRAK SYSTEM AND VIDEO FOOTAGE

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ABSTRACT

Every year millions of people in the United States suffer from brain injuries. Recently, it has grown to be a major concern because there are long-lasting effects from mild traumatic brain injuries and from sub-concussive impacts. Research about sub-concussive impacts has increased, however, there is still not an accurate way to measure the number of hits a player received. Currently, there have been strides in this area by introducing accelerometers to measure the location and frequency of hits. This study uses the BodiTrak accelerometer and compares its recorded hits to hits counted by video footage. It is expected that the number of hits recorded by the accelerometer will be less than the number of hits counted from video tapes. In an effort to test this comparison, accelerometers were placed into Penn State Football Player's helmets and hits were counted for each player by watching video clips. Data were analyzed to see if there was a difference or trends among hits and players or practice dates. The player's positions and practice dates were found to have a statistically significant difference on the number of hits from the two methods. In addition, further analysis was completed to see what positions had a difference, and it was found that non-speed and defensive players had significantly different results from the accelerometer and video footage.

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Chapter 1

Introduction

Background

Every year millions of people in the United States suffer from brain injuries. Whether it is a mild, moderate, or severe traumatic brain injury, it can have a wide range of symptoms. A mild traumatic brain injury (mTBI), or concussion, is classified by having loss of consciousness, confusion, or disorientation that lasts for less than 30 minutes (“Mild TBI symptoms,” n.d.). mTBI is the most prevalent TBI and is caused by a blow or impact to the head. Some of the common symptoms are fatigue, headaches, memory loss, poor attention, and sensitivity to light and sounds.

Recently, sub-concussive impacts have been highly investigated because of their invisible signs and long term effects on athletes. These occur by low impact, repetitive hits that are not as severe as a concussion, but an accumulation of the impacts can lead to neurological alterations (Bailes et al., 2013). Football players are at a high risk of sub-concussive hits and its effects because of their repetitive contact. A study used magnetic resonance imaging (MRI) to scan football athletes and non-collision sport athletes before and after the season. It was found that the football players, who were not diagnosed with concussions but received sub-concussive blows, had altered functional connectivity when compared to the non-collision group. This indicates there are short and long term effects of sub-concussive hits, which is a cause for concern due to the lack of diagnosable symptoms (Abbas, Shenk, & Poole, 2014).

Another major risk factor for football players is the high number of hits received during play. Players can receive up to 1444 hits in 1 season, with an average of 6.3 hits per practice and 14.3 hits per game. The frequency and location differed among players; linemen and linebackers have the highest number of impacts, and most players had the largest percentage of impacts to the front of the helmet, but quarterbacks received the most impacts to the back of the helmet (Crisco et al., 2010). In addition, the magnitude of impacts varied by player position, with running backs and quarterbacks having the highest magnitude hits (Crisco et al., 2011).

With the high number of sub-concussive blows, it is important to measure impacts in contact sports. This will help with the medical management of athletes and provide more information of the biomechanical forces of sub-concussive and concussive hits.

Purpose

The purpose of this study is to see if student-athlete football players' number of hits quantified from video footage is comparable to the number of hits recorded by BodiTrak's accelerometer. Many athletes continue to play in games and practice with the mentality of "play until I can't play anymore." This leads to more damage and can affect the athlete in the long-term. However, the accelerometers will notify coaches and other professionals when a certain threshold or magnitude of impacts is reached, so an athlete can stop playing to assess their situation. Because BodiTrak is a relatively new system, it needs to be confirmed that it measures number of hits accurately. Hopefully, BodiTrak's reliability will be an addition to medical screening and a diagnostic tool for play continuation and mTBI testing. In addition, with an increased understanding of the biomechanics of head impacts in collegiate football and human tolerance to head acceleration, better equipment can be designed to prevent head injuries.

Hypothesis

It is hypothesized that the number of hits based on BodiTrak's system will be less than the number of hits counted by the video footage. A few studies have done a comparison between accelerometer data and video and have not found comparable results (Gabbett, 2013). In addition, hits on video do not take impact force into account and each hit is counted. However, the BodiTrak accelerometer only accounts for hits that are greater than 25G, therefore, it will have less number of hits because it is missing the lighter impacts.

Chapter 2

Literature Review

Each year, tens of millions of adults and children participate in sports in the United States. According to the Centers for Disease Control, there are about 1.6 to 3.8 million concussions annually related to sports (Langlois, Rutland-Brown, and Wald, 2006). Participation in high school and collegiate sports continues to increase, therefore, the number of student-athletes sustaining concussions is similarly increasing. Looking more closely at the numbers reveals that there is a higher incidence of concussions in college athletes compared to high school athletes that stems from the intensity of the play (Gessel, 2007). Due to this high number, the National Collegiate Athletic Association (NCAA) has implemented a new concussion policy that educates athletes, removes player if a concussion is suspected, eliminates same-day return to play in concussed athletes, and a process that involves clearance by a medical professional (National Collegiate Athletic Association, 2014). Zuckerman et al. (2015) found that the concussion rate doubled from 1988 to 2003 and is still increasing, especially in particular sports such as men's football, women's ice hockey, and men's lacrosse. However, some argue that the rate has increased because of an increase in recognition and reporting by team physicians and due to the NCAA's new concussion policy (Kroshus, Baugh, Hawrilenko, & Daneshvar, 2015). Also, a gender difference in the rate of concussions was found. Overall, it was found that women are at a greater risk for a concussion. One possible explanation is the biomechanical differences because females have a smaller head-to-ball ratio, weaker necks, and are smaller (Mansell, Tierney, Sitler, Swanik, & Stearne, 2005).

Although the media mostly focuses on football players suffering from concussions, they are not the only ones. Football does have the highest number of sports related concussion, but it is followed by men's ice hockey, and women's soccer. Annually, it is estimated that there will be 3,417 sports related concussions in men's football (Zuckerman, 2015). Of these concussions, 78.5% occurred during competition rather than practice and 75% of the concussions are due to player-to-player contact. The common mechanisms were due to contact while blocking and tackling, which explains why linemen have the highest rates of concussion in football (Laker, 2011).

When a concussion happens, there are physical, biochemical, and neurological problems that occur. A concussion follows a blow to the head, so the brain is pushed against the inside of the skull and can be bruised (Ling, Hardy, & Zetterberg, 2015). However, different parts of the brain move at different speeds producing forces that can stretch and tear tissue. The brain is usually damaged at two sites in the brain, the coup and the countercoup. The coup is where the brain originally struck the skull, and the countrecoup is where the brain hits the opposite site of the impact (Smayda, 1999).

