HEADGEAR DOES NOT IMPROVE NEUROCOGNTIVIE FUNCTION AND
BALANCE PERFORMANCE FOLLOWING ACUTE BOUTS OF SOCCER
HEADING

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ABSTRACT

LAUREN M ASKEY: HEADGEAR DOES NOT IMPROVE NEUROCOGNTIVIE
FUNCTION AND BALANCE PERFORMANCE FOLLOWING ACUTE BOUTS OF
SOCCER HEADING
(Under the direction of Steve Zinder)

Our purpose was to investigate the effects of the Full90^{TM} protective headband on the Sport

Concussion Assessment Tool2 (SCAT2), Balance Error Scoring System (BESS), Simple

Reaction Time (SRT), and Sensory Organization Test (SOT) scores following two bouts of

heading using active, healthy college-aged soccer players. The study utilized a repeated

measures design involving baseline testing followed by two subsequent sessions, including a

heading intervention, performed with and without the Full90^{TM} headgear. Totally within

repeated measure ANCOVAs were computed with neck musculature strength and headgear

satisfaction serving as covariates. Detriments were not observed in the SCAT2, BESS, SRT,

or composite SOT scores following heading sessions ($p \geq 0.05$). Wearing soccer headgear

during the heading activity did not influence any of the scores ($p \geq 0.05$). Results suggest

that acute bouts of heading do not lead to impairments on clinical concussion measures and

wearing headgear provides no further protection in this regard.

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List of Abbreviations

ADP- adenosine triphosphate

ANAM- automated neuropsychological assessment metrics

BESS- balance error scoring system

BTA- brief test of attention

COG- center of gravity

CPT- continuous processing test

CRT- choice reaction time

CSF- cerebral spinal fluid

CVLT- California verbal learning test

FRT- facial recognition test

GFAP- glial fibrillar acidic protein

GSC- graded symptom checklist

HA- headache

HHD- hand- held dynamometer

HIP- head impact power

IDR- injury density ratio

ImPACT- immediate post-concussion assessment and cognitive testing

MRI- magnetic resonance imaging

MTBI- mild traumatic brain injury

MTH- math processing

NCAA- National Collegiate Athletic Association

PASAT- paced auditory serial addition test

ROCF- Rey-Osterrieth complex figure test

RPM- Progressive Matrices Test

SAC- standardized assessment of concussion

SCAT- sport concussion assessment tool

SDMT- symbol digits modalities test

SOT- sensory organization test

SRT- simple reaction time

STN- Sternberg memory

TOL- Tower of London

CHAPTER I

INTRODUCTION

Soccer is distinguished as the most popular team sport worldwide, with over 240 million active participants (Federation Internationale de Football Association, 2005; Kaminski, Wikstrom, Gutierrez, & Glutting, 2007). Head injuries have become a major concern in the sport, in part due to the purposeful use of the head to advance the ball, which is inherent in the game. During one competitive season, professional Dutch soccer players have been reported to perform approximately eight hundred headers (Matser, Kessels, Jordan, Lezak, & Troost, 1998). This can lead to cumulative impacts totaling nearly two thousand throughout a playing career (Tysvaer & Storli, 1981). It is often debated whether the cumulative effect of these blows is significant enough to contribute to neurocognitive deficits in soccer athletes.

Although the connection between the act of heading and concussions has not been confirmed, soccer players sustain a relatively high incidence of concussion. Barnes et al. (1998) interviewed a group of soccer players at the United States Olympics Festival, and found that males possessed a 50% chance of sustaining a concussion during a ten year career, while women had a 22% risk, with 89% of males and 43% of females suffering a head injury at some point during their soccer careers (Barnes et al., 1998). A subsequent study illustrated that among female collegiate soccer players, approximately 57% had suffered a concussion

and 48% faced multiple concussive events during their playing career (Kaminski & Dede, 2002). Considerable thought has examined neck musculature as a contributor to the sex discrepancy in concussion incidence. Males have been shown to possess greater isometric strength, neck girth, as well as head-neck segment mass and length (Mansell, Tierney, Sitler, Swanik, & Stearne, 2005). In addition to the possible involvement of neck musculature strength, the physical cause of concussions remains controversial. Some reports indicate that ball contact can lead to injury, while others suggest that concussions only result from contact with opponents or goalposts (Barnes et al., 1998; Boden, Kirkendall, & Garrett, 1998; Tysvaer & Storli, 1981). Regardless of whether the skill of heading directly leads to concussion, the high head injury statistics found in soccer warrant the need for further investigation.

Although heading may not cause concussion, there still exists the possibility of subconcussive effects resulting from the skill. These consequences could potentially produce minor neurocognitive function and balance performance impairments. This risk is currently a major area of interest in literature. However, the existing research on repetitive subconcussive impacts from heading is limited and is not comprehensive. This literature is divided between analyses of neurocognitive function following a prolonged period of heading and those subsequent to acute heading bouts. The studies that fall into the former group are divergent in the results produced. One particular project found that soccer players, especially those who were considered recent headers, performed worse on a variety of neurocognitive tests (Webbe & Ochs, 2003). Conversely, other researchers reported no relationship between heading and neuropsychological functioning (Kaminski, Cousino, & Glutting, 2008). The absence of impairments was supported by Stephens et al. (2005), who

found that no neuropsychological tests were influenced by cumulative heading, prior head injuries, or their interaction (Stephens, Rutherford, Potter, & Fernie, 2005). A final project summarizes the disparity, in that it reported statistically significant results on some testing instruments but not others (Ellemberg, Leclerc, Couture, & Daigle, 2007).

Considerable thought has also been dedicated to the possibility of neurocognitive deficits resulting from an acute soccer heading bout. The first study investigating acute heading indicated that the skill was not detrimental to neuropsychological performance (Putukian, Echemendia, & Mackin, 2000). Additional research regarding brief periods of heading examining balance-sensory interactions again found no impairments (Broglio, Guskiewicz, Sell, & Lephart, 2004; Mangus, Wallmann, & Ledford, 2004). Although this research points toward acute heading session being safe for athletes, symptoms do appear to be altered by the skill. Following an acute heading bout, concussive symptoms were found to be greater twenty four hours after the heading protocol (Schmitt, Hertel, Evans, Olmsted, & Putukian, 2004). The obvious disparity in research makes it impossible to conclude whether heading sessions are detrimental to soccer players.

Despite the fact that current research does not definitively report that soccer heading is harmful to athletes, companies have responded to the potential of impairments. Manufacturers have developed a variety of protective headbands, to be worn by soccer players in an attempt to dissipate the forces absorbed by the head following heading. Similar to other heading literature, foundational laboratory research has been contradictory in nature. Forceplate readings found headgear decreased forces by 12.5% (Broglio, Ju, Broglio, & Sell, 2003). Conversely, headform research revealed that headgear was not effective at diminishing the impact from the soccer ball (Withnall, Shewchenko, Wonnacott, & Dvorak,

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2005). When applied clinically, Delaney et al. (2008) found over the course of a season, that

the use of soccer headgear by females reduced the odds of suffering a concussion (Delaney,

Al-Kashmiri, Drummond, & Correa, 2008). Only one study to date examined the impact of

the headgear during acute heading bouts with regard to clinical measures (Janke, 2006). The

researchers found that the protective headband did not influence neurocognitive function

(Janke, 2006). Conversely, the protective piece of equipment lowered the severity and

number of concussive symptoms following the heading task (Janke, 2006). This study alone

is useful; however, balance performance was not evaluated and a potent heading protocol

was not utilized. This warrants further research regarding the clinical impact of soccer

headgear.

Overall, previous research involving soccer heading and headgear is lacking

consistency in results, and there is significant diversity in methodology. The effects of

soccer heading and the efficacy of protective headbands have continually offered conflicting

results. Also, the current literature in this area has three major limitations. The studies do

not use the most precise laboratory outcome measures, elite college-aged athletes are

commonly the subjects, and the heading protocols do not mimic training sessions (Broglio et

al., 2004; Ellemberg et al., 2007; Putukian et al., 2000; Webbe & Ochs, 2003).   Former

projects have used paper and pencil tools for evaluating cognition and reaction time or simple

center of pressure force plates measures to assess balance performance (Broglio et al., 2004;

Ellemberg et al., 2007; Schmitt et al., 2004; Stephens et al., 2005). Newly developed tools

such as the SCAT2 have never been used in conjunction with soccer heading. Furthermore,

instruments like the Sensory Organization Test and Automated Neuropsychological

Assessment Metric, which are often used clinically, have not been utilized enough in soccer

heading research. Additionally, soccer is a sport played by the masses, and previous research focusing on highly skilled individuals, is not representative of the entire population (Broglio et al., 2004; Putukian et al., 2000). The protocols formerly used employ one header every minute, for a total of twenty minutes (Broglio et al., 2004; Janke, 2006). The present study was novel for the reason that the heading protocol was more potent, in that the same number of headers was completed in half the amount of time. Thus, there exists a need to combine sensitive testing instruments as well as a more diverse subject pool and more potent heading protocol, in order to establish concrete conclusions about soccer heading.

The most important issue when looking at the literature is that only one research project has examined acute heading bouts with headgear in reference to clinical outcome measures. The headbands are designed to dissipate forces, but it is of more importance to study their effect in a clinical sense. There is a clear gap in the existing literature with regard to this domain.

Clearly, soccer heading is an area that consistently brings up numerous discussions relating to concussion and subconcussive impacts. There is a need for a study combining sensitive neurocognitive testing on recreational athletes along with the use of soccer headgear. Integrating these instruments, subjects, and methodology would provide a culminating project of the issues presently being debated. Clinicians and researchers consistently question whether heading affects neurocognitive function and if the protective soccer headbands are beneficial for athletes. Until a study evaluates the effect of headgear on sensitive neurocognitive function and balance performance tests following acute heading bouts, these questions cannot be answered.

<u>Statement of Problem</u>

To date, there is a great deal of uncertainty revolving around soccer heading and possible neurocognitive effects. The consensus seems to reveal that soccer heading does not typically result in concussion. Nonetheless, it does not suffice to say that neurocognitive impairments, at a sub-concussive level, do not result from the technique. Researchers have begun to investigate the potential deficits, in both an acute and chronic sense, using a battery of tests. However, the measures previously utilized are not the most sensitive to possible neurocognitive shortcomings. Additionally, much of the preceding work has been conducted on elite athletes, which does not appropriately represent the general soccer population. Another intriguing area of soccer research generating a great deal of interest is the use of protective headgear. Little investigation has been conducted to provide clinical implications of this apparatus. Most of the earlier work was either foundational in nature, or did not use sensitive testing measures to evaluate the efficacy of the product. Currently, a need exists to evaluate an acute bout of heading, in conjunction with the headgear, in order to establish trends in neurocognitive function under these different conditions. Thus, the purpose of this study was to investigate the effects of an acute bout of soccer heading with and without the Full90^{TM} headband on neurocognitive and balance performance in recreational college-aged soccer players.

<u>Dependent Variables</u>

Neurocognitive functioning and balance performance was measured following an acute bout of soccer heading, and the variables measured were:

    1. Neurocognitive Function

        a. SCAT2 scores

            i. Total score out of a possible 100 points

ii. Coordination component of SCAT2 out of a possible 1 point

b. SAC scores

i. Total score out of a possible 30 points

ii. Orientation component of SAC out of a possible 5 points

iii. Immediate memory component of SAC out of a possible 15 points

iv. Concentration component of SAC out of a possible 5 points

v. Delayed recall component of SAC out of a possible 5 points

b. SRT throughput scores (accuracy X speed)

c. Symptomatology

i. Symptom severity score

ii. SCAT2 symptom score

iii. Headache rating

2. Balance Performance

a. NeuroCom Sensory Organization Test (SOT) results

i. Composite score

ii. Somatosensory score

iii. Vestibular score

iv. Visual score

b. Balance Error Scoring System (BESS)

i. Firm condition errors

ii. Foam condition errors

iii. Total Score

Independent Variables

   1. Use of the Full90™ headgear

      a. Headgear

      b. No Headgear

   2. Test Session

      a. Baseline

      b. Heading Session 1

      c. Heading Session 2

Research Question

   Do acute bouts of soccer heading, with and without headgear, result in neurocognitive

   function, simple reaction time, symptomatology, and balance performance deficits in

   college-aged competitive soccer athletes?

      a) Are there any deficits in SCAT2 total scores, SAC total and subcomponent

      scores, SRT throughput scores, symptom severity, BESS error scores, or SOT

      composite and ratio scores in college-aged competitive soccer athletes

      following a single bout of heading?

      b) Does wearing the Full90™ soccer headgear during an acute heading bout

      affect SCAT2 total scores, SAC total and subcomponent scores, SRT

      throughput scores, symptom severity, BESS error scores, or SOT composite

      and ratio scores in college-aged competitive soccer athletes?

H_O: Acute bouts of soccer heading will not result in simple reaction time, and balance performance deficits in college-aged competitive soccer athletes.

a. There will be no deficits in SCAT2 total scores, SAC total and subcomponent scores, SRT throughput scores, symptom severity, BESS error scores, or SOT composite and ratio scores in college-aged competitive soccer athletes following a single bout of heading.

b. Wearing the Full90^{TM} soccer headgear during an acute soccer heading bout will not affect SCAT2 total scores, SAC total and subcomponent scores, SRT throughput scores, symptom severity, BESS error scores, or SOT composite and ratio scores in college-aged competitive soccer athletes.

