

HEAD IMPACT BIOMECHANICS IN COLLEGIATE FEMALE SOCCER PLAYERS

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ABSTRACT

Jaclyn Carrie Stucker: Head Impact Biomechanics in Collegiate Female Soccer Players
(Under the direction of Jason P. Mihalik)

Understanding head impact biomechanics incurred during soccer participation may allow clinicians to better implement interventions designed to reduce injury incidence. The objective of this thesis was to evaluate head impact biomechanics during college soccer. We studied a cohort of Division I female soccer players, all of whom participated over the course of the season while wearing head impact measurement devices. We video recorded eighteen games over the season and characterized body position and anticipation of head collisions. The specific findings of more severe head impacts occurring in practices suggests that coaches should consider limiting the amount of time and the number of days spent on heading drills. While there is no evidence to indicate that such heading practices lead to concussion, prior research has pointed to the possibility that subconcussive impacts may be associated with declining neurocognitive function later in life.

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CHAPTER I

INTRODUCTION

Traumatic brain injury (TBI) is a public health concern. Up to 3.8 million sport and recreation related TBIs occur each year.¹ Of these, approximately 90% are classified as concussions.²⁻⁴ Concussions result from induced biomechanical forces causing complex pathophysiological processes affecting the brain.⁵ Concussions typically result in immediate symptoms including behavioral changes, cognitive impairments, and sleep disturbances. While data collected from college football players suggest the majority of college concussions will resolve within 7-10 days,⁶ about 10% of concussions will result in prolonged symptoms.⁶ The long-term neuropathological effects of recurrent concussion, although not well known, may include depression, early-onset Alzheimer's disease, and chronic traumatic encephalopathy.⁶⁻¹²

Soccer is not considered a collision sport in the same way as football or ice hockey. Notwithstanding, it is a sport that carries a high concussion risk with some reports indicating concussion rates in soccer exceed those observed in football and ice hockey.¹³⁻¹⁷ During collegiate play, 11.4% of women and men will be diagnosed with a concussion.¹⁸ Understanding the mechanics associated with such injuries may allow clinical researchers to inform rule or policy changes to mitigate injury risk in this at-risk population.

While there is a growing body of research examining head impact biomechanics in football and ice hockey,¹³⁻¹⁷ there is a dearth of field-based soccer-related research in this arena. Studies have mostly examined soccer head impact biomechanics in controlled laboratory settings,^{13,14,18-20} and have focused on direct contact heading events.^{13,19,20} Only a few studies

have examined indirect contact,²¹⁻²³ which is where most of the injuries occur.²⁴ Further study of soccer head impact biomechanics, particularly as it relates to field-testing and examining both direct and indirect contact, is a necessary step to determine the forces that may contribute to injury. We believe that determining the biomechanics of soccer heading will ultimately aid in the prevention of head injuries. In order to prevent concussions, contributing risk factors need to first be identified and studied. The purpose of our study was to 1) to determine event-type differences (game vs. practice) in head impact biomechanics, and 2) to explore how heading opposition affects head impact severity in female Division I college soccer players.

Clinical Significance

This study to our knowledge is the first to describe the frequency and magnitude of the linear and rotational head acceleration sustained by female college soccer players during participation. Through a continued line of research, our results may help prevent concussions throughout the game, up to and including the final play. More importantly, this study helps create a better understanding of the nature of the game and help identify some of the injury risk factors for players.

Specific Aims & Hypotheses

Specific Aim 1. To test the hypothesis that female Division I college soccer players will demonstrate more severe head impact biomechanics (linear and rotational acceleration) in games compared to practices.

Hypothesis 1a: Linear and rotational accelerations will be greater in games than in practices.

Hypothesis 1b: Head impact severity (mild, moderate, severe) will be associated with event type (game, practice), such that a greater relative frequency of severe head impacts will occur in games compared to practices.

Specific Aim 2. To explore how heading opposition (opposed, unopposed) affects head impact severity (linear and rotational acceleration) in female Division I college soccer players.

Hypothesis 2a: Linear and rotational accelerations will be greater during opposed plays compared to unopposed plays during games.

Hypothesis 2b: Head impact severity (mild, moderate, severe) will be associated with opposition status (opposed, unopposed) such that a greater relative frequency of severe head impacts will occur in opposed head impacts compared to unopposed head impacts.

CHAPTER II

LITERATURE REVIEW

Introduction

In the United States alone, 3.8 million sport and recreation related TBIs occur each year.¹ This may not reflect the true rate of injury, as many concussions may go unreported.²⁵ As incidence of this injury has grown, so too has media exposure highlighting the early retirement and tragic deaths of high-profile professional athletes, which is often attributed to the long-term effects of this injury. This has led to a growing concern of how to best protect athletes and decrease the risk of head injury. Fortunately, more information has been gathered about concussion as researchers have started to look deeper into the biomechanics of the high-risk sports and the injury itself. Participation in football is often identified as having a high risk of concussion, but other sports similarly carry a high risk, including soccer.

In soccer, the greatest concern for concussion appears to be in the mechanism of heading.^{21,26,27} Soccer is unique in that it is a sport in which athletes intentionally head the ball without any equipment protecting their head. The player must properly stabilize the head using the neck musculature in order to correctly head the ball. The neck musculature acts as dynamic joint stabilizers for the head. Dynamic joint stabilization is “the ability of the myotendon unit to absorb external loads and minimize excessive joint movement.”²⁸ If the neck musculature is unable to stabilize the head and absorb the external forces during heading, greater acceleration/deceleration forces of the head will likely occur, theoretically increasing the risk for concussion. Various factors may affect one’s ability to stabilize the neck musculature including

whether or not the impact force is anticipated and if the play is opposed. Anticipation of an impending impact allows the athlete to properly stabilize their head. Opposition may distract the player from having the ability to properly stabilize and prepare to head the ball. The purpose of this review is to identify the incidence of concussions in soccer, and the role that linear and rotational accelerations play in head injury risk. Furthermore, this review will discuss the available literature pertaining to acceleration forces in soccer.

