

A COMPREHENSIVE PROSPECTIVE ANALYSIS OF SOCCER HEADING AMONG  
MALE AND FEMALE COLLEGIATE SOCCER ATHLETES

HUMBOLDT STATE UNIVERSITY

By

Elizabeth Anne Larson

A Thesis

Presented to

The Faculty of Humboldt State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science in Kinesiology

Department of Kinesiology and Recreation

May, 2011

## ABSTRACT

### A COMPREHENSIVE PROSPECTIVE ANALYSIS OF SOCCER HEADING AMONG MALE AND FEMALE COLLEGIATE SOCCER ATHLETES

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The purpose of this study was to conduct a comprehensive, multidisciplinary, prospective study of soccer heading and its potential effects among male and female collegiate soccer players. Specifically, this study evaluated individual neck strength and accelerations experienced by the head during bouts of routine soccer heading and examined this information in regard to videorecorded exposure data and neurocognitive performance. The participants for the study included 51 Division-II collegiate soccer players from the Humboldt State University women's ( $n=27$ ) and men's ( $n=24$ ) (part 1 of study); 13 of them participated in part 2; 7 women, 6 men. All subjects were voluntarily recruited from the Humboldt State University soccer teams. For part 1 of the study, a self-report heading index was administered, pre and post-season neurocognitive (ImPACT) scores were collected, and four randomly selected practices and games were videorecorded for collection of exposure data. In part 2 of the study a handheld dynamometer (BIOPAC) was used to gather neck strength information and a tri-axial accelerometer (G-Link) was used to record accelerations experienced by the head during heading trials in which a soccer ball was ejected from a ball machine at a prescribed rate and trajectory. The results of the study supported the hypothesis that there would be no significant neurocognitive changes after a season of soccer heading for the group as a whole. However, there was a significant difference in visual memory change scores for the "header" group versus the

“not a header” group. The hypothesis that there would be significant sex differences in neck strength and heading accelerations was also supported. However, males exhibited greater heading accelerations than females, contrary to initial expectations. Finally, the hypothesis that neck strength would be negatively correlated with heading accelerations was partially supported. Specifically, neck strength was positively correlated with accelerations experienced during flick-on headers. However, a number of additional non-significant trends for sex differences for each neck strength measure by header type were also supported.

## ACKNOWLEDGMENTS

This thesis would not have been possible without the guidance and support of several individuals who contributed their ideas and expertise to the project. Thank you for donating your time and energy.

First and foremost, to Dr. Anthony Kontos, without whom nothing in my life would be unfolding exactly as it is now. Somehow, I owe my educational, research, and career direction to a serendipitous string of events that ended with the two of us sharing a passion for sports and head injuries. It took a hurricane to rip our lives apart and bring the two of us together in a corner of the country far from where either of us thought we would ever be. Thank you for granting me so many wonderful opportunities and having faith that I could pull them off. Your honesty, humor, and general life advice are always appreciated.

To Dr. Justus Ortega, thank you for your patience and selflessness. The balance that you achieve between teaching, researching, mentoring, and living a full non-work life is truly incredible, and with a smile to boot! I am looking forward to many more days of “forcing it” in the lab and MacGyver-ing our way through life’s dilemmas.

To Dr. Sheila Kelly, thank you for your enthusiasm, support, and editing expertise. You jumped right in and it meant so much to me! I am glad we will get to keep working together.

To Dr. Ethan Gahtan, thank you for your ingenious ideas and figure wizardry. I owe many of the details that made this study successful to your savvy – a JUGS machine loaned to me free of charge, videographers that captured soccer games on film without inducing motion sickness upon later viewing, and some of the fanciest figures I have seen in a master's thesis to date.

To Sarah Nakamoto, my right-hand lady! You let me pay you in food that you did not like and never complained. Thank you for the endless hours you volunteered, for keeping me sane, and for not letting me lose any fingers to power tools.

There are many other people who helped in endless and immeasurable ways. You know who you are, and I thank you.

## TABLE OF CONTENTS

	Page
TABLE OF CONTENTS.....	vii
INTRODUCTION.....	1
Statement of the Problem.....	1
Nature of the Problem.....	4
Purpose of the Study.....	11
Hypotheses and Exploratory Questions.....	12
Assumptions.....	13
Delimitations.....	13
METHODS.....	15
Design.....	15
Participants.....	15
Measures.....	17
Procedures.....	21
Data Analysis.....	26

RESULTS.....	27
DISCUSSION.....	36
Summary of Results.....	36
General Discussion.....	38
Limitations.....	44
Future Research.....	45
Implications.....	46
Conclusion.....	47
REFERENCES.....	49

## CHAPTER ONE

### *Introduction*

#### *Statement of the Problem*

The game of football (soccer) most likely began in China 3,000 years ago and historical references and legend cite the use of human heads, mammal skulls, and stitched up bladders stuffed with hair and feathers as some of the earliest forms of the soccer ball (FIFA, 2010). Vikings were said to have kicked the heads of their enemies about and everyone from the Egyptians to the North American Indians are reported to have enjoyed a game comparable to soccer (FIFA, 2010). Today the game has moved away from the use of human heads as kicking implements and garnered the use of a much more civilized synthetic leather ball. However, instead of kicking heads around, players now use their heads to stop and redirect balls exceeding speeds of 50 miles per hour.

*Health Effects of Heading.* College soccer players commonly head the ball up to 10 times per game and more frequently during routine practices depending on the positions they play (Delaney, 2008). Witol & colleagues (1995; 2003) concluded that players who head the ball more than 10 times a game risk cumulative neurocognitive deficits. It is important to note that purposeful heading is a skill, and when properly executed, the risk of injury from ball to head contact diminishes significantly.

*Sex Differences.* Covassin, Swanik, and Sachs (2003) looked at sex differences in the incidence of concussions among collegiate athletes found that females athletes sustained a higher percentage of concussions during games than did their male counterparts, with soccer having the greatest incidence density ratio of all sports and

women's soccer (along with men's lacrosse) accruing the highest incidence of concussions. The skill of heading necessitates bracing the neck muscles in order to minimize the acceleration of the head and thus prevent subsequent head injury (Bauer, Thomas, Cauraugh, Kaminski, & Hass, 2001; Tierney et al., 2008). Neck strength and head acceleration are related and greater head accelerations are reported among females than their male counterparts. This finding may be due in part to females' lower overall neck strength compared to males (Tierney et al., 2008). Before soccer moms all over the world get too concerned and insist their children play badminton instead, it is imperative that the research community is able to shed some light on the safety and heading in soccer conundrum.

*Previous Research.* Researchers have debated the effects of heading on the neurocognitive health of athletes for decades. Much of this debate was based on flawed earlier data. In 1981, Tysvaer and Storli concluded that heading did not result in serious brain injuries. Their study was based on questionnaires that had been sent out in 1975 to the Norwegian First Division League Clubs and full neurological examinations of 60 percent of the players. None of the players had been operated on for brain damage, including epi- or subdural hematoma, and only a few concussions had been reported as directly resulting from heading (Tysvaer & Storli, 1981). After a number of players kept reporting prolonged and chronic headaches, dizziness, irritability, lack of concentration, and impaired memory, Tysvaer and colleagues performed a number of subsequent studies looking at neurological and electroencephalographic (EEG) examinations (Tysvaer, Storli, & Bachen, 1989; Tysvaer & Lochen, 1991; Tysvaer & Storli, 1989; Sortland &

Tysvaer, 1989; Tysvaer et al., 1992). Each of these studies concluded that repeated impacts from heading the ball led to long-term neurocognitive impairment and protracted symptoms in a significant number of athletes. Yet another study of Norwegian elite soccer players revealed that one third of the players had central cerebral atrophy (loss of neurons and neuronal connections in the brain) and 81 percent of players displayed mild to severe (mainly mild to moderate) neurocognitive deficits (Tysvaer, Sortland, Storli, & Lochen, 1992).

The next generation of research began looking more specifically at ball velocities and assessing exposure to head impacts during competition – attempting to muster a semblance of cause and effect (Andersen, Tenga, Engebretsen, & Bahr, 2004; Kirkendall & Garrett, 2001). Andersen and colleagues (2004) looked at 174 videotapes from Norwegian regular league match games in order to assess injury incidence, however, the majority related to knee, ankle, or thigh injuries, and “head injuries” were simply tallied and ranged from cuts to contusions resulting from head impacts against any surface. That study did nothing in the way of a comprehensive heading analysis and was solely concerned with incidence reports. Kaminski and colleagues (2008) attempted to keep heading logs as reports of exposure, however, there is no mention in the study of who was assigned to keep these logs and the study only reported on female collegiate soccer players. In one study, soccer revealed consistently higher accelerations of the head than did football or hockey (Naunheim, Standeven, Richter, & Lewis, 2000). Purposeful heading in soccer is abundant and headaches and dizziness are two of the more common

symptoms often reported by athletes after acute bouts of heading (Schmitt, Hertel, Evans, Olmstead, & Putukian, 2003; Witol & Webbe, 2003).