Research Hypotheses

Acute bouts of soccer heading will result in mental status, simple reaction time, and balance performance deficits in college-aged competitive soccer athletes.

a. There will be deficits in SCAT2 total scores, SAC total and subcomponent scores, SRT throughput scores, symptom severity, BESS error scores, or SOT composite and ratio scores in college-aged competitive soccer athletes following a single bout of heading.

b. Wearing the Full90^{TM} soccer headgear during a soccer heading bout will not affect SCAT2 total scores, SAC total and subcomponent scores, SRT throughput scores, symptom severity, BESS error scores, and SOT composite and ratio scores in college-aged competitive soccer athletes.

Operational Definitions

Acute bout of heading: For this study, an acute bout of heading consisted of twenty headers taken in direct succession within ten minutes.

Collegiate soccer players: All subjects were members of the club or a competitive division intramural soccer team at the University of North Carolina.

Cognition: This was tested using the results of the SCAT2 instrument.

Balance performance: For this study, balance was measured using the highly sensitive NeuroCom SOT device, as well as the BESS test.

Full90^{TM} headband: The Full90 Select headband from the Full90 company, Full90 Sports, Inc, San Diego, CA.

Header: A soccer ball which was contacted by the subject's head and initially moved in a forward direction.

Assumptions

1. The Soccer Tutor maintained a constant speed throughout the test session.

2. All club and intramural soccer athletes at the University of North Carolina were properly trained in the skill of heading.

3. All athletes performed to the best of their ability.

4. All subjects were truthful about injury history.

5. Together, the SCAT2, BESS, SRT, and NeuroCom give an accurate measure of neurocognitive function and balance performance.

6. The output provided by NeuroCom SOT and SRT software was accurate and reliable.

Delimitations

     1. All subjects were recreational college-aged soccer players.

     2. All subjects were free from a history of head injury within the past 6 months.

     3. The heading task was only representative of a practice drill, not a game situation.

Limitations

     1. Together, the SCAT2 and NeuroCom only measured a portion of neurocognitive

function.

     2. Only linear heading was utilized during heading intervention.

     3. Practice effects of the SCAT2 and BESS.

     4. Measurement of neurocognitive function in collegiate-aged athletes may be

difficult to relate to players of various ages.

     5. We did not measure forces from ball impact in this study.

     6. Neither the researcher nor the subjects were blinded to the intervention.

     7. The heading task was in a controlled environment, unlike game situations.

CHAPTER II

REVIEW OF LITERATURE

<u>Introduction</u>

In women's soccer, concussions have been attributed to approximately 12% of game injuries and 3% of practice injuries (Covassin, Swanik, & Sachs, 2003). These statistics have inspired further investigation of the risk factors, causes, and possible prevention of head injuries in the game. Soccer is a unique sport, in that it involves the purposeful use of the head in order to advance the ball during the run of play. Currently, there is uncertainty as to whether this skill may possibly lead to concussion, or at the least, neurocognitive deficits on a subconcussive level. Several researchers have begun to examine neurocognitive deficits as they relate to acute or repetitive bouts of heading. However, many of the previously published studies do not use the most innovative testing instruments, which are particularly sensitive to subtle impairments in neurocognitive functioning. Nonetheless, in response to the possibility of deficits resulting from heading, manufacturers have created headbands to be worn by athletes. These pieces of protective equipment are claimed to attenuate forces, and therefore, protect the players from head impacts. To date, minimal research using clinically applicable measures has been conducted on soccer headgear. Thus, there is a need for clinical and sensitive laboratory measures to be used in soccer concussion research, with the goal of determining effects of heading on neurocognitive and balance performance.

Introduction of Soccer

Participants

Soccer is distinguished as the most popular team sport worldwide. Across the globe, there are an estimated 240 million active soccer players according to a Federation Internatinale de Football Association (FIFA) survey from 2005. (Federation Internationale de Football Association, 2005). Before the turn of the millennium, approximately 15 million of those participants were residing in the United States and Canada alone (Delaney & Drummond, 1999). As of 2005, Mehnart et al. estimated that between 12.5 and 18.2 million athletes play this sport in the United States (Mehnert, Agesen, & Malanga, 2005). Furthermore, Bauer et al. recognized that among intercollegiate institutions, women's college soccer was the most frequently added sport as of 2001 (Bauer, Thomas, Cauraugh, Kaminski, & Hass, 2001). These data indicate the popularity of soccer, not only across the globe, but also in the United States population in particular.

Heading in Soccer

Soccer is considered a unique sport due to the purposeful use of the head to advance the ball during the run of play. Heading a soccer ball is an active process where players contact the ball on the frontal bone, high on the forehead (Mehnert et al., 2005). Kirkendall et al. explained the exact location for contact as the site where a person places their hand to feel for a fever (Kirkendall & Garrett, 2001). The technique requires a rigid neck musculature in order to stabilize the head during movement. This is a protective mechanism, which helps to decrease the amount of accessory motion of the skull. Naturally, this skill has caused a great deal of concern surrounding the game of soccer.

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Particular attention is being given to the effects of acute bouts of heading, in addition to, chronic exposure to impacts.

The issue of chronic heading is contemplated due to the large number of headers occurring within a game, season, and across a soccer player's lifetime. Matser et al. conducted a research study investigating this topic, which surveyed fifty three active male Dutch professional soccer players. (Matser et al., 1998). The average number of headers reported was sixteen during a match and eight hundred during a season of competition. Another study asserted that Norwegian soccer players had the potential to receive two thousand blows to the head over a career of three hundred top division games (Tysvaer & Storli, 1981). Moreover, an American study surveyed participants of the Olympic Sports Festival and found that the average number of headers for males and females was 7.3 and 8.4 in a game situation respectively (Barnes et al., 1998). These numbers rose to 9.5 and 8.6 correspondingly when examining practice sessions. Jordan et al. found slightly different numbers in his survey, as he reported that United Stated Men's National team averaged ten headers per match (Jordan, 1996). Lastly, Delaney et al. tracked adolescent soccer players between the ages of twelve and seventeen to find that this group averaged 4.6 headers per game. Although, these studies provided useful background information, they were all based strictly on recall and only investigated a specific subject population. To date, soccer research lacks a longitudinal study that examines the number of headers tracked in real time across a variety of populations.

Along with the number of headers, it is also essential that the ball speed be investigated. Clearly, the velocity of a soccer ball in flight is variable during the course of a match or practice. It is widely accepted that a skilled soccer player can kick a ball at

speeds of 100 km/h and greater (Kirkendall & Garrett, 2001). Despite this fact, an athlete

will rarely voluntarily head a ball at this velocity, although the contact may be incidental.

More commonly, an athlete will head a punt, drop kick, goal kick, or corner kick. It has

been established that a punted ball travels at approximately 45 miles per hour or 72.4

kilometers per hour, whereas drop kicks and goal kicks result in speeds of 55 miles per

hour or 88.5 kilometers per hour (Kirkendall, Jordan, & Garrett, 2001). These speeds can

result in significant forces absorbed by the skull during heading tasks. The brain will

naturally take up some of the impacts, which can result in injury. This raises concern

regarding the impacts sustained from not only a single bout of heading, but also

cumulative experiences. Despite these seemingly alarming speeds, Schneider et al.

reported that soccer heading does not result in the necessary forces needed to create

concussion (Schneider & Zerniche, 1988).

Composition of Soccer Balls

Originally, the issue of acute or repetitive heading was much more concerning

due to the composition of the soccer balls. Formerly, these balls were constructed from a

leather material, which had the potential to gain water weight during certain playing

conditions (Delaney & Drummond, 1999). It was reported that the ball could increase its

weight by up to 20% in raining conditions, which in turn, intensified the force absorbed

by the human skull following heading (Delaney & Drummond, 1999). However, this

issue has been resolved due to the modification of the composition of soccer balls.

Currently, there are three differing sizes and weights of soccer balls used in the

sport for various age groups. A size five soccer ball, used in all matches featuring

athletes over the age of 12, weighs between 396 and 453 grams (14-16 ounces) and is 68-

71 centimeters (27-28 inches) in circumference (Kirkendall & Garrett, 2001). Soccer

balls for younger players are smaller and lighter. The synthetic outer coating featured in

all three sizes is composed in such a way that water cannot be absorbed, unlike the

formerly used leather covering. Therefore, the weight and circumference seem to be

maintained throughout a soccer game, despite the environmental conditions, which

triggered Delaney's earlier declarations.

Concussion

Definition

It is not surprising that head injuries, specifically concussions, have always been a

major concern in the sport of soccer. A sports concussion was defined in the 2004

Prague guidelines as "a complex pathophysiological process affecting the brain, induced

by traumatic biochemical forces" (McCrory et al., 2005). This condition can be

characterized either as coup or countercoup in nature. The former is caused by a linear

force, which causes injury at the point of impact (Kirkendall et al., 2001). Conversely,

the latter refers to an injury that occurs distant from the location of impact due to the

recoiling of the brain inside the skull (Kirkendall et al., 2001). Both coup and

countercoup injuries can result in a variety of self-reported symptoms. These encompass,

but are not bound to "headache; dizziness; nausea; vomiting; feeling 'in a fog'; feeling

'slowed down'; trouble falling asleep; sleeping more than usual; fatigue; drowsiness;

sensitivity to light or noise; unsteadiness or loss of balance; feeling 'dinged,' dazed, or

stunned; seeing stars or flashing lights; ringing in the ears; and double vision"

(Guskiewicz et al., 2004; Maroon et al., 2000; McCrory et al., 2005; Piland, Motl,

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Ferrara, & Peterson, 2003). Additionally, post traumatic amnesia and loss of consciousness may result from head injuries.

The timing and duration of these symptoms are dependent upon the severity of injury, location of impact, concussion history, and other injury specific factors (Guskiewicz et al., 2005; Guskiewicz et al., 2003; Pellman, Viano, Tucker, & Casson, 2003). These symptoms may result from the physical disruption of tissue due to impact or from chemical disturbances. It is imperative that concussions are properly recognized, assessed, and studied within individual sports.

Anatomy and Biomechanics

Concussions are proposed to be the result of axonal dysfunction in the brain. Once connections between the axons are disrupted, activity is interrupted, and the aforementioned symptoms result. Brain injuries can result from focal harm or diffuse injuries. The former, results in contusions and bleeding from generalized trauma, whereas the latter, is produced by sheared axons.

Sports concussions are almost undoubtedly the result of an external force, which causes an impact on the skull. This may result from contact with another player, the playing surface, or a piece of sports apparatus. The impacts cause acceleration-deceleration forces, which bring about damage to central nervous system structures. The extent of injury is largely dependent on a variety of features, including the distribution of forces, anatomical features, and vectors of impact (Barth, Freeman, Broshek, & Varney, 2001).

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At this point, it appears that greater damage is caused when multiple vectors of acceleration and deceleration act upon the skull. In this situation, more neurological deficits usually transpire from the impact (Barth et al., 2001). Currently, a tremendous amount of time and effort is being invested into examining the result of linear, as opposed to, angular forces (Funk, Cormier, Bain, Guzman, & Bonugli, 2008). These forces have frequently been studied in conjunction with accelerometers placed within football helmets (Newman, Beusenberg, Shewchenko, Withnall, & Fournier, 2005; Rowson, McNeely, & Duma, 2007).

Head Impacts

To date, football has inspired most of the work being done regarding head impacts and accelerations, and their relation to injury. Recently technicians have developed six-accelerometer systems, which have been installed in football helmets for the purpose of collecting head impacts in real-time (Duma et al., 2005). These devices were used with a sample of Division I football players, and they showed a peak linear head acceleration of 32 *g* (Duma et al., 2005).

The average impact speed and resulting head velocity has also been examined using laboratory measures. Video analysis of National Football League (NFL) head impacts were reconstructed in order to determine the biomechanical elements of the hits (Pellman et al., 2003). An impact speed of 9.3 ± 1.9 meters/second (20.8 ± 4.2 miles/hour) was evidenced in concussion situations with a change in head velocity of 4.0 ± 1.2 meters/second (8.9 ± 2.7 miles/h) (Pellman et al., 2003). Much of this research served as foundational investigation, meaning there was a need to relate these impacts to clinical assessment of concussion.

This gap in the literature was accounted for in recent years when symptomatology, postural stability, and neuropsychological testing were all related to head impacts (Guskiewicz, Mihalik et al., 2007). It was found that, among collegiate football players, neither the rotational nor linear components of impact magnitude were predictors of these clinical measures when evaluating 13 instances of concussions (Guskiewicz, Mihalik et al., 2007). Thus, the magnitude of impact may not be the most predominant indicator of clinical signs of concussion. Furthermore, this study found that lower-magnitude impacts tended to result in larger symptom change scores, which may be of particular concern when considering soccer heading (Guskiewicz, Mihalik et al., 2007). Traditionally, impacts sustained from heading a soccer ball are of much less magnitude than those received during football contacts. The abovementioned study indicates that the former may cause more detrimental changes in concussive symptoms than the latter.