Traumatic Brain Injuries and Concussions

According to the 2012 Zurich Consensus Statement on Concussion in Sports, a concussion is defined as “a complex pathophysiological process affecting the brain induced by biomechanical forces.”⁵ It is caused by an impulsive force applied either directly to the head or elsewhere on the body. This leads to a head injury as a result of rapid acceleration/deceleration of the brain. The impulse can result from linear or rotational forces, with rotational forces likely contributing most to concussion incidence.^{29,30} One of the challenges of concussion diagnosis is that there is no identifiable structural neural injury when examined by conventional neuroimaging, such as computed tomography or low-field magnetic resonance imaging.⁷

Clinical Presentation of Concussions

Concussions result in a variety of outward signs, clinical symptoms, postural control deficits and neurocognitive deficits. Some key symptoms include headache,^{5,7,31} dizziness,^{7,31} nausea,³¹ vomiting,³¹ feeling ‘in a fog’,^{5,7} feeling ‘slowed down’,^{5,31} trouble falling asleep,^{7,31} and sleeping more than usual.⁵ Furthermore, a concussed individual may experience: fatigue, drowsiness, photosensitivity, feeling dazed or stunned, seeing stars or flashing lights, ringing in the ears, double vision, cognitive impairments, and postural stability effects such as unsteadiness or loss of balance.^{5,7,31} Balance is an integration of the visual, vestibular and somatosensory

system. Individuals who are concussed often present with altered balance because one of the systems is altered. When one system is altered, such as during concussion, the other systems have to adapt to maintain static posture.³²⁻³⁵ If the body is unable to adapt, stability and control are altered and the patient will present with poor postural stability and balance. Neurocognitive symptoms typically take the longest to recover, but most college athletes will recover in 7-10 days.³⁶

Long-term effects of concussion

Although immediate signs and symptoms of concussion usually resolve in 7-10 days, researchers have found that the long-term effects of concussion can last much beyond that time frame. In fact, studies have shown that athletes with a history of concussion are at an increased risk of developing another concussion in the future.⁶ Furthermore, high school athletes with three or more concussions are more likely to suffer anterograde amnesia, confusion, and loss of consciousness following a subsequent head injury,³⁷ indicating that the second injury is more likely to be more serious than the first.

The evaluation of athletes with concussion has conventionally focused on recognizing signs and symptoms associated with the concussive event. However, head impacts that commonly occur during contact/collision sports can result in both subconcussions and concussions. A subconcussion is a “cranial impact that does not result in known or diagnosed concussion on clinical grounds.”³⁸ Subconcussions are dangerous and become detrimental with repetitive occurrences and cumulative exposures.³⁸ The effects of concussion have also proven to be even more detrimental and long-lasting than initially thought, with recent literature suggesting that concussion may lead to increased risk of depression, and chronic traumatic encephalopathy.⁸⁻¹² Chronic traumatic encephalopathy is thought to be caused, in part by,

repetitive brain trauma.¹¹ The trauma may include concussions or subconcussive injuries.^{11,39-41} However, the signs and symptoms often do not begin until years or decades after the repeated brain trauma, when neurodegeneration is severe enough to present with clinical symptoms.⁴¹ The early symptoms include learning and memory impairment, mood changes, behavioral changes, aggression and even increased violence.⁴² As the disease progresses, the symptoms worsen and ultimately result in dementia in the advanced stages of CTE.⁴²

Anatomy and Biomechanics

While more attention continues to be placed on the long-term effects of concussions, there is also active investigation into the pathophysiology and biomechanics of concussion. Sport-related concussions are the result of an external force, causing an impact on the skull, and resulting from contact with another player, the playing surface, or a piece of equipment.⁴³ The impacts cause acceleration or deceleration forces that may lead to damage of central nervous system structures.⁴³ The extent of the resulting injury is dependent upon the distribution of forces, anatomical features of the area of impact, and vector of impact.⁴³ Greater damage is likely caused when multiple vectors of acceleration and deceleration act upon the brain.⁴³

Concussions in Soccer

As its popularity continues to grow both in the United States and across the world, the risk for concussion becomes more evident in soccer. According to FIFA, 265 million male and female players participate in soccer worldwide.⁴⁴ Of those, 12.5-18.2 million play the sport in the United States. In soccer, concussion rates range from 0.3 to 0.6 per 1000 athletic exposures.^{26,45} During collegiate play, 11.4% of women and 7% of men are diagnosed with concussions throughout their college careers.¹⁸ Unfortunately, the actual number of concussions may be

higher, as many go unreported. Only 20% of soccer players who sustain a concussion recognize and/or report the symptoms.⁴⁶

Causes of Concussion

The characteristics of soccer are very different compared to other sports because players intentionally try to head the ball to move it up or down the field. Heading involves contacting the ball high on the forehead.⁴⁷ The heading impact is most commonly to the temporal region of the skull,⁴⁸ whereas in football, the top of the head is more common.⁴⁹ Forces of up to 54.7 g of head acceleration have been found to occur in soccer compared to 29.2 g and 35 g in football and ice hockey respectively.¹³ However, the subjects in this particular study were wearing football helmets when hitting the soccer ball. The concussive forces in soccer occur in the form of direct or indirect contact forces. Direct contact refers to contact with another player, ground, goalpost or ball while heading. An example of indirect contact is body-to-body contact with another player while heading the ball.² Most concussions in soccer are attributed to some type of collision while heading the ball.⁵⁰ They are usually the result of inadvertent contact with a goalpost, the ground, or another player.^{26,51} Around 28% of concussions suffered by collegiate players were the result of impact from another athlete's head, followed closely by 24% produced by impact of the soccer ball, and 14% resulting from contact with the ground.²⁶ Purposeful heading is not identified as a mechanism of injury; however, injury can occur when the ball unintentionally strikes a player.²⁶

While conflicting in nature, there are some studies that show positioning on the field can influence the player's susceptibility of concussion.^{26,50,52} Forwards and midfielders sustained approximately 66-76% of all concussions in high school men's soccer,²⁶ while goalkeepers accounted for 11.9%.⁵⁰ In female high school soccer players, midfielders and forwards sustained

70.3% of concussions and goalkeepers sustained 18.8% of concussions.⁵⁰ Conversely, the examination of videotapes and physician reports revealed that 40% of concussions were suffered by defenders, 23% by forwards, 22% by midfielders, and 15% by goalkeepers.⁵² A survey across sexes revealed that forwards sustained the least number of concussions, with goalkeepers being just ahead of them.⁵³ Internationally, female defenders represented 34% of concussions, followed closely by midfielders and forwards.⁵² In a different study, goalkeepers have been identified as the most likely to suffer a concussive injury.⁵⁴ Many studies have examined the concussion rates across various positions in soccer with mixed results. Based on the contradictions and inconsistencies between the various studies, there is no conclusive evidence that one position is at a greater risk.