Research in the last few years has looked at whether purposeful heading has an effect on neurocognitive performance and has struggled to make a solid connection (Kaminski, Cousino, & Glutting, 2008). Sex differences in head accelerations have also recently gained some of the limelight (Tierney et al., 2008). All of this research has opened the door for more prospective, rather than cross-sectional, comprehensive research designs to step in and help sort the wash of evidence that is circulating today.

#### *Nature of the Problem*

Soccer is the most popular sport in the world and is rapidly gaining popularity in the United States. The Federation Internationale de Football Association (FIFA) estimates that 240 million people play soccer on a regular basis in over 200 countries (2006). FIFA was founded in 1904 and currently has more member nations than the United Nations. The popularity of soccer continues to grow in the U.S. particularly at youth levels. There are over three million players between the ages of five and 19 that play under the United States Youth Soccer Association, more than 300,000 players between the ages of four and 19 that play under the American Youth Soccer Organization, and nearly 1,000 teams and tens of thousands of players from the ages of 13 to 20 that play under the United Soccer Leagues (Wikipedia, 2010). It is due to this ever-growing population that soccer is now one of the most played sports by youth in the United States. With this increased participation, there is a concomitant increase in heading exposure.

Unlike other sports, soccer is the only sport where the unprotected head is purposefully used to advance the ball using a skill called heading. The very nature of the skill of heading may put athletes at risk of injury, such as head contusions, lacerations, neck strains, facial fractures, and concussions (Andersen et al., 2004). Kirkendall and Garrett (2001) reviewed literature on purposeful heading and concluded that as many as 20 percent of all soccer injuries are head injuries, though only a small number result from ball to head contact. When heading, soccer players are often simultaneously looking up, jumping in the air, have their head twisted, and may be unable to see other players encroaching from the side or behind them. A different study from Andersen and colleagues (2004) using video analysis of elite soccer games revealed that 58 percent of injury cases resulted from heading duels (Andersen, Arnason, Engebretsen, & Bahr, 2004). Opportunities to head the ball in a game are numerous. In fact, research suggests that the typical collegiate soccer player heads the ball up to 10 times per game and with balls that are commonly kicked at speeds of 70-85 km/h (44-53 mph), proper form is imperative in order to avoid injury (Delaney, 2008; Kirkendall & Garrett, 2001).

There are three main types of soccer headers: 1) “flicked” or passing headers of low velocities; 2) headers involving driven balls of high velocities (e.g., shot on goal from a corner kick); and 3) headers involving high-flighted balls (e.g., heading a ball that was kicked by the goalkeeper). Proper, intended contact with the ball in heading occurs at the forehead, regardless of the type of header. Technique is a crucial component of purposeful heading, but the accelerations of headers vary considerably and add a whole other level to the skill. Some of the highest velocity headers result from a driven ball as

from a drop kick, punt, or goal kick with approximate velocities of 85 km/h (53 mph), 70 km/h (44 mph), and 85 km/h (53 mph), respectively (Kirkendall & Garrett, 2001). In 2002, a fundamental scientific and engineering analysis (Business Editors and Sports Writers 2002 FIFA World Cup) allowed researchers to analyze David Beckham's free kick goal against Greece during the World Cup Qualifiers in 2001. The researchers surmised that the shot left his foot at about 36 m/s (80 mph) from about 27 m out. Much like free kicks, corner kicks and crosses can reach incredibly high velocities. Successfully redirecting a corner kick or cross using ones head requires precise timing and advanced skill in order to head the ball into the goal. Furthermore, heading the ball may involve head to head collisions when two or more players go for the same ball, and collisions with the ground or goalposts during diving headers. Exposure to heading varies among players and positions. For example, Matser and colleagues found that neurocognitive performance varied by position, with forward and defensive players exhibiting greater impairments (Matser, Kessels, Jordan, Lezak, & Troost, 2001). Concerns about the neurocognitive health of athletes who head the ball have been debated for decades. Headaches and dizziness are two of the more common symptoms often reported by athletes after acute bouts of heading (Schmitt et al., 2003; Witol & Webbe, 2003).

Proper heading of a soccer ball is a difficult skill to master, especially when other components such as running, jumping, and backpedalling are added to the mix. In order to minimize impact accelerations, and prepare the head and neck, it is important for players to strike the ball with their head as opposed to letting the ball strike them in the head. Purposeful heading is largely linear. Preparation and neck strength are important

factors in regard to resulting linear accelerations. If a ball strikes the forehead of an unprepared player or a player with weaker neck muscles, the resulting linear accelerations push the head posteriorly to a greater extent and resulting effects can be compounded by rotational accelerations (Kirkendall & Garrett, 2001).

Neck strength is an important component of purposeful heading. Without activation of the sternocleidomastoid (neck) and the upper trapezius (lower neck down toward shoulder blades) muscles, the neck cannot brace the head for impact with the ball (Bauer et al., 2001; Tierney et al., 2008). Furthermore, the stronger these muscles are, the better the neck is able to brace the head and help provide the framework for a reciprocal linear head acceleration toward the oncoming ball. To further illustrate the importance of neck muscle activation for the skill of heading, Witol (2002) surmised that there is increased muscle activation during jumping headers versus standing headers, which appears to better stabilize the connection between the head, neck, and body. Few studies have considered both acceleration accelerations and neck strength in regard to possible long-term effects of repetitive purposeful heading (Rutherford, Stephens, & Potter, 2003).

In a recent study of the effects of heading exposure and previous concussions on neurocognitive performance among Norwegian elite soccer players, researchers reported no relationship between heading exposure or previous concussions and neurocognitive impairments (Straume-Naesheim, Andersen, Dvorak, & Bahr, 2005). The researchers used a computerized neurocognitive test (i.e., CogSport) that was different from previous studies using pen and pencil tests that have supported significant long-term neurocognitive deficits associated with heading exposure (Witol & Webbe, 2003; Webbe

& Ochs, 2003). The problem with traditional pen and pencil tests is that they often yield larger differences in scores between two parts of the same test (i.e., Parts A and B) when compared to computerized versions of the same test (Drapeau, Bastien-Toniazzo, Rous, & Carlier, 2007). Still, there are issues with the aforementioned study, which did use computerized neurocognitive test batteries. Straume-Naesheim et al. (2005) only looked at elite male soccer players, calling into question age, sex, and skill generalizability, and relied on self-reported heading exposure data. Kirkendall & Garrett (2001) adduced that it was difficult to pinpoint purposeful heading as the cause of reported cognitive deficits when the actual exposure (versus self-reported) and details of the nature of the head-ball impact were not known.

Repetitive head impacts may yield negative long-term neurological effects. Naunheim, Standeven, Richter, & Lewis (2000) compared peak accelerations as measured at the surface of the head for hockey, football, and soccer athletes. They found that peak accelerations for heading a soccer ball were 160 to 180% greater than routine impacts during hockey or football. As such, their study concluded that repeat impacts at this level may lead to cumulative, long-term neurologic impairments (Naunheim et al., 2000).

There has been much debate on the possible effects of repeated head impacts, as in purposeful heading of a ball. Webbe and Ochs (2003) discovered that soccer players with the highest self-reported heading exposures that also performed purposeful headers within the last seven days performed significantly worse on neurocognitive tasks when compared with other combinations of heading and recency. Like many other studies,

Webbe's and Ochs' (2003) was cross-sectional (no individual baselines) and consisted of an all male population of "high-ability" soccer players. A more recent study from Straume-Naesheim et al. (2009) concluded that the reduced neurocognitive performances found among professional male soccer players after minor head impacts were significant. Furthermore, these neurocognitive deficits were apparent even in otherwise asymptomatic players. The effects of repeated impacts from heading a ball are unknown.

Straume-Naesheim et al. (2009) performed a prospective case-control study that compared the baseline neurocognitive tests of Norwegian elite male soccer athletes to their post-impact test scores. The athletes who received a "head impact" (assessed through video observation) during a game were tested again the next day. However, neurocognitive tests should not be given within the first 24 hours (after concussion) due to the fact that athletes can actually perform better in the acute (24 hour) phase essentially due to the influx of sugars and blood to the brain to promote healing. A reduction in neurocognitive performance was reported for the head impact group, still, this study is only generalizable to the elite male soccer athlete population.

A connection between purposeful soccer heading, sub-concussive head trauma, and cumulative neurological damage was first proposed in the 1970s. Since then, research has largely compared athletes' self-reported heading exposure and their neurocognitive test scores (Rutherford & Fernie, 2005). However, research strongly implies that soccer athletes' self-reported estimation of their heading frequency is inaccurate (Rutherford & Fernie, 2005). In 1992, Tysvaer's cross-sectional studies suggested that, much like in boxing, repeated heading in soccer might lead to chronic brain injury. Since 1992, several

other cross-sectional studies have pointed to long-term brain decrements as a result of continued purposeful heading (Downs & Abwender, 2002; Witol & Webbe, 2003). Other studies propose that there are no long-term effects associated with purposeful heading of the ball (Barnes et al., 2008; Guskiewicz, 2002). Kaminski and colleagues (2008) found no significant relationship between soccer heading frequency and neurocognitive test performance. However, the issue with these studies is that they have been cross-sectional in nature and relied heavily on athletes' self-reported exposure to heading. Rutherford and colleagues (2005) attempted to address the issue of self-report inaccuracies by logging headers for each athlete during a single game for male university soccer athletes in the United Kingdom. They distinguished no relationship between heading frequency and neurocognitive test performance, however, important methodological limitations were identified and a need for further research on the long-term effects of repeated sub-concussive blows was established (Rutherford, Stephens, Fernie, & Potter, 2005).

