

**EXAMINING THE RELATIONSHIP BETWEEN PURPOSEFUL HEADING  
AND NEUROCOGNITIVE PERFORMANCE DURING THE PLAYING  
CAREERS OF FEMALE COLLEGIATE SOCCER PLAYERS**

by

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the requirements for the degree of Master of Science in Exercise Science

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## ABSTRACT

**Context:** Despite the popularity of soccer worldwide, there is considerable risk for injury including concussions as well as the potential for repetitive head impact exposure. It is important to determine if purposeful heading has a detrimental effect to the brain and if there are cumulative effects resulting in impaired neurocognitive functioning.

**Objective:** The primary aim was to identify if there is a relationship between purposeful heading and measures of neurocognitive test performance in female collegiate soccer players over a career span. The secondary aim of this study was to identify if there is a difference between the total number of headers and measures of neurocognitive test performance between female soccer players of different field positions (offense, midfield and defense). **Design:** Retrospective longitudinal study. **Setting:** Intercollegiate soccer fields as well as a climate controlled neurocognitive testing environment **Participants:**

Eighty-eight collegiate women's soccer players with ranging careers from two to four playing seasons over the last 15 years. **Interventions:** Prior to the first soccer season each athlete completed a computerized neurocognitive test that served as a baseline measure to all subsequent tests administered. At the conclusion of each season the test was performed again. The number of headers by each athlete were tallied using a simple tally system for both soccer matches and practices. **Main Outcome Measures:** Total headers over the playing career, ImPACT composite scores including total symptom score. Multiple regression analyses were performed to examine the relationship between heading and neurocognitive test performance over the playing career. In addition, analysis of covariance was used to better understand differences between playing

positions. **Results:** The number of headers varied by playing position (offense, midfield, defense), however there were no significant relationships between total headers during a collegiate career and the neurocognitive performance measures as well as total symptom score. Likewise, there were no significant differences in neurocognitive scores and symptoms across the three different playing positions. **Conclusion:** In our cohort of collegiate female soccer players there appears to be no detrimental effects on neurocognitive performance and related concussion symptoms, despite a career associated with repetitive head impacts from purposeful heading in soccer.

## **Chapter 1**

### **INTRODUCTION**

Soccer is the most popular team sport in the world, and it is one of the fastest growing sports in the United States. Worldwide there are nearly 200 million players.<sup>1,2</sup> Although soccer is not often considered a collision sport in the same way as American football, ice hockey, or rugby, it carries a high concussion risk,<sup>3</sup> with up to 11.4% of all game and 4% of all practice soccer injuries resulting from concussions.<sup>4</sup> Soccer is unique in that athletes purposefully use the unprotected head to control and advance the ball.<sup>5,6</sup> While a large number (15-30%) of concussions have been reported during the act of heading very few actually result from head/ball contact.<sup>7</sup> Instead, the mechanism producing these concussions is the result of direct head to head, head to other body part, or head to ground contact, or whiplash mechanisms, whereby the brain is “stunned” through the accelerated motion of the head snapping forward and/or backward.<sup>6</sup> In 2015, Comstock and colleagues stated while many of the concussions reported in soccer occurred during the act of purposeful heading most of the concussive impacts were not from the ball instead they were from contact with body parts (head, shoulder, elbow, knee, etc....) from other players (62-78%).<sup>7</sup>

Players may utilize their head to pass the ball to another player, clear the ball down the field or even score a goal. Heading the ball is an integral part of the game, that some collegiate or professional soccer players may be subjected to an average of 6-12 headers per game, whereby the ball can reach extremely high velocities.<sup>8</sup> Moreover, practice heading sessions most likely involve repeated head impacts at lower velocities.<sup>9</sup>

In light of the recent purposeful heading guidelines in soccer set forth by the United States Soccer Federation in 2015, youth soccer players in the United States are not allowed to head a ball until they turn 11 years old.<sup>10</sup> Furthermore these guidelines call for restrictions in heading in both practice and games between the ages of 11 to 13. In theory, this should greatly reduce heading exposures in this age group population during a period of rapid growth and brain development. As these youth athletes turn 14 and begin high school, some will end their soccer playing careers with very few exposures to purposeful heading. The proportion of soccer players who continue in competitive soccer beyond youth levels to interscholastic matches and collegiate level competition will further decline; indicating there is a rather small population that needs to be monitored when determining the deleterious effects from soccer heading. There is an even smaller number of athletes that go on to play at the professional level and whose career of exposure to purposeful heading may be of unique interest to the research community.

Purposeful heading in soccer is a unique technical aspect of the game and as a result participants are subjected to subconcussive head impacts.<sup>9</sup> It is estimated that between 1.6 and 3.8 million concussions occur annually in the United States, accounting for 5-9% of all sports related injuries.<sup>10</sup> Perhaps even more intriguing are the number of subconcussive impacts that occur to the heads of sport participants that do not result in a concussion. Bailes and colleagues suggest that subconcussion is a cranial impact that does not result in known or diagnosed concussion on clinical grounds.<sup>11</sup> It can also occur with rapid acceleration or deceleration of the body or torso, when the brain is free to move within the cranium, creating a “slosh” phenomenon.<sup>12</sup> One theory is that

subconcussion has its greatest effect through repetitive occurrences by which cumulative exposure becomes deleterious.<sup>11</sup> Symptoms may not develop and there are no outward or visible signs of neurological dysfunction. Kutcher and Giza<sup>13</sup> proposed that a concussive injury must increase above the symptom threshold to be diagnosed as a concussion. It could be extrapolated that subconcussive impacts would therefore fall below the symptom threshold line. This is especially important to researchers examining head impacts associated with purposeful heading in soccer.

With millions of participants worldwide and purposeful heading part of the game, it is imperative to determine if heading is detrimental to the cognitive function of the brain, especially in those who experience chronic exposure to heading. Neurocognitive testing has emerged as a means to objectively assess the scope of cognitive function. The various tests are able to provide data about the speed of information processing, reaction time, attention and concentration, scanning and visual tracking ability, memory recall, and problem-solving abilities.<sup>14</sup> The most widely used and recognized computer-based neurocognitive test in sport is the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT Applications Inc., San Diego, CA).<sup>15,16</sup> The ImPACT test focuses on three major categories including demographics and descriptive data, concussion symptoms, and neurocognitive function. There are six neurocognitive test modules that combine to measure cognitive functioning, including attention, verbal and visual memory, reaction time, and information processing speed.

Repetitive insults to the head during purposeful heading as part of the sport of soccer need to be examined further, with previous research being limited in collegiate

soccer. Putukian et al. showed no significant effects of heading on cognitive function during one practice session for men and women collegiate soccer players.<sup>14</sup> This study is limited however due to the use of a small sample size and because it was performed during soccer practice sessions. The intensity and effort during the heading drills may have been lower during the practice session than if heading data had been collected during games.<sup>14</sup>

In a 2002 study by Guskiewicz et al., soccer athletes did not demonstrate impaired neurocognitive function when compared with the non-soccer athletes or non-athletes.<sup>17</sup> This study relied on a history of heading questionnaire to determine the frequency of heading during the athlete's soccer career. This is an unreliable method of determining frequency because it relies solely on the athlete's memory and honesty. Lamond and colleagues observed one season of soccer heading.<sup>18</sup> Researchers looked at the differences in head accelerations across different impact types. A limitation to this study was it was only observed across one season, therefore does not provide long term outcome data. Most recently, Press and Rowson conducted a study utilizing female collegiate soccer athletes and sensor technology.<sup>19</sup> Only 19% of the almost 9,000 impacts were positively identified as head impacts, showing that error is associated with real-time head impact sensor technology.<sup>19</sup>

Although previous research has indicated no deleterious effects of acute bouts or one season of soccer heading,<sup>14,20</sup> no research exists examining the frequency of headers during practices and games over an athlete's playing career and neurocognitive functioning. Therefore, the purpose of this study was twofold. The primary aim is to

identify if there is a relationship between purposeful heading and measures of neurocognitive (ImPACT) test performance in female soccer players over their collegiate playing careers. Our secondary aim was to identify if there is a difference between different field positions (offense, midfield and defense), measures of neurocognitive test performance, and total number of headers in this cohort of soccer players. Neurocognitive testing is traditionally a component of a multimodal concussion management plan and is easily administered by athletic trainers and other sports healthcare professionals. More recently, researchers have utilized these tests to examine the influences of repetitive head impacts in a variety of sport athletes. Enabling clinicians and researchers an opportunity to gain a greater understanding of the consequences of repetitive head impacts in soccer may help to improve health outcomes in the future.

## **Chapter 2**

### **METHODS**

#### **2.1 Participants**

In order to address the primary aim of this study, an extensive database was utilized involving a cohort of collegiate female soccer student-athletes tested on multiple occasions from 2003 to 2017. Eighty-eight student athletes ranging from 18-23 years old ( $166.9 \pm 5.61\text{cm}$ ,  $60.9 \pm 4.73\text{ kg}$ ) were included in the study. Years of playing at the collegiate level ranged 2 to 4 years, with a minimum of two full seasons of competition. In order to be included in the analysis examining neurocognitive performance over time (career) all participants signed a UD IRB approved (143300-9) consent form (Appendix B) and were medically cleared for participation by the team physician. Table 1 presents data for athlete playing position (offense, midfield, defense).