Timing of Injury in Soccer

Finally, there is evidence to suggest that game situations versus practice situations may play a role in concussion occurrences. Heading in practices occurs in a controlled setting, with drills being planned and players being prepared to head the ball, while in a game situation the focus of the player is not usually on preparing themselves to head a ball. In a study comparing concussion incidence among ACC men's and women's soccer teams, 69% of all concussions occurred during games, with the rest occurring during practice.²⁶ In males, concussions account for 1.7% of all practice injuries and 7% of all game injuries.¹⁸ For female players, the incidence of concussion is 16.7 times greater during contests as compared to games.¹⁸ Concussion rates for male high school soccer players are 16.2 times greater in games than practices, and 14.4 times greater for females in games vs. practices.⁵⁰ Therefore, it can be concluded that concussions tend to occur later in a game and are more likely to occur in games versus practices.

Results of Acute and Chronic Heading

There is evidence suggesting that acute and chronic bouts of heading may play a role in long-term neurocognitive effects. A survey of American soccer players revealed that the average number of headers in a game for males is 7.3 and for females is 8.4.⁵³ Practice resulted in higher averages of headers with males reporting 9.5 headers per practice and females reporting 8.6.⁵³ The level of play likely influences the average number of headers each player completes per game. For example, Dutch professional soccer players reported an average of sixteen headers during a match and eight hundred during a season of competition.⁵⁵ Active professional soccer players who underwent neuropsychological exams possessed poorer function on visual and verbal memory, visuoperceptual tasks, and planning when compared to a control group consisting of elite noncontact athletes.⁵⁵ This suggests that there may be a link between heading and neurocognitive deficits. However, it should be noted that this particular study was limited by inherent differences between the soccer players and control group that may have existed before the project.⁵⁵

Head Impacts

When there is an impact to the head causing a rapid change in velocity of the head over time, acceleration or deceleration of the brain occurs within the skull.⁴³ Not all acceleration or deceleration forces occur in the sagittal plane because of the mobility of the cervical spine. The vector of acceleration of the head can be changed during an impact, causing rotational forces to the brain, resulting in various neuronal injuries.⁴³ Heading of the soccer ball involves a combination of linear and angular acceleration. Brain injuries may be classified as coup or contrecoup. A coup injury is caused by a linear force⁵⁶ and occurs on the same side as the blow

to the head.^{31,43} A contrecoup injury is when the brain shifts to the opposite side of impact, causing the brain to hit the skull, and injury to occur on the opposite side.^{31,43}

Linear and Rotational Acceleration

A complete understanding of the biomechanics of head injuries is critical in the development of prevention strategies. Research investigating brain injury biomechanics has often focused on two main injury mechanisms: direct and indirect impacts. A direct impact includes an injurious blow making direct contact with the head. An indirect impact occurs when an impact results in a head motion with directly hitting it. Direct and indirect impacts are caused by a combination of two forces: acceleration-deceleration forces (linear) and rotational (angular).⁵⁷ Brain injuries that are linear acceleration based are thought to result from a transient intracranial pressure gradient, while those that are rotational acceleration based are thought to result from a strain response.⁵⁸ Both forces can be present in the mechanism leading to brain injury, but it is believed that usually only one force is the main cause.⁵⁷

In order to better understand the causes and factors related to concussion, researchers have developed methods of biomechanical analysis. In recent literature, accelerometers are most commonly used and can be inserted into helmets or directly on the subject's body to collect data on head impact acceleration, magnitude, frequency, and location. Methods involve linear and angular accelerometry paired with video footage collected during sporting events, and laboratory replication of observed impacts to predict the body's biomechanical response.⁵⁹

Accelerometer Based Research Studies

In recent years, head acceleration studies have been conducted in the context of many sports, including football and ice hockey.¹³⁻¹⁷ Few studies have focused on head acceleration in soccer and the possible impacts it could have on head trauma. The majority of studies examining

acceleration in soccer have been conducted in the laboratory setting making it difficult to translate the results to a game situation.^{13,14,19,20} Most voluntary opportunities for heading in soccer occur at ball velocities of less than 65 km per hour.⁶⁰

Females seem to be more susceptible to greater forces in soccer than males, likely due to anatomical differences. In a group of 40 physically active males and females, females had a greater head-neck segment, greater peak angular acceleration and greater displacement than their male counterparts.⁶¹ These differences in acceleration and displacement may be attributed to differences in head-neck segment mass and dynamic stabilization: females exhibited 29% less stiffness and 50% less isometric strength.⁶¹ Using Newton's law of acceleration ($F=ma$), less head mass correlates with greater head acceleration and therefore a greater risk of concussion.^{43,61} If the force stays constant and the individual is creating the force, such as in heading, then someone with less head mass wouldn't be able to produce as great a force. In a similar study, women exhibited 15% less head-neck segment mass, 5% less head-segment length, and 12% less neck girth compared to males. Women also exhibited less isometric neck flexor strength and 53% less isometric extensor strength comparatively.⁶²

Linear accelerations of approximately 15-20 g and angular accelerations of 1000-2000 $\text{rad} \times \text{s}^2$ during heading of a soccer ball traveling 9-12 m x s have also been identified.¹⁹ For a ball speed of 9 m x s, the average heading maneuver resulted in head injury criterion (HIC) of 10s and Gadd Severity Index (GSI) of 12 s. The Gadd Severity Index correlates the severity of head injury with the time and deceleration upon impact.⁶³ A GSI of 1200 has been accepted as the maximum value that a sports helmet can sustain to be deemed acceptable for play.⁶³ The Head Injury Criterion is a measure of the likelihood of a head injury arising from an impact. For a ball speed of 12 m x s the average maneuver resulted in HIC of 18 s and GSI of 21 s.¹⁹ Head

accelerations yielding HIC and GSI scores of approximately 1000 s are considered capable of causing death.⁶⁴ One important discrepancy to note in this study was that triaxial accelerometers were placed in headpieces to allow for attachment to the head. The acceleration measures reported are based on the assumption that the headpiece is rigid and firmly attached to the skull, which is not true.¹⁹