Although most research regarding head impacts and accelerations has been linked to American football, some investigation has been conducted in soccer. Withnall et al. reported HIPmax and mean head acceleration values that stayed below a 5% risk level for concussion (Withnall, Shewchenko, Gittens, & Dvorak, 2005). Despite this fact, the data from a few trials were above this critical level (Withnall, Shewchenko, Gittens et al., 2005). This study, in particular, analyzed game videos from FIFA sanctioned matches, which included sixty two cases of head impacts (Withnall, Shewchenko, Gittens et al., 2005). From this information, laboratory re-enactments were created for various types of head impacts, and the data were analyzed in relation to head injury.

Metabolic Cascade

In addition to the physical disruption that occurs in the brain, there is also a metabolic cascade which takes place following head impacts (Giza & Hovda, 2001). This process begins within an hour of injury, and may persist for several days (Giza & Hovda, 2001). During this process, potassium (K+) channels open, and cause an increase in this ion (Giza & Hovda, 2001). As a result, glucose metabolism rises and blood flow in the area decreases in an attempt to maintain homeostasis (Giza & Hovda, 2001). Consequently, increased amounts of adenosine triphosphate (ATP) are utilized to counterbalance the hyperglycolysis (Giza & Hovda, 2001). The result of this cascade is a disparity between glucose supply and demand, which disrupts energy at the cellular stage (Gardiner, Smith, Kagstrom, Shohami, & Siesjo, 1982; Giza & Hovda, 2001; Takahashi, Manaka, & Sano, 1981; Yang, DeWitt, Becker, & Hayes, 1985). This process occurs immediately following a physical or biomechanical injury, and triggers chemical imbalances. It is possible that the forces from soccer heading result in the cascade, which is responsible for lasting concussive symptoms. Recently, this imbalance has received much attention in the literature, and is possibly being deemed one of the causes of many concussive symptoms following head injuries in sport.

Assessment

There is a great deal of complexity surrounding the mechanism of head injuries and concussive symptoms. Therefore, the assessment and management of concussion are extremely difficult tasks. Head injuries can frequently go unnoticed due to ignorance, inadequately staffed sporting events, and inaccurate information given by the athlete. Currently, there is an assortment of measures, which provide insight into the nature of a

concussion. Postural assessments, graded symptom checklists, neuropsychological tests, balance protocols, and mental status measurements are all integral aspects of the evaluation.

Within athletics, concussion assessment instruments can be used as sideline or laboratory tools to detect deficits in areas of brain function. The forces from an acute bout of heading or a career of repetitive heading can affect the cerebellum, cerebral cortex, and brain stem (Guskiewicz, 2003). Heading can also result in symptoms such as headache, dizziness, and visual disturbances. These indicators of concussion may be caused by the force of one header, especially if improper technique is present. The biomechanical disruptions from the skill may also impair cognitive performance on neuropsychological test protocols. The abovementioned consequences may have a short-lived duration, yet they must not be overlooked. Heading introduces a force to the skull, which may impact brain function in a variety of ways, which presents a need for thorough examination.

Baseline measures should ideally be taken prior to athletic participation in order to establish normative data on each individual. Moreover, serial assessments must be conducted to monitor and track deficits following injury. This allows comparisons in all domains to be made following a concussive event. An athlete may be returned to competition only when all deficits resolve, and exertional testing can be performed without a recurrence of symptoms (Guskiewicz et al., 2004). The period between, onset of concussion and return to activity, is now garnering a fair amount of attention, with regards to the intensity of activity warranted. Currently, a notion exists that this period should fall somewhere between intense activity and complete inactivity (Majerske et al.,

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2008). Previously, it was thought that a concussed individual should rest and avoid

stimulation. However, clinicians began to question why a head injury was different than

another musculoskeletal injury that used proper rehabilitation for recovery. Regardless of

the proper treatment protocol, it is imperative that medical personnel first recognize the

condition, and accurately make return to play decisions.

Three measures commonly used to assess concussions are the SCAT2, Automated

Neuropsychological Assessment Metric (ANAM), and the NeuroCom Sensory

Organization Test (SOT). The first is an on-field evaluation of mental status,

symptomatology, postural stability, and cognitive functioning. The latter two are

laboratory measures used to assess head injury. The ANAM is a computerized program

used to evaluate neuropsychological function. Postural stability using a forceplate system

is assessed through the SOT. Although the three tools have contrasting purposes and

uses, they are all integral aspects of concussion assessment.

SCAT2

The Sport Concussion Assessment Tool (SCAT2) evolved from the previously

established SCAT, which was created at the Prague conference in 2004 (McCrory et al.,

2005). The original tool evaluated physical signs, memory, symptoms, cognitive ability,

and neurological factors (McCrory et al., 2005). This initial version served as the basis

for the SCAT2, which was developed with certain modifications. The second version

was released at a conference in Zurich, and it added the Glasgow Coma Scale (GCS),

Maddocks scores, an orientation assessment, a balance task assessed through the firm

surface portion of the BESS, and a coordination aspect (McCrory et al., 2009). These

additions make the SCAT2 a much more inclusive instrument used to assess concussion.

Essentially, the SCAT2 was developed as a more in-depth sideline concussion measure, compared to the formerly used Standardized Assessment of Concussion (SAC) and SCAT. This more innovative tool is comprised of three major components, the Graded Symptoms Checklist, the Balance Error Scoring System (BESS), and the Standardized Assessment of Concussion (SAC). The result of this instrument is a composite score out of a total 100 points. It measures amnesia, symptoms, postural stability, cognitive function, and alertness. Each component of the SCAT2 is highly reliable and accepted as a valid concussion assessment measure.

The SCAT2 uses the previously created BESS test to evaluate balance performance. This assessment tool was created by researchers and clinicians at the University of North Carolina, Chapel Hill (Guskiewicz, 2003). The intent of this instrument is to provide a valid sideline measure of overall balance (Guskiewicz, 2003). The test simply requires a timing device and a piece of medium density foam, ten centimeters in thickness (Guskiewicz, 2003). The protocol involves a total of six trials, using combinations of three stances and two surfaces. (Guskiewicz, 2003). The double leg, single leg, and tandem stances are used in conjunction with a firm and foam surface (Guskiewicz, 2003). The testing position requires a subject to place their hands on their hips for each twenty second trial, with their eyes closed (Guskiewicz, 2003). Under the single leg conditions, the nondominant leg is used for weight bearing (Guskiewicz, 2003). The contralateral hip is flexed between 20˚ and 30˚, in addition to the knee being flexed between 40˚ and 50˚ (Guskiewicz, 2003). The tandem stance requires the nondominant foot to be positioned at the rear of the dominant (Guskiewicz, 2003). The test is scored using an error system, which dictates six specific faults (Guskiewicz, 2003).

These consist of lifting forefoot or heel, opening eyes, lifting hands off of the iliac crests, moving hip into more than 30˚ of flexion or abduction, stepping/stumbling/falling, or remaining out of the testing position for more than five seconds (Guskiewicz, 2003). The errors of each condition are calculated, with a maximum score of ten per trial, and added together from all trials to give a composite score (Guskiewicz, 2003). This sideline tool has been shown to correlate with advanced forceplate postural sway calculations with values ranging from 0.78 to 0.96 for intertester reliability (Riemann, Guskiewicz, & Shields, 1999).

There is a known practice effect associated with this tool (Valovich, Perrin, & Gansneder, 2003). Scores have been shown to improve up to the fifth trial (Valovich et al., 2003). It appears at this point that the BESS is a more widely accepted sideline postural stability tool, compared to the Romberg, which was previously used to assess this domain of concussion. This is largely due to the BESS test's ability to quantify results.

The SAC, another component of the SCAT2, is a sideline measure, which examines orientation, immediate memory, concentration, and delayed recall (McCrea et al., 1998). The first of these aspects is measured by asking the time, week, date, month, and year. A set of five dissimilar words are given to the athlete to assess both immediate and delayed recall later during the examination. Concentration is evaluated by asking the player to list the months in reverse order, and also, reiterating strings of various amounts of numbers in reverse order. The tool can be administered in approximately five to seven minutes in its entirety (Valovich McLeod, Barr, McCrea, & Guskiewicz, 2006). The test

contains three various forms, which can be used to diminish the practice effects (McCrea et al., 1998).

SRT

Lately, concussed athletes have also been evaluated using computerized neuropsychological test batteries. They provide an objective system used to serially assess people who have sustained suspected neurocognitive deficits (Kaminski, Groff, & Glutting, 2008). The Automated Neuropsychological Assessment Metric (ANAM) is a battery which consists of five individual modules and two repeated subtests (Kaminski, Groff et al., 2008). These include simple reaction tine (SRT), matching to sample (MTS), continuous performance test (CPT), math processing (MTH), and Sternberg memory procedure (STN) (Kaminski, Groff et al., 2008). The battery calculates a throughput score, which computes the number of correct responses by a subject per unit of time. Thus, the overall score from this instrument investigates efficiency, which is derived from accuracy, as well as, speed.

Overall, the ANAM battery is very useful due to its brief administration time, multiple alternate forms, and ease of administration (Cernich, Reeves, Sun, & Bleiberg, 2007). Additionally, many individuals can be tested during one session, which aids with large numbers of subjects (Cernich et al., 2007). Furthermore, practice effects can be minimized by using alternate forms, randomizing different test stimuli, and through the precise measurements of the instrument (Kaminski, Groff et al., 2008). The disadvantages of the ANAM include the influence of computer interaction, size of the display, individual computer experience, and the appearance of stimuli (Kane & Kay, 1992).

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The Simple Reaction Test (SRT) task of the ANAMA requires subjects to respond to a stimulus on the computer as quickly as possible (Collie, Maruff, Darby, & McStephen, 2003). The participant clicks a spacebar as soon as the stimulus appears, and response time is measured in milliseconds (Kaminski, Groff et al., 2008). This module is very sensitive to small differences, and thus, is extremely effective in measuring neuropsychological performance.

NeuroCom Sensory Organization Test (SOT)

The NeuroCom (SOT) is another instrument commonly used when assessing concussion. It measures balance performance through utilizing a forceplate, in order to calculate vertical ground reaction forces (Guskiewicz, 2001). The system ultimately measures postural stability, as a function of the a person's center of gravity shifting around an unchanging axis (Guskiewicz, 2001). The instrument methodically upsets available sensory information by changing accessible visual or somatosensory input (Guskiewicz, 2001). A combination of eyes open and eyes closed conditions are performed with sway referencing to evaluate balance performance (Broglio, Sosnoff, Rosengren, & McShane, 2009). A measurement of the subject's ability to reduce postural sway during these tasks is computed, ultimately by comparing actual sway to the hypothetical potential sway (Guskiewicz, 2001; Riemann et al., 1999). A total score of equilibrium is calculated, with lower scores indicating poorer balance (Guskiewicz, 2003). A somatosensory, visual, and vestibular score are also computed, in order to decipher where deficits actually exist. The device is widely accepted and has currently been used as the gold standard to evaluate innovative measures, such as the PROPRIO (Broglio et al., 2009).

The NeuroCom is founded on the principle that healthy individuals have the ability to interpret visual, vestibular, and somatosensory information (Riemann & Guskiewicz, 2000). The visual component produced from the NeuroCom (SOT) calculates points of reference in relation to surroundings (Guskiewicz, 2003). The visual system is integrated closely with the vestibular system, which is responsible for balance (Guskiewicz, 2003). The somatosensory portion is the final element, and it offers input regarding orientation of body segments (Guskiewicz, 2003). These three areas work together using afferent information, in order to ultimately achieve a state of equilibrium (Guskiewicz, 2003). Once one system is disrupted, the healthy person has the potential to counteract and maintain postural control (Riemann & Guskiewicz, 2000). However, a concussed athlete does not have this ability, and thus, a disruption of one structure upsets overall equilibrium (Riemann & Guskiewicz, 2000).

Subconcussive and Long-term Effects

Along with the immediate recognition and treatment of concussion, the future of the injuries must also be considered by clinicians. Concussions draw a great deal of attention from an injury standpoint, due to the thought of long-term consequences from the trauma. This idea has been the center of much of the concussion research recently. Collie et al. reported that sport-related concussion did not seem to result in long- term outcomes (Collie, McCrory, & Makdissi, 2006). This study included 521 male Australian rules football athletes, using CogSport to evaluate neurocognitive function (Collie et al., 2006). However, this project allowed a practice session, which may have influenced results prior to completing baseline tests (Collie et al., 2006). A more sound longitudinal study reported that retired football players, who had a history of recurrent

concussion, were more likely to exhibit depression later in life (Guskiewicz, Marshall et al., 2007). This is indicative that there may be lasting consequences of head injuries in athletics. Clinicians must be aware of this possibility, and factor it into sound decisions with the athlete's health in mind.

In addition to the long-term effects of concussions, there is a considerable amount of skepticism surrounding subconcussive blows to the head. Although this topic has been questioned, very little research has been conducted in this area. It seems that healthcare personnel have begun to understand the effects of concussions, but the impact of repetitive subconcussive blows has garnered a non-significant amount of research. This area is very important in the sport of soccer, due to the recurring forces sustained following heading.