Table 1: Total headers by player position

<b>Position</b>	<b>Number of participants</b>	<b>Total Number of Headers</b>	<b>Mean Number of Headers</b>
Defense	29	6,870	286.3
Midfield	35	11,882	339.5
Offense	24	11,992	413.5

#### **2.2 ImPACT Testing**

The IMPACT software program was used as the computerized cognitive test battery. The ImPACT instrument is a computer-based program used to assess

neurocognitive function and concussion symptoms. It consists of three main parts: demographic data, neurocognitive tests, and the Post-Concussion Symptom Scale (PCSS). The software program consists of six neurocognitive test modules that evaluate different aspects of cognitive functioning. The Word Memory and the Design Memory test modules assess immediate and delayed memory for words and designs, respectively. Attention, concentration, and working memory are both measured by the X's and O's and the Three Letters test modules. X's and O's also measure reaction time, whereas Three Letters measures processing speed. Visual processing speed, learning, and memory are assessed through the Symbol Match test module. The Color Match test module serves as a measure of focused attention, response inhibition, and reaction time. Five composite scores (verbal memory [VEM], visual memory [VIM], reaction time [RT], processing speed [PS], impulse control [IC]) are calculated based on combinations of various aspects of these six test modules. Impulse control composite score indicates the sum of errors committed during certain aspects of the ImPACT test. Higher scores may suggest carelessness (sandbagging) in completing ImPACT, thus is not of interest to researchers in this project. The symptom portion of the test requires the participant to rate the severity of 22 concussion symptoms such as headache, dizziness, sensitivity to light etc. on a Likert scale ranging from 0 to 6, indicating "how they are feeling in the past 24 hours." A score of 0 indicates not having the symptom, 1 is minor, and a score of 6 means severe. The ImPACT test has been shown to be valid and reliable measure of neurocognitive function and useful in assessing changes post-concussion.<sup>21</sup> In contrast, there have been reports that have questioned the test-retest reliability of the

ImPACT.<sup>22</sup> Until a better battery of neurocognitive computerized tests is put forth, the ImPACT continues to be the most widely used in sport.

Each soccer player completed their first ImPACT prior to the start of their first season as part of the routine pre-participation physical examination for all intercollegiate student-athletes. The ImPACT scores established at that time served as baseline comparison for all subsequent tests administered throughout the playing career. All testing occurred in a quiet climate-controlled testing environment. Within two weeks following the conclusion of each fall soccer season, the student-athletes returned to perform another ImPACT session in a similar testing environment. Data from this post-season test session were used to compare to the baseline score throughout the student-athlete's playing career. ImPACT test sessions during the season for post-concussion management were not included in the analysis.

### **2.3 Purposeful Heading Monitoring**

Manual recording of all head impacts was done by visual identification using a simple tally system at each practice and game by the certified athletic trainer or the athletic training students assigned to work with the team (Appendix C). The validity and reliability of monitoring head impacts through visual identification was studied by Caccece and colleagues.<sup>23</sup> They identified a strong inter-rater (0.964) reliability utilizing this system.<sup>23</sup>

The different types of purposeful headers along with unintentional deflections were carefully recorded using this tally system, specifically the ten categories include, clear, pass, shot, and unintentional deflection. The headers were also tallied during the

spring season exhibition games, which traditionally is limited to no more than 5 to 6 matches. These headers were added to the previous fall season's game (18 to 25 matches) headers. Upon completion of each season, the headers were totaled and entered into the database. For the purposes of this research study, only the total number of headers were analyzed.

#### **2.4 Data Analysis**

For the first specific aim, data were analyzed using multiple regression analysis (MRAs). MRAs were employed in favor of univariate associations as multivariate associations obtained during MRAs are generally superior to univariate correlations because they better capture the full network of relations among predictors and criteria.<sup>24,25</sup> Therefore, our data were analyzed using a series of direct-entry (standard) MRAs.

The MRAs used the ImPACT variable obtained at year 4 as the criterion; while the first predictors (independent variables) were the ImPACT composite scores obtained at baseline; these scores also served as covariates. The second predictor was the total number of headers. These analyses enabled us to answer the question of how does the number of headers effect ImPACT scores in year 4 after controlling for baseline ImPACT scores.

*A priori* power was assessed for the proposed MRA. Following the recommendation of Green, the *a priori* analysis evaluated both: (a) the overall significance of the MRA model and (b) the unique contribution of individual predictors.<sup>26</sup> The significance level for both analyses was set at  $p = .05$ , as per standard scientific

conventions. Medium effect sizes were postulated in keeping with Cohen's recommendations for MRA (i.e., both  $\eta^2$  values = .15).<sup>27</sup> In addition, power was set to 0.80, suggesting there would be an 80% probability of reaching statistical significance if the predictors had an effect in the population.

Results from the power analysis required that 68 cases would be necessary to evaluate the overall model and 55 cases would be necessary to evaluate individual predictors. The largest  $N$  was chosen so that the MRA would be sensitive to the least powerful comparison (i.e., 88 participants).

Specific aim 2 data were analyzed using a one-way analysis of covariance (ANCOVA). There were three position groups in the study: offense, midfield, and defense (goalkeepers were purposefully excluded as they typically are not included in purposeful heading) which served as the independent variables. The dependent variable was the composite score (VEM, VIM, RT, MS, TSS) taken in the final year. The dependent variables were measured at the beginning (baseline) and at the end of the athlete's collegiate playing career. Baseline results served as the covariate. *Post-hoc* comparisons were apportioned using the Bonferroni adjustment.

## **Chapter 3**

### **RESULTS**

The purpose of aim 1 was to identify a relationship between purposeful heading and measures of neurocognitive test performance. Table 2 shows a compilation of the means and standard deviations for each of the ImPACT composite scores (verbal memory, visual memory, processing speed, and reaction time) as well as the total symptom checklist both at baseline and the final year.

Table 2: ImPACT Composite Scores ( $\bar{x} \pm \text{sd}$ )

<b>ImPACT Test Modules</b>	<b>Mean</b>	<b>Standard Deviation</b>
Verbal Memory (VEM) Baseline	88.0	9.3
Verbal Memory (VEM) Final Year	91.0	9.7
Visual Memory (VIM) Baseline	77.5	13.4
Visual Memory (VIM) Final Year	78.4	14.3
Processing Speed (PS) Baseline	40.0	8.0
Processing Speed (PS) Final Year	43.5	8.0
Reaction Time (RT) Baseline	0.61	0.48
Reaction Time (RT) Final Year	0.54	0.87
Total Symptom Score (TSS) Baseline	8.2	9.3
Total Symptom Score (TSS) Final Year	3.4	8.1

The means of the ImPACT composite scores and total symptoms scores were evaluated to see if there was a significant increase or decrease from baseline to final year, using a paired-samples t-test (dependent-samples t-test). On average, participants only

showed significantly higher composite scores for verbal memory ( $t = 3.287, df= 87, p= 0.001$ ) and processing speed ( $t = 3.692, df= 87, p= 0.001$ ). The effect size is small to medium ( $d=0.33, d=0.44$ ) for both verbal memory and processing speed respectfully and represents a mild difference between the two-time periods. Higher scores in both of these areas indicate better performance. Similarly, total symptom score had a significant decrease in scores from baseline to final testing ( $t = -3.120, df= 59, p= 0.003$ ), with a medium effect size ( $d=0.54$ ) showing a moderate difference between the two-time points. The decrease in this area from baseline to final year suggest that the soccer players reported less concussion-like symptoms in their final year of test taking. There were no statistically differences found in the visual memory ( $t = 0.616, df= 78, p= 0.540$ ) and reaction time ( $t = -1.472, df= 87, p= 0.145$ ) composite scores.

A multiple regression analysis was conducted on each of the above-named variables in an attempt to predict final year score in each of these variables. The midfield position served as the base/reference group because it has the largest sample size (n=35).<sup>28</sup> This is because the mean of this group will be involved in all of the comparisons and therefore should have the smallest error.<sup>28</sup> A total of 5 separate analyses were conducted and are presented here.

### **3.1 Verbal Memory (VEM)**

**Descriptive Statistics**

	Mean	Std. Deviation	N
VEM4	90.98	8.679	88
TOTHEAD	349.36	303.616	88
offense	.2727	.44791	88

defense	.3295	.47274	88
VEMB	87.98	9.275	88

Model Summary										
Mod el	R el	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	
1	.548 <sup>a</sup>	.300	.266	7.436	.300	8.886	4	83	.000	

a. Predictors: (Constant), VEMB, defense, TOTHEAD, offense

Coefficients <sup>a</sup>					
Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
1	(Constant)	45.490	8.293		5.485
	TOTHEAD	2.574E-5	.003	.001	.009
	offense	.136	1.985	.007	.069
	defense	.497	1.881	.027	.264
	VEMB	.515	.090	.550	5.710

a. Dependent Variable: VEM4

From the model summary, it is noted that 30% of the variance of the criterion VEM4 (Verbal Memory final year) was accounted for by the linear combination of the predictors. Additionally, the overall predictive model is statistically significant as noted by the column labelled “Sig. F Change.” It is also important to note, that the computed effect size from the Model Summary was 0.429 representing a large effect.<sup>27</sup> Lastly, we were interested in determining which of the variables contributed most to VEM4, and from the “Coefficients” table above only VEMB (Verbal Memory Baseline) had a

significant t-test indicating the greatest contribution to VEM4. Interestingly, total headers (TOTHEAD) and player position were not unique contributors.