Various methodologies have been used to measure the magnitude of head acceleration in soccer. One method attached markers to subjects via Velcro tape and used a 14-camera Vicon Motion Capture System to examine differences in head acceleration and neck strength between sexes.⁶⁵ Translation acceleration, angular acceleration and neck strength were measured during low velocity heading often seen as practice, with soccer balls being served to subjects from 3 meters away.⁶⁵ For all subjects, the mean translational acceleration was $101.73 \pm 51.68 \text{ m/s}^2$ and mean angular acceleration was $877.93 \pm 472.13 \text{ rad/s}^2$.⁶⁵ These measurements of acceleration were consistent with previous investigations.^{19-21,27} Another method involves placing head accelerometers directly on the body by utilizing a headband with a built-in HIT system. This allowed for recording of accelerations but did not provide a protective padding mechanism to the head.²⁷ All accelerometers were placed in the back of the headband to avoid ball contact. The headband had a threshold of 10 g. Any impact at or above this level was recorded/downloaded 8 ms before impact and 32 ms after impact.²⁷ This study demonstrated that the HIT system for soccer correlates well with the standard measurement system of Hybrid 3-2-2-2 accelerometer system for football, which uses a dummy fitted with a football helmet and accelerometers to measure acceleration, based on impacts and location of impacts that take place in soccer.²⁷

Importance of Neck Muscles in Injury Reduction

It has been hypothesized that head acceleration is minimized after ball contact if the neck muscles are properly contracted.⁶⁶ An athlete who anticipates an oncoming collision or force to the head will be better able to control movement by contracting the cervical musculature. When an impact is not anticipated, the cervical musculature is not tensed and prepared for collision and effective mass is reduced. The head will therefore experience a greater acceleration and be more likely to sustain an injury. Players must therefore prepare for impact by bracing the neck musculature and moving the body in one motion.⁶⁷ This requires rigid neck musculature in order to stabilize the head during movement. Such a mechanism creates protection for the head, which helps to decrease accessory motion of the skull.⁶⁷

To properly stabilize the head and neck, there are two primary dynamic stabilizers: the sternocleidomastoid (SCM) and the trapezius.⁶⁸ Theoretically, the timing and amount of activation of these muscles before or in response to an external force should reduce resultant head acceleration.^{66,69,70} Therefore, poor muscle strength could put individuals at greater risk for concussion because of an inability to counter external forces that result in greater head acceleration. Following this theory, some studies have suggested that females are at a greater risk for head injury than males.^{61,62,71} Furthermore, it has been found that kinematics, electromyography, stiffness values, and activation strategies do not differ significantly concerning sex.⁷¹ However, males have been shown to possess greater isometric strength, neck girth, and head-neck segment mass and length,⁷¹ further supporting that women are at a greater risk for head injury based on stabilization abilities.

Neck activation also plays a role in magnitude of head acceleration. In a study with a focus on neck activation and head acceleration, subjects attempted to head balls to a target with a

predetermined level of neck activation: normal, pretensed or relaxed. Results from this study demonstrated differences in both linear and angular accelerations based on the level of neck activation.²⁰ While this study did not measure real-time game impacts, it showed the importance of neck musculature in head control and theoretically injury reduction.

Head Acceleration Differences Between Males and Females

Another characteristic that has been shown to affect head acceleration is gender. Epidemiological data of athlete exposures during the 1990s displayed that females had a higher incidence of concussions compared to males at the high school and college level in a variety of sports including soccer, baseball, softball and basketball.^{18,50} While the exact reason behind this difference is unknown, researchers have hypothesized that it may be due to differences in head-neck segment mass and dynamic stabilization between genders. Some studies have revealed that women have less head mass than their male counterparts.^{61,72} Less head mass associates with greater head acceleration, thus a higher risk for head injury when an external load is applied. In fact, one study examining soccer reported an increased risk of head injury during heading for individuals with a lower head mass to soccer ball mass ratio, which for this particular study was women and children. Furthermore the dynamic stabilizers of the neck, the SCM and Trapezius I, work to stabilize the head and reduce head acceleration when an external load is applied. Poor muscle strength could predispose individuals to head injuries if they are unable to use the dynamic stabilizers to counter the external force being applied. In one particular study comparing physically active males and females, females demonstrated significantly greater head-neck segment peak angular acceleration and displacement than males during an external force application.⁶¹ These findings were consistent with other similar studies that found females to have less head and neck mass, strength, and ability to use the dynamic stabilizers.^{70,71,73,74}

Anticipated vs. Unanticipated Heading

Another consideration in regards to head acceleration and neck activation pertaining to soccer is the body positioning of the player when heading the ball. The act of heading, when broken down, reveals that the SCM is largely involved in head acceleration prior to initial ball contact, with the trapezius also firing prior to initial contact.⁶⁶ The trapezius is then responsible for deceleration of the head after heading.⁶⁶ There is greater integrated and peak normalized electromyography in the SCM and trapezius bilaterally during jump headers, compared to standing headers.⁶⁶ While many former studies reported that impact from heading the ball can cause injury,^{50,51} it has now been believed that concussions are not caused from ball impact if there is proper execution of heading.⁵³

In an investigation of forty-eight concussions via video analysis, researchers found that only one was the result of ball impact.⁵² In that instance, the athlete was struck in the head by a ball being cleared by a defender, demonstrating an unanticipated header. This study shows that concussions do not typically result from direct contact, but are more likely when players make contact with the ball when they are unprepared.⁵⁶ Furthermore, skilled soccer players can kick a ball at a speed of 100 km/hr and greater.⁵⁶ Athletes will rarely voluntarily head a ball at this velocity, but contact may be incidental.⁷⁵ Kirkendall et al stated that “the highest-velocity ball a player might voluntarily head would be from a punt (approximately 70 km/h), drop kick (approximately 85 km/h), or goal kick (also approximately 85 km/h)”.⁷⁵ In soccer, ball contact usually results from rotational contact of the ball to the head. If a player is struck in the head and did not anticipate or prepare for the blow, linear and transverse rotation can couple to cause a whiplash injury and possible concussion.⁷⁵

Rationale for Study

Although previous research has been conducted investigating head acceleration during soccer, little research has been done in a real-time setting. Previous research has shown that linear and rotational acceleration play a large role in head injuries, but little focus has been placed on the biomechanics behind how these accelerations occur in soccer. This study will be the first to describe the frequency and magnitude of the linear and rotational head accelerations sustained by soccer players and will identify important factors during which these scenarios occur (area on field, type of contact, anticipation status, etc.). If successful, this study will provide head impact biomechanics for both direct and indirect contact in a field setting, and will create better understanding of the nature of the game and the major points of injury risk for players.

CHAPTER III

METHODS

Study Design and Participants

This study employed a prospective cohort design. During this study, frequency and magnitude of head acceleration were recorded for each participant. These data were collected for eighteen games and forty practices during a regular college soccer season.