One study investigated repetitive low head impacts, and noted no statistical difference in the number of symptoms reported (McCaffrey, Mihalik, Crowell, Shields, & Guskiewicz, 2007). This study provides an initial claim; however, many more projects must delve into this topic in the future.

Cumulative Effects

As evidenced in the aforementioned study, there is concern that there is a detrimental cumulative effect resulting from concussions. Repeated head injuries, result in certain physical repercussions, such increased intracranial pressure, anoxia, and altered blood flow (Cantu, 2003). One very sound research study demonstrated that high school athletes may be more susceptible to sustain a concussion based on an injury history (Collins et al., 2002). When investigating 173 athletes, subjects with three or more

concussions, were more apt to suffer anterograde amnesia, confusion, and loss of consciousness following a subsequent head injury (Collins et al., 2002). This line of thinking was confirmed amongst collegiate football players as well (Guskiewicz et al., 2003). A prospective cohort study utilized 2905 football athletes in order to establish that those players with a history of three or more concussions were three times more likely to sustain a subsequent concussion (Guskiewicz et al., 2003). The literature, at this point, seems to support the notion that a history of at least three concussions predisposes an athlete to future injury. This knowledge must be applied clinically during the treatment of head injuries, in order to reduce long term effects.

Neurocognitive Measures used in Conjunction with Heading

Previous Measures

With the recent research that has investigated the effects of concussions, question has arisen surrounding the game of soccer. There is legitimate concern that the act of heading, which is inherent in the sport, many cause neurocognitive deficits. To date, most studies that have examined neurocognitive effects, resulting from soccer heading, have used pencil and paper testing procedures. These tools are not sensitive to speed of action or emotional states, such as mood, anxiety, or effort. Also, many of the tests, especially those used in the younger population, do not offer several alternate forms. These drawbacks limit the reliability and validity of the instruments.

The few studies that have examined balance used either more crude measures, such as the BESS and Romberg, or the conceptual basis of the NeuroCom instrument. However, only one has measured postural sway using the actual NeuroCom device,

which currently is the gold standard in balance performance. Thus, a need is present to use this particularly sensitive apparatus, to monitor deficits in postural control. Although the common consensus seems to state that concussions in soccer are not actually sustained from the intentional impact of a soccer ball, there may be minor subconcussive impairments from the skill (Boden et al., 1998). For this reason, it is imperative that the most sensitive testing measures are used to examine the effects of heading in soccer.

Additionally, little work has been done using common sideline measures to determine deficits resulting from heading. The newly developed SCAT2 may be a helpful on-field predictor of injury following acute bouts of heading. Certain impairments could possibly be inherent in the skill, but remain below a concussive level. These detriments may be detected through the symptom checklist portion of the SCAT2, which provides a means of assessing indicators of head injury. It is crucial that exploration of this innovative tool be conducted first in research, leading to its clinical application in the future.

Concussion in Soccer

Rates in Collegiate Participation

As mentioned earlier, head injuries are of great concern in soccer, and consequently, concussion rates in the game, have garnered particular attention. The injury rate per one thousand athlete exposures was reported to be approximately .6 for men and .4 for females (Rutherford, Stephens, & Potter, 2003). These statistics seem very low; however, Injury Surveillance System (ISS) data presented by the National Collegiate Athletic Association (NCAA) appear to be much more alarming. When

investigating men's soccer, a population including 267 teams across a three year period revealed 123 concussions (Covassin et al., 2003). These head injuries accounted for 1.7% of all practice injuries and 7% of all game injuries (Covassin et al., 2003). The same study investigated 288 female teams, and reported 192 concussions (Covassin et al., 2003). The Incidence Density Ratio (IDR) for females, in this situation, was about 16.7 times higher for contests compared to practice sessions (Covassin et al., 2003). Although issues always exist when reporting data, these numbers hold substantial weight. All Injury Surveillance System (ISS) data are submitted by certified athletic trainers, who are trained in assessing head injuries.

Rates amongst Elite United States Players

Elite United States soccer athletes have received noteworthy interest with regards to concussion rates. At the US Olympic Festival, Barnes et al. found that the odds of sustaining a concussion during a ten year playing career was 50% for males and 22% for female counterparts (Barnes et al., 1998). The same researcher reported over half of the athletes had experienced at least one headache subsequent to heading the ball when 137 soccer players were questioned (Barnes et al., 1998). Furthermore, when looking at the same population, he found that approximately 89% of men and 43% of females had suffered a head injury during their careers as soccer players (Barnes et al., 1998). This information was strictly based off surveys and follow-up telephone interviews, which brings up the possibility of recall error and inaccuracy (Barnes et al., 1998). Another research project reported 7 of 20 United States' Men's National Team players possessed a history of a head injury (Jordan, 1996). These studies were again strictly an interview format, and thus, introduced a selection and recall bias. The data available examining

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concussions rates among United States professional players have been produced solely from retrospective study designs.

Rates amongst International Players

Similar work has also been conducted regarding international soccer players. During the 2000 Dutch Professional soccer season, 6% of 297 acute injuries reported were head injuries (Andersen, Arnason, Engebretsen, & Bahr, 2004). This information was collected from video recordings, which assisted in validating the statistics. Furthermore, 79% of Dutch professional players, during their soccer career, had sustained at least one head collision with another player (Matser et al., 1998). Again, these striking numbers in the sport spark concern in the medical community.

Unreported Concussions

Not only are the concussions themselves alarming, but so too, is the failure to report them. It has been stated that only about 20% of soccer players who sustained a concussion, recognized the symptoms (Delaney et al., 2008). Furthermore, another study reported that as low as 23.4% of football players with concussions and 19.8% of soccer players realized they had sustained a head injury (Delaney, Lacroix, Leclerc, & Johnston, 2002). These numbers were produced based off surveys with questions that indicated concussion history implicitly. They are extremely distressing because a head injury cannot be properly treated if it is not first recognized.

Characteristics of Concussions in Soccer

Soccer Concussions amongst Sex

The concussions, which have been reported, are being broken down in various demographic categories. For instance, sex differences have inspired many studies in the field. It seems that female soccer players are more likely to sustain concussions than male counterparts (Covassin et al., 2003). Concussions in women's soccer have been shown to account for up to 13.8% of all injuries in the sport (Covassin et al., 2003). Conversely, concussions were only responsible for 8.7% of injuries, reported from ISS data, for male athletes (Covassin et al., 2003). When investigating data from twenty Federation Internationale de Football Association (FIFA) tournaments, the incidence of concussion was reported to be 2.4 times greater in women than men (Fuller, Junge, & Dvorak, 2005). These data suggest that females may be at a higher risk to sustain a concussion, although both groups seem to be in jeopardy.

Concussion Related to Position

Moreover, concussion rates are being investigated based on factors inherent in soccer, such as player position, timing during competition, and location on the field. When examining videotapes and physician reports, it was concluded that internationally, 40% of concussions were suffered by defenders, followed by 23%, 22%, and 15%, for forwards, midfielders, and goalkeepers respectively (Fuller et al., 2005). In opposition, Boden et al. suggested that forwards and midfielders sustained approximately 76% of all male concussions in the sport (Boden et al., 1998). Another statistic showed that these two positions were responsible 66.1% of the injuries in high school men's soccer (Powell & Barber-Foss, 1999). The goalkeepers accounted for approximately 11.9% in the same

population (Powell & Barber-Foss, 1999). At this point, there do not appear to be any consistent tendencies as to number of concussions amongst positions in men's soccer.

When investigating high school females, the same researcher reported midfielders and forwards comprised 70.3% of mild traumatic brain injuries (MTBIs), and goalkeepers sustained 18.8% (Powell & Barber-Foss, 1999). Conversely, defenders suffered 67% of all female concussions according to a study of collegiate athletes (Boden et al., 1998). Internationally, female defenders represented 34%, followed closely by midfielders and forwards (Fuller et al., 2005). Barnes et al. conducted a survey study across sexes, which revealed forwards sustained the least number of concussions, followed by goalkeepers (Barnes et al., 1998). A contrasting study named goalkeepers as the most likely to suffer the injury (Delaney et al., 2002). In summary, there do not seem to be any conclusive trends in soccer positions and the likelihood of sustaining a concussion. Although various researches have proposed certain tendencies, there does not appear to be any strong evidence suggesting that certain positions within the sport of soccer are more or less susceptible to concussion. At this point various positions have been deemed as being the most at risk for concussion, but overall conclusive evidence is not present in the literature.

Timing of Injury

A considerable amount of effort has also been invested into linking the point in the game and the type of activity to the risk of sustaining a concussion. It has been reported that generally, concussions were sustained during the 72nd minute of the game for males, and the 63rd for females (Boden et al., 1998). Furthermore, the same researcher found that games accounted for 69% of all concussions, and practices

represented the other 31% (Boden et al., 1998). Similarly, the concussion rate for male

high school soccer players was 16.2 times greater than practice sessions (Powell &

Barber-Foss, 1999). Likewise, female counterparts possessed an IDR 14.4 times larger in

games, compared to practices (Powell & Barber-Foss, 1999). Thus, concussions in

soccer tend to occur late in game situations, for the most part from this preliminary

research.

Causes of Concussions

Concussions in soccer typically result from either acceleration and deceleration

forces impacting the brain (Rabadi & Jordan, 2001). Overall, forces of up to 54.*7g* have

been found to result from the sport, which contrasts to forces of 29.2*g* and 35*g*,

corresponding to football and ice hockey respectively (Naunheim, Standeven, Richter, &

Lewis, 2000). However, the exact cause of these head injuries in soccer also brings up

much debate. Usually, they are the result of inadvertent contact with the goalposts, the

ground, or another player on the field (Boden et al., 1998; Tysvaer & Storli, 1981). To

date, mild traumatic head injuries in soccer are generally attributed to some type of

collision sustained while heading the ball (Powell & Barber-Foss, 1999). Approximately

28% of the concussions suffered by collegiate players were the result of impact from

another athlete's head (Boden et al., 1998). This was followed closely by 24% produced

by the impact of the soccer ball, and 14% resulting from contact with the ground (Boden

et al., 1998). Currently, it seems that disagreement exists as to the mechanism of impact

for concussions in soccer. Despite the discrepancy, the one consensus amongst causes of

concussion injury in soccer is that the location of impact is most commonly to the

temporal region of the skull (Scott Delaney, Puni, & Rouah, 2006). This differs from

football players, where concussions were most commonly reported from impacts to the top of the head (Mihalik, Bell, Marshall, & Guskiewicz, 2007).

Injury from Heading Impact

Although many former studies reported that the actual impact from heading can cause injury (Powell & Barber-Foss, 1999; Tysvaer & Storli, 1981) , it is now believed that concussions are not caused from ball impact, if there is proper execution (Barnes et al., 1998). In a study that investigated 48 concussions via video analysis, only one was the result of ball impact (Fuller et al., 2005). In this instance, an athlete was struck in the head by a clearing ball from a defender (Fuller et al., 2005). This situation demonstrates that, although concussions are not usually the result of direct contact, they become more prevalent when an athlete strikes the ball with an unprepared head (Kirkendall & Garrett, 2001).

Importance of Neck Muscles in Injury Reduction

Sex Differences in Neck Activation

This point brings about an area of prevention that is presently being widely studied. It is believed that head acceleration is minimized after ball contact if the neck muscles are contracted properly (Bauer et al., 2001). As a result of this conception, many researchers have looked into neck muscle activation patterns, especially between sexes. Males have been shown to possess greater isometric strength, neck girth, as well as head-neck segment mass and length (Mansell et al., 2005). Despite this, it has been reported that kinematics, electromyography, stiffness values, and activation strategies do not differ significantly concerning sex (Mansell et al., 2005).

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Heading Differences in Neck Activation

In addition to sex differences, neck activation has also been evaluated using different heading techniques. It was found that there is a greater integrated and peak normalized electromyography, in the sternocleidomastoid and trapezius bilaterally, during jumping headers, compared to standing (Bauer et al., 2001). The act of heading was broken down to reveal that the sternocleidomastoid is largely involved in head acceleration prior to initial ball contact (Bauer et al., 2001). The trapezius is also firing preceding initial contact, but this muscle is responsible to deceleration of the head (Bauer et al., 2001). Although this information is very valuable, the findings originate from a study which utilized an investigator tossing a soccer ball to the participants (Bauer et al., 2001). Therefore, the speed was not accurately maintained, and was not applicable to a realistic situation.

Sex Differences in Head Acceleration

Although activation seems to be similar amongst sexes, there have been differences in head accelerations, which relates back to neck musculature. Tierney et al. found that females possessed a 10% higher head accelerations when performing headers, compared to male counterparts (Tierney et al., 2008). This discrepancy was magnified when soccer headgear was used for the same heading task (Tierney et al., 2008). Thus, accelerations have been shown to be much higher in women under a variety of heading conditions.

Cervical Neck Resistance Programs

In response to the theory of decreased neck strength leading to injury, researchers have looked into the implementation of a cervical resistance program. The training series

was eight weeks in duration, and it focused on isotonic neck strengthening (Mansell et al., 2005). It was concluded that although these protocols did possess the ability to alter the structure of muscle, they did not diminish head accelerations (Mansell et al., 2005). The dynamic restraint of the head-neck segment during ball impacts to the skull was not improved in either female or male collegiate players (Mansell et al., 2005).