Previous research in the area of ball velocities, neck strength, head accelerations, heading exposure, and neurocognitive performance associated with purposeful heading of a soccer ball has failed to encompass all of the abovementioned variables into one cohesive study in order to better assess the relationship between each of the variables. Furthermore, several recent studies allow limited conclusions because they employed cross-sectional designs, relied on athletes' self-reported heading exposure estimates, and have been largely confined to a population of elite male soccer players (Andersen et al., 2004; Rutherford et al. 2005; Tysvaer et al., 1992).

### *Purpose of the Study*

Previous studies have been cross-sectional in nature and/or have focused on head accelerations with or without the presence of neurocognitive testing, and were limited by self-reported exposure data. Other recent studies have been limited to elite male soccer players. The current study set out to fill in gaps in the current research by comparing self-reported heading exposure to videotaped observations of actual heading exposure and head impact mechanisms in a college-aged population. Baseline and end-of-the-season computerized neurocognitive assessments were collected and compared to gain insight into whether or not repeated low-level head impacts have any cumulative, lasting effects. Neck strength and head accelerations (velocities and accelerations) for male and female division-II soccer athletes were compared within and across genders. This study was the first to attempt to take into account a full spectrum of variables in order to gain a more cohesive, generalizable picture of purposeful heading in soccer and a better understanding of the possible effects of repeated low-level head impacts sustained over the course of a soccer season.

Therefore, the purpose of this study was to conduct a comprehensive, multidisciplinary, prospective study of soccer heading and its potential cognitive effects among male and female collegiate soccer players. Specifically, this study evaluated individual neck strength and head accelerations (velocities and accelerations) during bouts of heading and compare this information to videotaped exposure data and neurocognitive performance. A second purpose was to compare the athletes' baseline and end-of-the-season neurocognitive test scores to help surmise whether or not routine low-

level impacts from purposeful heading had any cumulative effects on cognitive performance. This data was qualitatively compared to exposure data collected from video-analysis of each 2010 home game. An ancillary purpose of this study was to qualitatively assess aspects of heading technique and types of headers gathered from lab observation and videotaped games.

### *Hypotheses and Exploratory Questions*

The following hypotheses were proposed for this study:

#### *Laboratory Soccer Heading Analyses*

1. Neck strength will be negatively correlated with head accelerations during bouts of routine heading.

#### *Neurocognitive Performance/Change*

1. Low-level impacts from purposeful heading throughout a season will have no significant affect on neurocognitive test performance when the participants are looked at as a whole, however,
2. Athletes with the greatest level of exposure will show greater decrements in neurocognitive performance from baseline to post-season.

#### *Sex Differences*

1. Males will experience lower forces on the head during bouts of routine heading compared to females.
2. Males will exhibit greater neck strength compared to females.

The following exploratory questions were also examined:

1. Which factors are most predictive of forces experienced by the head during bouts of routine heading?
2. Which factors are most predictive of heading exposure?
3. Which factors are most predictive of neurocognitive performance following a soccer season?
4. Do males and females differ in neurocognitive performance changes following and soccer season?

#### *Assumptions*

The following assumptions were made for this study:

1. Participants responded honestly and accurately on all questionnaire and demographic components.
2. All measures in the study are both valid and reliable.
3. The soccer heading laboratory trials emulated an accurate representation of real-life soccer heading performance.
4. The four practices and four home games were representative of the entire soccer season's heading exposure.

#### *Delimitations*

This study was delimited by the following factors:

1. The participant population was limited to NCAA Division-II male and female collegiate soccer players, ages 18-28 years.
2. Heading exposure was only recorded for home games (and practices) and then extrapolated to infer away game exposures.
3. Data were only collected during one competitive season.
4. Heading assessments occurred in a laboratory setting (field house).

## CHAPTER TWO

### *Methods*

#### *Design*

This study employed a prospective design with select repeated measures to provide a comprehensive analysis of soccer heading including neck strength, velocities and accelerations, video exposure data, and the neurocognitive performance of collegiate soccer athletes. Part 1 of the study included the administration of a cross-sectional heading index, collection of video exposure data over the course of a soccer season, and the pre-season and post-season neurocognitive tests. Part 2 of the study included the laboratory heading and neck strength analyses. For part 1 of the study, the independent variables were self-report and actual heading exposure and the dependent variables were neurocognitive performance score changes (verbal memory, visual memory, motor composite, reaction time, symptoms). For part 2 of the study, the variables were neck strength (linear and rotational) and header accelerations (high-clear, driven, and flick-on). Sex was also used as a predictor variable throughout the study.

#### *Participants*

Fifty-one Division-II soccer athletes ages 18-22 from Humboldt State University were enrolled in the study. Twenty-seven were from the women's soccer team and 24 were from the men's. All participants partook in part 1 of the study, while 13 (seven women, six men) were chosen for part 2 of the study. Exclusion criteria for the neurocognitive performance portion of part 1 included a history of diagnosed learning disability or attention deficit/hyperactivity disorder, a diagnosed concussion during the

2010 season, or a prior severe traumatic brain injury. Exclusion criteria for part 2 included a recent (within the past 12 months) or current head (e.g., concussion) or neck injury; or a history of moderate to severe brain injury, substance abuse, and major psychiatric or neurological disorder. Any athlete under the age of 18 was excluded from the study.

Table 1.

*Participant Descriptives.*

	<i>Males</i>	<i>Females</i>
	<i>(n= 24)</i>	<i>(n=27)</i>
	<i>M(SD)</i>	<i>M(SD)</i>
<i>Age (yrs)</i>	19.46 (1.22)	19.81 (1.21)
<i>Height (inch)</i>	70.83 (3.03)**	65.93 (2.18)**
<i>Weight (lbs)</i>	167.46 (24.34)**	140.48 (15.96)**
<i>Years Experience (college)</i>	1.36 (1.11)	1.63 (1.28)

*Note: \*\*p<.01*

### *Measures*

*Soccer Heading Index.* Participants self-reported date of birth, age, height, and weight. Participants also self-reported their position, heading experience and exposure, perceived heading ability compared to teammates, and years of experience playing at the collegiate level.

*BIOPAC Systems Hand Dynamometer.* A handheld dynamometer was used to measure linear and rotational neck strength. A 48-inch square piece of plywood was bolted to an already existing structure made of square metal tubing and slots were cut in the plywood to allow for adjustments of shoulder and waist straps. The heights of the four horizontal slots (6" X 1/2") cut into the center of the board for the shoulder straps to cross through was determined by measuring the shortest and tallest participants in the study as the extremes and spacing an additional two slots in between those heights. The spacing of the vertical slots (10" X 1/2") cut to allow the waist strap to pass through and secure around the board was determined by measuring a range of waist widths and making slots which would allow the belt to enter and exit the board behind the sacrum of each participant in order to achieve a snug fit. The participants were strapped to the board with both a criss-cross backed shoulder harness and a waist belt made of 2-inch nylon strap, Velcro, and metal d-rings. An additional nylon strap was fastened around their head with a metal o-ring attached to a nylon cord that ran to the dynamometer. The dynamometer was resting on a plank six feet behind and level with the back of each participants head and the cord was adjusted to ensure there was no excess slack or tension at rest. The device measured maximum voluntary contractions of the neck muscles in both linear and

rotational directions. Handheld dynamometers have been verified as valid and reliable in studies testing isometric neck strength (e.g., Cagnie, Cools, De Loose, Cambier, & Danneels, 2007; Soderman, Bergstrom, Lorentzon, & Alfredson, 2000).

*JUGS Soccer Machine.* A JUGS soccer machine was used to deliver soccer balls at a consistent velocity and height for each of the heading trials. This is a common tossing machine used throughout the sport world for practice situations. The machine was set so that balls exited at a velocity of 25 mph, which was used in previous studies and is on the low-end of the range at which balls are commonly headed in soccer (Kirkendall & Garrett, 2001). A velocity of 25 mph was chosen in order to ensure participants' safety during the heading trials. JUGS machines have been used in previous soccer studies to consistently and accurately toss balls for heading trials (e.g., Broglio, Ju, Broglio, & Sell, 2003).

*MicroStrain G-Link Tri-axial Wireless Accelerometer.* A tri-axial accelerometer was used to measure head accelerations throughout the heading trials. The accelerometer was screwed on to the back of a standard water polo cap (with chin strap, but ear caps removed) through a 1/4-inch thick piece of foam in order to better mold to the back of each participants' head. The smallest screws possible were used in order to keep excess weight at a minimum. The accelerometer was affixed to the cap so that it would rest at the center back of the participants' heads. Previous researchers have chosen to place the accelerometer on the head nearest to the center of gravity (Bussone, 2005; Naunheim et al., 2003a; Naunheim et al., 2003b; Reed, Feldman, Weiss, Tencer, 2002). For the current study, the device was affixed to the center back of the head so as to not impede

participants' ability to properly head the soccer ball or add any additional risk, while also preventing excess noise from the accelerometer sliding back and forth across the top of the skull. The use of a tri-axial accelerometer secured to the head as close as possible to the center of gravity has yielded valid and reliable results in previous studies on soccer heading (Bussone, 2005; Naunheim et al., 2003a; Naunheim et al., 2003b; Reed et al., 2002).