Participants

Twenty-five NCAA Division I female collegiate soccer players volunteered to participate in this study (age = 19.58 ± 1.15 years; height = 167.35 ± 4.24 cm; mass = 62.51 ± 6.33 kg). As this was a descriptive study of female college soccer players actively involved in competitive soccer, there were no exclusion criteria for participation. An *a priori* power estimate (Power = 0.80) based on linear acceleration differences between females and males determined we would need 23 participants to achieve an adequate sample size for our study (female = 20.16 ± 4.12 g; male = 18.25 ± 4.48 g; Cohen's $d=0.44$).⁶² However, we chose to recruit players from a women's soccer program into our study, which included 25 subjects to account for potential injury, attrition, or athletes who chose not to participate in study. Participant recruitment consisted of an informational team meeting with the soccer players and coaches before the first practice to inform them about the study, including its purpose and a description of the procedures. Participants signed an informed consent form and were allowed to withdraw from the study at any time. Participants eligible and willing to participate were asked to report to attend a meeting on day 1 of the study to be fitted and assigned accelerometers.

Instrumentation

X2 Biosystems xPatch

Head acceleration biomechanics were captured using the xPatch system (X2 Biosystems, Seattle, WA). The xPatch is a small and lightweight device affixed to the participants' head with an adhesive patch attached to the right mastoid process (immediately behind ear). It is capable of measuring linear and rotational acceleration with 6 degrees of freedom along with the location of each impact on the head.⁷⁶ Once activated, the xPatch has the capability to record data for up to six hours. In the beginning of the season, study participants were each assigned an xPatch. Each xPatch was labeled with a pre-assigned participant identification number. Players wore the same xPatch for all games and practices for the entirety of the season. Prior to application, each xPatch was fully charged via the charging dock and activated. The researcher/research assistant secured each xPatch to the corresponding player and the xPatch remained in place for the entire game or practice. Information gathered by the X2 sensor module was stored in the individual xPatch until data were extracted to a local laptop.

Contact Description Data Chart

The Contact Description Data Chart (Appendix A) was created to determine the factors involved in a given heading event during games only, which resulted in measurable head acceleration during games. This checklist, which allows researchers to catalog anticipation status opposition status and play instances that occur during heading, was created based on ideas and feedback from previous soccer players in response to their idea of proper body positioning to head the ball. An opposed header was operationally defined as a header in which both the study participant and at least one opponent were airborne at the time of the heading instance. If both players were not airborne, the play was considered unopposed.

Video Camera

In order to synchronize head acceleration data with game film, the operations team recorded all games using Canon XH A1 and Canon XA 10 high-definition video cameras. Video personnel imported the footage into TeamXStream (TeamXStream, Monument, Colorado) where videos were grouped by game and individual player, and coded for different event scenarios (header, shot on goal, etc.). Coding was done using the Sportscore Elite software system (Sportstec; Warriewood New South Wales). Research assistants recorded the date and time of day of play start at the beginning and end of each half. This was necessary for time synchronizing the video and xPatch data.

Procedures

Application of the xPatch

One to two hours prior to practice and games starting, players reported to the locker room to have their xPatch secured in place by the researcher/research assistant. The xPatch was worn directly behind each athlete's right ear over the mastoid process, with the arrow on the patch pointing towards the ear (see Figure 1 below). Prior to application, this area was cleaned with an adhesive prep pad and all hair was moved out of the area prior to application. The xPatch was placed directly over the cleaned area, and secured with Coverall athletic tape. Immediately following practice and games, players removed their xPatch and returned it to the research assistant who prepared the xPatch for data export and re-charging.

Video Recording

The soccer operations team digitally recorded all varsity women's soccer games and posted the video to a private password protected website for the researcher to access. Video recording and analysis were performed only for games to address research question two. The

video camera time capture started with time zero at kickoff. To link acceleration biomechanical data with game footage, research assistants recorded the exact time of play start and end each half based on time of day. These times were then matched to the video camera based on time elapsed from the camera. The accelerations were then evaluated using the Contact Description Data Chart (Appendix A).

Collecting xPatch Data

The team athletic trainers synchronized the laptop of the xPatch database to the time on their phones. They recorded exact start and end times of practices and games. Time stamps on the xPatch were compared to the recorded start and end times of practices and games, and only the accelerations that occurred during that time period were analyzed. After every game and practice, each patch was hooked up to the data unit, where data were exported from the xPatch and stored in the assigned cloud database. After data were exported, patches were placed on their respective charging stations until their next use.

Statistical Analyses

Only head accelerations greater than 10 g were included in the analyses. Accelerations were categorized as followed: mild (linear: <30g, rotational: <4600g), moderate (linear: 30-60g, rotational: 4600-7900g), and severe (linear: >60g, rotational: >7900g). These cut-offs were determined based on descriptive analysis of the data we collected in our study. We applied natural logarithmic transformations to our linear and rotational acceleration data to conform to the assumptions of data normality for our analyses.

To address event-type differences in head impact biomechanics for Specific Aim 1, separate random intercepts general linear mixed models were performed for linear and rotational acceleration. The independent variable for these analyses was event type (game vs. practice) and

player was treated as a repeating factor. Additionally, tests of independence were employed to determine the association between head acceleration severity (mild, moderate, or severe) and event type (game or practice). Similarly, separate random intercepts general linear mixed models were performed for linear and rotational acceleration to determine the differences in head acceleration biomechanics for header opposition (opposed vs. unopposed). The independent variable for these analyses was header opposition status, and player was again treated as a repeating factor in the models. Tests of independence were subsequently employed to determine the association between head acceleration severity (mild, moderate, or severe) and header opposition status (opposed or unopposed). All statistical analyses were performed in SAS (Version 9.3; SAS Institute, Inc, Cary, North Carolina). An alpha level of 0.05 was set a priori for each respective test.

CHAPTER IV

MANUSCRIPT

Introduction

Traumatic brain injury (TBI) is a public health concern. Up to 3.8 million sport and recreation related TBIs occur each year.¹ Of these, approximately 90% are classified as concussions.²⁻⁴ Concussions result from induced biomechanical forces causing complex pathophysiological processes affecting the brain.⁵ Concussions typically result in immediate symptoms including behavioral changes, cognitive impairments, and sleep disturbances. While \ the majority of concussions in college athletes will resolve within 7-10 days,⁶ about 10% of concussions will result in prolonged symptoms.⁶ The long-term neuropathological effects of recurrent concussion, although not well known, may include depression, early-onset Alzheimer's disease, and chronic traumatic encephalopathy.⁶⁻¹²

Soccer is not considered a collision sport in the same way as football or ice hockey. Notwithstanding, it is a sport that carries a high concussion risk with some reports indicating concussion rates in soccer exceed those observed in football and ice hockey.¹³⁻¹⁷ During collegiate play, 11.4% of soccer players will be diagnosed with a concussion.¹⁸ Concussion should be a concern for soccer players, coaches, and medical professionals due to the high incidence and the potential long-term detrimental effects of concussion among soccer players. Understanding the mechanics associated with such injuries may allow clinical researchers to inform rule or policy changes to mitigate injury risk in this at-risk population.