Extensive biomechanical studies show that concussion is related to linear and rotational acceleration of the head. While rotational acceleration may be the predominant mechanism of a mTBI and may cause larger diffuse axonal injury (DAI), linear acceleration still plays a role (Wilberger, Ortego, and Slobounov, 2006). Meaney and Smith (2011) cited studies that show a strong correlation between linear acceleration and internal brain pressure. The reports concluded that the level of neurological dysfunction correlated with the peak pressure during the injury period.

A study by Roth, Nayak, Atanasijevic, Koretsky, Latour, and McGavern (2014) focused on how the brain responds to the damage. The primary response is to protect the meninges, the brain's barrier to blood and fluids. It is important to keep the border between the meninges and brain intact because blood and fluids that leak into the brain kills neurons. However, during a hit, the blood vessels were obstructed and some leaked into the meninges causing cell death of both neurons and glia. To fix the gaps in the border, microglia swell to fill in the holes and cause inflammation to keep the fluids from flowing freely into the brain. Sometimes the process is too slow allowing free radicals to pass through the membrane and into the brain tissue, which causes cell death.

Concussions cause a neurometabolic cascade of events that involves axonal dysfunction, an imbalance of ions and chemicals in the brain, and an increase need for glucose. The biomechanical forces on the neurons and glia can also damage the microstructural components including the dendrites and axons. The loss of structure in axons can potentially disrupt the synapse diminishing the normal neurotransmission or in severe cases, disconnection of the axon. Studies cited by Giza and Hovda (2014) demonstrate that severing an axon may result in atrophy and shrinkage of the neuron but not always cell death. It is also shown that unmyelinated axons, or white matter, are more vulnerable to impairment than myelinated axons, or gray matter. These damages to axonal networks and white matter can lead to cognitive impairments after traumatic brain injury (Giza and Hovda, 2014). Another study supports this finding in an experiment where axonal degeneration and abnormal axonal function was present 14 days postinjury (Bailes, Petraglia, Omalu, Nauman, & Talavage, 2013).

mTBI also results in ionic flux and acute glutamate release. There is an increase in extracellular potassium and intracellular calcium concentration. The potassium causes a depolarization that triggers voltage-gated ion channels and releases an excess of glutamate. The excessive accumulation of calcium can damage the mitochondria and may be caused by the axonal stretching (Wilberger et al., 2006). These imbalances can lead to a phenomenon called spreading depression that is related to migraines, loss of consciousness, and changes in mental status (Giza & Hovda, 2014).

Normally, cerebral blood flow (CBF) and glucose utilization are coupled. However, during a mTBI CBF is reduced and brain requirements for glucose significantly increase. The need for glucose is related to the need for ATP production to help power the ionic pumps to reach homeostasis. Thus, significant uncoupling of glucose supply and demand results in an energy crisis (Wilberger et al., 2006). This crisis is also worsened by the mitochondria sequestering the excess calcium creating problems with oxidative metabolism. This impairment is associated with problems in spatial learning and working memory (Giza & Hovda, 2014).

In addition to these primary injuries, there are many secondary injuries, an indirect result of the injury that occurs in the hours and days following the primary injury. Secondary damage may be caused by the breakdown of the blood-brain barrier (BBB) that results in an inflammatory response. Also, poor blood flow can cause secondary damage. A blow to the head can increase intracranial pressure preventing blood from flowing to the brain and depriving it of oxygen, which can permanently damage brain function (NINDS, 2016).

Clinically, this complex cascade of events eventuates in neurological deficits, cognitive impairment, and somatic symptoms. Some of the acute symptoms are prolonged headache, vision disturbances, dizziness, vomiting, impaired balance, confusion, memory loss, and difficult concentrating (AANS, 2011). McCrea et al., (2002) found that 85% of concussed subjects did not have a loss of consciousness (LOC) but still exhibited deficits in orientation, concentration, and memory function. Therefore, LOC is not necessary for a concussion. They also were the first to correlate the severity of neurocognitive impairment with the occurrence of LOC. In addition, the symptoms and severity of symptoms differ on each person. For example, in football, offensive linemen report more frequent symptoms than other players, such as a higher frequency of dizziness and headaches. This may occur as a result of offensive linemen receiving the highest number of head impacts compared to other positions (Baugh 2015). These findings are also supported by McCrea et al. (2003) who found that 10% of collegiate football players needed more than a week for symptoms to resolve and that they demonstrated different patterns in recovery.

The acute symptoms should resolve in one to six weeks, but some long-term effects are memory problems, lack of inhibition, intense anger, personality changes, and problems organizing and problem solving (UT Dallas, 2015). Post-concussion syndrome can also occur in some people and results in physical, cognitive, and emotional problems such as headache, dizziness, and irritability (Weill Cornel Medical Group, 2012). It is very important to prevent second impact syndrome, which is when a second concussion is sustained before a complete recovery from a previous concussion (AANS, 2011). The brain loses its ability to autoregulate intracranial pressure and can brainstem herniation and death, in severe cases (Bey & Ostick, 2009).

Repetitive brain trauma causes Chronic Traumatic Encephalopathy (CTE), a neurodegenerative disease. CTE results in memory and cognitive impairment, depression, suicidal behavior, aggressiveness, and eventually dementia. In some cases, CTE can lead to a motor neuron disease that is similar to amyotrophic lateral sclerosis. CTE is characterized by accumulations of hyperphosphorylated tau and TDP-43 proteins (Stern et al., 2011). The symptoms do not present until years after the trauma-producing activity and is mostly common in former contact sports athletes. Studies have confirmed CTE in football players without diagnosed concussions suggesting that this neurodegenerative disease can be caused by repetitive sub-concussive hits (Baugh et al., 2012).

Sub-concussive hits refer to events similar to concussion, but sub-concussive impacts do not have visible signs or symptoms of neurological dysfunction. It occurs with rapid acceleration-deceleration of the body allowing the brain to freely move in the cranium, creating a slosh phenomenon (Bailes et al., 2013). Sub-concussion has its greatest effective through repetitive occurrences. Many clinical studies identified athletes with no history of identified concussions, but have neurodegenerative pathology consistent with CTE. These athletes also have laboratory data that suggests axonal injury, disruption to the blood-brain barrier, and neuroinflammation, all in the absence of behavior changes. Therefore, the sub-concussive hits can also lead to neurological alterations (Bailes et al., 2013). Axonal damage has been found following a single sub-concussive experimental head injury, even with no alternation of consciousness or responsiveness. However, not every hit results in a sub-concussive injury because it depends on the magnitude of exposure, recovery periods, individual vulnerability, and others (Bailes et al., 2013).