The MicroStrain G-Link tri-axial wireless accelerometer is compact in size (25 mm x 25 mm x 5 mm), weighs only 47 grams, has 2 MB of on board memory storage, and runs off a 9-volt battery (MicroStrain, 2010). Tri-axial accelerometers provide information on acceleration in the lateral, anterior and posterior, and vertical directions, or the X, Y, and Z axes, respectively. They have a maximum acceleration reading of 500 g (500 x the acceleration of gravity) (MicroStrain, 2010).

*Video Recording.* Selected games and practices were videorecorded using a digital video camera/recorder (Panasonic) in order to analyze individual and overall exposure to heading, types of headers, and qualitative observation of heading skill (location of impact on head). Researchers worked in pairs to keep a pen and paper log of heading exposure in addition to the videos as backup to confirm recorded data. Information about heading exposure including player number, header type, and location of impact on the head, were recorded by both the person running the camera and the person writing in the log.

*Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT).*

ImPACT is a user-friendly, web-based program that can be administered to as many

participants at a time as there are computers available, however, smaller groups should be considered to avoid distractions. The ImPACT test battery has been identified in many studies as both reliable and valid (Iverson, Lovell, & Collins, 2003; Iverson, Lovell, & Collins, 2005; Schatz, Pardini, Lovell, Collins, & Podell, 2006). In addition, ImPACT is sensitive to the mild effects of head injury (Lovell, Collins, Iverson, Johnston, & Bradley, 2004). The test battery includes a participant profile and health history questionnaire, current symptoms and conditions scale, and a thorough neurocognitive test. The entire test is self-paced and takes about 30 minutes.

The ImPACT uses six modules to generate five index scores in verbal memory, visual memory, processing speed, reaction time, and impulse control. Module 1 assesses attentional processes and verbal recognition memory using a word discrimination model. Module 2 assesses attentional processes and visual recognition memory using a design discrimination model. Module 3 assesses visual working memory and visual processing speed using a visual memory model with a distractor task. Module 4 assesses visual processing speed, learning, and memory using symbol matching. Module 5 assesses reaction time, impulse control/response inhibition using color matching. Module 6 assesses working memory and visual-motor response speed using three-letter recollection and a distracter task. The five index scores are displayed graphically for the investigator: higher scores for visual and verbal memory, and processing speed signify better performance, while lower scores for impulse control and reaction time signify better performance. ImPACT detects the speed in which participants answer questions and presents models randomly to guard against memorization. A relative confidence interval

(RCI) is included for each composite score to alert investigators if a participant's score falls below a clinically significant level due to some external factor (ImPACT, 2010).

### *Procedures*

The Humboldt State University Institutional Review Board approved this study. Informed written consent was obtained from each participant and approval was received from the head soccer coach before the study began. The study commenced at the start of the fall 2010 intercollegiate soccer season with a brief team meeting addressing the parameters of the study and informing participants of their involvement in the video and neurocognitive portions (part 1) of the study and the possibility of their involvement in the heading trial portion (part 2). All 51 participants completed the soccer heading index during the initial meeting. The meeting took about fifteen minutes.

*Part 1- Video Analysis.* Throughout the season, both the men's and women's soccer teams had four practices and four home games, chosen at random, videotaped by and investigator using a digital video camera in order to analyze individual and overall exposure to heading, types of headers, and qualitatively observe heading skill (location of impact on head). Video recording included data on all HSU soccer athletes and was considered a portion of part 1 of the study. The video footage was watched in the biomechanics lab and three separate investigators recorded data. Investigators kept track of the number of individual headers, header type, area of the head impacted, and position of player heading the ball. Documented events included high-clear, driven, and flick-on headers, and header totals for the team, by position, and per player. All exposure data was

confirmed during viewing and any discrepancies between the three investigators were addressed by re-watching the incident before moving on to the rest of the film.

*Part 1- Post-season Neurocognitive Test.* After completion of the season, the neurocognitive performance of all 51 participants was measured again using the current online version of ImPACT. Participants were tested by team in a computer lab on the HSU campus. Every other computer was used in order to minimize distraction. Participants were informed that they must read all the instructions carefully and do their best (there were built in mechanisms to detect purposeful sabotage or neglect on the test). They were instructed to turn off their cell phones and refrain from talking or distracting others for the duration of the test, and that they were to raise their hands if they did not understand something or had any questions. Once all participants completed their post-season ImPACT, the PI compared their baseline performance to their post-season performance and assessed any significant differences in their composite scores.

*Part 2- Heading Trials.* The soccer coaches were asked to randomly pick six males and six females, two from each position (forward, midfielder, defender) to participate in part 2 of the study. The coaches selected an extra female, so each of the 13 participants for part 2 of the study reported to the West Gym in the kinesiology building at HSU for their initial assessment on a Saturday in September when they did not already have a practice or game scheduled. The date was chosen so as to allow the athletes to have the month of August to get re-accustomed to the rigorous training, including heading practice, which occurs early in the season. Participants were screened for exclusion criteria, including any recent head or neck injury or pain. They were informed

that they were to notify the investigator at any time if they experienced any discomfort. All 13 participants were present in the gym during the heading trials and confirmed that the prescribed speed and trajectory of the ball mimicked “easy” headers that they were accustomed to and would routinely be exposed to during competition. The presence of all participants throughout the trials was also beneficial, as they encouraged each other, “performed” for each other, and helped verify that each header was executed properly. Participants (one at a time) were fitted with the heading cap that was secured using athletic pre-wrap and cloth tape. Participants stood at a distance 35 ft (10.67 m) from the JUGS machine in a box marked by tape on the floor. They were instructed to try their hardest and perform each of the headers with their feet on the floor, using “proper heading technique” as they had been taught. Investigators were stationed at the JUGS machine and at the accelerometer base station/computer station. Once the participant called out “ready,” both stations confirmed that they were ready and the data collection began with the sound of the ball exiting the JUGS machine. The first header type was the high clear ball, which approached the participant from a high trajectory, at the bottom of a parabola (JUGS angle of 42.1 degrees). For high-clear headers, participants headed the ball using the front of their upper forehead and directed it back at the JUGS machine. Data was recorded and once the header was confirmed by everyone to be successful, the next trial was performed. A total of three successful trials were recorded for high-clear headers before moving on to driven headers. The JUGS machine was adjusted between the high-clear and driven/flick-on portions of the trials and test balls were ejected from the machine. The driven balls approached the participant from a low trajectory, straight

on (JUGS angle of 26.8 degrees). For the driven headers, participants headed the ball using the front of their upper forehead and directed it back at the JUGS machine. Data was recorded and once the header was confirmed by everyone to be successful, the next trial was performed. A total of three successful trials were recorded for driven-type headers before moving on to flick-on headers. The flick-on balls approached the participant from a low trajectory, straight on (JUGS angle of 26.8 degrees). A flick header is where the ball grazes off the head, allowing the athlete to play the ball in any direction, rather than bouncing it directly off their head in a forward motion. For the flick-on headers, participants headed the ball using the front and side of their upper forehead and directed it either to the left or the right of where they were standing. Data were recorded and once the header was confirmed by everyone to be successful, the next trial was performed. A total of three successful trials were recorded before moving on to the next participant. All participants already had extensive experience with each header type throughout their soccer training. Upon completion of their heading trials, each participant signed up for a 15 minute appointment on one of two days during the next week to come in to the biomechanics lab and have their neck strength measured. The heading trials portion of the study took a total of two hours to complete for all 13 participants.

*Part 2- Neck Strength Measures.* During their scheduled appointment time, each of the 13 participants in part 2 of the study came in to the biomechanics lab at HSU to have their linear and rotational neck strength measured. Again, they were screened for any recent head or neck injury or pain. No one was excluded based on the criteria. One at

a time, participants were asked to stand as straight as possible with a flat back against the board and then strapped to the board as tight as possible without causing excess discomfort. They were fitted with the head strap and any necessary adjustments in cord tension and height were made to ensure consistency across subjects. The device measured maximum isometric acceleration of the neck muscles. The neck strength trials began with max voluntary linear contractions. Proper linear contractions were demonstrated, showing each participant how to slide their head in a straight fore-aft motion. An investigator instructed the participant that they would need to pull as hard and steady as they could for a total of three seconds before they would be told to rest until the next trial. Investigators were stationed at the BIOPAC base/computer station, in front of the participant, and to the side of the participant. The PI would begin data collection and simultaneously instruct the participant to “pull, pull, pull... hard as you can... harder, hold it... rest.” Data was collected for three seconds and the trial was verified as valid by all investigators before moving on to the next trial. The participants were given 30 seconds rest between each trial. After three trials in the linear direction, a demonstration was given on rotational neck strength measures. The participants were told to again pull as hard and steady as they could, this time while rotating their neck forward and down, touching their chin to their collar bone. Three valid trials were collected for rotational neck strength in the same manner as linear neck strength before moving on to the next participant. The entire neck strength portion of the study took three-and-a-half hours split over two days.