While there is a growing body of research examining head impact biomechanics in football and ice hockey,¹³⁻¹⁷ there is a dearth of field-based soccer-related research in this arena. Studies have mostly examined soccer head impact biomechanics in controlled laboratory settings,^{13,14,18-20} and have focused on direct contact heading events.^{13,19,20} Only a few studies have examined indirect contact,²¹⁻²³ which is where most of the injuries occur.²⁴ Further study of soccer head impact biomechanics, particularly as it relates to field-testing and examining both direct and indirect contact, is a necessary step to determine the forces that may contribute to injury. We believe that determining the biomechanics of soccer will ultimately aid in the prevention of injuries. In order to prevent concussions, head accelerations occurring in soccer and contributing risk factors need to first be identified and studied. The purpose of our study was to 1) to determine event-type differences (game vs. practice) in head impact biomechanics, and 2) to explore how heading opposition affects head impact severity in female Division I college soccer players.

Methods

Study Design

This study employed a prospective cohort design. During this study, frequency and magnitude of head acceleration were recorded for each participant. These data were collected for all games and practices during the entirety of a regular college soccer season.

Participants

Twenty-Five NCAA Division I female collegiate soccer players volunteered to participate in this study (age = 19.58 ± 1.15 years; height = 167.35 ± 4.24 cm; mass = 62.51 ± 6.33 kg). This number was not inclusive of an entire team, but was identified based on subjects who regularly participated in practices and games. As this was a descriptive study of female

college soccer players actively involved in competitive soccer, there were no exclusion criteria for participation. However, we chose to recruit members of a women's soccer program into our study, which included 25 subjects to account for potential injury, attrition, or athletes who chose not to participate in study.

Participant recruitment consisted of an informational team meeting with the soccer players and coaches before the first practice to inform them about the study, including its purpose and a description of the procedures. Participants signed an informed consent form and were allowed to withdraw from the study at any time. Participants who were eligible and willing to participate were asked to attend a meeting on day 1 of the study to be fitted and assigned accelerometers.

Instrumentation

X2 Biosystems xPatch

Head acceleration biomechanics were captured using the xPatch system (X2 Biosystems, Seattle, WA). It should be noted that the xPatch technology has been validated previously in a mouth guard but has not been validated in its current form.⁷⁷ It is a small and lightweight device affixed to the participants' head with an adhesive patch attached to either mastoid process (immediately behind ear). It is capable of measuring linear and rotational acceleration with 6 degrees of freedom along with the location of each impact on the head.⁷⁶ Once activated, the xPatch has the capability to record data for up to six hours. In the beginning of the season, study participants were each assigned an xPatch. Each xPatch was labeled with a pre-assigned participant identification number. Prior to application, each xPatch was fully charged via the charging dock and activated. The researcher/research assistant secured each xPatch to the corresponding player and the xPatch remained in place for the entire game or practice.

Information gathered by the X2 sensor module was stored in the individual xPatch until data were extracted to a local laptop.

Contact Description Data Chart

The Contact Description Data Chart (Appendix A) was created to determine the factors involved in a given heading event during games only, which resulted in measurable head acceleration during games. This checklist, which allows researchers to catalog anticipation status opposition status and play instances that occur during heading, was created based on ideas and feedback from previous soccer players based on their idea of proper positioning to head the ball. An opposed header was operationally defined as a header in which both the study participant and at least one opponent were airborne at the time of the heading instance. If both players were not airborne, the play was considered unopposed.

Video Camera

In order to synchronize head acceleration data with game film, the operations team recorded all games using Canon XH A1 and Canon XA 10 high-definition video cameras. Video personnel imported the footage into TeamXStream (TeamXStream, Monument, Colorado) where videos were grouped by game and individual player, and coded for different event scenarios (header, shot on goal, etc.). Coding was done using the Sportscore Elite software system (Sportstec, Warriewood, New South Wales). Research assistants recorded the date and time of day of play start at the beginning and end of each half for synchronizing the video and xPatch data.

Procedures

Application of the xPatch

One to two hours prior to practice and games starting, players reported to the locker room to have their xPatch secured in place by the researcher/research assistant. The xPatch was worn directly behind each athlete's right ear over the mastoid process, with the arrow on the patch pointing towards the ear (see Figure 1 below). Prior to application, this area was cleaned with an adhesive prep pad and all hair was moved out of the area prior to application. The xPatch was placed directly over the cleaned area, and secured with Coverall athletic tape. Immediately following practice and games, players removed their xPatch and returned it to the research assistant who prepared the xPatch for data export and re-charging.

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The soccer operations team digitally recorded all varsity women's soccer games and posted the video to a private password protected website for the researcher to access. Video recording and analysis were performed only for games to address research question two. The video camera time capture started with time zero at kickoff. To link acceleration biomechanical data with game footage, research assistants recorded the exact time of play start and end each

half based on time of day. These times were then matched to the video camera based on time elapsed from the camera. The accelerations were then evaluated using the Contact Description Data Chart (Appendix A).

Statistical Analyses

Only head accelerations greater than 10 g were included in the analyses. Accelerations were categorized as followed: mild (linear: <30g, rotational: <4600g), moderate (linear: 30-60g, rotational: 4600-7900g), and severe (linear: >60g, rotational: >7900g). These cut-offs were determined based on descriptive analysis of the data we collected in our study. We applied natural logarithmic transformations to our linear and rotational acceleration data to conform to the assumptions of data normality for our analyses.

To address event-type differences in head acceleration biomechanics for Specific Aim 1, separate random intercepts general linear mixed models were performed for linear and rotational acceleration. The independent variable for these analyses was event type (game vs. practice) and player was treated as a repeating factor. Additionally, tests of independence were employed to determine the association between head acceleration severity (mild, moderate, or severe) and event type (game or practice). Similarly, separate random intercepts general linear mixed models were performed for linear and rotational acceleration to determine the differences in head acceleration biomechanics for header opposition (opposed vs. unopposed). The independent variable for these analyses was header opposition status, and player was again treated as a repeating factor in the models. Tests of independence were subsequently employed to determine the association between head acceleration severity (mild, moderate, or severe) and header opposition status (opposed or unopposed). All statistical analyses were performed in SAS

(Version 9.3; SAS Institute, Inc, Cary, North Carolina). An alpha level of 0.05 was set a priori for each respective test.