These sub-concussive events are fairly common in contact sports, especially football. A helmet telemetry system was used to find the total number of head impacts across four seasons in a study cited by Bailes et al. The average player had 652 impacts, with linemen having the greatest number of impacts (868 his), followed by tight ends, running backs, and linebackers (619 hits). The high number of hits were associated with cumulative impact burdens. Other studies have also found contact sports producing subclinical cognitive impairments resulting from the cumulative effects of the sub-concussive hits. The most reliable marker of neurological impairment has been found to be the number of cumulative hits instead of the force of the impact (Bailes et al., 2013).

The 2014 McAllister et al. study also found similar results. They studied Division I football and ice hockey players, analyzing their accelerometer data and neuropsychological tests to players in noncontact sports. The researchers found that athletes in contact sports performed worse on performance tests and that poorer scores correlated with greater number of head impacts (Bailes et al., 2013). Sub-concussive impacts can also affect activity in the prefrontal cortex, as shown by a functional magnetic resonance imaging study (Graham, Rivara, Ford, & Spicer, 2014).

Although the NCAA does not have guidelines for sub-concussive impacts, it has a return-to-play protocol for athletes who suffered a concussion. The protocol has a stepwise progression that ultimately ends in a player returning to normal play. The first step is no activity, then light aerobic exercise, such as walking. The third stage is sport-specific exercise, such as running drills but no head-impact activities. Then, there is noncontact training drills, such as passing drills, leading to full-contact practice. After medical clearance, a player can return to normal game play (NCAA, 2014).

With the increasing amount of concussions and dangerous long-term effects, there needs to be an effective way to diagnose concussions. Currently, the diagnosis of concussion relies on a variety tests, such as a neurological examination, neuropsychological evaluation, and neuroimaging. However, the neuroimaging techniques, magnetic resonance imaging (MRI) and computed tomographic (CT) scan, have slight problems. CT scans have radiation exposure and have low sensitive to diffuse brain damage, while MRI is restricted by cost and its exact role in diagnosing mTBI.

Accelerometers have recently been on the rise, especially in contact sports. Because concussion is common in sports and is challenging to diagnose, head impact measures, or accelerometers, have enabled measurement of head kinematics in contact sports. The development of this resulted from a need of better understanding of the biomechanics of concussion. In addition, this head piece can also measure head impact exposure, which can improve head protection and medical management of athletes. However, accelerometers cannot be a definitive diagnosis technique. They cannot because there is not an identified concussion injury threshold and there is a range of magnitudes at which players sustain concussion and sub-concussive hits. Therefore, the reports from the accelerometers can be used as alerts when medical screening athletes for potential concussions (Brennan et. al, 2017).

Many studies have found valuable results from accelerometers studies. Wellman, Coad, Goulet, and McLellan (2016) found positional differences for distribution of impacts within offense and defensive players. Wide receivers sustained light impacts, whereas running backs were involved in more severe impacts and quarterbacks sustaining slightly heavier impacts. In the defensive players, linebackers and defensive backs were subject to light impacts and defensive tackles sustained very heavy impacts. These varying loads experienced by collegiate football players highlight the need for position-specific monitoring and training to prepare for these impacts.

Similar to this study, another study quantified hits and impact force. The number of impacts varied by playing position, but linemen sustained the highest number of impacts followed by tight ends, running backs, and linebackers, and then quarterbacks, and receivers, cornerbacks, and safeties. Lineman also received the greatest cumulative linear accelerations and the lowest was with the wide receivers, cornerbacks, and safeties (Broglio et. al, 2011).

There are a few accelerometer systems such as MinimaxX and Head Impact Telemetry. This study used the BodiTrak system, which has only been used by two other universities. BodiTrak uses a pressure-mapping smart fabric that registers each hit. When an impact or collection of impacts registers hard enough, a team official is automatically notified via a mobile device (Rogers, 2015).

Although accelerometers are widely used, a question remains over the validity of the technology to quantify impacts. Some studies have shown significant differences in the number of impacts recorded by technology and the actual number of collisions coded from video. However, a study involving MinimaxX found to show no significant differences. There was a strong correlation between collisions recorded from the minimax and those coded from video footage (Gabbett, 2013). There are not many studies that correlate video footage to technology because quantifying hits through video is labor intensive, especially with large data sets.

If there are more studies similar to Gabbett (2013), then they can confirm that accelerometers are reliable. They can also be used to help screen athletes for concussions and create standards and thresholds to help medical professional and coaches determine if a player should continue playing.

Chapter 3

Methods

Subjects

The subjects in this study are all Pennsylvania State University football players (n=23) who are healthy and some have had previous concussions that are in the table below (Table1). The study started with 24 subjects, but ended with 23 subjects. About half of the participants played offensive positions and half played defensive positions, with the exact positions below (Table 2).

Table 1. Previous Concussions

# of Previous Concussions	0	1	2
# of Players	14	7	2

Table 2. Positions

	Position	**# of Players**
Offense	Running Back	1
	Lineman	8
	Tight End	2
Defense	Safety	2
	Linebacker	2
	Lineman	8

After IRB approval was obtained in December 2015, recruitment of participants began. Football players were selected based on position and playing time. They were also compensated for their time participating in the study.

Video Quantification

Video footage of Penn State's football practices was obtained and watched through XOS ThunderCloud. The number of hits were quantified by two people, so the counts were verified. A hit was counted if it was a head to head, head to torso, or head to ground impact. This study includes the following dates: 8/19, 8/20, 8/21, 8/22, 8/25, 8/28, 8/29, 9/1, 9/2, 9/3, 9/8, 9/10, 9/15, 9/16, and 9/17. Each date had about 23 offensive files and 20 defensive files. Within each file, there were 3-20 video clips, depending on the file. Files such as, team periods, ½ line skelly, and redzone period had the most clips, whereas punt, kickoff, and kickoff return, had the least number of clips.