### 3.2 Visual Memory (VIM)

Descriptive Statistics			
	Mean	Std. Deviation	N
VIM4	78.43	14.303	79
TOTHEAD	371.80	308.894	79
offense	.2911	.45719	79
defense	.3165	.46806	79
VIMB	77.5086	13.37617	79

Model Summary										
Mod el	R el	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	
1	.559 <sup>a</sup>	.313	.276	12.173	.313	8.420	4	74	.000	

a. Predictors: (Constant), VIMB, TOTHEAD, offense, defense

Model	Coefficients <sup>a</sup>				t	Sig.
	Unstandardized Coefficients		Standardized Coefficients	Beta		
1	(Constant)	34.040	8.430		4.038	.000
	TOTHEAD	-.005	.005	-.099	-1.001	.320
	offense	2.882	3.375	.092	.854	.396
	defense	3.749	3.307	.123	1.134	.261
	VIMB	.569	.104	.532	5.487	.000

a. Dependent Variable: VIM4

31% of the variance of the criterion of VIM4 (Visual Memory final year) was accounted for by the linear combination of the predictors, VIMB (visual memory

baseline), total headers, offense and defense. As indicated in the Model Summary, the overall predictive model was significant ( $p < 0.05$ ). The computed effect size for visual memory is 0.456, which was large.<sup>27</sup> Finally, the largest contributor to VIM4 was VIMB; neither TOTHEAD nor position contributed.

### 3.3 Processing Speed (PS)

Descriptive Statistics			
	Mean	Std. Deviation	N
PS4	43.4700	7.95121	88
TOTHEAD	349.36	303.616	88
offense	.2727	.44791	88
defense	.3295	.47274	88
PSB	40.0000	7.96697	88

Model Summary									
Mod el	R el	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.410 <sup>a</sup>	.168	.128	7.42518	.168	4.191	4	83	.004

a. Predictors: (Constant), PSB, TOTHEAD, offense, defense

Model	Coefficients			t	Sig.
	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta		
1	(Constant)	29.416	4.257		6.909 .000
	TOTHEAD	-.003	.003	-.129	-1.275 .206
	offense	-1.108	1.973	-.062	-.561 .576
	defense	.127	1.876	.008	.067 .946
	PSB	.387	.100	.388	3.869 .000

a. Dependent Variable: PS4

16.8% of the variance of the criterion PS4 (Processing Speed final year) is accounted for by the linear combination of the predictors of PSB, TOTHEAD, and position. Additionally, the overall predictive model is statistically significant ( $p= 0.004$ ) as noted by the column labelled “Sig. F Change.” It is also important to note, that the computed effect size from the model summary was 0.201 representing a medium effect.<sup>27</sup> Lastly, in determining which of the variables contributed most to PS4, only PSB had a significant t-test indicating the greatest contribution.

### 3.4 Reaction Time (RT)

Descriptive Statistics			
	Mean	Std. Deviation	N
RT4	.5365	.08730	88
TOTHEAD	349.36	303.616	88
offense	.2727	.44791	88
defense	.3295	.47274	88
RTB	.6127	.48017	88

Model Summary									
Mod el	R Square	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.121 <sup>a</sup>	.015	-.033	.08872	.015	.307	4	83	.872

a. Predictors: (Constant), RTB, TOTHEAD, offense, defense

Model	Coefficients <sup>a</sup>			t	Sig.
	B	Unstandardized Coefficients	Standardized Coefficients		
1	(Constant)	.530	.022	24.290	.000
	TOTHEAD	7.380E-6	.000		
	offense	-.009	.024		

defense	.016	.023	.084	.689	.493
RTB	.002	.020	.008	.076	.939

a. Dependent Variable: RT4

Only 1.5% of the variance of the criterion of RT4 (Reaction Time final year) is accounted for by the linear combination of the predictors. The overall predictive model was not statistically significant (Sig. F Change = 0.872) and there were no significant unique contributing variables to RT4.

### 3.5 Total Symptom Score (TSS)

Descriptive Statistics			
	Mean	Std. Deviation	N
TSS4	3.43	8.127	60
TOTHEAD	405.17	326.913	60
offense	.2333	.42652	60
defense	.3000	.46212	60
TSSB	8.17	9.332	60

Model Summary										
Mod el	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	
1	.370 <sup>a</sup>	.137	.074	7.821	.137	2.175	4	55	.084	

a. Predictors: (Constant), TSSB, defense, TOTHEAD, offense

Model	Coefficients <sup>a</sup>			t	Sig.
	B	Unstandardized Coefficients	Standardized Coefficients		
1	(Constant)	.309	2.070	.149	.882
	TOTHEAD	.009	.003		
	offense	1.667	2.589		

defense	-3.655	2.459	.208	-1.486	.143
TSSB	.032	.112	.036	.283	.778

a. Dependent Variable: TSS4

Our last analysis considered TSS4 (Total Symptom Score final year). A total of 60 student-athletes scores were included in this specific analysis in ImPACT reporting. Approximately 13.7% of the variance of the criterion of TSS4 is accounted for by the linear combination of TSSB (Total Symptom Score baseline), position, or total headers. Moreover, the overall predictive model was not statistically significant ( $p= 0.084$ ). Total headers (TOTHEAD) was the greatest contributor to TSS4, rather than position or TSSB.

### **3.6 Field Position and Neurocognitive Test Performance**

Table 1 displays the three different soccer field positions, the number of participants at each position, and the mean total number of headers per position across the playing career of our participants. Data were analyzed using a one-way analysis of variance (ANOVA) to determine the presence of a statistical significant difference between total headers and playing positions. The overall ANOVA itself was not statistically significant therefore there was no difference between groups ( $F= 1.387$ ,  $df= [2,86]$ ,  $p= 0.255$ ) or soccer playing positions in regards to total number of headers over a collegiate career.

To compare measures of neurocognitive test performance between female soccer players across the three different playing positions a total of five ANCOVAs were run using the ImPACT composite scores (VEM, VIM, RT, PS, TSS). There was a statistically significant relationship between baseline scores for VEM, VIM and PS and their

subsequent final year value (VEM4, VIM4, PS4). Neither analysis involving RT and TSS produced any significant relationships. Furthermore, the main effect of position was not significant for any of the 5 composite scores (Table 3). In other words, soccer field position had no appreciable effect on ImPACT composite scores once baseline levels were controlled through covariation.

Table 3: ANCOVA Results

	<b>Offense</b>	<b>Midfield</b>	<b>Defense</b>	<b>R<sup>2</sup></b> (correlation between baseline test and year 4)	<b>Main effect</b> (F-test) of position on year 4
<b>VEM4</b>	92.17±7.26	90.71± 8.02	90.31± 10.54	R <sup>2</sup> = 0.300 <i>p</i> = 0.000	<i>p</i> = 0.964
<b>VIM4</b>	80.83±11.39	75.97± 16.73	79.28± 13.50	R <sup>2</sup> = 0.303 <i>p</i> = 0.000	<i>p</i> = 0.523
<b>PS4</b>	42.62±9.12	43.72±7.75	43.88±7.36	R <sup>2</sup> = 0.152 <i>p</i> = 0.000	<i>p</i> = 0.885
<b>RT4</b>	0.52± 0.06	0.53± 0.06	0.55±0.12	R <sup>2</sup> = 0.014 <i>p</i> = 0.942	<i>p</i> = 0.566
<b>TSS4</b>	4.6± 14.85	3.9±5.31	1.8±3.40	R <sup>2</sup> = 0.029 <i>p</i> =0.444	<i>p</i> = 0.583

## **Chapter 4**

### **DISCUSSION**

This research set out to examine purposeful heading, soccer position, and neurocognitive functioning over the playing careers of female collegiate soccer players. There were no significant relationships between total headers over the course of the playing career and the four primary neurocognitive predictors using the ImPACT composite scores (VEM, VIM, PS, RT); however, a significant relationship was noted with the predictor total symptom scores and TOTHEAD. While part of the ImPACT test program, TSS, is not a true neurocognitive measure, instead it is a barometer for concussion symptom severity. In fact, if you carefully examine TSS in Table 2, you'll note that the scores actually declined (got better) from baseline to final year and it is most likely this decrease that is accounting for the significant relationship noted by the multiple regression analysis. Conversely, had symptom score increased from baseline to final year the significant relationship would have been easier to explain.

There are several other publications that provide soccer heading exposure information. An early study by Tysvaer and Storli provided an estimate for professional soccer players suggesting that those that play approximately 300 games, head the ball more than 2000 times during their careers.<sup>29</sup> This number does not account for headers accumulated during practices, therefore the estimated total number of lifetime headers is probably much greater than 2000. In a 2012 published abstract by Kaminski et al. involving *male* soccer players they reported total headers over three playing seasons ranged from 160 to 422.<sup>30</sup> The main finding of the Caccese and Kaminski study in 2015,

was there was no evidence of diminished cognitive function between men's and women's soccer players and non-contact student athletes at the start of their collegiate careers despite years of purposeful heading.<sup>31</sup> Additionally, the changes in neurocognitive performance were not associated with the number of headers.<sup>31</sup> In comparison, we report an average of  $349 \pm 303.6$  headers (range 1-1360) in our cohort of *female* soccer players with careers spanning two to four years. With so few studies involving female collegiate soccer players<sup>3,18,19,32</sup> making comparisons in regards to total career headers is difficult. Lynall et al. found the median number of impacts sustained per player in NCAA Division I female soccer players for all games during a single season was 42, ranging from 1 to 272 impacts per player. Similarly, during practice the median number of impacts was 36, ranging from 5 to 296 impacts per player.<sup>3</sup> It can be extrapolated from this research that after a four year career, these collegiate soccer athletes may have accumulated up to 1,088 head impacts during games and 1,184 head impacts during practice.