### *Data Analysis*

Descriptive data were used to describe the sample and measures. Hypothesis 1 from the laboratory soccer heading analysis: neck strength will be negatively correlated with accelerations experienced by the head during bouts of routine heading, was measured using a series of Pearson product moment correlations to assess the relationships among the neck strength and heading acceleration variables. There were two hypotheses pertaining to sex differences: males will experience lower accelerations on the head during bouts of routine heading compared to females (H1), and males will exhibit greater neck strength compared to females (H2). Both hypothesis 1 and hypothesis 2 were measured using a series of separate Pearson product moment correlations for both males and females to assess sex differences in the relationships among the variables of neck strength and heading acceleration. Heading exposure was averaged across four games and athletes were separated into “low” (0 headers), “medium” (.10-4.99 headers), and “high” (5+ headers) groups. A series of 3 (heading exposure – low, medium, high) X 2 (time – pre-season, post-season) repeated measures ANOVAs for neurocognitive performance and symptoms were performed. A 2 (header status- yes, no) X 2 (time: pre-season, post-season) repeated measures ANOVA was used to assess whether header status (yes, no) had an affect on neurocognitive scores after a soccer season. A series of one-way ANOVAs for sex differences on the three header types and neck strength measures was conducted to analyze sex differences in heading. All results were analyzed using SPSS Version 18.0. A significance level of  $p < .05$  was set for all statistical tests.

## CHAPTER THREE

### *Results*

#### *Evaluation of Hypotheses and Exploratory Questions*

*Laboratory Soccer Heading Analysis Hypothesis 1 – Neck strength will be negatively correlated with accelerations experienced by the head during bouts of routine heading.* A series of Pearson product moment correlations were performed to assess the relationships among the neck strength and soccer heading accelerations variables. A summary of the correlations is presented in Table 2. The results supported positive correlations between neck strength and accelerations experienced by the head during bouts of flick-on type headers. Accelerations (g) measured during flick-on header trials were positively associated with max linear,  $r(13) = .57, p = .02$ , and max rotational,  $r(13) = .61, p = .01$ , contractions.

Table 2.

*Results for Heading Analysis Hypothesis 1 – Relationship of Heading Accelerations to Neck Strength Correlations*

	<i>High-clear Header Accelerations</i>	<i>Driven Header Accelerations</i>	<i>Flick-on Header Accelerations</i>
<i>Linear Neck Strength</i>	.21 (p=.25)	.44 (p=.07)	.57* (p=.02)
<i>Rotational Neck Strength</i>	-.13 (p=.33)	.16 (p=.30)	.61** (p=.01)

*Note: \*p < .05, \*\*p<.01*

*Sex Differences Hypothesis 1 – Males will experience lower accelerations on the head during bouts of routine heading compared to females. Sex Differences Hypothesis 2 – Males will exhibit greater neck strength compared to females.* A series of separate Pearson product moment correlations were performed for both males and females to assess sex differences in the relationships among the variables alluded to above. A summary of the correlations is presented in Table 3. For males, driven-type headers were positively correlated with high clear-type headers,  $r(6) = .76, p = .04$ . Male athletes that experienced the greatest accelerations while performing driven-type headers, also experienced the greatest accelerations while performing high clear-type headers. For females, a negative correlation was supported between linear neck strength and driven

type headers,  $r(7) = -.73, p = .03$ . As linear neck strength (N) increased for females, the accelerations (g) experienced by the head during driven-type header trials decreased. In addition, a number of non-significant trends were identified among the separate correlations for males and females. These trends will be addressed in the discussion section.

Table 3.

*Results for Sex Differences Hypotheses – Neck Strength and Heading Accelerations**Correlations*

	<i>High-clear Header</i>		<i>Driven Header</i>		<i>Flick-on Header</i>	
	<i>Accelerations</i>		<i>Accelerations</i>		<i>Accelerations</i>	
	<i>M(n=6)</i>	<i>F(n=7)</i>	<i>M(n=6)</i>	<i>F(n=7)</i>	<i>M(n=6)</i>	<i>F(n=7)</i>
<i>Linear Neck Strength</i>	.38	-.53	.50	-.73*	.53	.54
	(p=.23)	(p=.11)	(p=.16)	(p=.03)	(p=.14)	(p=.11)
<i>Rotational Neck Strength</i>	-.41	-.21	-.17	-.65	.33	.64
	(p=.21)	(p=.33)	(p=.38)	(p=.06)	(p=.26)	(p=.06)
<i>High-clear Header</i>			.76*	.45	.22	.22
<i>Accelerations</i>			(p=.04)	(p=.16)	(p=.34)	(p=.32)
<i>Driven Header</i>	.76*	.45			-.04	-.43
<i>Accelerations</i>	(p=.04)	(p=.16)			(p=.47)	(p=.17)
<i>Flick-on Header</i>	.22	.22	-.04	-.43		
<i>Accelerations</i>	(p=.34)	(p=.32)	(p=.47)	(p=.17)		

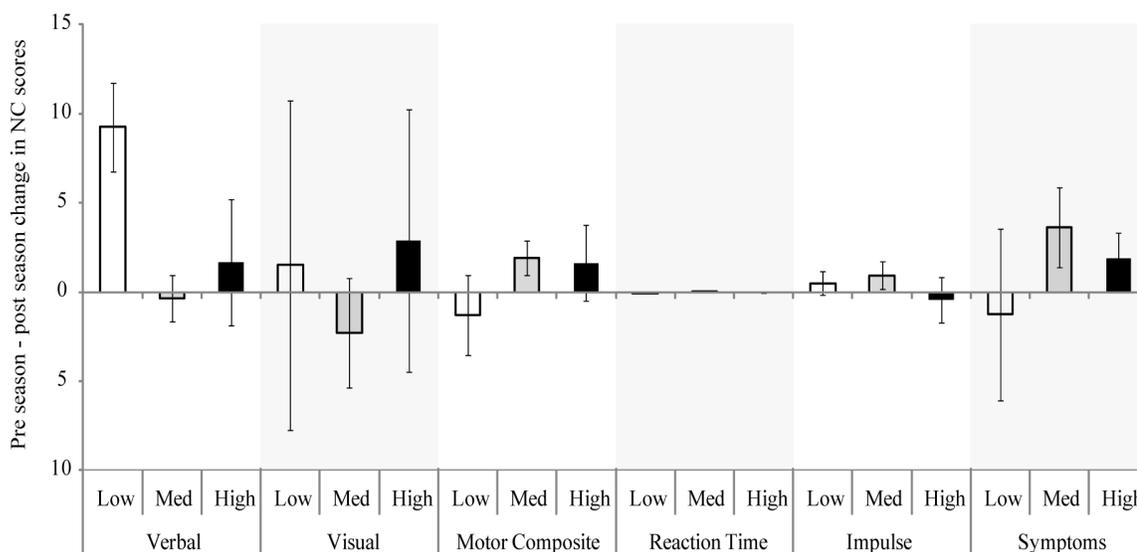
Note: \*p < .05

*Pre- to Post-season Neurocognitive Performance Changes*

*Heading Exposure.* The results of a series of 3 (heading exposure – low, medium, high) x 2 (time – pre-season, post-season) repeated measures ANOVAs supported no significant changes in neurocognitive test scores from pre-season to post-season for the three heading exposure groups. Figure 1 illustrates the results of the pre- to post-season neurocognitive and symptom scores for each header group. Although, there were no significant differences, the medium exposure group demonstrated a non-significant decrease in verbal and visual memory scores, as well as a non-significant increase in symptom scores over the course of the season. The high exposure group also demonstrated a non-significant increase in symptom scores over the course of the season. The low exposure group exhibited a non-significant decrease in motor composite scores over the course of the season.

Figure 1.

*Results for Neurocognitive Performance Hypothesis – The Relationship between Heading Exposure and Neurocognitive Test Performance.*



*Player Header Status.* The results of a 2 (header status- yes, no) X 2 (time: pre-season, post-season) repeated measures ANOVA supported a significant header status by time interaction for visual memory scores (see Figure 2). Specifically, the heading group declined in visual memory scores from pre- ( $M = 78.75$ ,  $SD = 16.16$ ) to post-season ( $M = 72.70$ ,  $SD = 15.37$ ), whereas, the non-heading group increased in visual memory scores from pre- ( $M = 70.67$ ,  $SD = 17.52$ ) to post-season ( $M = 81.89$ ,  $SD = 14.52$ ). A complete summary of the means and standard deviations for the ANOVA are presented in Table 4.

Figure 2.