<u>Structural Anatomical Deficits from Heading</u>

Chemical Imbalances from Heading

Although neck musculature may be one aspect important to concussion research, these structures cannot completely dissipate forces. Therefore, it is essential that other internal consequences of heading also be examined. In addition to the external signs of concussions in soccer players, many metabolic results have been studied. Specifically, it has been found that S-100B and neuron specific enolase have risen with practice and game sessions in the sport (Stalnacke, Ohlsson, Tegner, & Sojka, 2006; Stalnacke, Tegner, & Sojka, 2004). Furthermore, these number appear to exhibit a direct trend, which correlates with the number of headers performed (Stalnacke et al., 2006). This research was negated by Zetterberg (2007), who found no evidence of metabolic imbalances following heading (Zetterberg et al., 2007). In particular, serum biomarker concentration and cerebral spinal fluid (CSF) were unaffected by an acute bout of 10-20 headers (Zetterberg et al., 2007). Moreover, the same study did not reveal dangerous levels of serum levels S-100B or albumin ratios (Zetterberg et al., 2007). Although the changes were noted, they did not result in astroglial or neuronal injury (Zetterberg et al., 2007). The metabolic changes were not equivalent to elevated NF-L, T-tau, and GFAP markers, which, in boxers, have been shown to compare to the amount of punches

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received (Zetterberg et al., 2006). This area of research appears to be sparse due to the invasiveness of the procedures, but it may offer crucial information in concussion literature.

Electroencephalopathy Results

Perhaps more prevalent and notarized than chemical imbalances, is the potential to develop electroencephalopathy from soccer heading. Presently, a great deal of research is being conducted on this condition across a variety of sports. In 1992, Tysvaer et al. investigated both former and active soccer players, and found that approximately one third had altered electroencephalopathy readings (Tysvaer, 1992). This percentage of players demonstrated evaluations that were characterized within the range of slightly abnormal, to abnormal (Tysvaer, 1992). This finding was negated in 1996, when Jordan et al. reported no correlation between heading and abnormalities on magnetic resonance imaging (MRI) (Jordan, 1996). This study of United Soccer National Team soccer players failed to discover chronic encephalopathy (Jordan, 1996). The debate in this area of research has sparked other studies investigating neurocognitive effects from the skill of heading using clinical measures.

Neurocognitive Effects of Heading

The effects of soccer heading, both from repetitive exposure and acute bouts, have also been investigated through a battery of neuropsychological and neurocognitive tests. The results of these studies are varied, due to differing methodology. A few of these investigations looked at neuropsychological testing following a competitive soccer season, whereas others examined results after an acute heading bout.

Results of Chronic Heading

The first of these studies analyzed was conducted in the early 1980s by Tysvaer and Lochen. This project used a wide range of pencil and paper neuropsychological tests to determine function within Norwegian soccer players. It was reported that approximately 81% of the participants tests displayed impairments in concentration, memory, judgment, and attention (Tysvaer & Storli, 1981). A great deal of skepticism surrounds this project because other factors are thought to contribute to these findings. For example, substance abuse, concussion history, and lifestyle habits may lead to the impairments found, rather than the repetitive act of heading.

Matser et al. furthered the research, utilizing Dutch soccer professional soccer players and a neuropsychological test battery (Matser et al., 1998). The researcher used fifty three active male players and twenty seven controls of the same sex (Matser et al., 1998). The battery included the Puncture Test, 15- Word Learning Test, Verbal Fluency Test, Raven Progressive Matrices Test (RPM), Wisconsin Card Sorting Task, Benton's Facial Recognition Test, Figure Detection Test, Stroop test, and the Bourdon-Wiersma test (Matser et al., 1998). Additionally, the Paced Auditory Serial Addition Task (PASAT), Digit Symbol Test, subtests of the Wechsler Memory Scale, Trail Making A and B, and the Complex Figure Test (Matser et al., 1998). From these pencil and paper tasks, it was established that players possessed poorer function on visual and verbal memory, visuoperceptual tasks, and planning, compared to the control groups. This study is limited by the fact that inherent differences between soccer players and the controls may have existed in this particular project. Although, the researcher attempted to

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control for extraneous factors such as concussion history and substance abuse, it is impossible to normalize all factors and ensure results were not impacted.

The next study investigating the possibility of a detrimental cumulative heading exposure came in 2003 from Witol and Webbe (Witol & Webbe, 2003). The researchers examined a group of sixty soccer players in comparison to a control group of twelve other subjects (Witol & Webbe, 2003). Only two of the neurocognitive tests implemented, the Trail Making and Shipley test of IQ, displayed significant differences between the two groups (Witol & Webbe, 2003). These results are also questioned due to the discrepancy in the numbers of the two groups, and because a history of acute head injury was not controlled for in the study.

The recency and frequency of heading was then compared to neurocognitive function. Webbe et al. used a population of sixty four elite male soccer athletes, and twenty athletic individuals who served as controls (Webbe & Ochs, 2003). The soccer players were equally distributed between recent and nonrecent groups for comparison purposes based on their heading habits (Webbe & Ochs, 2003). Subjects were excluded for drug and alcohol use, history of serious head trauma, and presence of a learning disability (Webbe & Ochs, 2003). The neurocognitive tests used were the California Verbal Learning Test (CVLT), CVLT (Delayed Recall), Shipley (IQ), ROCF (Delayed Recall), Facial Recognition Test (FRT), and Paced Auditory Serial Addition Test (PASAT) (Webbe & Ochs, 2003). The study found impaired scores on Trailmaking, FRT, and PASAT amongst soccer players, when compared to the control group (Webbe & Ochs, 2003). Furthermore, the soccer athletes possessed poorer scores in the CVLT preservations, 2.0 interval of the PASAT, as well as the Shipley IQ test (Webbe & Ochs,

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2003). Those who were considered "recent" headers received worse scores on the

Shipley CQ, Trailmaking Parts A and B, PASAT 2.4 Trial, in addition to CVLT Trial 5

and total scores (Webbe & Ochs, 2003). Despite these significant results, the project did

not reflect a correlation between history of head injury and neurocognitive functioning

(Webbe & Ochs, 2003). This study was limited by the fact that groups were determined

strictly based off a questionnaire, and only elite level athletes were investigated.

Moreover the testing instruments were administered in the same sequence, which may

have impacted the results.

Kaminski et al. continued this line of research when he conducted a longitudinal

study, which looked at the impact of a season of heading on neuropsychological test

performance. The researcher utilized 393 female high school soccer players to assess

effects on Simple Reaction Time, matching to sample, continuous performance test, math

processing, and Sternberg memory (Kaminski, Cousino et al., 2008). The researcher

obtained a baseline on each individual, and performed post-season testing within one

week of the conclusion of the competitive season (Kaminski, Cousino et al., 2008). The

results of the study indicated that there was no correlation between the headers performed

in one season and neuropsychological functioning (Kaminski, Cousino et al., 2008). In

fact, the scores on math processing (MTH) and continuous performance test (CPT2)

improved at the postseason testing session (Kaminski, Cousino et al., 2008). This finding

may be attributed to the learning and practice effect of these neuropsychological tools.

The limitations from this work include the fact that the numbers of headers during

practice were not tracked, and there was a lack of sensitive neuropsychological testing

instruments. Despite these drawbacks, this study is novel in that it utilized high school

subjects, whom have been evaluated much less frequently than collegiate individuals. The results are pertinent because former studies have found that high school athletes tend to demonstrate memory deficits longer than their collegiate counterparts (Field, Collins, Lovell, & Maroon, 2003).

This same researcher also reported that balance, as measured through the Balance Error Scoring System (BESS) and Romberg conditions, was not influenced by total number of game headers, across a season, amongst female soccer players (Kaminski et al., 2007). The subjects in this study were high-school and collegiate players, who were given a neuropsychological and balance battery prior to, and following, a competitive soccer season. Once again, the methodology employed is not the most sensitive in detecting small changes in functioning.

A battery of thirteen neuropsychological tests, with twenty five dependent factors, was used by Stephens et al. to investigate the potential effects from cumulative heading. The tests included many of the same tests from Webbe's project, such as Trailmaking and Stroop (Stephens et al., 2005; Webbe & Ochs, 2003). Stephens reported that no neuropsychological tests were influenced by cumulative heading, prior head injuries, or their interaction (Stephens et al., 2005). The discrepancy in results may be attributed to the fact that this researcher used a group of subjects, ranging in age from thirteen to sixteen, compared to most others who used elite college-aged individuals. This young group had not been exposed to the amount of cumulative impacts of collegiate individuals, which may explain the contrasting results. Stephens' project is limited by small sample size and the fact that some subjects headed on the day of testing, which may have skewed results.

One study published shortly thereafter investigated subjects who had sustained a concussion during a soccer season, and the possibility of neurocognitive deficits following the season (Ellemberg et al., 2007). A group of twenty two female soccer players from the university level served as subjects for this project (Ellemberg et al., 2007). From this sample, twelve athletes possessed no history of concussion, and ten others who had suffered their first concussion during the preceding outdoor soccer season (Ellemberg et al., 2007). All participants were assessed using the California Verbal Learning Task (CVLT), Ruff 2 & 7 Selective Attention Test, Brief Test of Attention (BTA), Symbol Digits Modalities Test (SDMT), Stroop Color Word Test, and Tower of London DX (TOL^{DX}) (Ellemberg et al., 2007). The Letter Fluency Test, Forward and Backward Digit Span, Simple Reaction Time (SRT), and Choice Reaction Time (CRT) tests were used as well to measure neuropsychological and neurocognitive functioning (Ellemberg et al., 2007). Any athlete with psychiatric disorders, attention deficit conditions, or learning disabilities was excluded from participation (Ellemberg et al., 2007). The results from the study demonstrated that differences were evidenced in the response time of the Choice Reaction Time (CRT) test, the planning time of the Tower of London DX (TOL^{DX}) test, in addition to both the flexibility and inhibition speed, of the Stroop Color Word Test between the two groups (Ellemberg et al., 2007). Conversely, statistical differences were not noted in the accuracy of the CRT, the execution time of the TOL, or flexibility accuracy of the Stroop Color Word Test (Ellemberg et al., 2007). Furthermore, significance was not evidenced in the speed or accuracy of the Ruff 2 &7, the total immediate recall or delayed recall of the CVLT, the Digit Span Fluency, BTA, SRT, or SDMT tests (Ellemberg et al., 2007). Despite the fact that these results provide

valuable information, they only address one area of neurocognitive functioning, using basic pencil and paper tests.

Results of Acute Bouts of Heading

In addition to investigating cumulative effects from soccer heading, researchers have also looked into acute bouts. Tysvaer et al. began the work in this area in the early 1980s. He found that following ten minutes of heading with correct form, all four soccer players investigated, possessed a headache from the task (Tysvaer & Storli, 1981). This study obviously did not utilize a sufficient sample size, and it was not based on sound methodology. In another project, the researcher used a survey format to determine that 64 of a total 128 players demonstrated acute symptoms following the skill of heading (Tysvaer & Storli, 1981). Furthermore, it was reported that ten of the players affected needed hospitalization for their conditions (Tysvaer & Storli, 1981). These results may be attributed to the aforementioned composition of soccer balls and the lack of quality medical attention at sporting events almost three decades ago. Although these studies are slightly remedial, they may have inspired more comprehensive studies in this area of research.

A subsequent study examined an acute bout of heading, which was integrated into a ninety minute training session (Putukian et al., 2000). Male and female NCAA Division I college soccer players from Penn State University were used as subjects in the study (Putukian et al., 2000). All athletes were put through a typical practice session, with twenty minutes of heading drills (Putukian et al., 2000). This included headers from distances of ten feet, twenty five feet, between 30-40 feet, as well as headers from a punt (Guskiewicz et al., 2004; Putukian et al., 2000). Following this session, the subjects were

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asked to complete Alphabet Backwards, Trail Making Test A and B, Stroop Color, and the Word modified version of VIGIL/W. On all neuropsychological functioning tests, Putukian et al found no effect from a twenty minute heading session (Putukian et al., 2000). Moreover, there was no statistical difference amongst sex reported from this work (Putukian et al., 2000). However, this project was limited by learning effects, and the difficulty of defining a "typical" practice session (Putukian et al., 2000). Also, only elite athletes were utilized, which is not representative of the majority of soccer participants. Moreover, the neuropsychological battery was not comprehensive, and a gender effect may have impacted the Stroop 2 and Alphabet backwards tests.

Broglio et al. conducted another study that looked at an acute bout of soccer heading amongst forty collegiate soccer players (eighteen men and twenty two women) (Broglio et al., 2004). Subjects were excluded from investigation if they were currently receiving treatment for a lower extremity or head injury (Broglio et al., 2004). Participants performed twenty headers over a period of twenty minutes (Broglio et al., 2004). The soccer balls were expelled from a JUGS machine at a distance of eighty feet and at an initial speed of fifty five miles per hour (Broglio et al., 2004). Subjects completed a linear portion, where balls were headed straight forward, and a rotational component, which involved heading at a ninety degree angle (Broglio et al., 2004). Following the intervention, a center of pressure measure was taken on all subjects (Broglio et al., 2004). These measures revealed that balance and sensory relationships were not affected by an acute soccer heading bout (Broglio et al., 2004). The shortcomings of this study include the limited reporting of data from the results, the practice effect for testing procedures, and the fact that only elite soccer athletes were

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evaluated. Furthermore, rotational heading was defined as "jumping and rotating the head at 90˚ at the moment of ball impact" (Broglio et al., 2004). This leaves room for a great deal of subjectivity, and, once more, leads to threats of the soundness of the study. Despite the few limitations of the study, it proposed a novel idea in that it evaluated balance performance using more sensitive instrumentation.