McCuen et al. followed female collegiate soccer players over one competitive season finding the mean impacts for practice was 3.52 per player per session whereas games was 6.98 per player per session.<sup>32</sup> Although exact specifics on number of games and practices were not provided, we contend that a traditional collegiate soccer season includes approximately 20 games and 40 practices. To extrapolate total headers over four years from this data set, athletes would then have accumulated approximately 560 headers for games and 565 for practices totaling 1,125 headers per player. Finally, in the Press and Rowson paper, researchers followed female soccer student-athletes across one season consisting of 26 practices and 20 games.<sup>19</sup> A total of 1703 head impacts were

identified of which 1,525 were actual headers, whereas the remaining impacts were a mixture of head to head, head to body, head to ground, and unintentional ball to head contact.<sup>19</sup> Given the number of headers collected from the single season presented in this data set it can be extrapolated that at the end of four years, a total of 6,100 head impacts could result. Considering they had a total of 26 players, we suggest a conservative estimate of 235 headers per player over a four-year playing career. It is likely that there would be players both above and below this estimate. With soccer heading such an important part of the game and with evidence here suggesting a wide-ranging number of headers, it is essential to gain a better understanding of cognitive function over a playing career.

The ImPACT test is a neurocognitive test widely-used by the sports medicine community as a method to evaluate sport-related concussion.<sup>15</sup> Because this tool was used on multiple occasions with subjects in our study, it is important to discuss normal changes in ImPACT composite scores from multiple test occasions, as well as the controversial findings on validity and reliability. Broglio et al. reported the sensitivity of the ImPACT as 79.2% in identifying a concussion, however it is recommended that computerized neuropsychological testing is just one part of a multifaceted concussion assessment.<sup>33</sup>

It is important to note that neuropsychological testing is designed to detect deficits following concussion, but has not been fully validated as an accurate means of detecting the minor changes that may result from the repetitive head impacts associated with soccer heading. A 2003 report by Iverson and colleagues shows stability in the ImPACT

test with test-retest reliability scores of 0.70 for verbal memory, 0.67 for visual memory, 0.79 for reaction time, 0.86 for processing speed, and 0.65 for total symptom scale.<sup>21</sup> In 2010, Schatz researched the long-term test-retest reliability of baseline cognitive assessments using the ImPACT program involving collegiate athletes completing baseline cognitive testing approximately 2 years apart. The study reported intraclass correlation coefficients estimates for visual memory, processing speed, and reaction time composite scores that reflected stability over the 2-year time period, with greater variability in verbal memory and symptom scale scores.<sup>34</sup> In contrast, a study by Resch adds evidence suggest that ImPACT has varying reliability.<sup>22</sup> A total of 50% of ICC values met the study's definition of acceptable reliability ( $\geq 0.75$ ) for 1-week testing intervals, which is not how the ImPACT is used clinically.<sup>22</sup> With more clinically relevant time points, 92% of the test-retest coefficients were suboptimal. In addition, ImPACT misclassified 22-46% of the healthy college-aged sample as impaired on 1 or more indices at 1 or both time points after baseline testing in the study.<sup>22</sup>

Still speculation exists as to whether repetitive head impacts affect neurocognitive functioning. Gysland and colleagues examined the relationship between football head impacts and concussion history on measures neurocognitive function.<sup>35</sup> Collegiate football players completed 5 clinical measures of neurological function commonly used in concussion evaluation including the Automated Neuropsychological Assessment Metrics (ANAM), Sensory Organization Test, SAC, BESS, and Graded Symptom Checklist, while head impact data were collected using the HITS System. Results showed that football players did not demonstrate any clinically meaningful changes from

preseason to postseason on the measures of neurological function.<sup>35</sup> More recently, Rau et al. examined if asymptomatic high school football players demonstrated neuropsychological deficits following games using the ImPACT test.<sup>36</sup> The findings indicated no significant group differences in comparison to matched controls; interestingly several participants showed clinically significant improvements in verbal and visual memory with the second administration of the test during the competitive season.<sup>36</sup> According to the ImPACT test manual, the test was designed to reduce practice effects through randomization of stimuli presentation, nevertheless test score change over repeated administration is to be expected.<sup>37</sup> Reliable Change Index Scores (RCI's) help clinicians and healthcare professionals determine when the change is significant and clinically meaningful. The RCI provides an estimate of the probability that a given difference in a test taker's obtained score would not be obtained as a result of measurement error.<sup>37</sup> This allows clinicians to reduce any effects of measurement error, usually in the form of practice effects or inattentiveness or fatigue.<sup>38</sup> Iverson and colleagues present the probable changes in measurement of error: Verbal Memory Composite= 6.83 points, Visual Memory= 10.59 points, Reaction Time= 0.05s, Processing Speed= 3.89 points, and Post-concussion Symptom Scale= 7.17 points.<sup>21</sup> The 80% confidence intervals for estimating change are as follows: Verbal Memory  $\geq$  9 points, Visual Memory  $\geq$  14 points, Reaction Time  $>$  0.06s, Processing Speed  $\geq$  5 points, and Post-concussion Symptom Scores  $\geq$  10 points.<sup>21</sup> These changes in ImPACT scores can be used to identify deficits in specific individual's performance when no statistically significant changes are observed across individuals.

There may be a dose response with regard to impacts that must be considered over the course of a player's career, as the measures of neurocognitive function may not be sensitive enough to detect subclinical neurological dysfunction in athletes sustaining repetitive head impacts.<sup>11</sup> Perhaps the symptoms or sequelae of repetitive head impacts require a greater amount of time to develop than during a single season of competition or even a 2-4 collegiate playing career. Recently, Montenigro and colleagues have developed a metric of cumulative exposure in football for repetitive head impacts known as "the CHII."<sup>39</sup> The CHII is a measure that includes self-reported exposure and estimated quantitation of head impacts based on published helmet accelerometer studies.<sup>39</sup> Through this, these researchers are able to examine the relationship between cumulative repetitive head impacts and later-life cognitive, mood, and behavioral impairment in samples of former football players whose highest level of play was either high school or college. Specifically, they found that the risk of impairment increases steadily every 1000 impacts, or about twice the sample's average season number of impacts (545) above the baseline change point.<sup>39</sup>

With regard to our secondary aim, an interest in examining headers across the three different playing positions, our results indicate there are no statistical differences in total number of headers between those who play defender positions versus those in the midfield and forward playing positions. It is also important to note that style of play and individual coaching preferences can also impact total number of headers by position; whereas some coaches use tactical on the ground thus increasing the chances for purposeful heading exposures. Interestingly, with the increase in media attention over the

last ten years with regard to brain injury and repetitive head impacts we contend that there may be an attitude gaining momentum whereby soccer athletes are more reluctant to head soccer balls than they were in the past. Additional research is needed to gain greater insight into this hypothesis.

A limitation of the current study is that we did not control for any student-athletes that sustained previous concussions and their data is included in this analysis.

Additionally, the purpose of this study was to examine the effects of heading over the athlete's *collegiate* playing career, however we were not able to monitor heading exposure during off-season (summer) play and we had no knowledge of heading exposure in the years leading up to their collegiate experience. One might argue that any cognitive deficits as a result of soccer heading may have already been sustained prior to the athlete reaching the collegiate level of competition; although we contend that the soccer heading exposure is relatively low prior to collegiate competition. Several factors contribute to this notion including less aggressive style of play, coaching methods, and tactical considerations whereby the ball is not played in the air as much at lower levels of competition. Furthermore, we did not have a measure of heading magnitude or a cumulative magnitude for the total number of headers. All purposeful headers impact the head differently, therefore future studies should include head acceleration monitoring. Lastly, we are aware there has been multiple versions of the ImPACT. Most research to date has used Version 1.0, however Version 2.0 is very similar to the original version.<sup>21</sup> However, there have been some changes such as Version 2.0 includes an additional test module (design memory), and one of the working memory tasks (X's and O's) was

expanded and altered, making it more difficult than it was previously.<sup>21</sup> Version 2.0 additionally yields two memory composite scores (Verbal Memory and Visual Memory) while Version 1.0 contains only one memory composite score.<sup>21</sup>

Ideally, future studies should begin tracking heading exposures at practices and games beginning at age of 11, especially here in the United States where current guidelines prohibit heading in youth players ages 10 and under. Similarly, monitoring neurocognitive assessments during this time period could prove useful. More importantly though is the consideration for tracking changes (if any) in measures of quality of life such as cognition or memory in cohorts of soccer players after their careers have ended. Only then will we have a better idea of the long-term effects of repetitive head impact exposures during their soccer playing careers.