Operational Manual for Video Quantification

1. Log on to XOS Thundercloud
2. Click video → offense or defense in the top left hand corner → all game plans →2015
3. If watching preseason: click preseason → find practice date that needs to be watched
4. If watching regular season: click opponent scout – offseason → week/game that needs to be watched → scroll down to exact date that needs to be watched
5. Start watching files in each date as shown in Figure 1

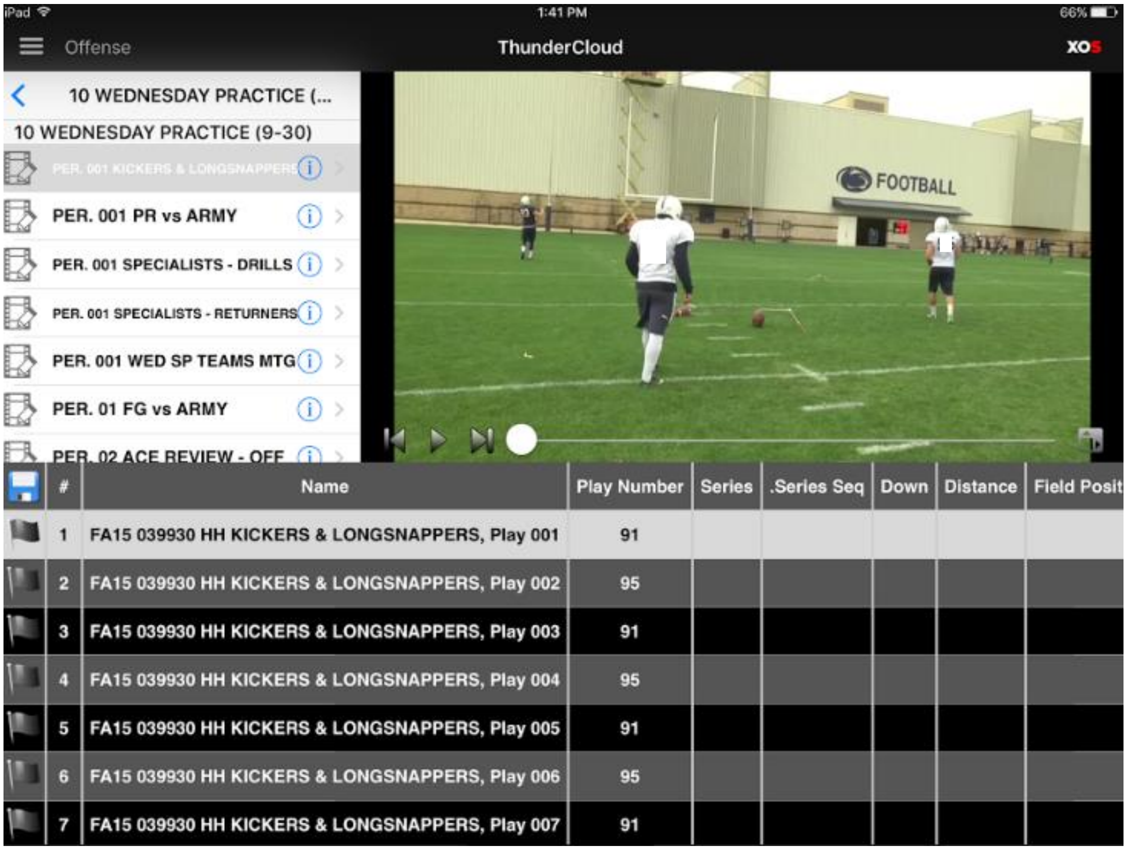


Figure 1. XOS file/clip example

6. When watching each clip (ex. FA155 039930 HH KICKERS & LONGSNAPPERS, Play 001) in the file, first note all the players that are in the video that are also part of the study
7. Moving from left to right on the frame, focus on each player when watching the clips
8. Watch each clip in entirety for each subject before moving on to the next clip in the file
9. A hit is head to head, head to torso, head to ground, or head to equipment
    a. A head to head hit is shown by the red circle in Figure 2

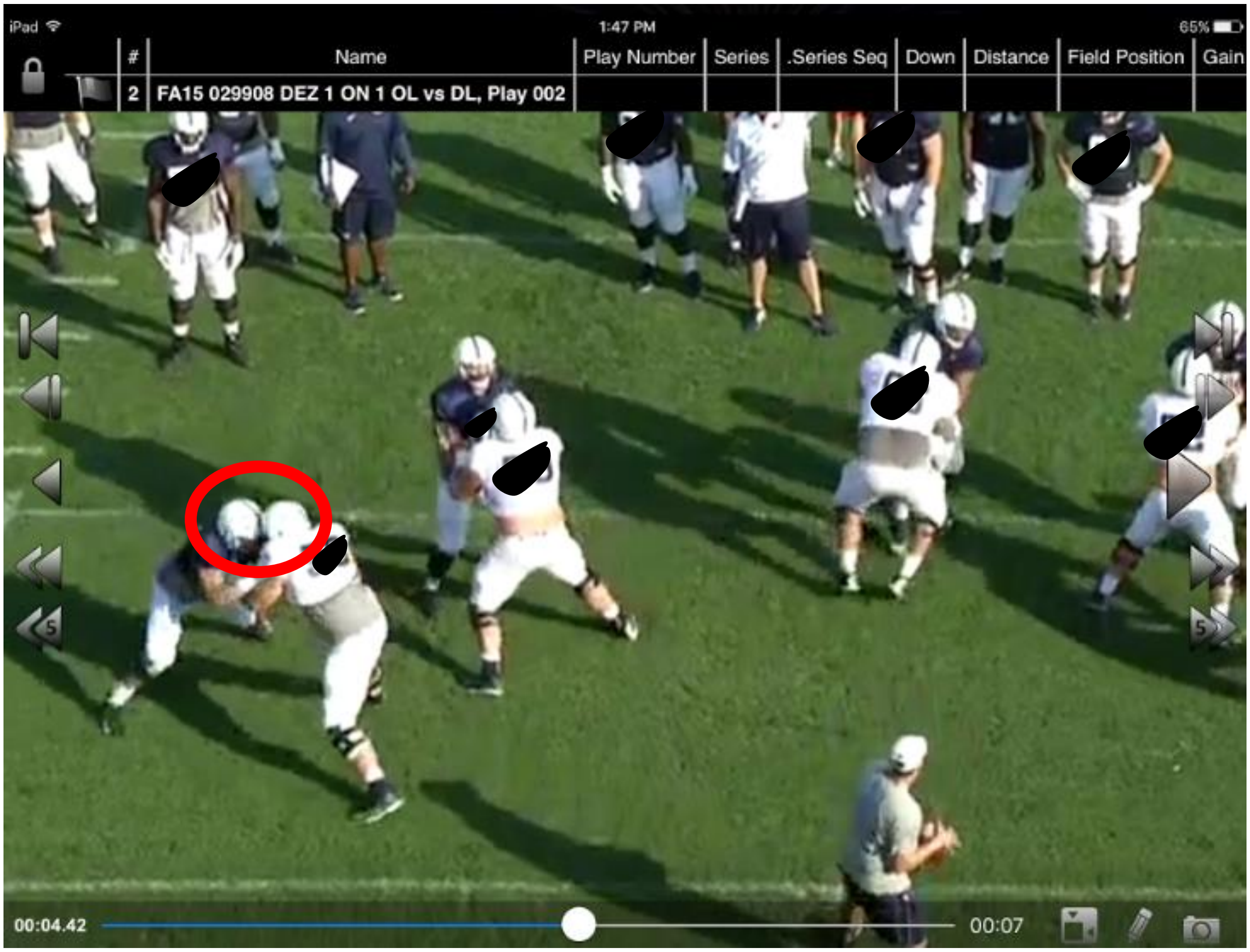
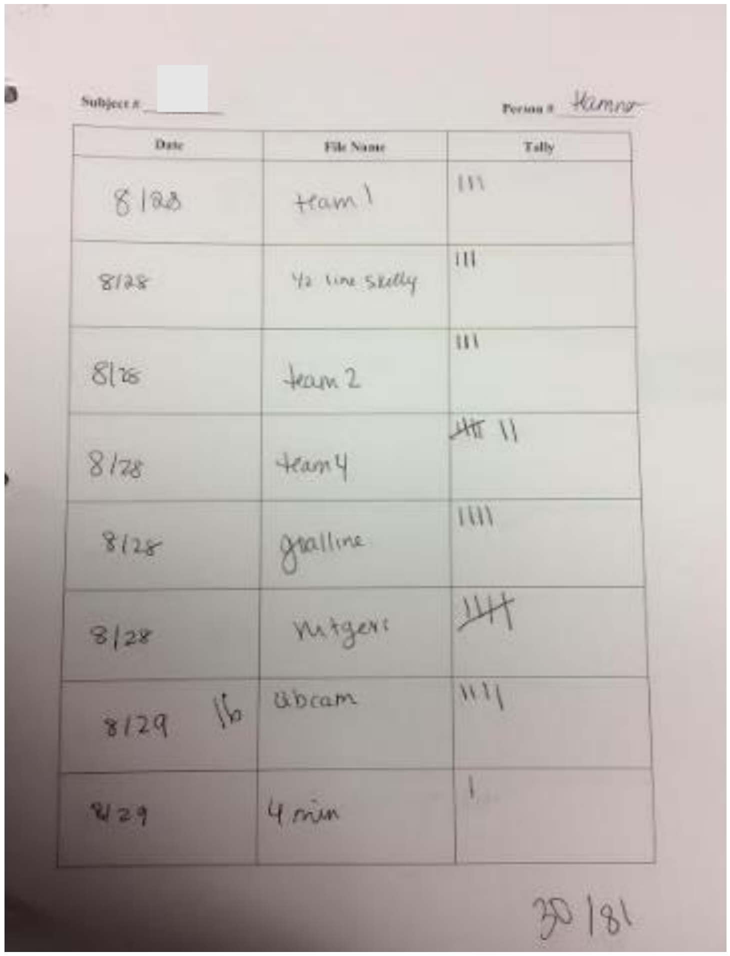