A similar study was conducted by Mangus et al., which confirmed Broglio's work. This study was also aimed at determining balance performance effects of an acute bout of soccer heading (Mangus et al., 2004). The project consisted of eight males and two females heading twenty soccer balls that were kicked by a teammate from a distance of approximately twenty five meters (Mangus et al., 2004). The SOT was used in this study to evaluate balance performance at a baseline session, and also following the heading protocol (Mangus et al., 2004). The authors observed no impairments in scores after heading twenty soccer balls; however, the research may be limited by the small sample size and the inability to maintain the speeds of the flighted balls (Mangus et al., 2004).

Schmitt et al. also investigated the neurocognitive effects of an acute bout of heading amongst college-aged soccer players (Schmitt et al., 2004). In addition to using postural control measures on a forceplate, the researcher examined symptom checklist, which was innovative at the time (Schmitt et al., 2004). This was the first study of the kind to look into this dependent variable as a possible predictor of neurocognitive dysfunction (Schmitt et al., 2004). The project utilized subjects who were divided between a kicking and heading group, both of whom completed eighteen of the designated skill over forty minutes (Schmitt et al., 2004). The subjects were assessed

prior to the task, immediately after, and twenty four hours following the activity (Schmitt et al., 2004). From this project, it was reported that the group who completed headers possessed more concussive symptoms immediately after the task (Schmitt et al., 2004). However, this discrepancy was resolved at the reading taken twenty four hours following the bout (Schmitt et al., 2004). It was also determined that there were no significant differences between the kicking and heading group with regards to postural control (Schmitt et al., 2004). Additionally, a previous history of concussion did not seem to influence the outcomes following the heading bouts, which confirmed previous studies (Schmitt et al., 2004). This study was limited by the lack of potency and inconsistency of the heading intervention. Nonetheless, the discovery of possible concussive symptoms, immediately after an acute bout of heading, warrants further research in the area.

Recommendations for Soccer

Rule Changes

In response to the concerns of soccer heading, many changes have been proposed in the game. Many people assert that equipment and rule changes should be contemplated, in much the same way that the composition of the soccer ball was refurbished and modernized (Delaney & Drummond, 1999). The use of smaller soccer balls for youth players, was first suggested, and then implemented into the game (FIFA, 2008/2009; Green & Jordan, 1998). Also, proposals have been made to delay the teaching of heading until proper coordination is exhibited (Green & Jordan, 1998). These recommendations have been made in soccer, in order to limit the number of head injuries.

Equipment Changes

Additionally, the use of mouthguards has gained considerable thought by medical researchers in the field (Delaney & Drummond, 1999). Mouthguards are believed to diminish the amount of energy transferred between the jaw and skull, thus reducing heading injury (Delaney & Drummond, 1999). Also, manufacturers have constructed soccer headgear, which is proposed to decrease the forces sustained from heading a soccer ball (Broglio et al., 2003). Currently, the Federation Internationale de Football Association (FIFA) authorizes the use of "soft football headgear in games" (FIFA, 2008/2009).

Soccer Headgear

Composition

There have been many recommendations made for soccer headgear, in order to prevent it from drastically changing the sport. The various types are lightweight, and typically, range in thickness from eight to eleven millimeters (Delaney & Drummond, 1999; Tierney et al., 2008). The weight is a very important aspect because it will be worn for a ninety minute soccer game, and a heavy apparatus could become tiring and change mechanics (Delaney & Drummond, 1999). Along these lines, the headbands ought to be composed of a waterproof substance, to prevent fluid uptake, which could increase weight (Delaney & Drummond, 1999). They must also be able to maintain their characteristics after recurring contact, similar to rugby headgear (McIntosh, McCrory, Finch, Chalmers, & Best, 2003). These bands are traditionally composed of ethyl vinyl acetate polyethylene (EVA PE), which creates a malleable foam (McIntosh et al., 2003). Furthermore, the headbands should be adjustable, with the intention of fitting the shape

of the athlete's head (Delaney & Drummond, 1999). Additionally, it has been decided

that a hard outer shell should not be present, so as to protect opposing players who may

strike the headgear (Delaney & Drummond, 1999). Lastly, these headbands must have

the potential to allow for proper ventilations (Delaney & Drummond, 1999). All of these

characteristics are essential to an effective piece of equipment that will not interfere with

the integrity of the sport.

Brands

To date, several types of headbands have been developed with the

abovementioned characteristics in mind. The Headblast is a neoprene band, which

contains a plastic piece in the frontal aspect of the apparatus (Broglio et al., 2003). This

band has not gained a great deal of popularity due to the fact that there is a potential for

injury to opponents, who may contact the band. The Protector is an alternative brand

available, which is about ten to eleven millimeters in thickness (Broglio et al., 2003). It

is a terry-cloth material with foam contained within the fabric (Broglio et al., 2003). Yet

another variety of headgear is the one that has garnered the most popularity. This

headband was originally called Headers, but has since taken on the name Full90^{TM}

(Broglio et al., 2003). This piece of headgear utilizes foam in a closed-cell form, which

is positioned within an outer fabric, over the areas of the skull that provide the greatest

concern (Broglio et al., 2003). Three other headbands include Soccer Docs, Kangaroo,

and Head'r, none of which have gained extreme recognition (Naunheim et al., 2003).

Clearly, there are a variety of manufacturers that have tried to address the issue of

heading in soccer by constructing bands with various characteristics. Nonetheless, the

Full90^{TM} band is the one that currently is being worn most by soccer players.

Benefits

There are many proposed benefits for the use of properly designed soccer headgear. Naturally, the headbands are thought to possibly prevent concussion and the injury sustained from recurring blows to the head (Delaney & Drummond, 1999). It has been suggested that three specific groups of players have the potential to receive tremendous benefit from soccer headgear (Delaney & Drummond, 1999). The first of these groups, is athletes who have a concussion history, and may have a lowered threshold for suffering a future injury (Delaney & Drummond, 1999). Secondly, players who are in positions of heightened risk, such as goalkeepers, who have the potential to engage in many collisions with other players and the goalposts (Delaney & Drummond, 1999). Lastly, it is hypothesized that children may receive benefits from the headbands seeing as their cranium may not be fully developed until the age of eighteen or older (Delaney & Drummond, 1999; Tysvaer & Storli, 1981). In addition to the three aforementioned groups, soccer headgear is also thought to protect players not wearing the apparatus, who may come in contact with another player utilizing it (Delaney & Drummond, 1999). The impact that both players sustain would theoretically be reduced due to the attenuation of force.

Effectiveness of Soccer Headgear

Foundational Research

The first step in evaluating the effectiveness of these headbands is conducting foundational research related to their ability to dissipate forces. Most of these efforts began around 2003, as Broglio and Naunheim initiated the investigations. Broglio et al. began the efforts in this field by using a mounted force platform in conjunction with the

Headers, Headblast, and Protector headbands (Broglio et al., 2003). A total of fifty trials were performed, and calculations of peak force, time to peak force, and impulse were obtained (Broglio et al., 2003). All soccer balls were expelled from a JUGS machine at a velocity of thirty five miles per hour and a distance of sixty inches (Broglio et al., 2003). Results indicated that the Protector headband exhibited a significant decrease in time to peak force compared to the other two headbands and a control condition (Broglio et al., 2003). The Headblast and Headers did not demonstrate a reduction between bands or when compared to a no-headband condition (Broglio et al., 2003). Additionally, the Protector headgear displayed a diminished impulse, while the Headers showed a significantly larger impulse, when compared to the other conditions (Broglio et al., 2003). Overall, the soccer headbands were found to decrease forces by roughly 12.5%, which supports the notion that their use would be protective in nature (Broglio et al., 2003). Although these results may provide valuable information, the study was limited by a variety of factors. To begin with, the headbands were attached to flat surface, which is not indicative of a human skull. Also, only linear forces were measured, and rotational elements were not considered. Finally, all trials were conducted under a constant speed and the distance was not realistic in a game or practice situation.

Naunheim et al. expanded previous research by addressing many of the limitations of the past study. He utilized headforms with accelerometers to replicate the biomechanics of a human skull and neck. Speeds of nine, twelve, and fifteen meters per second were used to expel soccer balls from a distance of three meters (Naunheim et al., 2003). The Soccer Docs, Kangaroo, Head Blast, and Head'r headbands were attached to the headforms, and impacts were sampled at a rate of 4,800 samples per second

(Naunheim et al., 2003). The results of this study found that soccer headgear had a slight ability to attenuate peak acceleration only at higher speeds (Naunheim et al., 2003). However, not one of the bands offered protection for soccer balls traveling at lower velocities (Naunheim et al., 2003). The authors suggested that headbands would only have a positive impact if they did not compress entirely and if they were as conforming as the soccer ball (Naunheim et al., 2003).

Withnall et al. investigated the Full90[TM], Head Blast, and Kangaroo Soccer headgear, and found no particular benefit of any three (Withnall, Shewchenko, Wonnacott et al., 2005). Each one was attached to a headform and balls were released at speeds ranging between six and thirty meters per second (Withnall, Shewchenko, Wonnacott et al., 2005). The lower speeds were used to simulate voluntary headers, and higher speeds equated to inadvertent headers (Withnall, Shewchenko, Wonnacott et al., 2005). Not one of the three headbands was effective in attenuating forces in either condition (Withnall, Shewchenko, Wonnacott et al., 2005).

Impact of Headgear on Head Accelerations

In addition to its ability to dissipate force, considerable attention has centered on its effect on head accelerations. It has been shown that the headbands are able to decrease acceleration in males only (Tierney et al., 2008). Conversely, females exhibited accelerations 10-45 greater than those of males, which is thought to elevate the risk of concussion (Tierney et al., 2008). The study that produced these findings was limited by the fact that mouthpiece accelerometers were used and the measurements were only collected for linear accelerations. When using headforms, there appeared to be no apparent decrease in head acceleration or HIPmax while using soccer headgear (Withnall,

Shewchenko, Wonnacott et al., 2005). Oddly enough, at a speed of thirty meters per second, head accelerations were increased under the headgear condition (Withnall, Shewchenko, Wonnacott et al., 2005). However, the overall results indicated that the headgears as a group resulted in a 33% reduction in linear acceleration and HIPmax (Withnall, Shewchenko, Wonnacott et al., 2005).

Effect of Headgear following Purposeful Heading

Currently, researchers are beginning to investigate the impact of soccer headgear in relation to clinical measures. It has been presented that use of the headbands during purposeful soccer heading does not impact neurocognitive function (Janke, 2006). This was assessed using the computerized ImPACT program (Janke, 2006). Composite memory verbal, visual, motor, reaction, and impulse scores were assessed (Janke, 2006). The study also examined symptoms following a bout of twenty headers over the course of twenty minutes, with balls traveling between forty five and fifty miles per hour (Janke, 2006). A total of thirty four NCAA Division I soccer players were used as subjects, and they were separated into three groups (Janke, 2006). The classifications included no headgear, Full90™ group, and Forcefield group (Janke, 2006). All subjects performed the heading protocol on three consecutive days (Janke, 2006). Although neurocognitive function deficits were not noticed following heading, concussive symptoms were higher following the task (Janke, 2006). These were reduced when the Full90™ band was worn during heading protocol (Janke, 2006).

The major limitation of this project is the fact that an across subjects design was employed, rather than a within subjects design. The latter would have better allowed

conclusions to be drawn about soccer heading and the use of protective headgear. Also, the protocol was not very potent, and balance performance was not investigated. These issues must be addressed in the future, in order to give clinicians an idea of the efficacy of soccer headgear.

Use of Headgear amongst Females and Youths

Particular interest has been centered on the use of headgear in the youth and female populations. Delaney et al. reported that females wearing headbands possessed a decreased risk for suffering a concussion, in addition to, abrasions, lacerations, or contusions (Delaney et al., 2008). This study was based off of self-reported measures from 12-17 year old soccer players of the Oakville Soccer Club in Canada (Delaney et al., 2008). They were asked about whether they wore headgear, and if so, which type was worn and how often (Delaney et al., 2008). It was reported that in the group wearing headgear, 27% of athletes sustained a concussion, compared to about 53% of the group who did not wear headgear (Delaney et al., 2008). Although these numbers provide a striking difference, there are two main considerations that must be addressed. Firstly, the groups varied in number of subjects a great deal (Delaney et al., 2008). The headgear group was composed of fifty two athletes, in contrast to 216 players not wearing the headbands. Thus, it is difficult to draw a conclusion from the two groups with the significant demographic discrepancy. Also, there may exist some recall bias and inaccuracy from the youngsters polled.