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## **Appendix A**

### **LITERATURE REVIEW**

#### **Introduction**

With the over 265 million people playing soccer, soccer is by far the most popular sport in the world and one of the fastest growing sports in the United States.<sup>1</sup> Unfortunately, as the total number of soccer participants increases, so does the number of injuries.<sup>2</sup> Soccer is not often considered a collision sport in the same way as American football, ice hockey, or rugby, but it carries a high concussion risk,<sup>3</sup> with up to 11.4% of all game and 4% of all practice soccer injuries resulting in concussions.<sup>4</sup> This may be due to the uniqueness of soccer; purposefully using the unprotected head to control and advance the ball.<sup>5,6</sup> However heading the ball only accounted for 15.3%-32.3% of concussions in youth athletes.<sup>7</sup> Players may utilize their head to pass the ball to another player, move the ball down the field or even score a goal. Heading the ball is such an integral part of the game, that some collegiate or professional soccer players may be subjected to an average of 6-12 headers per game, whereby the ball can reach extremely high velocities.<sup>8</sup> Moreover, practice heading sessions most likely involve repeated head impacts at lower velocities.<sup>8</sup> In light of the recent purposeful heading guidelines in soccer set forth by the United States Soccer Federation<sup>9</sup> in 2015, youth soccer players in this country won't be allowed to head a ball until they turn 11 years old. Furthermore, these guidelines call for restrictions in heading in both practice and games between the ages of 11 to 13. In theory this should greatly reduce heading exposures in this age group population during a period of rapid growth and brain development. As these youth

athletes turn 14 and begin high school some will end their soccer playing careers with very few exposures to purposeful heading. The proportion of soccer players who continue in competitive soccer related to travel teams, interscholastic matches, and collegiate level competition will further decline; indicating that it is a rather small population that needs to be monitored when determining if there are any deleterious effects from soccer heading during their playing careers. There is an even smaller number of athletes that go on to play at the professional level and whose career of exposure to purposeful heading maybe of unique interest to the research community. It is important to point out that the types head impacts soccer athletes are exposed to can vary.

The majority of the concussions that occur in soccer are not a result of direct contact between the head and ball as is done while performing purposeful heading.<sup>6</sup> Instead, the mechanism producing these concussions is the result of direct head to head, head to other body part, or head to ground contact, or whiplash mechanisms, whereby the brain shifts around through the accelerated motion of the head snapping forward and/or backward.<sup>6</sup> In 2015, Comstock and colleagues were quick to point out that while many of the concussions reported in soccer occurred during the act of purposeful heading most of the concussive impacts were not from the ball instead they were from contact with body parts (head, shoulder, elbow, knee, etc....) from other players (62-78%).<sup>7</sup>

### **Concussions:**

A concussion is a historical term “representing low velocity injuries that cause brain ‘shaking’ resulting in clinical symptoms and which are not necessarily related to a pathological injury.”<sup>10</sup> The clinical syndrome of concussion is thought to be the result of

biomechanical forces including “a complex and multifaceted cascade of ionic, metabolic, and physiologic events.<sup>11</sup> This cascade involves impaired neurotransmitter function, excitotoxicity, and abnormal concentrations of intracellular and extracellular ions.”<sup>12</sup> The clinical presentations of concussions are heterogeneous and are difficult to localize to one specific anatomic location.<sup>12</sup> The varied and diffuse nature of the injury produces clinical syndromes that often involve the disruption of functional brain networks, such as those responsible for memory,<sup>11,12</sup> balance,<sup>12</sup> vision,<sup>13</sup> gait,<sup>14</sup> and vestibular control.<sup>12,13</sup>

The diagnosis of concussion is varied due to lack of objective signs and symptoms.<sup>15</sup> Traditionally athletic trainers have utilized a variety of tools including a symptom checklist, the Balance Error Scoring System, and the Standardized Assessment of Concussion to evaluate a concussion. It is recommended the scores on each of these tests be compared to the athlete’s normal baseline scores, in order to determine a difference.<sup>13</sup> In addition, each concussion is unlike the next and manifests itself differently from person to person. The clinical presentation is very subjective and can range from symptoms that resolve within a week to impairments lasting for months.<sup>16</sup> In a study of collegiate and high school athletes, at the time of injury the most commonly reported symptoms were headache (87%), balance/dizziness (77%), “feeling in a fog” (62%) and difficulty concentrating (52%).<sup>16</sup> Interestingly despite common public perception less than 10% of diagnosed concussions involve a loss of consciousness.<sup>12</sup>

Sport-related concussions have been associated with alteration in brain function including areas involved with gait,<sup>17,18</sup> postural control,<sup>19–21</sup> vision,<sup>22</sup> and mental-status.<sup>23</sup> Although long-term neurocognitive impairment is rarely associated with a single

uncomplicated concussion, multiple concussions have been associated with prolonged symptoms, recovery time and risk for future concussions<sup>24</sup> or additional injuries.<sup>25</sup>

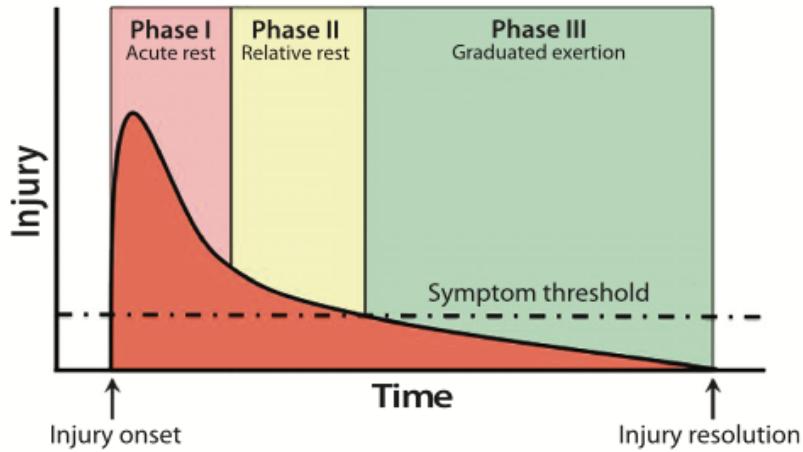
Lately more attention has been focused on athletes participating in sports where the potential for repeated head impacts without concussion are numerous (American football, rugby, boxing, Australian rules football, soccer). Concerns regarding a potentially devastating neurodegenerative syndrome caused by episodic and repetitive blunt force impacts to the head and transfer of acceleration-deceleration forces to the brain called chronic traumatic encephalopathy (CTE) has ensued.<sup>26</sup> Chronic traumatic encephalopathy represents a “distinct tauopathy with unknown incidence in athletic populations,” especially those who participated in collision-type sports.<sup>10</sup> Tauopathies are a class of neurodegenerative diseases associated with the pathological aggregation of tau protein in neurofibrillary or gliofibrillary tangles in the human brain.<sup>27</sup> Following lengthy asymptomatic period patients with this disease typically present with mood disorders, neuropsychiatric disturbance, and cognitive impairment.<sup>28</sup> Imaging of the brain is typically normal and does not disclose any area of remote injury, infarction, or atrophy; it is only post-mortem brain tissue dissection where the diffuse tauopathy is revealed.<sup>26</sup> While no definitive cause and effect relationship has been determined involving CTE and concussions; there has been more contemporary evidence is pointing to a link between CTE and athletes who have participated in collision sports involving repetitive head impacts.<sup>29</sup> A recent report by Ling and colleagues points to the development of CTE in a cohort of retired English soccer players after years of profession play.<sup>30</sup> While the concern is real, there is still more research that is needed to better understand the effects

of repeated purposeful heading in soccer and whether or not there are any long-term negative neurological consequences as a result. Newer and more widely available sensors to monitor head impacts especially in the soccer population should enable more evidence to be exposed in the near future.

### **Subconcussive Impacts**

In the United States alone, it has been estimated that there is an excess of 300,000 sport-related brain injuries each year.<sup>31</sup> Perhaps even more intriguing are the number of subconcussive impacts that occur to the heads of sport participants that do not result in a concussion. Bailes and colleagues suggest that subconcussion is a cranial impact that does not result in known or diagnosed concussion on clinical grounds.<sup>26</sup> It can also occur with rapid acceleration or deceleration of the body or torso, when the brain is free to move within the cranium, creating a “slosh” phenomenon.<sup>32</sup> Subconcussion has its greatest effect through repetitive occurrences by which cumulative exposure becomes deleterious.<sup>26</sup> Kutcher and Giza<sup>12</sup> described the three phases of concussion management beginning with injury onset where the injury must increase above the symptom threshold to be diagnosed as a concussion (Figure 1). One could extrapolate from this figure that subconcussive impacts would therefore fall below the symptom threshold line as purported in the diagram. This is especially important to researchers examining head impacts associated with purposeful heading in soccer.