*Results for Neurocognitive Performance – Heading Status and Changes in Visual Memory Scores*

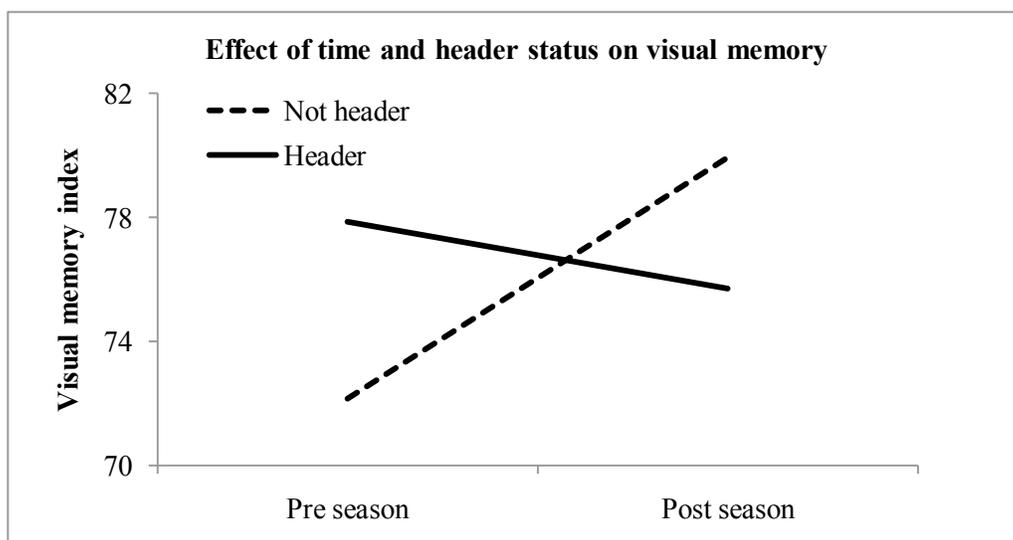


Table 4.

*Results for Neurocognitive Performance Hypothesis – The Relationship between Heading Exposure and Neurocognitive Test Performance.*

	<i>Header</i>		<i>Non-header</i>	
	<i>(n=20)</i>		<i>(n=9)</i>	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<i>Verbal Memory Pre-season</i>	89.95	7.94	88.11	8.39
<i>Verbal Memory Post-season</i>	91.45	6.11	88.00	9.25
<i>Visual Memory Pre-season</i>	78.75*	16.16*	70.67*	17.52*
<i>Visual Memory Post-season</i>	72.70*	15.37*	81.89*	14.52*
<i>Motor Composite Pre-season</i>	41.78	6.45	38.76	4.03
<i>Motor Composite Post-season</i>	42.09	8.47	38.71	4.13
<i>Reaction Time Pre-season</i>	.55	.09	.56	.07
<i>Reaction Time Post-season</i>	.54	.06	.58	.10
<i>Symptoms Pre-season</i>	3.40	4.17	4.89	6.70
<i>Symptoms Post-season</i>	6.25	7.87	7.11	7.06

*Note: \*p < .05*

#### *Sex Differences in Heading*

The results of a series of one-way ANOVAs supported the hypothesis for sex differences in one of the three header types and in both of the neck strength measures. Specifically, accelerations (g) experienced by the head during driven type headers were

significantly ( $F[1, 12] = 5.15, p = .04$ ) higher for males ( $M = 14.07, SD = 1.45$ ) than females ( $M = 12.43, SD = 1.16$ ). There was also a significant main effect for sex on both linear ( $F[1, 13] = 9.84, p = .009$ ), and rotational neck strength ( $F[1, 13] = 10.49, p = .007$ ). A complete summary of the means and SDs for males and females from the ANOVA are presented in Table 5.

Table 5.

*Results for Sex Differences Hypotheses – Means and Standard Deviations by Sex*

	<i>Males</i>	<i>Females</i>
	<i>(n= 6)</i>	<i>(n= 7)</i>
	<i>M(SD)</i>	<i>M(SD)</i>
<i>Linear Neck Strength</i>	395.81 (113.24)**	262.21 (51.50)**
<i>Rotational Neck Strength</i>	435.03 (123.03)**	271.16 (78.95)**
<i>High-Clear Header Accelerations</i>	14.00 (1.44)	13.59 (1.01)
<i>Driven Header Accelerations</i>	14.07 (1.45)*	12.43 (1.16)*
<i>Flick-on Header Accelerations</i>	16.11 (1.04)	13.71 (2.91)

*Note:* \* $p < .05$ ; \*\* $p < .01$

## CHAPTER FOUR

### *Discussion*

#### *Summary of Results*

The purpose of this study was to conduct a comprehensive, multidisciplinary, prospective study of soccer heading and its potential effects among male and female collegiate soccer players. The comprehensive approach employed in the current study involved both field research and laboratory testing of several variables pertaining to three primary areas: 1) changes in neurocognitive performance and symptoms across a competitive season, 2) heading accelerations and neck strength, 2), and 3) sex differences in the preceding variables.

With regard to neurocognitive changes, there were no significant neurocognitive changes over the course of the season for the overall sample. However, when looking at differences within each exposure group, the medium exposure group, which was the largest group ( $n = 17$ ), had a non-significant decrease in verbal and visual memory scores over the course of the season as well as an increase in symptom scores. The high exposure group also had an increase in symptom scores over the course of the season. One of the main research findings of this study was that athletes who self-reported as headers had a significant decrease in visual memory scores over the span of a season, whereas those athletes who self-reported as non-headers increased their visual memory scores.

Comparisons of heading accelerations and neck strength supported several non-significant trends and significant relationships for both header type and sex. With regard to heading and neck strength during flick-on type headers, the greatest accelerations were experienced among athletes with the greatest neck strength (both linear and rotational), regardless of sex. This positive association between neck strength and accelerations experienced during bouts of heading was only significant for flick-on type headers. A number of non-significant trends were also observed, including a positive association between linear neck strength and driven header accelerations for males, but not for females, and a negative association between linear neck strength and high-clear header accelerations for females. In addition, two non-significant trends for females suggested that 1) rotational neck strength might be positively associated with flick-on accelerations and negatively associated with driven accelerations and 2) linear neck strength was negatively associated with accelerations experienced during both driven and high clear headers. Not surprisingly, accelerations experienced during driven headers and high clear headers were positively correlated, however the association was only significant for males. For both males and females, driven header accelerations were negatively associated with flick-on accelerations. The exploration of sex differences in the variables in the study yielded only two significant findings related to accelerations experienced during heading and neck strength measures. Males experienced significantly greater accelerations for flick-on type headers, however, there were no significant differences between males and females for either driven or high-clear type headers. The neck strength of males was significantly stronger across both linear and rotational measures.

### *General Discussion*

The most important findings of the current study were: 1) soccer heading over the course of a season did not have any significant detrimental effects on neurocognitive performance, however, when looking at athletes who reported themselves as headers versus those who did not, the non-headers fared better in visual memory scores over the course of a season; 2) with regard to the role of neck strength in soccer heading, stronger muscles did not seem to attenuate accelerations experienced by the head during bouts of heading; and; and 3) sex differences were apparent in both neck strength and heading accelerations, but not in the other variables of interest in the study.

#### *Lack of Changes in Neurocognitive Performance and Symptoms over the Season.*

The major finding of the current study was that there were no significant changes in neurocognitive performance after a season of soccer heading. Previous studies (Downs & Abwender, 2002; Webbe & Ochs, 2003; Witol & Webbe, 2003) have pointed to long-term effects from purposeful heading, however, these studies were cross-sectional in nature, used pen and pencil neurocognitive tests, self-reported heading exposure, and all male, highly-skilled, populations. The current study was prospective in nature, utilized computerized neurocognitive testing measures, and verified exposure through researcher observation and video analysis. The only significant finding from the present study arose when headers versus non-headers were looked at and a significant reduction in visual memory scores was found in the header group compared to the non-header group. This reduction among the header group could be due to the coup-contrecoup nature of heading a soccer ball. Coup-contrecoup injuries can occur without an impact, from acceleration or

deceleration alone (Hardman & Manoukian, 2002). When the ball impacts the forehead, the brain first impacts the front of the skull before bouncing back and impacting the back of the skull (Gengenbach & Hyde, 2007). Neck strength, technique, and a number of other variables could affect the linear force of those impacts, but the biomechanics is still the same. Both the frontal lobe and, most notably, the occipital (back) lobe play a large role in the visual pathways in the brain. Perhaps the repetitive coup-contrecoup nature of heading a ball over the course of a soccer season reduces the brains visual memory capabilities. This is not to say that the effects would be long-term, but it is worth noting that when tested at the end of a soccer season, visual memory scores were significantly lower among the header group when compared to the non-header group.

Neurocognitive scores may actually increase slightly across time due to potential learning effects. This concept of a learning effect is in line with the results from the current study where there was an improvement in visual memory scores among non-headers, but not among headers in the current study. Previous research has looked at recency and frequency of soccer heading among males aged 16-34 years and found decreases in neurocognitive scores (Webbe & Ochs, 2003). The current study found no effect for soccer heading over the course of a season on neurocognitive scores. The Webbe and Ochs (2003) study used only self-report measures and a different neurocognitive test battery than the current study. The same study also used a less homogenized age sample, but all the participants were males, and actual heading impacts were not observed. The current study compared both males and females and kept record of head impacts. In addition, decreases in neurocognitive scores observed during the

Webbe and Ochs (2003) study could have been due to the immediate (recency) effects of exertion on neurocognition.