SCAT2

The SCAT2 is a revolutionary neurocognitive testing instrument, which

originated from the SAC. The SAC has been shown, in healthy individuals, to provide

comparable scores during practices and games, which validates its efficacy as a sideline

measure (McCrea et al., 1998). A study that examined concussed athletes found that

these individuals scored poorer on all sections, compared to controls (McCrea et al.,

1998). Overall, it appears that significant differences between these groups exists only in

the first forty eight hours immediately after the head injury (McCrea, 2001). Moreover,

the participants with a head injury scored lower than their baseline following injury,

which suggests that the SAC is an effective sideline evaluation of concussion (McCrea et

al., 1998). It also evokes the idea that the tool is serial in nature, and should continually

be administered in a periodic manner to properly track neurocognitive and mental status

changes (McCrea et al., 1998). Although it has been established that the SAC is fairly

resistant to a ceiling effect, the one major drawback to the tool is that the SAC is not

completely immune to the phenomenon (McCrea et al., 1998). Also, a practice effect

has been evidenced in the concentration portion, which may not be ameliorated by the

alternate forms (McCrea, 2001).

One study, evaluating the nature of this tool found that scores remained at the

same level or increased from preseason to midseason to postseason in a group of healthy

individuals (Miller, Adamson, Pink, & Sweet, 2007). All differences in scores were

reported to be within one unit of measurement of one another (Miller et al., 2007).

Obviously, this test is not meant to be used exclusively, rather it is only a fraction of a

thorough concussion assessment (McCrea, 2001).

The Graded Symptom Checklist (GSC) is a tool, which examines eighteen

indicators of concussion (McCaffrey et al., 2007). These symptoms are strictly self-

reported, and they are quantified using a Likert scale (McCaffrey et al., 2007). Each item

contains a seven point system, which ranges from an absence of the symptom (Sports)to

severe (6) (McCaffrey et al., 2007). The GSC has been shown to be a reliable assessment

tool in concussion management (Maroon et al., 2000; McCrory, Ariens, & Berkovic,

2000). When applied serially, this tool is very important in determining resolution

patterns of symptoms.

Recently, normative values have been published in regards to the initial Sport

Concussion Assessment Tool (SCAT). Investigators evaluated scores between sexes and

between people with and without a history of a concussion (Shehata et al., 2009).

Females possessed higher normative values than their male counterparts when

investigating symptomatology (Shehata et al., 2009). Furthermore, women had more

symptoms overall than men (Shehata et al., 2009). The most commonly reported

symptoms during testing was fatigue/low energy, drowsiness, and neck pain (Shehata et

al., 2009)

When evaluating the subjects on the five word recall, all participants correctly

named at least four of the five words (Shehata et al., 2009). Surprisingly, subjects who

had formerly sustained a concussion performed better than nonconcussed individuals

(Shehata et al., 2009). People struggled on the delayed recall trying to remember the

same set of words (Shehata et al., 2009). Females possessed a higher frequency recalling

all five words after a period of time, compared to their male counterparts (Shehata et al.,

2009). Subjects with a concussion history comprised the greatest number of people who

were unable to remember any words during the delayed recall (Shehata et al., 2009).

Women also performed better than males when investigating the months in reverse order

task (Shehata et al., 2009). Subjects with a previous history of concussion possessed a

higher frequency of correctly reciting the six digit string of number compared to people

without a history of head injury (Shehata et al., 2009). Overall, females performed higher

than males on cognitive tests, which confirms previous research (Covassin et al., 2006;

Shehata et al., 2009). Also, subjects with a history of a head injury scored higher than

those without a history, except in the delayed recall portion (Shehata et al., 2009). This

seems inherently contradictory, but may be attributed to their former experience with the

testing instruments.

Since the SCAT2 was recently released, reliability studies have not been

conducted on the tool. However, the sum of all of its parts has been shown to be valid

and reliable time after time. This indicates that the SCAT2 will most likely be a

dependable measure.

SRT

As a whole, the Automated Neuropsychological Assessment Metric (ANAM)

computerized test battery is a valid tool in differentiating concussed and nonconcussed

athletes (Bleiberg, Halpern, Reeves, & Daniel, 1998). This is partly due to the precise

timing utilized by the software, which cannot be replicated using a stopwatch (Bleiberg et

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al., 1998).   The logistical advantages of the battery make it appealing to clinicians in addition to the associated precision.

Kaminski et al. reported that the results from this neuropsychological test become stable after two testing sessions (Kaminski, Groff et al., 2008). It seems that scores display progress, with stability being reached after the second test session (Kaminski, Groff et al., 2008). In response to this finding, it was suggested to perform double baseline sessions, using only the information from the second trial as the final baseline data (Collie et al., 2003). When using a two week interval, the neuropsychological scores were relatively stable (Kaminski, Groff et al., 2008).

When the modules are investigated individually, many seem to mirror tasks which are already tested by the SCAT2. However, the SRT is novel and is clinically relevant to athletes, who are forced to rely on split second reaction time. This module also seems to be the least affected by practice effects when compared to other tests that comprise the ANAM battery (Bleiberg et al., 1998). The impairments seen with this particular task were present at longer time intervals (Bleiberg et al., 1998). This is essential when testing cognitive deficits which may exist at a subconcussive level. The Simple Reaction Time task has also been shown to exhibit deterioration over time, which is important when using repeated measure designs (Bleiberg et al., 1998). This module has been reported to show significant differences when testing in season versus out of season athletes, which again indicates the sensitivity (Brown, Guskiewicz, & Bleiberg, 2007). Additionally, Kaminski et al. previously demonstrated that the change scores from the SRT task were affected by purposeful heading (Kaminski, Cousino et al., 2008).

NeuroCom

This testing instrument has been employed in a great deal of concussion research. Guskiewicz et al. found that concussed athletes demonstrated significant deficits, as compared to control subjects, one day following injury using NeuroCom measures (Guskiewicz, Ross, & Marshall, 2001). Athletes with more severe head injuries have also demonstrated higher anterior/posterior and medial/lateral sway values, compared to those who suffered minor trauma (Ingersoll & Armstrong, 1992) One study reported that 61.9% of all subjects who had sustained a concussion, demonstrated some type of impairment on the NeuroCom, one day after initial injury (Broglio, Macciocchi, & Ferrara, 2007). A significant practice or learning effect is associated with this task (Wrisley et al., 2007). This improvement in the composite SOT scores was shown to plateau after the third session (Wrisley et al., 2007). Although studies have identified impairments in postural sway subsequent to head injury, many believe that this test is only one aspect of concussion assessment. Broglio suggests using the instrument, in conjunction with, verbal cognitive tasks, with the goal of performing a multi-dimensional approach (Broglio, Tomporowski, & Ferrara, 2005).

Rationale for Study

Although previous research has been conducted investigating the effect of heading on neurocognitive performance, little has been done using sensitive testing instruments. Preceding work focuses on measures which are less responsive to subtle deficits in performance. The majority of this research also focuses on Division I collegiate or elite soccer athletes with little focus on younger and less skilled populations. Also, very little exploration has been completed on soccer headgear, and its ability to

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lessen the impairments, if any, from heading. Therefore, our study investigated the effects of wearing one type of soccer headgear on neurocognitive function following an acute soccer heading bout. The understanding of these two factors is very important from a clinical standpoint, in order to improve the care following head impacts in the sport.

CHAPTER III

METHODS

Introduction

       Currently, the assessment and management of sports concussion is receiving widespread attention in the literature. However, the concept of repetitive subconcussive blows, especially as it relates to soccer heading, has received less notoriety. It is commonly accepted that all possible brain trauma must be assessed using a multi-faceted approach, entailing postural control, symptomatology, and cognitive functioning. These domains include both laboratory and sideline tools, which are integral to proper recognition and treatment of mild traumatic brain injuries. The most important aspect of concussion assessment is the continuity of testing protocols between and within clinicians. In our study, we followed the directed protocols for the Sport Concussion Assessment Tool (SCAT2), the Balance Error Scoring System (BESS), the Simple Reaction Time task module of the Automated Neuropsychological Assessment Metrics, and the Sensory Organization Test (NeuroCom International, Clackamas, OR). Our goal was to examine the effect that an acute soccer heading bout, with and without headgear, may have on these measures.

Subjects

A prospective repeated measures design was employed to assess neurocognitive function and balance performance following an acute bout of soccer heading. Subjects consisted of 29 (16 male and 13 female) recreational college-aged soccer players (age = 18-25 years old, 20.48 ± 1.90, height = 173.54 ± 8.61 cm, weight = 72.13 ± 11.24 kg) from the University of North Carolina, Chapel Hill. Due to mal-functioning equipment, only 27 of these have complete data from the Sensory Organization Test. All participants were recruited from the club sports or competitive division intramural soccer teams at the institution and were informed of all procedures involved in this study. A rolling recruitment was used, meaning that subjects each completed their three weeks of participation randomly over the course of three months. While some participants were completing baseline, others were completing a heading session. The timing between sessions remained consistent, but start dates differed.

All subjects were notified of inherent risks, and were asked to read and sign an informed consent form in accordance with the University of North Carolina's Institutional Review Board (# 09-1264).

Inclusion Criteria

Subjects were included in this study if they were a member of the women's or men's club or competitive division intramural soccer teams at UNC Chapel Hill, who did not possess any excluding factors. They all possessed field player experience, and thus, no subject was exclusively a goalkeeper for their entire soccer career. Their participation on the club or intramural teams indicated an adequate heading skill level to reduce injury risk.

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Exclusion Criteria

Subjects were excluded in this study if they were under the age of 18 or if they had suffered a concussion in the past six months as assessed by a certified athletic trainer or diagnosed by a physician. Also, subjects who had sustained a lower extremity injury within the past three months, which altered participation levels, were excluded. Additionally, all subjects were prohibited from participation if they possessed any known medical conditions such as vertigo, equilibrium disorders, vestibular deficits, or diagnosed learning disabilities, including Attention Deficit Hyperactivity Disorder (ADHD).

Instrumentation and Outcome Measures

Neck and Head Strength and Anthropometric Measurements (Appendix 1)

Neck strength has garnered a great deal of attention with regard to the possibility of its link to concussion and control of the head during heading tasks. The results from previous studies are mixed (Bauer et al., 2001; Mansell et al., 2005). We collected neck strength measurements in various testing positions during the baseline session. The data were analyzed and used as covariates for the statistical design.

Neck circumference measurements were taken on each subject using a standard clinical tape measure. This was measured at the level just above the thyroid cartilage. Head circumference was also measured using a standard clinical tape measure across the middle of the forehead. Medial-lateral and anterior-posterior diameters were measured using an anthropometer. The former was measured just above the top of the ears, and the

latter was measured from the middle of the forehead to the middle of the posterior aspect of the head.

Handheld Dynamometer (Figure 1)

Isometric neck musculature strength values were collected using a hand-held dynamometer (HHD) (Lafayette Manual Muscle Test System Model number 01163, Lafayette, IN). This device has been shown to be a reliable and efficient method of assessing muscle strength. As long as the examiner's strength is greater than the muscle being tested, the measurement is shown to be accurate (Stratford & Balsor, 1994). Testing positions for isometric strength testing have been outlined by Kendall (Kendall, 2005).

Traditional "break tests," as described by Kendall et al. were used to measure cervical muscle strength with a hand-held dynamometer (Kendall, 2005). Recordings for anterior neck flexors, anterolateral neck flexors, cervical rotators, posterolateral neck extensors, and upper trapezius were taken bilaterally. The cervical rotators were based off the protocol described by Hislop and Montgomery (Hislop, 1986). For all measurements, three values were taken and averaged into a single score. Prior to the test trials, two practice trials were performed on each measure. All trials were separated by a rest period of thirty seconds. The averages of all break forces were normalized to the subject's body weight. Height and mass were recorded on a standardized medical scale.

The headgear was worn during all cervical neck musculature measurements. Following this portion of baseline testing, subjects were asked if simply wearing the headband caused a headache. All participants answered negative, which allowed us to

affirm that all headaches following heading, were a product of the skill, not of the apparatus.

Figure 1. Handheld Dynamometer

Anterior Neck Flexor Strength (Appendix 1)

Anterior flexor strength was measured with the subject in a supine position. The subject's elbows were bent and hands were overhead on a treatment table. The participant lifted their head, while depressing their chin, and approximating it towards the sternum. The researcher then applied pressure against the forehead in a posterior direction using a handheld dynamometer.

Anterolateral Neck Flexor Strength (Appendix 1)

The subject maintained the same position from the previous strength testing measure. However, they rotated their head, in order to isolate the anterolateral muscles. In this situation, the pressure was delivered to the temporal region of the head in an obliquely posterior direction, after the head was lifted. This task was completed bilaterally to test strength.

Cervical Rotator Strength (Appendix 1)

The subject remained supine with their head supported on the table, with their head turned as far to one side as possible. They were instructed to rotate their head toward a neutral position against resistance. This task was completed bilaterally to test rotator strength.

Posterolateral Extension Strength (Appendix 1)

   The subject next moved into a prone position to test posterolateral neck extension strength. Their elbows were bent and hands again, were positioned overhead resting on a treatment table. The subject moved their neck into posterolateral neck extension with their face turned in the direction being tested. Pressure was applied by the researcher against the posterolateral aspect of the head in an anterior direction. This task was completed bilaterally.