Figure 1: Three phases of concussion management<sup>12</sup>



An excellent review article by Rodrigues and colleagues examining brain structure and function suggests that there is evidence of association of heading and abnormal brain structure but the data is still preliminary.<sup>8</sup> Conversely, results from studies examining cognitive function are mixed so much so that questions persist as to whether or not heading is deleterious to cognitive functioning.<sup>8</sup>

A few studies<sup>33–36</sup> have investigated the impact of heading on brain structure in soccer athletes by using neuroimaging techniques, such as cerebral computed tomography (CCT) or magnetic resonance imaging (MRI), after either short-term exposure or long-term exposure. Structural changes found using neuroimaging include moderate central atrophy,<sup>33</sup> abnormal white matter microstructure,<sup>36</sup> and cortical thinning of the brain.<sup>34</sup> Of the four studies only the study by Jordan et al. reported no differences in brain structure between soccer players and matched controls.<sup>35</sup> Furthermore, studies examining biochemical markers of brain damage in soccer players have focused on measuring serum levels of S-100B, a calcium-binding protein that is present in the astroglial cells of the central nervous system.<sup>37,38</sup> Typically the increased concentrations

of this biomarker may reflect the presence and severity of brain tissue damage.<sup>8</sup> Both Mussack et al. and Stalnacke et al. discovered elevated S-100B serum levels after immediate exposure of heading the ball.<sup>37-39</sup> It is important to emphasize that research into serum S-100B levels has produced controversial results, meaning some research has not shown elevated levels in soccer athletes compared to controls after purposeful heading.<sup>40,41</sup>

Similarly, to studies regarding brain structure, studies focusing on brain function have also produced conflicting results. First, multiple studies<sup>42-47</sup> all found evidence of brain function impairment after either immediate, short, or long-term heading exposure. Athletes participating in these studies were both male and female athletes ranging from amateur to professional soccer players matched with either non-soccer players or non-contact sport controls. Specific areas of deficits found included areas of attention<sup>42,45,46</sup>, verbal memory and performance<sup>43,45</sup>, cognition<sup>42,44</sup> and reaction time<sup>44</sup>. Conversely, there have been a number of studies examining the above named constructs that have reported no differences between heading and brain functioning impairments. Tysvaer and Storli reported only 50% of players reported acute symptoms (e.g., disorientation), 16.4% related protracted symptoms (e.g., headache), and only 4.7% described prolonged symptoms (e.g., weakened memory) due to heading<sup>48</sup>. This data suggests a low percentage of serious head injuries associated with heading.<sup>48</sup> Both Putukian et al. and Janda et al. found no differences in pre-test and post-test scores of amateur soccer athletes measuring reaction time, concentration, attention, information processing, and problem solving.<sup>49,50</sup> Stephens et al. and Straume-Naesheim et al. found no differences

between groups in scores of neuropsychological tests in long-term exposure in males,<sup>51,52</sup> whereas Kaminski et al. and Kontos et al. found no relationship in neuropsychological test performance following in short-term exposure in male and female soccer players.<sup>53-55</sup> What remains less understood is the long-term effects of soccer heading (repetitive/subconcussive impacts) on brain structure and function. Examining soccer athletes at time points at the end of their playing career as well as points beyond that may help to better elucidate whether or not long-term brain impairments exist.

### **Head Accelerations and American Football**

Traditionally the sport of American football has lent itself to the study of sport-related concussion and subconcussive impacts. Research has focused on developing a more comprehensive understanding of the biomechanics associated with American tackle-football where protective helmets are worn to prevent skull fractures. Unfortunately, despite significant technology advances in helmet design and manufacturing, these helmets cannot prevent 100% against sport-related concussions.

The Committee on the Medical Aspects of Sports of the American Medical Association was concerned with the incidence of head injuries in American football and suggested the gathering of head impact data.<sup>56</sup> Aagaard and Du Bois constructed a suspension helmet with a triaxial accelerometer, which was able to telemeter impact data for athletes during an American football game.<sup>57</sup> This design was developed and transformed to better capture both linear and rotational accelerations. A very influential advancement in instrumented helmets was the development of the Head Impact Telemetry System (HITS) (Simbex, Lebanon, NH), by Greenwald et al.<sup>58</sup> This system

uses a computational algorithm to process information obtained from a nine-accelerometer array embedded within a helmet, also allowing clinicians to monitor head impacts in real-time.<sup>56</sup> Likewise, the GForceTracker (GFT) (GForceTracker, Richmond Hill, Ontario) allows real-time collection of head impacts but uses a triaxial accelerometer and gyroscope.<sup>56</sup> The GFT unit is mounted to the helmet rather than within like the HITS.

Zhang et al. duplicated professional football head injuries using finite computer brain models to investigate the correlation between impact site and mild traumatic brain injuries. Each injury was analyzed and it was reported that head impacts exceeding 66g, 82g, and 106g were associated with a 25%, 50%, and 80% probability of sustaining a concussion, respectively.<sup>59</sup> As research continues to be published outside of the laboratory these injury thresholds are likely to evolve.

One of the first studies in head acceleration research used in-helmet accelerometers (HITS) in collegiate football players during games and practices.<sup>60</sup> A total of 3,312 impacts were observed during 35 practices and 10 games in 38 football players. In the study, 3,311 impacts recorded an average linear acceleration of  $32g \pm 25g$  and did not result in a concussion, whereas the one concussion observed recorded a linear acceleration of  $81g$ .<sup>60</sup> The researchers arbitrarily set an 80g threshold to which they theorized that accelerations above this point resulted in concussion.

Schnebel et al. used accelerometers in the helmets of both high school and collegiate football players<sup>61</sup> and reported numerous high-speed collisions in skill positions (quarterbacks, running backs, wide receivers, cornerbacks, and safeties) with

forces ranging from 90-120g over a time of 15msec.<sup>61</sup> Reinforcing the work of Duma et al,<sup>60</sup> Schnebel and colleagues identified a threshold range of 60-90g for concussion and asserted collegiate athletes tend to have higher impact accelerations than high school athletes in similar positions. The authors were also interested in the number of subconcussive impacts of 20-30g encountered by linemen on almost every play. Equally impressive is the fact that some of the linemen would experience impacts as high as 120g in 1 out of every 120 plays.<sup>61</sup> Evidence from this report and the fact that football players in linemen roles experience numerous subconcussive head impacts during the course of practice and game situations has accelerated the need to better understand the long-term consequences of these repetitive brain impacts.

In attempt to better understand biomechanical characteristics of concussive impacts, another study looked into all football-related head impacts in 78 players in a three-year timeframe.<sup>62</sup> A total of 54,247 impacts were recorded and 13 concussions were observed. Further analysis of these 13 concussions indicated that linear acceleration averaging 96.1g, and rotational acceleration averaging 5582.3 rad/sec<sup>2</sup> along with impact location (front, top, and back) were the highest predictors of concussions.<sup>62</sup> Evidence from the Broglio et al. paper lends support to the increase in the concussion threshold as research continues to evolve.

Recent research conducted by Campolettano and colleagues has focused on specific activities associated with high-magnitude (acceleration >40g) head impacts in youth football practices.<sup>63</sup> A total of 34 players on two youth teams were equipped with helmet-mounted accelerometers, recording 6,813 impacts; 408 of them exceeding 40g.

Their results indicating that the tackling drill known as “King of the Circle” had the highest impact rate, and that tackling drills both with and without a blocker did not differ from game impact rates. Additionally, tackling drills were observed to have a greater proportion (between 40% and 50%) of impacts exceeding 60g than games (25%). It was concluded that in youth football, high-magnitude impacts occur more often in practices than games, and some practice drills are associated with higher impacts rates and accelerations than others.<sup>63</sup> Perhaps this is a strong argument for changing the way practices are conducted in youth football and making a case for less high speed tackling drills.

### **Head Accelerations and Soccer**

Head acceleration technology and research has primarily focused on head impacts in the sport of American football because of the high incidence of concussion in that sport. Because soccer is unique in that the head can be used to purposefully advance the soccer ball as to pass, shoot, and score, measurement technology to monitor and examine head impacts in the sport has gained popularity over the last five years. Interestingly, the sport involving both male and female players lags only slightly behind American football in sport-related concussion incidence in the United States.<sup>3,7</sup> This concept is reinforced by data shown below in Table 1 for high school athletes and Figure 2 for student-athletes in NCAA sports.<sup>64,65</sup>

Table 1: Concussion Rates Among High School Athletes by Sport: High School Sports-Related Injury Surveillance Study, United States, 2008-2010 School Years<sup>64</sup>

Figure 2: National Annual Estimate of Concussions for practice and competition in 14 NCAA sports<sup>65</sup>

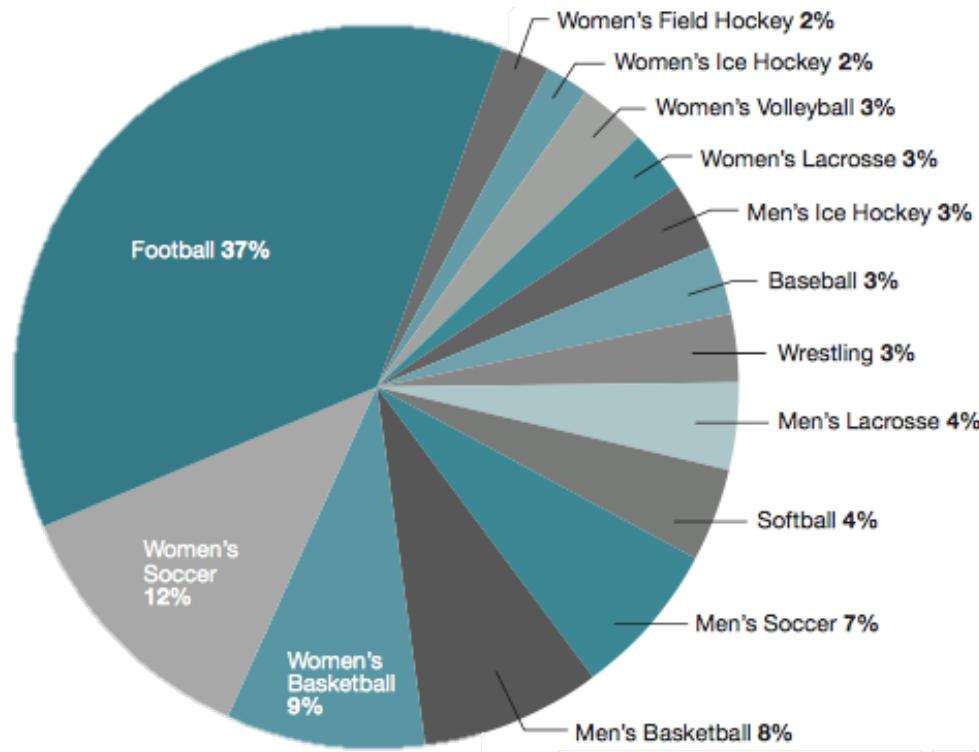


TABLE 1  
Concussion Rates Among High School Athletes by Sport: High School Sports-Related Injury Surveillance Study, United States, 2008-2010 School Years<sup>a</sup>