*Heading and Neck Strength.* Neck strength was positively correlated with accelerations experienced during flick-on headers. Both linear and rotational neck strength, regardless of sex, seemed to play a role during this type of header that requires the athlete to redirect the soccer ball while letting it skim off the forehead. Based on a single previous study (Tierney et al., 2008) that measured neck strength in conjunction with soccer heading accelerations, we expected to find that neck strength would be negatively associated with the accelerations experienced by the head during heading trials across the board. However, the findings in the current study did not support this hypothesis or previous findings. The lack of a finding may have been due to several factors including, the small sample size, the technique of each individual athlete, and differences in the utilization of specific neck muscles to brace for and redirect each header. Tierney and colleagues (2008) concluded that females had 50 percent less neck strength than males, respectively, and experienced 32 and 44 percent greater head accelerations while wearing two different headgear apparatuses (21.52 +/- 5.47 g and 21.84 +/- 5.34 g for females versus 16.27 +/- 6.16 g and 15.20 +/- 5.83 g for males), but only ten percent greater head accelerations during the control headers without headgear. The current study observed accelerations among females at 13.24 +/- 1.69 g versus 14.73 +/- 1.31 g among males. In contrast to the present study, the Tierney (2008) study focused on head accelerations while wearing headgear, tested only one header type (driven), had proportionally more females than males who participated (29 versus 15),

and used college-aged volunteer participants who had “at least five years heading experience,” not necessarily collegiate athletes over the course of a season. The current study differed from the Tierney (2008) study in results, likely because the central focus of the study was not headgear and included a more homogenized population (Division-II athletes) with a higher skill level than the volunteers in the Tierney study. The greater accelerations experienced by females in the Tierney (2008) study could have been due to weaker technique, not merely neck strength.

Only three published research studies have examined accelerations during soccer heading (Naunheim et al., 2003; Self et al., 2006; Tierney et al., 2008). Two of the studies did not involve human participants, but rather measured accelerations using dummies that received simulated soccer heading impacts (Naunheim et al., 2003; Self et al., 2006). The Self and colleagues (2006) study focused on the observation of accelerations associated with heading a soccer ball at prescribed speeds. Like the Tierney (2008) study, Naunheim et al. (2003) focused on whether or not headgear would attenuate the accelerations experienced by the head during bouts of heading. The present study was the first of its kind to use collegiate soccer athletes in comparing neck strength and accelerations experienced during bouts of routine heading. The accelerations observed during bouts of heading with human participants were similar to the ones observed in the Tierney (2008) study, with averages ranging from approximately 10 – 25 g. The dummy studies utilized balls released at higher speeds, and therefore, reported relatively higher g accelerations.

Not surprisingly, accelerations experienced during driven headers and high clear headers were positively correlated, however the association was only significant among males. For both males and females, driven header accelerations were negatively associated with flick-on accelerations. Our study also produced a number of non-significant trends regarding neck strength and accelerations during heading. A non-significant positive association between linear neck strength and driven header accelerations was observed for males, but not for females. Anecdotally, the current researcher observed that males appeared to be aggressively bracing and engaging their neck muscles in order to meet the ball with a rigid head-neck segment and forcefully direct the ball back toward the target more so than did females. This anecdotal evidence suggests that males may execute their headers with better and more consistent technique than females. However, specific accelerations imparted to the ball were not recorded in this study.

Sex comparisons for neck strength and heading accelerations yielded a number of non-significant trends, including a negative association between linear neck strength and high-clear header accelerations for females. This trend follows our original hypothesis that increased neck strength would lead to a reduction in heading accelerations. Perhaps the females with greater neck strength, compared to other females in the study, were able to brace better for high-clear headers and reduce the overall acceleration experienced by the head. The same trend of a negative association for linear neck strength and high-clear header accelerations did not occur among males. There was also a non-significant trend for males toward a negative association between rotational neck strength and high-clear

headers. Male athletes may be more effective at getting their body and heads over the ball (meeting the ball at a higher place in its arc) and using their rotational neck strength to brace and redirect the ball, while females are merely bracing for the impact using their linear neck strength. Another non-significant trend for females was a negative association between both neck strength measures and driven type header accelerations. In line with what was previously stated and expected, it appears that females with greater neck strength were able to moderate accelerations experienced by the head while performing driven type headers. It is possible that females with greater neck strength, when compared to other females in the study, were able to brace better for driven headers and reduce the overall acceleration experienced by the head. Again, the opposite trend appeared for males: linear neck strength was positively associated with driven header accelerations.

*Sex Differences.* Surprisingly, there were no significant sex differences in the accelerations (g) experienced by the head during the high clear heading trials. Based on differences in neck strength and potentially technique and practice exposure, it was logical to expect that high-flighted balls (i.e., clear headers) would be the most problematic for females. As such, it was hypothesized that women would experience greater accelerations on the head across all three header types. The results, however, indicated that greater accelerations were observed for males across all three header types, with the only significant sex difference showing up during driven headers. There were no significant differences between sexes for high clear or flick-on headers, which suggests that the accelerations experienced by females during those two header types were closer

in magnitude to their male counterparts than during driven headers. This finding helps to illustrate, in line with our hypothesis, that females are actually experiencing greater relative accelerations during high clear and flick-on headers when compared to males. This result, in turn, seems to add to the notion that high clear balls may be more problematic for females than males, perhaps due to technique and neck strength.

### *Limitations*

The current study was limited by several factors. For example, the generalizability of the findings is limited to the nature and size of the sample, which only included 51 NCAA Division-II male and females collegiate soccer players, aged 18-22 years. As such, the findings do not apply to youth players, professionals, or even higher and lower level NCAA Division I and III level players. Moreover, many of the non-significant trends that were may have changed if more athletes had participated in the heading and neck strength portions of the study. In addition, this study was limited to only one collegiate season and heading exposure was only recorded for a sample of four home games and four practices. As such, sampling bias may have played a role in the results. Another limitation of this study was the laboratory setting in which the heading and neck strength trials were collected. The lab setting provided strong internal validity, but limited external validity. This lack of external validity is often an obstacle with experiments as it is important to control and standardize the tests as much as possible. The only effective method for collecting information on heading accelerations would be to attach accelerometers to the heads of each player and collect heading accelerations with balls moving at full speeds usually observed during competitions. However, such a study

would be impractical for players and unrealistic financially. Hence, a controlled laboratory setting that mimics real-world heading scenarios is the next best environment. Finally, some studies have used intraoral accelerometers (mouthpiece), which have been found to be valid and reliable in measuring head accelerations during heading trials (Higgins, Halstead, Snyder-Mackler, Barlow, 2007; Tierney et al., 2008). However, the use of mouthpiece accelerometers was not possible for the current study due to resource limitations. Moreover, the triaxial accelerometers used in the current study have been reported to be valid to measure heading accelerations (Naunheim et al, 2003).

#### *Future Research*

The current study provided a comprehensive, multidimensional methodological basis for future research on the effects of soccer heading. Ideally, future research would obtain full exposures across a season and include multiple seasons and measurements in a longitudinal study. Conducting the study over the span of four collegiate soccer seasons would be ideal, but even extending it across two seasons would allow us to follow the same athletes throughout their collegiate careers and undoubtedly add to the robustness of the results. In addition, expanding the study to include youth, high school, and other levels of athletes would allow for direct comparisons of the potential differences in heading exposure and effects compared to the current sample of collegiate soccer players. Future research should also focus on the precise effect of neck muscle strength and activations in attenuating accelerations experienced during soccer heading. It is unclear if the anecdotal observation that females have poorer heading technique and brace less

when heading is true, and if so, what role these behaviors play in the outcomes potentially associated with heading across a soccer career.

More in-depth biomechanical research that would aid in the understanding of kinematics, angles, accelerations, and EMG associated with soccer heading should also be conducted. Assessments of muscle activity, angular, and timing information would allow for a better examination of factors influencing potential individual differences during bouts of heading and allow researchers to glean better insight into the role of each variable. In addition, mouthpiece accelerometers custom-fitted to each athlete would minimize the likelihood of outside forces affecting the accelerations measured during bouts of routine heading. Acceleration transducers could be embedded in the target (a pad) in order to record accelerations on the ball from the heading maneuver of the athlete. This would allow us to not only observe the acceleration of the ball-head, but also the resultant acceleration that the athlete exerted on the ball as it arrives at a target. Finally, additional outcome measures such as dizziness, balance, and migraine-like symptoms should also be assessed in relation to heading exposure.

### *Implications*

The current study's finding did not support effects for soccer heading exposure on neurocognitive performance. However, there was a non-significant trend that heading exposure was associated with increased concussion symptoms among players who head the ball an average of .01 – 4.99 times per game. As such, it is important for players, coaches and to be aware of changes in symptoms and be sure to involve trained sports medicine professionals when these symptoms are present.