Figure 2. Example of hit on video

10. Record the number of hits for each subject in the tally sheet as shown below (Figure 3)
    a. Note: only include file name in the tally sheet and date of practice
    b. Ex from Figure 1: file name – Per. 001 Kickers and Longsnappers



Subject # ______ Person # Hamner

Date	File Name	Tally
8/28	team 1	|||
8/28	1/2 line skelly	|||
8/28	team 2	|||
8/28	team 4	卌 ||
8/28	goalline	||||
8/28	rutgers	卌
8/29 16	abcam	||||
8/29	4 min	|

30/81

Figure 3. Example of tally sheet

11. Watch the next file until all offense files for that day are finished
12. Watch the defense videos for that day before moving on to the next day by repeating steps 2-11
13. Some of the defense files will be copied and pasted from the offense files
    a. Check for repeating files by noting the number of clips in each file and watching a few clips to see if they match the offense clips

BodiTrak Accelerometer

BodiTrak was used to count the number of hits through an accelerometer. The product, a piece of fabric, was inserted into each subject's helmet and records the location and magnitude of impact. The pressure mapping smart fabric registers each hit taken in real-time and sends it to their online system.

Chapter 4

Results

The study involved 23 Penn State football players who were healthy at the beginning of the study. Using the accelerometer data and video footage acquired from football, the study compared the number of hits from the accelerometer and video. The overall observation supported the hypothesis that the number of hits counted from video footage is greater than the number of hits recorded by the accelerometer. The total number of hits recorded by the accelerometer from 8/19/15 to 9/17/15 was 1,076 hits and total hits from video was 1,399 hits.

The results for each player are shown in Table 3, which includes both hits from the accelerometer and video. However, each player did not play for the same number of dates in the study, so the normalized data is in Table 4. This table shows the number of hits per day for each player.

Table 3. Total Hits by Player

Subject	Accelerometer Hits	Video Hits
1	3	0
2	17	14
4	33	161
5	20	31
6	35	21
7	64	127
8	190	188
9	18	53
10	78	74
11	28	30
12	61	29
13	41	21
14	17	26
15	15	25
16	0	0
17	6	15
18	54	78
19	55	77
20	5	22
21	117	146
22	71	104
23	25	29
24	123	128

Table 4. Normalized Total Hits by Player

Subject	Accelerometer Hits	Video Hits
1	0.27	0.00
2	3.40	2.80
4	2.54	12.38
5	5.00	7.75
6	4.38	2.63
7	5.82	11.55
8	17.27	17.09
9	2.57	7.57
10	6.00	5.69
11	7.00	7.50
12	4.69	2.23
13	2.73	1.40
14	2.43	3.71
15	3.75	6.25
16	0.00	0.00
17	3.00	7.50
18	3.60	5.20
19	6.11	8.56
20	1.00	4.40
21	7.80	9.73
22	5.92	8.67
23	5.00	5.80
24	8.20	8.53

Statistical analysis was completed to see if there is a statistical difference between players and their number of hits. Based on the normalized data, the average number of hits a player recorded on the accelerometer was 4.72 hits and 6.39 hits from video footage. The p-value for a one-tailed paired t-test is 0.004, which confirms statistical significance and supports the hypothesis that that the number of hits from video is greater than the number of hits from the accelerometer.

In addition, a correlation test was completed to see if there is a relationship for each player's recorded and counted hits (Figure 4). The coefficient of correlation is 0.75, which means there is a strong relationship between the number of hits from accelerometer and video. The coefficient of determination is 0.56, so about 56% of the variability in video hits can be explained by its linear relationship with accelerometer hits.