Sport <sup>b</sup>	Concussions			Athlete Exposures (AEs)			Rate per 10,000 AEs			Rate Ratio (95% CI) <sup>c</sup>
	Competition	Practice	Total	Competition	Practice	Total	Competition	Practice	Total	
Football	548	364	912	239,445	1,176,395	1,415,840	22.9	3.1	6.4	7.4 (6.5-8.4)
Boys' ice hockey	69	11	80	47,418	99,857	147,275	14.6	1.1	5.4	13.2 (7.0-25.0)
Boys' lacrosse	75	18	93	71,990	159,980	231,970	10.4	1.1	4.0	9.5 (5.5-15.5)
Girls' soccer	133	26	159	145,139	328,241	473,380	9.2	0.8	3.4	11.6 (7.6-17.6)
Girls' lacrosse	45	15	60	52,331	117,865	170,196	8.6	1.3	3.5	6.6 (3.8-12.1)
Girls' basketball	85	22	107	153,655	350,554	504,209	5.5	0.6	2.1	9.2 (5.5-14.1)
Boys' soccer	88	15	103	166,572	383,076	549,648	5.3	0.4	1.9	13.5 (7.8-23.3)
Boys' wrestling	63	49	112	132,203	365,981	498,184	4.8	1.3	2.2	3.6 (2.5-5.2)
Girls' field hockey	29	22	51	70,430	156,735	227,165	4.1	1.4	2.2	2.9 (1.7-5.1)
Boys' basketball	71	25	96	181,941	433,661	615,602	3.9	0.6	1.6	6.8 (4.3-10.7)
Girls' softball	36	22	58	123,815	239,850	363,665	2.9	0.9	1.6	3.2 (1.9-5.4)
Girls' gymnastics <sup>d</sup>	2	1	3	8431	35,882	44,313	2.4	0.3	0.7	8.5 (0.8-93.9)
Cheerleading <sup>e</sup>	2	21	23	16,412	145,124	161,536	1.2	1.4	1.4	1.2 (0.3-5.1)
Boys' baseball	19	4	23	167,233	312,033	479,266	1.1	0.1	0.5	11.0 (3.0-26.1)
Girls' volleyball	16	15	31	162,854	322,371	485,225	1.0	0.5	0.6	2.1 (1.04-4.3)
Girls' swim/diving <sup>d</sup>	2	2	4	45,564	187,588	233,152	0.4	0.1	0.2	4.1 (0.6-29.2)
Girls' track/field <sup>d</sup>	3	5	8	82,360	356,285	438,645	0.4	0.1	0.2	4.1 (0.6-10.9)
Boys' track/field	3	8	11	100,050	441,052	541,102	0.3	0.2	0.2	1.5 (0.4-6.2)
Boys' swim/diving <sup>d</sup>	0	2	2	37,556	162,135	199,691	—	0.1	0.1	—

As previously mentioned soccer is unique in that the head can be used to strategically move the ball during play; as such it creates a unique environment to study head impact biomechanics. During the last ten years as technology advanced for helmeted sports such as American football, ice hockey, and lacrosse similar technology has been introduced to examine impact forces to the head in soccer athletes. Researchers have used instrumented mouthpieces, which resemble mouthguards used for orofacial protection, to investigate head kinematics during soccer heading.<sup>56</sup> Paris et al. instrumented a custom acrylic mouthguard with a single dual-axis accelerometer, which was able to transmit linear acceleration data wirelessly.<sup>66</sup> This technology was further advanced via the incorporation of three accelerometers that could also measure angular acceleration.<sup>67</sup> Furthermore advances in technology have also yielded instrumented skin patches, skullcaps, and headbands to aid in the securing of the accelerometers during soccer activities. For example the X2 X-Patch (X2 Biosystems, Seattle, WA) contains a small microelectromechanical system that contains a triaxial accelerometer and gyroscope, embedded a small patch-like electrode that can be worn over the left or right mastoid process.<sup>56</sup> Additionally, there are sensor devices that have been integrated into wearable skullcaps and headbands; one such example includes the CheckLight sensor device (MC10, Lexington, MA). Rather than providing useful impact data the CheckLight sensor device emits a colored signal (green, yellow, red) through a LED light that is triggered by impact severity (mild, moderate, severe).<sup>56</sup> The sensor has rotational acceleration, multi-directional acceleration, impact location, and impact duration

sensors.<sup>68</sup> Data from the sensors is run through a proprietary algorithm to determine when to fire the LEDs. A key feature that separates CheckLight from other athletic impact sensors is that it reportedly measures impacts on the wearer's head as opposed to impact on a helmet, providing more relevant and accurate data.<sup>68</sup>

Smart Impact Monitors (SIMs) (Triax Technologies Inc., Norwalk, CT) are wireless monitors embedded with triaxial accelerometers and gyroscope that measure g-force of head impacts and report both peak linear and angular acceleration values. When an impact above a set threshold occurs, information regarding 10ms before and 52ms after the impact is recorded is transmitted to a computer on the sideline. SIMs also determine location of impact (front, front right boss, right side back right boss etc...) through a proprietary algorithm. The capacity to store up to 140 impacts if the athlete is outside the wireless range is a distinct feature separating SIMs from their competitors. These advances in technology have allowed for the study of head impacts in soccer both in controlled laboratory environments as well as some very interesting contemporary on-field studies.

### Laboratory Studies

Laboratory studies have benefits such as controlled ball speeds, allow for specific header types, and use of validated equipment to measure head accelerations.<sup>3</sup> However, the sterility of laboratory environments make them difficult to simulate the forces that soccer balls can impart on the head during live action. The discrepancies are especially evident with regard to direction of the ball, spin, and location of impact.<sup>69</sup>

One laboratory study measured head acceleration values with ball velocities of 9 and  $12\text{m}\cdot\text{s}^{-1}$  for linear and angular accelerations.<sup>69</sup> The ball velocity of  $9\text{m}\cdot\text{s}^{-1}$  resulted in an average linear acceleration of  $158 \pm 19 \text{ m}\cdot\text{s}^{-2}$  and an average angular acceleration of  $1302 \pm 324\text{rad}\cdot\text{sec}^2$ . When the ball velocity was increased to  $12\text{m}\cdot\text{s}^{-1}$  both linear ( $199 \pm 27\text{m}\cdot\text{s}^{-2}$ ) and angular velocity ( $1457 \pm 297\text{rad}\cdot\text{s}^{-2}$ ) increased as well. Despite the fact that acceleration values were well below thresholds considered to cause mild traumatic brain injury, research still needs to be done to determine the cumulative effects of the impacts.<sup>69</sup>

Caccese and colleagues measured peak linear and rotation head accelerations in collegiate women's soccer and investigated variations in accelerations across different playing scenarios, such as bounce, secondary header, punt, throw-in, goal kick, corner kick, and kick.<sup>70</sup> Both goal kick and punt resulted in higher linear and rotational head accelerations than the base variable of kick. Data suggested that limiting headers from goal kicks and punts may limit cumulative linear and rotational accelerations.<sup>70</sup>

Gutierrez et al. explored how to attenuate head impacts by examining neck strength, impact, and neurocognitive function after an acute bout of purposeful heading in female high school soccer players.<sup>6</sup> The athletes completed ImPACT neurocognitive testing and had their isometric neck strength tested prior to heading drills. Each participant performed 15 directional headers (5 forward, 5 left, and 5 right) in a random order, and then retook the ImPACT test. Though neurocognitive testing revealed no significant changes following the bouts of heading, there was a moderate correlation between neck strength and resultant header acceleration. Participants with weaker neck

strength sustained greater impacts; thus arguing the need for neck strengthening as an important component in head injury prevention.<sup>6</sup> Gutierrez's findings confirmed a study conducted by Bauer et al. examining different types of purposeful headers and heading approaches to quantify impact forces and neck muscle activity.<sup>71</sup> Although the study reported impact forces and impulses did not differ among header types or approaches, higher EMG recordings were found for jumping compared to standing headers. Increased muscle activity that was observed in the neck during the jumping approach appeared to stabilize the connection between the head and body, thereby increasing the stability of the head-neck complex.<sup>71</sup>

### On Field Studies

The unpredictable on-field environment in soccer is difficult to reproduce in a laboratory setting, thus advances in sensor technology have enabled researchers to study real-time impacts on the field over the last five years. Hanlon and Bir creatively affixed the HITS technology previously used in football helmets to a headband that could be worn during soccer play.<sup>72</sup> Their population of 24 female youth soccer players participated in six scrimmage matches lasting between 30 and 65 minutes. A total of 47 header impacts and 20 non-header impacts were observed during the study. The peak linear acceleration ranged from 4.5 to 62.9g with an average of 11.9g. The single maximum number of headers per scrimmage was four reported in two players. A singular peak angular head acceleration was reported at 8869 rad·sec<sup>-2</sup>, however the average was 723.2 rad·sec<sup>-2</sup>.<sup>72</sup> Interestingly, the non-header impacts created the largest both linear and angular acceleration, and were related primarily to falls or player collisions.