Results

We recorded 13,479 head accelerations in 25 different soccer players in our study. At the start of the study, we had twenty participants. Two participants dropped out because of injury and five were added throughout the season. We analyzed data for anyone that was included in the study for any amount of time. Linear ($F_{1,24} = 50.14$, $P < 0.001$) and rotational ($F_{1,24} = 19.28$, $P < 0.001$) accelerations sustained during practice were significantly greater than those sustained during games. We recorded accelerations for a total of 40 practice sessions (55.7%) and 18 games (44.3%). There were 187.5 accelerations per practice (7502 total accelerations in practice) and 332.1 accelerations per game (5977 total accelerations in games). We observed an association between event type and severity of linear acceleration such that more severe head accelerations occurred in practices compared to games ($X^2[2] = 53.30$, $P < 0.001$). Specifically, athletes were 1.13 times more likely to suffer a severe head acceleration in practice as compared to games. We observed an association between event type and severity of rotational acceleration such that more severe head accelerations occurred during practices compared to games ($X^2[2] = 45.53$, $P < 0.001$). Specifically, athletes were 1.18 times more likely to suffer a severe head acceleration in practice as compared to games.

Specific to header opposition, we were able to match 159 out of 316 videotaped headers to a specific biomechanical data point. Out of the 159 videotaped headers, 91 were opposed and 68 were unopposed. We did not observe a significant effect of header opposition on linear acceleration ($F_{1,11} = 0.05$, $P = 0.826$) or rotational acceleration ($F_{1,11} = 0.17$, $P = 0.687$) measures. Likewise, we did not observe an association between opposition status and severity of linear

($X^2[2] = 1.98, P = 0.414$) or rotational ($X^2[2] = 1.95, P = 0.377$) acceleration. Tables 4.1 and 4.2 include all descriptive and statistical results for our analyses.

Discussion

To our knowledge, this is the first study to investigate real-time head acceleration biomechanics during competitive matches of women's soccer. The most important finding in our study was that female soccer head accelerations were more severe in practices compared to games, as measured by linear and rotational acceleration. We observed mean peak linear accelerations in line with previously published football data, but report seemingly higher rotational acceleration values.^{30,78,79} One possible reason that explains why a sport like soccer has similar or greater acceleration measures than a contact sport like football is because of the device used in this particular study. Our device (head mounted vs. helmet mounted) may have been more sensitive to rotational measures than helmet-based systems that have partially estimated rotational acceleration from linear accelerometers. Another plausible explanation may simply be that soccer players experience more rotationally-based accelerations due to isolated head-neck movement involved with heading a soccer ball. Previous studies have examined soccer head impact biomechanics in controlled laboratory settings,^{13,14,18-20} and have focused on direct contact heading events.^{13,19,20} Only a few studies have examined indirect contact.²¹⁻²³ Naunheim et al. reported peak head linear accelerations associated with heading a soccer ball to be 54.7 g.¹³ Although the soccer player in her study wore an instrumented football helmet to perform the heading task, Naunheim's values are similar to some of the peak accelerations we observed in our study.

In regards to our event type differences, we can only speculate as to why head accelerations are more frequent and severe in practices compared to games. One possible

explanation is that practices often specific involve drills focused on improving heading skills. These drills often involve numerous repetitions for each player compared to a game where there may be much fewer instances and opportunities for heading to occur. During this time, starters will often practice and compete in drills with non-starters. The non-starters may be working harder to prove themselves and create situations that would allow for more frequent and severe accelerations. We did not study injury risk associated with these header activities and specific drills. As such, future studies should explore the short- and long-term injury risks associated with heading drills, as well as further investigate the specific biomechanical accelerations and impacts that occur among the different drills. The findings of such studies may drive college and recreational soccer policies governing the frequency and/or type of heading drills in practice.

In addition to comparing frequency and magnitude of acceleration in regards to event type, we also examined how heading opposition (opposed vs. unopposed heading scenarios) would affect head acceleration biomechanics. Contrary to our hypothesis, we found no significant difference between opposed and unopposed heading scenarios. Thus, opponent pressure does not seem to play a role in head acceleration biomechanics as it relates to head acceleration forces. However, we feel that this particular aspect of heading should be further examined in other populations. For example, younger players may not possess the same degree of heading skills, and males may engage more recklessly during opposed headers. It is possible our athletes—elite college female soccer players—have likely learned how to protect themselves during opposed headers. It should be acknowledged that our particular definition for opposition may have created a limitation in this study. Contact and actual competition to “win the ball” may be different than our chosen definition of “both players being airborne,” where one player may not truly be in competition for the ball.

We acknowledge that header anticipation may play a role in soccer, just as it has with collision anticipation in other sports where head impact biomechanics have been studied.^{49,80} We had originally sought to study header anticipation in this study. However, we only captured nine unanticipated headers, and could not formally analyze these data in a meaningful way. Notwithstanding, our data suggest that unanticipated head accelerations in women's soccer are rare. The low number of unanticipated head accelerations may help to explain why we saw no differences. It is also possible that head-neck muscle activation in the header events we studied may have mitigated head acceleration severity during heading tasks. We are unable to address sex-specific differences. As previous studies have reported females have a greater head-neck segment, greater peak angular acceleration, and greater displacement than their male counterparts,⁶¹ this would be an interesting area for future inquiry.

There is a lack of published soccer head acceleration data; therefore, we did not have a precedent for categorizing head acceleration severity in our sample. However, previous football studies have attempted this.^{30,78,79} Given the novelty of our data, we elected to categorize our head acceleration severity as mild, moderate, and severe. The football literature prompted us to categorize our accelerations in this fashion; but mild-moderate-severe categorizations in football are vastly different given the higher propensity of larger head accelerations sustained during football. We feel our categorizations are reasonably defined, and our findings offer some insights with respect to female soccer players' exposure to head accelerations. Future soccer-specific research will likely refine these models, and help to inform innovations intended to improve player safety and injury prevention.

Due to the nature of our study and the minimal prior research regarding heading in soccer, the biggest limitation of our study was the selection of the xPatch to measure

acceleration. We feel that our data is very meaningful but this study is the first study to use the xPatch as a means of measuring on-field head acceleration biomechanics in soccer. Thus there are no measurements regarding the validity and reliability of the device. Further research needs to be conducted looking at these measures pertaining to soccer.