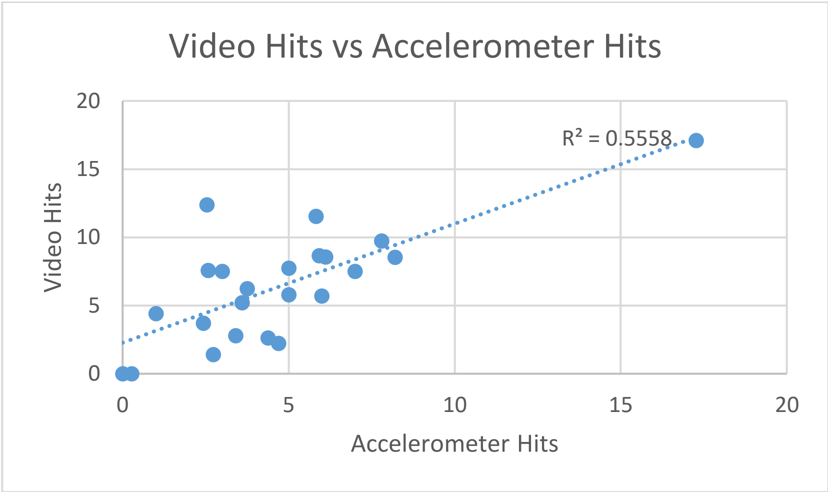


Figure 4. Total hits relationship based on players

The results were also sorted by date. This was to see if there was a statistical significance for each date. The tables below show the total number of hits for each date (Table 5) and normalized total hits for each date depending on how many players participated in practice that day (Table 6).

Table 5. Total Hits by Date

Date	Accelerometer Hits	Video Hits
8/19	28	0
8/20	83	79
8/21	68	97
8/22	99	86
8/25	51	70
8/28	116	251
8/29	72	93
9/1	124	155
9/2	75	110
9/3	15	44
9/8	134	84
9/10	36	85
9/15	106	152
9/16	48	69
9/17	21	24

Table 6. Normalized Total Hits by Date

Date	Accelerometer Hits	Video Hits
8/19	1.65	0.00
8/20	5.53	5.27
8/21	5.67	8.08
8/22	7.07	6.14
8/25	3.92	5.38
8/28	7.73	16.73
8/29	4.80	6.20
9/1	8.27	10.33
9/2	5.00	7.33
9/3	1.07	3.14
9/8	8.93	5.60
9/10	2.40	5.67
9/15	7.07	10.13
9/16	5.33	7.67
9/17	2.33	2.67
8/19	1.65	0.00

Statistical analysis was also completed to see if there is a significance change between dates. Based on the normalized data, the average number of hits from the accelerometer was 5.12

and from video was 6.69 hits. This is statistically significant (p-value < 0.05), which also supports that there is a significant difference of hits from the two methods based on the dates played. A correlation was also completed to see if there was a relationship between the two methods based on the dates (Figure 5). There is a slightly weaker correlation between dates than there was between players. The coefficient of correlation is 0.70, which suggests a strong relationship between number of hits from video and accelerometer. The test also explains that about 48% of the variability in video hits can be explained by its linear relationship with accelerometer hits.

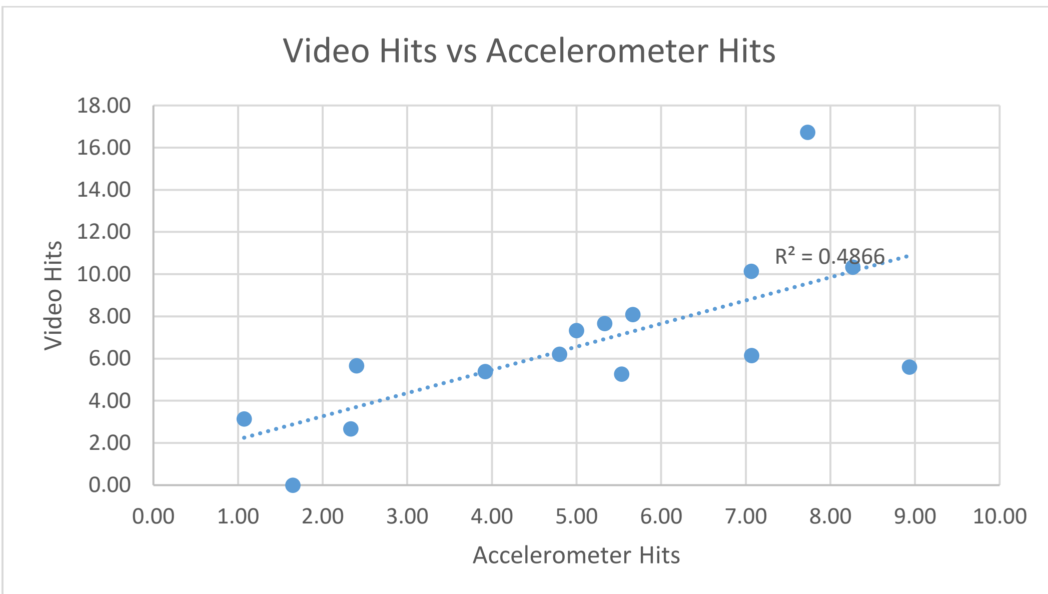


Figure 5.Total hits relationship based on dates

Figure 6 shows that pre-season practice (8/19 – 8/22) had consistently higher total hits compared to the regular season. The regular season had peaks at the first day of practice for the week and had dips at the last practice of the week, which is right before the game.