Using the X2 Patch, McCuen et al. in 2015, reported soccer head acceleration measurements comparing high school and collegiate female players.<sup>73</sup> While linear and rotational acceleration values were similar per impact (30-31.9g, 6301-6792rad·s<sup>2</sup>) in both groups the collegiate players (3.52 px, 6.98 gm) experienced more headers in both practices and games than their high school (1.69 px, 2.85 gm) counterparts leading them to conclude that the collegians would experience greater cumulative impacts. However, their findings still leave doubt as to whether or not increased cumulative exposure increases risk for long-term neurological deficits.

A more recent publication by Press and Rowson examining head impact exposures in collegiate women's soccer players utilized the X2 Patch technology.<sup>74</sup> A total of 26 players participating in 26 practices and 20 games were monitored for head impacts. Interestingly, only 19% of the 8,999 head impacts recorded were positively identified as head impacts; of which 90% of those were from heading the ball. Linear acceleration for all impacts ranged from 6g to 113g with an average of  $25g \pm 16g$ , compared to rotational acceleration ranged from  $380 \pm 26,222$  rad·sec<sup>-2</sup>. Perhaps the most important conclusion from the Press and Rowson paper is that there is a tremendous amount of error associated with real-time head impact sensor data and caution when interpreting such data is warranted.

In a similar study of women's collegiate soccer players, Lynall et al. reported head impact biomechanical measures on a sampling of 22 female collegiate soccer players.<sup>3</sup> Data from X2Patch (X2 Biosystems, Seattle, WA) sensors were recorded across 18 matches and 39 practices. They reported head impact frequency rates of 74.17 impacts

per game and 40.10 impacts per practice. The 90th percentile head impact during games was 18.59g of linear acceleration and  $4015.85 \text{ rad}\cdot\text{sec}^{-2}$  of rotational acceleration during games. The 90th percentile head impact during practices was 21.84g of linear acceleration and  $4844.23 \text{ rad}\cdot\text{sec}^{-2}$  of rotational acceleration during practice. No impacts leading to clinical concussion diagnoses were captured during this observation period.<sup>3</sup>

Lamond and colleagues examined linear acceleration of the head during collegiate women's soccer matches over one season.<sup>75</sup> Using the Triax SIM-G sensor headband, linear acceleration was recorded above a 20g threshold. Across all impacts the average head acceleration 39.72g. They reported that differences in head acceleration existed across different impact types. Unintentional deflections (55.39g $\pm$ 26.46) and clears (44.59g $\pm$ 17.23) resulted in the highest average acceleration, followed by head-to-ground (43.69g $\pm$ 23.33), shot (39.90g $\pm$ 24.62), and pass (33.19g $\pm$ 10.39). While this series of season long studies of soccer head impacts are important the question remains is there a concern over the cumulative nature of these subconcussive impacts over a playing career.

## Conclusion

Heading the ball is an integral part of the game of soccer and can subject an athlete to an average of 6-12 head impacts per competitive game, where the ball can reach high velocities.<sup>8</sup> With the intentional use of the head, athletes may be increasing their risk for concussion or subconcussive impacts due to frequency of heading the ball.<sup>71</sup> Of concern are the number of head impacts soccer athletes may receive throughout their career and whether or not they are detrimental to their long-term health and cognitive well-being. Therefore, a greater understanding of the effects of repetitive head impacts

(magnitude, frequency, summation, etc...) both in the short and long-term in this athletic population is critical.

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## Appendix B

### IRB CONSENT FORM

1 of 3



#### **University of Delaware Informed Consent Form**

**Title of Project:** "Examination of Purposeful Heading and Neuropsychological Test Performance in Intercollegiate Soccer Players"

**Principal Investigator:** Thomas W. Kaminski, PhD, ATC, Professor, University of Delaware

You are being asked to participate in a research study. This form tells you about the study including its purpose, what you will do if you decide to participate, and any risks and benefits of being in the study. Please read the information below and ask the research team questions about anything you do not understand before you decide whether to participate. Your participation is voluntary and you can refuse to participate or withdraw at anytime without penalty or loss of benefits to which you are otherwise entitled. If you decide to participate, you will be asked to sign this form and a copy will be given to you to keep for your reference.

#### **WHAT IS THE PURPOSE OF THIS STUDY?**

This study is examining the usefulness of neuropsychological testing in the evaluation and management of concussion in a student-athlete population. Because you are a student-athlete and "at risk" for concussion during participation in soccer, you are being asked to participate in this research study.

#### **WHAT WILL YOU BE ASKED TO DO?**

- 1.) As part of the UD medical examination process, you are required to complete the ImPACT neuropsychological test program. The ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing) computerized test program consists of three parts and includes: (1) sports and health history, (2) current symptoms and conditions, and (3) neurocognitive testing [8 modules]. The neurocognitive test domains measured include memory, processing speed, motor functioning, executive functioning, and attention. The entire test is normally completed in 25 minutes. Data derived from the ImPACT test will be used in this study.
- 2.) If you experience a blow to the head or body during the course of the soccer season that results in confusion, disorientation, memory disturbance, or loss of consciousness, **we ask that you report the incident immediately to your coach, athletic trainer, and/or physician**. If upon examination by UD's team physician you are diagnosed with a concussion you will be involved with follow-up care provided by UD's Sports Medicine staff. Notice of this concussion event will be provided to the Principal Investigator listed above. ALL return-to-play decisions rest solely with UD's team physicians.
- 3.) If you **do not** suffer from a concussion during the season you will be asked to participate in another ImPACT test session at the end of the season.
- 4.) Throughout the season at both practices and matches a designated member of the athletic training staff will be tracking any purposeful headers that you perform as part of playing soccer. The heading data will eventually be compared with your ImPACT data.

**Time required:**

Subject Initials:  
Date:  
UDIRB 11/14

Two test sessions requiring 30 minutes each. Athletes suffering in-season concussions will require more than two test sessions that will be scheduled on an individual basis.

**WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?**

There are no known physical risks in completing the computerized tests. The tests do require active attention, concentration, and mental effort and may result in mental frustration, particularly when completed during a post-concussion state. If severe mental frustration is apparent, testing will be discontinued.

**WHAT ARE THE POTENTIAL BENEFITS?**

There are no direct benefits to you for participating.

**HOW WILL CONFIDENTIALITY BE MAINTAINED?**

Data will be kept confidential. Your information will be assigned a code number. The list connecting your name to this number will be kept in a locked file. When the study is completed and the data have been analyzed, the list will be destroyed. Data will be kept securely in electronic storage formats and saved indefinitely. Your name will not be used in any report. We will make every effort to keep all research records that identify you confidential to the extent permitted by law. In the event of any publication or presentation resulting from the research, no personally identifiable information will be shared. Your research records may be viewed by the University of Delaware Institutional Review Board, but the confidentiality of your records will be protected to the extent permitted by law.

**WILL THERE BE ANY COSTS RELATED TO THE RESEARCH?**

There are NO costs associated with your participation.

**WILL THERE BE ANY COMPENSATION FOR PARTICIPATION?**

You will receive no payment for participating in the study.

**WHAT IF YOU ARE INJURED BECAUSE OF THE STUDY?**

If you are injured during research procedures, you will be offered first aid at no cost to you. If you need additional medical treatment, the cost of this treatment will be your responsibility or that of your third-party payer (for example, your health insurance). By signing this document, you are not waiving any rights that you may have if injury was the result of negligence of the university or its investigators.

**DO YOU HAVE TO TAKE PART IN THIS STUDY?**

Taking part in this research study is entirely voluntary. You do not have to participate in this research. If you choose to take part, you have the right to stop at any time. If you decide not to participate or if you decide to stop taking part in the research at a later date, there will be no penalty or loss of benefits to which you are otherwise entitled. Your refusal will not influence current or future relationships with the University of Delaware. As a student, if you decide not to take part in this research, your choice will have no effect on your academic status or your grade in the class.

**WHO SHOULD YOU CALL IF YOU HAVE QUESTIONS OR CONCERNS?**

If you have any questions about this study, please contact the Principal Investigator, **Dr. Thomas W. Kaminski** at 302-831-6402 or [Kaminski@udel.edu](mailto:Kaminski@udel.edu)

If you have any questions or concerns about your rights as a research participant, you may contact the University of Delaware Institutional Review Board at 302-831-2137.

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Subject Initials:  
Date:  
UDIRB 11/14

Your signature below indicates that you are agreeing to take part in this research study. You have been informed about the study's purpose, procedures, possible risks and benefits. You have been given the opportunity to ask questions about the research and those questions have been answered. You will be given a copy of this consent form to keep.

By signing this consent form, you indicate that you voluntarily agree to participate in this study.

**Signature of Participant**

**Date**

**Printed Name of Participant**

**Principal Investigator**

**Date**

Subject Initials:  
Date:  
UDIRB 11/14

# **Appendix C**

## **HEAD IMPACT TALLY SHEET**

*University of Delaware Fall 2017 WSOC Collegiate Header Study --- Header Tally Sheet*

Date: \_\_\_\_\_ Time: \_\_\_\_\_ Game / Practice (circle one)

**Opponent's Name:**

*Please denote using an asterisk (\*) an athlete who sustains a concussion during the game that these headers were being recorded!*

*Please put a "DNP" next to any student-athlete who Does Not Play in the match!*