The results of the current study also suggest that neck strength plays a role in accelerations experienced while heading a soccer ball. However, it may not be as simple as stronger neck muscles result in reduced accelerations on the head. It is possible that technique plays a role and that timing and preparation before heading a soccer ball are the best ways to attenuate accelerations on the head. Soccer athletes should learn proper technique as soon as they begin heading a ball and that technique should continue to be stressed throughout their careers. More importantly, young athletes should not begin heading the ball until they have the appropriate neck strength. Twelve is an age that has been tossed around as developmentally appropriate, but this would depend on the individual child and could be an older age for females. This has important implications for coaches who should stress proper technique to their players and be aware that some young athletes may not be ready to begin heading. Athletes should be proficient at heading the soccer ball using proper technique in a controlled practice setting long before they try to head the ball in any type of game setting.

In addition, the findings in the current study imply that males and females differ in heading technique related to neck strength and heading accelerations. Again, early mastery of technique and awareness about the mechanics of soccer heading and possible negative effects from ineffective heading, in particular, should be stressed at all ages, but not until an athlete is age appropriate for heading.

### *Conclusion*

Using both laboratory heading analyses and observed heading exposures, the current study has provided new insight and data about the strength and accelerations

involved in heading, as well as the neurocognitive effects of heading. The most important findings of the study were: 1) the role of neck strength in soccer heading is not as simple as thought before, that is to say that stronger muscles do not necessarily attenuate accelerations experienced by the head during bouts of heading, 2) among athletes who head the ball, routine soccer heading over the course of a season does not appear to have any significant detrimental effects on neurocognitive performance, however, when looking at athletes who head the ball versus those who do not, the non-headers fare better in neurocognitive visual memory performance over the course of a season, and 3) sex differences are apparent in both neck strength and heading accelerations.

In conclusion, the current study was the first of its kind to provide a comprehensive, prospective analysis of soccer heading. From here, future studies should be conducted using the same methodology, but increase the number of participants and extend the number of seasons over which data is collected. There is also a need for more in-depth biomechanical research using a larger sample of human participants across multiple skill and age levels during bouts of routine heading. Hopefully, the results attained from the current study will provide the groundwork from which researchers can develop a better understanding of the complexities of soccer heading and the possible effects from heading a soccer ball over the span of an athlete's career.

*References*

- Anderson, T. E., Arnason, A., Engebretsen, L., & Bahr, R. (2004). Mechanisms of head injuries in elite football. *British Journal of Sports Medicine*, 38(6), 690-696.
- Andersen, T. E., Tenga, A., Engebretsen, L., & Bahr, R. (2004). Video analysis of injuries and incidents in Norwegian professional football. *British Journal of Sports Medicine*, 38(5), 626-631.
- Barnes, B. C., Cooper, L., Kirkendall, D. T., McDermott, T. P., Jordan, B. D., Garrett, W. E., Jr. (2008). Concussion history in elite male and female soccer players. *Research Quarterly for Exercise and Sport*, 79(2), 235-244.
- Bauer, J. A., Thomas, T. S., Cauraugh, J. H., Kaminski, T. W., & Hass, C. J. (1998). Impact accelerations and neck muscle activity in heading by collegiate female soccer players. *American Journal of Sports Medicine*, 26(3), 433-438.
- Broglio, S. P., Ju, Y., Broglio, M. D., & Sell, T. C. (2003). The efficacy of soccer headgear. *Journal of Athletic Training*, 38(3), 220-224.
- Business Editors and Sports Writers 2002 FIFA World Cup. Lebanon, N. H., Sheffield, England, Wavre, Belgium, and Yamagata, Japan--(BUSINESS WIRE)--May 20, 2002--Three collaborating groups of researchers.
- Bussone, W. R. (2005). *Linear and angular head accelerations in daily life* (Master's thesis). Virginia Polytechnic Institute and State University, Blacksburg, VA.
- Cagnie, B., Cools, A., De Loose, V., Cambier, D., & Danneels, L. (2007). Differences in isometric neck muscle strength between healthy controls and women with chronic

- neck pain: The use of a reliable measurement. *Archives of Physical and Medical Rehabilitation*, 88(11), 1441-1445.
- Covassin, T., Swanik, C. B., Sachs, M. L. (2003). Sex differences and the incidence of concussion among collegiate athletes. *Journal of Athletic Training*, 38(3), 238-244.
- Delaney, J. S. (2008). Canadian study examined more than 260 adolescents playing club soccer. *British Journal of Sports Medicine*, 42, 110–115.
- Downs, D. S., & Abwender, D (2002). Neuropsychological impairment in soccer athletes. *Journal of Sports Medicine and Physical Fitness*, 42, 107-107.
- Drapeau, C. E., Bastien-Toniazzo, M., Rous, C., & Carlier, M. (1998). Nonequivalence of computerized and paper-and-pencil versions of Trail Making Test. *Neurology*, 51(3), 791-796.
- Gengenbach, M. S., & Hyde, T. (2007). *Conservative Management of Sports Injuries*. Sudbury, Massachusetts: Jones & Bartlett Publishers.
- Hardman, J. M., & Manoukian, A. (2002). Pathology of head trauma. *Neuroimaging Clinics of North America*, 12(2), 175-187.
- Iverson, G. L., Lovell, M., & Collins, M. (2003). Interpreting change on ImPACT following sport concussion. *Clinical Neuropsychology*, 17, 460-467.
- Iverson, G. L., Lovell, M., & Collins, M. W. (2005). Validity of ImPACT for measuring processing speed following sports-related concussion. *Journal of Clinical and Experimental Neuropsychology*, 27, 683-689.

- Kaminski, T. W., Cousino, E. S., & Glutting, J. J. (2008). Examining the relationship between purposeful heading in soccer and computersized neuropsychological test performance. *Research Quarterly for Exercise and Sport*, 79(2), 235-244.
- Kirkendall, D. T., & Garrett, E., Jr. (2001). Heading in soccer: Integral skill or grounds for cognitive dysfunction? *Journal of Athletic Training*, 36(3), 328–333.
- Matser, J. T., Kessels, A. G., Jordan, B. D., Lezak, M. D., & Troost (2001). Chronic traumatic brain injury in professional soccer players. *Journal of Sports Science*, 19(3), 171-179.
- Naunheim, R. S., Bayly, P. V., Standeven, J., Neubauer, J. S., Lewis, L. M., & Genin, G. M. (2003). Linear and angular head accelerations during heading of a soccer ball. *Medicine and Science in Sports and Exercise*, 35(8), 1406–1412.
- Naunheim, R. S., Ryden, A., Standeven, J., Genin, G., Lewis, L., Thompson, P., & Bayly, P. (2003). Does soccer headgear attenuate the impact when heading a soccer ball? *Academy of Emergency Medicine Journal*, 10(1), 85-90.
- Naunheim, R. S., Standeven, J., Richter, C., Lewis, L., M. (2000). Comparison of impact data in hockey, football, and soccer. *Journal of Trauma*, 48(5), 938-941.
- Rutherford, A., Stephens, R., & Potter, D. (2003). The neuropsychology of heading and head trauma in Association Football (soccer): A review. *Neuropsychological Review*, 13, 153-179.
- Rutherford, A., Stephens, R., Potter, D., & Fernie, G. (2005). Neuropsychological impairment as a consequence of football (soccer) play and football heading:

Preliminary analyses and report on university footballers. *Journal of Clinical and Experimental Neuropsychology*, 27(3), 299-319.

Schatz, P., Pardini, J. E., Lovell, M. R., Collins, M. W., & Podell, K. (2006). Sensitivity and specificity of the ImPACT test battery for concussion in athletes. *Archives of Clinical Neuropsychology*, 21, 91-99.

Schmitt, D. M., Hertel, J., Evans, T. A., Olmstead, L. C., & Putukian, M. (2003). Effect of an acute bout of soccer heading on postural control and self-reported concussion symptoms. *International Journal of Sports Medicine*, 25(5), 326-331.

Soccer in the United States. (2010, April 15). In *Wikipedia, The Free Encyclopedia*.

Retrieved 02:20, April 25, 2010, from

[http://en.wikipedia.org/w/index.php?title=Soccer\\_in\\_the\\_United\\_States&oldid=424240397](http://en.wikipedia.org/w/index.php?title=Soccer_in_the_United_States&oldid=424240397)

Soderman, K., Bergstrom, E., Lorentzon, R., & Alfredson, H. (2000). Bone mass and muscle strength in young female soccer players. *Calcified Tissue International*, 67(4), 297-303.

Tierney, R. T., Higgins, M., Caswell, S. V., Brady, J., McHardy, K., Driban, J. B., & Darvish, K. (2008). Sex differences in head acceleration during heading while wearing soccer headgear. *Journal of Athletic Training*, 43, 578-584.

Tysvaer, A. T., Sortland, O., Storli, O. V., & Lochen, E. A. (1992). Head and neck injuries among Norwegian soccer players: A neurological, electroencephalographic, radiologic and neuropsychological evaluation. *Norwegian*, 112(10), 1268-1271.

Tysvaer, A., & Storli, O. (1981). Association football injuries of the brain. *British Journal of Sports Medicine*, *15*, 163-166.

Webbe, F. M., & Ochs, S. R. (2003). Recency and frequency of soccer heading interact to decrease neurocognitive performance. *Applied Neuropsychology*, *10*(1), 31-41.