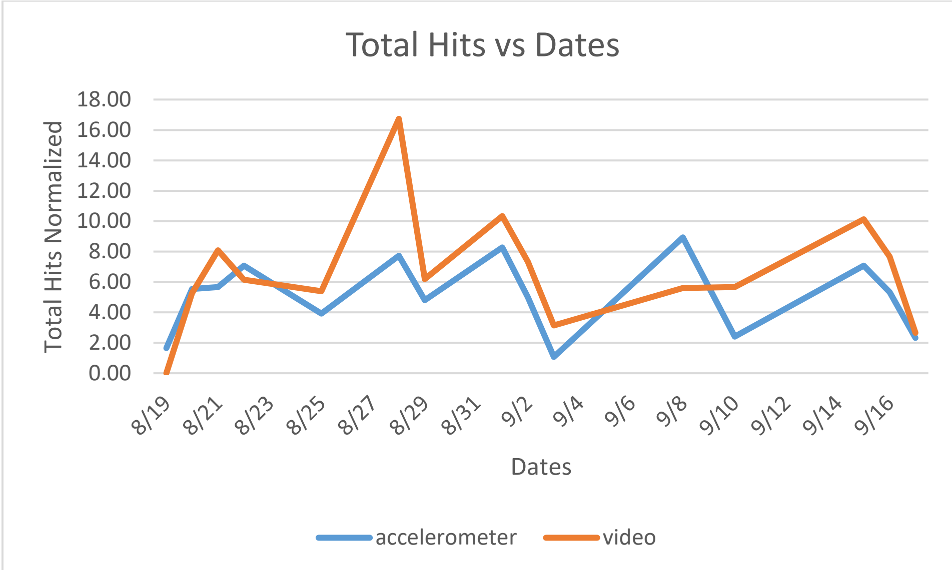


Figure 6. Number of hits based on dates

The remaining analysis focused on the type of player and if the player was offensive or defensive. When analyzing between the type of player, it was found that there is a statistical difference of hits from the two methods in the non-speed players (linemen). However, there was no statistical difference of hits in the speed players (running backs, tight ends, safeties, and linebackers). In addition, there was not a difference in hits for the offensive players, but there was a statistical difference for the defensive players. Table 7 summarizes the results with their respective p-values.

Table 7. P-Values based on Positional Groups

Non-Speed Players	Speed Players	Offensive Players	Defensive Players
0.002	0.183	0.103	0.012

Data analysis was also manipulated to see if separating non-speed and speed players based on if they were offensive or defensive played a role. The results are in the table below (Table 8). The t-test indicates there is only statistical significance between the accelerometer data and video hits on the non-speed defensive players.

Table 8. P-Values based on Combination of Positional Groups

Non-Speed Offensive	Non-Speed Defensive	Speed Offensive	Speed Defensive
0.066	0.006	0.498	0.179

Based on this same grouping, the average number of hits was calculated (Figure 7). A one-tailed paired t-test was also completed on the same data set with a p-value of 0.042. Therefore, there is a statistical difference between the positions of the subjects and hits recorded from the accelerometer and video footage.

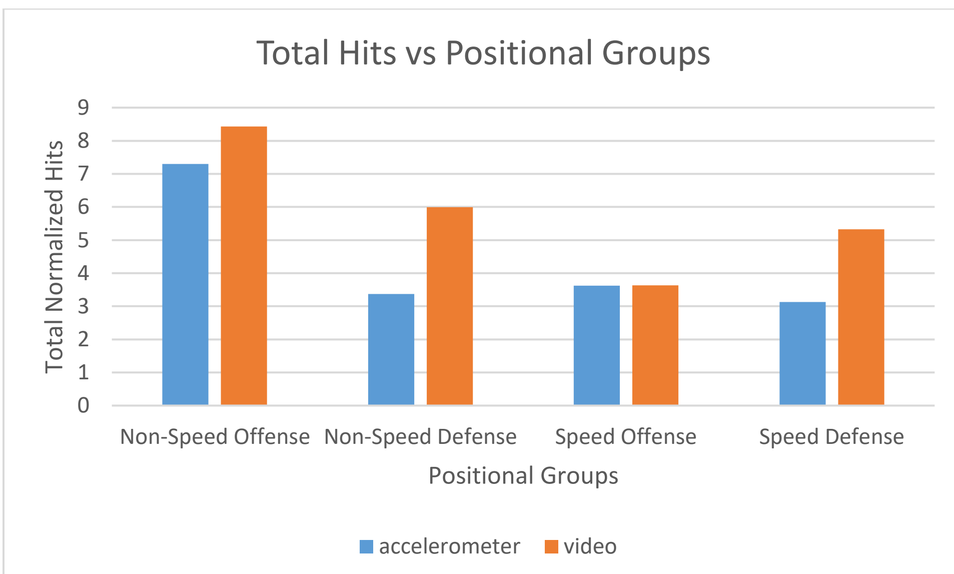


Figure 7. Total hits based on positional groups

Chapter 5

Discussion

This study consisted of 23 Pennsylvania State University Football Players, who were uninjured at the beginning of the study. Each subject gave their signed consent to allow for a BodiTrak accelerometer to be placed in their helmet. Each subject was also videotaped for each practice. Data were recorded from the accelerometers and video footage. Both counted the number of impacts each subject received. However, the accelerometer only recorded hits over 25G and the video footage counted every impact.

The purpose of this study was to see if there is a relationship between the hits recorded from the BodiTrak accelerometer and from hits counted via video footage. Accelerometers have become popular in high impact sports, especially football, because of their ability to count the frequency and location of hits. Their increasing use would lead to a more accurate understanding of the biomechanics of hits and concussion and allow for better equipment to be designed and help medically screen players. However, the accelerometers need to be compared to video footage to check for reliability. It is hypothesized that the number of hits based on BodiTrak's system will be less than the number of hits counted by the video footage.

Accelerometers have been used for many studies, however, only a few studies have compared it to video footage (Gabbett, 2015). This study is unique because there have been no published studies of the BodiTrak accelerometer compared to video footage. In addition, the BodiTrak accelerometer has only been used by three universities, including Penn State.

There are several findings of interest from this study. Based on players and dates of practices, there is a statistically significant difference between the hits acquired from the accelerometer and video footage., with video footage having a higher count compared to accelerometers.

The first test was completed to see if the individual players had a significant difference in their hits from accelerometers and video. The paired t-test had a p-value of 0.004, so there was a difference. Although there was a difference, a conclusion could not be made based on each individual player. Some of the possible explanations for this difference could be because of the way they were taught to tackle and block, the number of years they have played football, and the number of previous concussion. An in-depth look of the various groups with these possible reasons will occur later in this section.

The second test was completed to see if there was a statistical difference based on dates. The purpose of this test was to see if sensor malfunction played a role in accelerometer recordings. The p-value was 0.023, so there are less hits counted by the accelerometer than video footage. However, it is still uncertain if the dates varied because of sensor malfunction or for other reasons. This is because the sensor malfunction dates were removed from the study. Even though the dates did not provide very helpful information, it did show that pre-season practice had consistently higher total hits compared to the regular season. The regular season had peaks at the first day of practice for the week and had dips at the last practice of the week, which is right before the game.

The third grouping of tests was based on non-speed (lineman) and speed (running back, tight end, safety, and linebacker) positions. The non-speed positions had a significant difference of total hits, whereas the speed positions did not. This is possibly due to the fact that the accelerometer did not register hits less than 25G. Therefore, the non-speed players have lighter impacts than speed players, which is supported by the conclusions from Wellman, Coad, Goulet, and McLellan (2016). The speed players did not have a difference in their number of hits from the accelerometer compared to the video footage because they registered harder hits. This is also supported by other studies (Wellman, Coad, Goulet, & McLellan, 2016). In addition, the speed players are running fast and tackled by multiple players, so that suggests they have harder hits, which is also concluded by Broglio et. al (2011).