Another limitation of our study is that we only studied female soccer players. This particular group was chosen based on previous research stating that females appear more susceptible to greater forces in soccer than males, and that these were likely due to anatomical differences.^{43,61,62} Our study is the first in a line of research addressing soccer head accelerations, and future studies by our group and others should be inclusive of other populations (e.g., males, different age groups, competitive levels).

Future research projects should try to synchronize game time (used by the soccer operations team) and real time (used by the head acceleration measurement devices), which for this particular study required multiple people and software packages working in orchestration. While we had the human and financial resources to accomplish this, future studies should explore more innovative synchronization applications to accomplish this same objective. Our current methods do not allow for wide scale application of our study methods at this time. Our head acceleration measurement devices were affixed to the mastoid process. This attachment site allows for an approximation of the head center of gravity, and a good measure of head acceleration during participation. It is possible that skin artifact may be introduced with such devices. Skin artifact introduces an accepted level of error in other research areas (e.g., lower extremity kinematic modeling). Short of bone indwelling, it would be difficult to overcome this limitation.

This study was the first to describe the frequency and magnitude of the linear and rotational head acceleration sustained by female college soccer players during participation. It reports on head impact biomechanics captured during sports participation, adding to only one previous study.²¹ This is surprising given soccer's global popularity, and heightened media interest with concussion in many sports. The specific findings of more frequent and more severe head accelerations occurring in practices compared to games suggests that further research needs to be done looking at practices and the specific heading drills that are occurring. This may further reveal that coaches should start to consider limiting the amount of time and the number of days spent on heading drills. While there is no evidence to indicate that such heading practices lead to concussion, prior research has pointed to the possibility that subconcussive impacts may be associated with declining neurocognitive function later on in life.⁸¹ This study establishes the foundation on which future studies will continue to explore the world's most popular sport, and to develop the evidence base needed to positively affect policy and injury risk programs designed to keep athletes safe.



Figure 3.1. X2 Biosystems xPatch application on right mastoid process

Table 3.1. Data Summary Table

Aim	Objective	DATA SOURCE	COMPARISON	METHODS
1	To test the hypothesis that female Division I college soccer players will demonstrate more severe head acceleration biomechanics (linear and rotational acceleration) in games compared to practices.	IV: Event Type DV: Head Acceleration Magnitude	Event Type: 1. Practice 2. Games Magnitude of acceleration 1. Mild 2. Moderate 3. Severe	General estimating equations (magnitude is categorical) Random Intercepts General Linear Mixed Model (magnitude is continuous)
2	To explore how heading opposition (opposed, unopposed) affect head acceleration severity (linear and rotational acceleration in female Division I college soccer players.	IV: Heading opposition DV: Head Acceleration Magnitude	Magnitude of acceleration: 1. Mild 2. Moderate 3. Severe Opposition status identified by checklist 1. Opposed 2. Unopposed	General estimating equations (magnitude is categorical) Random Intercepts General Linear Mixed Model (magnitude is continuous)

Table 4.1. Mean resultant linear and rotational acceleration of head impacts sustained by event type and presence of opposition

	Frequency (%)	Impacts per Session	Linear acceleration (g)				Rotational acceleration (rad/s ²)			
			95% CI				95% CI			
			Mean	L	U	F	P	Mean	L	U
Event Type										
Practice	7502 (55.6)	187.5	20.4	19.9	20.8			3230.7	3136.1	3328.2
Competition	5977 (44.34)	332.1	18.5	18.1	18.9	50.14	<0.001	2898.5	2785.7	3015.9
										19.28
										<0.001
Opposition Status										
Opposed	91 (57.2)	N/A	18.6	15.4	22.3			2984.8	2309.8	3857.1
Unopposed	68 (42.8)	N/A	18.2	16.8	19.6	0.05	0.826	2823.5	2438.4	3269.6
									0.17	0.687

Table 4.2. Frequency (percentage) of recorded accelerations sustained by event type and opposition status based on linear and rotational accelerations.

	Head Acceleration Severity- Linear Acceleration Frequency (%)			Head Acceleration Severity-Rotational Acceleration Frequency (%)		
	Mild <30g	Moderate 30-60g	Severe >60g	Mild <4600g	Moderate 4600-7900g	Severe >7900g
Event Type						
Practice	5553 (41.20)	$\chi^2 = 53.30, P < 0.001$ 1526 (11.32)	423 (3.14)	5451 (40.44)	$\chi^2 = 45.53, P < 0.001$ 857 (6.36)	1194 (8.86)
Competition	4739 (35.16)	941 (6.98)	297 (2.20)	4641 (34.43)	529 (3.92)	807 (5.99)
Opposition Status						
Opposed	73 (45.91)	$\chi^2 = 1.98, P = 0.414$ 14 (8.81)	4 (2.52)	70 (44.03)	$\chi^2 = 1.95, P = 0.377$ 7 (4.40)	14 (8.81)
Unopposed	55 (34.59)	7 (4.40)	6 (3.77)	52 (32.70)	9 (5.66)	7 (4.40)

Appendix A: Contact Description Data Chart

Participant ID:

--	--	--	--	--	--	--	--

Date of contact

--	--	--	--	--	--	--	--

Time of contact

--	--	--	--	--	--

C1. Where did the play occur?

- ☐ Offensive end (0)
☐ Defensive end (1)

C2. What kind of play was it?

- ☐ Direct kick (0)
☐ Corner kick (1)
☐ Goal kick (2)
☐ Goalkeeper punt/dropkick (3)
☐ Other (4)

C3. Closing distance of the ball

- ☐ Less than 20 yards (0)
☐ Greater than 20 yards (1)

C4. Was the play anticipated?

- ☐ Yes (0)
☐ No (1)

C5. Was the player injured on the play?

- ☐ Yes (0)
☐ No (1)

C6. Was the play opposed?

- ☐ Yes (0)
☐ No (1)

C7. What did the player's head strike? (**Check all that apply**)

- ☐ Unable to tell (0)
☐ The ball (1)
☐ Another object (goal post, ground, etc.)
(2) Define: _____
☐ Another player (3)
Define what part (elbow, head, forearm, shoulder, etc)

C8. Did an infraction/penalty occur on the play

- ☐ Yes (0)
☐ No (1)

C9. Did the player win the header?

- ☐ Yes (0)
☐ No (1)

C10. Where did the ball strike the player's head?

- ☐ Front of the head (0)
☐ Top of the head (1)
☐ Side of the head (2)
☐ Back of the head (3)
☐ Unable to tell (4)

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