The next grouping was offensive versus defensive players. The offensive players did not have a statistical difference in their total hits (p-value = 0.103), but the defensive players did (p-value = 0.012). It may seem that they should have the same results because they are playing each other. However, that is not the case because in this study the defensive players played the second string offensive players and occasionally played the starting offensive players. The results also suggest that the defensive players have lighter hits that were not accounted for by the accelerometer. In addition, the defensive players had on average less number of hits compared to the offensive players. This suggests that their coaching style was different and the defensive players used their hands more to block and avoid high force hits. The offensive players have heavier impacts that are more likely to be registered by the accelerometer because the players generally move faster (ie running backs and tight ends compared to linebackers and safeties).

To better understand the driving forces of these difference, statistical tests were run by separating the offensive and defensive players in the non-speed and speed category, resulting in four groups (non-speed offensive, non-speed defensive, speed offensive, and speed defensive). The only group that had significantly different values for accelerometer and video hits was the non-speed defensive group. This study suggests that this occurred because their light impacts were counted on video but not by the accelerometer. In addition, the defensive linemen are lighter in weight, so they have a smaller force for their hits (Frank, 2012). The defensive linemen also need room for error, so they have more, lighter hits to allow them to react faster and potentially run to the quarterback. Also, the defensive linemen are taught to use their hands to block and bypass the offensive linemen. Therefore, they have lighter impacts when they are moving around the offensive linemen and have less number of hits in general. The offensive linemen had the highest average for number of years playing football and the lowest average for previous concussions. Therefore, their experience made them able to hit harder and prevent the defensive line from approaching their quarterback. The offensive linemen are also heavier compared to the defensive linemen because their only purpose is to block, so they have heavier force hits (Frank, 2012). Both speed offensive and defensive groups had similar hits from the accelerometer and video because they receive harder hits. In addition, the speed offensive players had the lowest number of years playing football average and the highest previous concussion average. Therefore, they were more inexperienced and had harder hits. This possible explanation is also supported by other studies because inexperienced players have not fully learned proper technique (Broglio et. al, 2011).

There are a few limitations to this study. One limitation is a small sample size. There were only 23 players in this study, which led to some of the insignificant results. Although this study was meant to focus on the starters, including second-string players would increase the sample size.

Another limitation of this study was to see if a hit was truly a hit on the video footage. Some of the clips had multiple views, so it was easy to confirm if it was actually a hit or if their helmets were close enough that the video made it seem like a hit. In the future, I would include multiple views of all the plays to ensure proper hit counting.

One of the biggest limitations of this study was the small number of dates. Only practices were recorded, so game hits were not in the study. Players sustain more hits in the game compared to practice, so that would have been more beneficial to the study. In addition, this was only a preliminary study. More dates need to be watched that have corresponding accelerometer data, so those results could also be incorporated in this project. In the future, it is imperative that the video counts are validated by another person. Since this was a preliminary study, each date was only watched by one person. Also, a future study should be completed that includes all hits from the accelerometer, so it is not limited to hits greater than 25 G.

In conclusion, the study showed a statistically significant difference on hits based on accelerometer and video footage when it was grouped by players ($p = 0.004$), practice dates ($p = 0.023$), non-speed players ($p = 0.002$), defensive players ($p = 0.012$), and non-speed defensive players ($p = 0.006$). The data also showed that the offensive linemen had heavier and more hits, whereas, the defensive linemen had lighter and less hits in total. This suggests that non-speed and defensive players have lighter hits that were not accounted for by the accelerometer. Although there are some differences in the total hits based on accelerometer and video footage, accelerometers will soon be a staple in sports and concussion management. Accelerometers will help with fast, on-site medical screening and help create more safe equipment for high-impact sports. Even though accelerometers may be misleading if it is the only technology used, it is complementary to video quantification. When using both techniques, it will ensure a more accurate count of sub-concussive impacts.

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ACADEMIC VITA

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EDUCATION:

The Pennsylvania State University **University Park, PA**
Schreyer Honors College & Eberly College of Science May 2017

Science – Biological Science and Health Professions Major
Rehabilitation and Human Services Minor

MEDICAL EXPERIENCE:

Clinical Preceptorship Program **Hershey, PA**
Internship at Penn State Hershey Medical Center and Children's Hospital June 2015

- Shadowed attending physicians and residents in different departments
- Gained knowledge about the power of teamwork in medicine and qualities of an excellent physician

Global Water/Medical Hybrid Brigade **El Paraiso, Honduras**
Brigade to Honduras May 2015

- Provided clean water to a village by working on a project with local engineers to dig trenches, connect pipes, install in-home water faucets, and provide education to improve family health
- Assisted in in-take, triage, medication packing, and education while shadowing local physicians and pharmacists

Global Medical Brigade **Yaviza, Panama**
Brigade to Panama May 2014

- Set up a mobile clinic in a rural community in Panama to provide community members access to medical care
- Examined patients by taking vitals in triage and observed physicians/dentists

Molani Welfare Clinic **Karachi, Pakistan**
Internship in Pakistan. June – July 2014

- Assisted a local doctor check vital signs and improved my knowledge of diseases in an urban setting
- Working to establish a foundation benefiting polio patients who are in need of medical mobility equipment

ACTIVITIES:

Global Brigades **University Park, PA**
Treasurer, Co-President August 2013 - present

- Manage the funds of all seven brigades
- Plan and oversee the bi-weekly meetings and major events, such as the regional exchange and Global Brigades Week
- Volunteer at a local farm and food bank on a weekly basis

Penn State Pediatric Cancer Dance Marathon (THON) **University Park, PA**
Rules and Regulations Committee, Secretary of subcommittee August 2013 - present

- Collaborate with a team of 40 members to ensure the safety of 700 dancers and thousands of attendees
- Train and educate the team about the rules and objectives of the other three main committees

Penn State Homecoming **University Park, PA**
Alumni Relations, University Relations Captain January 2015 – present

- Contact and network with the Alumni Association of PSU to set up the events and select the Grand Marshal
- Collaborate with co-captains to create new events before and during Homecoming week to celebrate Penn State pride
- Volunteer at the Day of Service and concession stands

RESEARCH:

Traumatic Brain Injury Research **University Park, PA**
Research assistant under Dr. Slobounov August 2014 – present

- Examine and test athletes for baseline tests and post-concussion tests (EEG, Virtual Reality, and memory tests)
- Analyze and evaluate the Virtually Reality tests that examine the alteration of brain functions and structure
- Designed senior thesis project