Upper Trapezius Strength (Appendix 1)

   The upper trapezius was tested with the subject in a seated position. They were then asked to elevate the acromial end of the clavicle and scapula while also moving their occiput toward the elevated shoulder. The subject was also instructed to turn their face opposite to the side being tested. As the head was stabilized, the researcher attempted to depress the scapula. This task was repeated on the opposite side.

Full90^{TM} Headgear (Figure 2)

   The Full90 Select Headguard^{TM} (Full90 Sports, Inc, San Diego, CA) was used for the purposes of this study. This headband is constructed of "dual-density Forcebloc^{TM} foam," and was manufactured as a protective piece of equipment for soccer players.

Figure 2. Full90^{TM} Headband

Soccer Tutor Machine (Figure 3)

A calibrated Gold Model Soccer Tutor (Sports Tutor Inc., Burbank, California, USA) was used to expel soccer balls at the desired exit velocity. The validity of this device was verified using a Stalker Sport digital sports radar gun (Applied Concepts, Inc., Plano, Texas, USA) prior to testing. A series of twenty soccer balls were expelled to determine the accuracy of the exit velocities. This procedure was conducted on three consecutive days to ensure validity.

Figure 3. Soccer Tutor

SCAT2 (Appendix 2)

The Sport Concussion Assessment Tool 2 (SCAT2) was used to assess mental status, cognitive ability, and postural control. This instrument is comprised of three existing reliable sideline concussion measures; the Standardized Assessment of Concussion (SAC), the Graded Symptom Checklist (GSC), and the Balance Error Scoring System (BESS). The SAC portion examines orientation through five standard questions; immediate memory by evaluating recall of five dissimilar words; delayed

recall by assessing the same five words from the previous section after a period of time; and concentration by asking the athlete to repeat a string of numbers in reverse order.

The Graded Symptom Checklist section utilizes a seven point Likert grading scale in order to permit subjects to report a range of concussive symptoms. A total of twenty two symptoms were examined using the SCAT2. Overall, the GSC has been shown to be a reliable assessment tool in concussion management by providing a serial measure of symptomatology (Maroon et al., 2000; McCrory et al., 2000).

The SCAT2 also incorporates a balance performance task. It strictly utilizes the firm surface condition of the BESS; however, this study employed both this and the foam condition. The SCAT2 yielded a composite score out of one hundred points based on all domains of the instrument. The addition of the foam condition of the BESS, in this study, also produced a total balance score for the entire battery.

Balance Error Scoring System (Appendix 3)

The BESS is a reliable sideline instrument that examines postural stability (Riemann et al., 1999). The intent of this tool is to provide a valid sideline measure of overall balance. The test simply requires a timing device and a piece of medium density foam, ten centimeters in thickness. The protocol involves a total of six trials, using combinations of three stances and two surfaces. The double leg, single leg, and tandem stances are used in conjunction with a firm and foam surface. The testing position requires a subject to place their hands on their hips while attempting to remain still for each twenty second trial, with their eyes closed. Under the single leg conditions, the nondominant leg is used for weight bearing. The contralateral hip is flexed between 20°

and 30˚, in addition to the knee being flexed between 40˚ and 50˚. During the tandem

stance, the nondominant foot is positioned at the rear of the dominant. The test is scored

using an error system, which dictates six specific faults. These consist of lifting forefoot

or heel, opening eyes, lifting hands off of the iliac crests, moving hip into more than 30˚

of flexion or abduction, stepping/stumbling/falling, or remaining out of the testing

position for more than five seconds. The errors of each condition are calculated, with a

maximum score of ten per trial, and added together from all trials to give a composite

score (Guskiewicz, 2003).

SRT

The Simple Reaction Time task is one module from the Automated

Neuropsychological Assessment Metric (ANAM). It is a computerized test, which is

used to assess one aspect of neuropsychological function. The task takes only a few

minutes for each subject to complete. The SRT module requires participants to click a

computer mouse when a stimulus appears. The stimulus comes into view at different

time intervals, in order to challenge the subject's reaction time. The score is a product of

accuracy and speed of performance. A final throughput score was computed as the

dependent variable in this study.

NeuroCom (Appendix 4)

The Sensory Organization Test (SOT) (NeuroCom International, Clackamas, OR)

is an instrument designed to disrupt the selection sensory process of an individual in a

systemic manner. This is achieved by adjusting the amount of somatosensory

information, visual information, or both, and subsequently, measuring the subject's

ability to reduce postural sway. Overall, the NeuroCom uses a forceplate system to

measure vertical ground reaction forces, which are created as the participant's center of gravity deviates around a fixed base of support (Guskiewicz, 2001; Register-Mihalik, Mihalik, & Guskiewicz, 2008).

The protocol for this instrument is comprised of eighteen total trials, broken down into six conditions, each lasting twenty seconds, performed three times each. During each trial, the subject is instructed to stand with this feet shoulder width apart, as still as possible. There are a total of three unique visual conditions (eyes open, eyes closed, sway-referenced visual surround), which are matched up with two different surface types (fixed, sway referenced). All sway-referenced indicates a tilting of either the support surface, visual surround, or a combination of both. The support surface sway-referenced conditions (4-6) involves the synchronous tilting of the forceplate, with respect to the subject's anterior-posterior (A-P) COG sway. This is similar to visual sway-reference conditions (3, 6), in which the visual surround moves in the same manner. In all conditions, the movement is continually oriented comparative to a subject's body position (Guskiewicz, 2001; Register-Mihalik et al., 2008).

The testing instrument yields a composite equilibrium score, as well as, somatosensory, vestibular, and visual ratio scores. The composite score is indicative of overall performance across the trials, denoted through a weighted average of conditions. Higher composite equilibrium values signify less postural sway or better performance. Additionally, a vestibular ratio is yielded as the ratio of Condition 5 equilibrium score to that of Condition1. The visual ratio is computed by comparing Condition 4 to Condition 1, and the somatosensory score is calculated as a ratio of Condition 2 to Condition 1 (Guskiewicz, 2001; Register-Mihalik et al., 2008).

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Condition 1 of the NeuroCom is a reference trial where all sensory information is undisturbed. Ratios with higher values are indicative of the subject's increased ability to preserve balance under situations, where the vestibular (Condition 5), visual (Condition 4), and somatosensory (Condition 2) systems are forced to compensate for adjustments of the other systems. All four scores; the composite, vestibular ratio, visual ratio, and somatosensory ratio, functioned as dependent variables in our study (Register-Mihalik et al., 2008).

Headgear Satisfaction Survey (Appendix 5)

A headgear satisfaction survey was given to all subjects at the end of their third testing session. Five statements that were graded on a five point Likert scale comprised the survey. The first declaration asked about experiencing dizziness, lightheadedness, or headache following the bout of heading with the headband. The second inquired about comfort, and the third about altering heading mechanics. Statement number four on the survey questioned about whether the headband was cumbersome, and the final point related to the consideration of wearing headgear during competition. All questions were graded from five equaling strongly agree to one meaning strongly disagree. The statements were worded in a manner that higher numbers coincided with more approval. Thus, a total score of twenty five points equaled absolute satisfaction with the headgear.

Procedures

Subjects reported to the Sports Medicine Research Laboratory (FG 06F) on three occasions for testing. During the first session, subjects signed an informed consent form, completed a questionnaire (Appendix 5), and took part in baseline testing of the SCAT2, BESS, SRT, and NeuroCom SOT. The second and third sessions required the subject to

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complete a heading protocol followed by the same four tests (**Table 1**). During either the second or third session, the subject completed the heading task while wearing the protective headband based on a counterbalanced order.

Session 1

The initial session required subjects to complete a questionnaire, which asked about demographics, injury history, and sport specific information. Additionally, neck and head circumference measurements were taken using a standard tape measure. Strength of neck musculature was tested using a handheld dynamometer. Participants wore the headgear during the strength measurements. This served to make the subjects acquainted with the band before it was later worn for the heading task. Following measurements, subjects were asked if simply wearing the headgear resulted in a headache. This provided valuable information when later investigating the symptom checklist scores following heading bouts. All subjects then partook in baseline testing of the SCAT2, the BESS, a short computerized reaction time task, and the NeuroCom SOT. Testing order remained constant during baseline.

Session 2 and 3

One week subsequent to baseline testing, subjects reported for the first heading intervention. One half of the participants completed the first intervention (session 2) with the headgear, and the other half without the apparatus. All athletes wearing the headband were fitted properly by the investigator according to the manufacturers' guidelines. Headgear condition (no headgear vs. headgear) was applied in stratified assignment across subjects in a sequential fashion. Therefore, the first subject wore the headgear during their second session and did not wear it during their third. Conversely, the second subject did not wear the headband for their second session, but did during their third.

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This system of stratified assignment persisted across the twenty nine subjects, in an alternating order.

<u>Heading Protocol</u>

We employed a heading protocol involving a series of twenty headers, consistent with work conducted by previous researchers (Broglio et al., 2004; Putukian et al., 2000; Schmitt et al., 2004). All soccer balls travelled at an initial exit speed of 72.42 kph (45 mph) from a distance of eighty feet, also in agreement with past work (Broglio et al., 2004; Putukian et al., 2000; Schmitt et al., 2004). The speed was consistent with preceding work in the sport of soccer, which has determined this value to be equal to the speed of corner kicks during competition (Kirkendall, Jordan, & Garrett, 2001). The heading was performed at a rate of one every thirty seconds, slightly quicker than previous studies, which employed one header per minute (Broglio et al., 2004).

The protocol began with each subject taking five practice trials. These trials involved the ball being expelled at the specified distance, speed, and rate. The subjects were instructed to simply catch the five soccer balls with their hands, in order to get acquainted with the process and familiarized with the ball dynamics. Subsequent to the five practice trials, the testing protocol began. During the protocol, the subjects were instructed to head the ball only if they felt that they were able to head it with proper technique. In the case that a subject chose not to head the ball, another one was expelled directly after to ensure the overall rate. Participants were told to head all soccer balls for maximum distance in a linear direction back towards the Soccer Tutor machine. To standardize trials, a horizontal line was placed fifty feet from the subjects, serving as a target. There was no penalty for balls that did not reach the target. In order for a trial to

be counted, the initial flight of the ball following head contact was required to be in a forward direction. This advancement indicated an impact for this study. When soccer balls did not initially move forward, a retrial occurred immediately following the mistrial. All unsuccessful headers were logged throughout the study for each session. Prior to data collection it was determined that if one individual exceeded five mistrials, their session was disqualified. No subject exceeded two mistrials.

All soccer balls used in this study were size five, and were inflated to 0.70 bars of pressure and were between 27 and 29 inches in circumference, which met manufacturer's guidelines. The balls were checked prior to each session, in order to ensure proper pressure.

Table 1. Testing Order for Subjects

	1st Heading Intervention	2nd Heading Intervention
Baseline (all 29 subjects)	Headgear = 15 subjects	Headgear = 14 subjects
	No headgear = 14 subjects	No Headgear = 15 subjects

The heading intervention was completed in the indoor sports facility on campus. The heading protocol was preceded by an adequate cardiovascular and musculoskeletal warm up (Appendix 6). This included five minutes of jogging, as well as, a dynamic warm up focusing on stretching all major muscle groups. Participants were permitted to partake in the parts of the warm up that they felt necessary. Many had come from a

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practice, and thus, stated that they were ready for the protocol. Subjects were then asked to perform the heading intervention, which replicated a heading drill during a soccer training session. Immediately following the 20th header, the SCAT2 was administered to the subject at the testing location. Any subject who reported a Graded Symptom Checklist Score on the SCAT2 that was greater than their baseline was contacted via email for follow-up. Subjects then performed the foam conditions of the BESS at the same location, in order to generate a total BESS error score. Following this test battery, the subject was escorted to the Sports Medicine Research Laboratory to complete SRT and NeuroCom testing. The timing from completion of the BESS and initiation of the SRT was between six and eight minutes in all instances. For the first run through of the NeuroCom, each of the six conditions was done in condition order (1-6). The second and third runs were conducted in a randomized order obtained by the tester drawing numbers from a hat.

The overall order of instrumentation was chosen based on the fact that the SCAT2 and BESS are sideline tools designed to be administered instantly after injury or insult. Although the SAC has been shown to detect changes up to forty eight hours postinjury, it is most frequently used as an assessment tool immediately following an injury (McCrea, 2001). Without extensive literature on the SCAT2, we based our decision to use it first in our protocol on the fact that it was created as a sideline tool to evaluate concussions directly after the insult. Additionally, the SCAT2 has the ability to assess neurocognitive function as well as balance performance, which makes this testing instrument of higher priority due to its dual function. Thus, it was imperative to complete this first, so as to assess both areas of interest immediately after the protocol. Conversely, the SRT and

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NeuroCom SOT were created as more sensitive laboratory measures, which are meant to be used after a period of time has elapsed following initial injury. These instruments are better able to detect minute deficits after a prolonged time frame due to the nature of its design. They have been shown to sense differences up to five days following concussion (Guskiewicz et al., 2001). Clinically, the SRT and SOT are rarely used on the day of injury, which led to our decision to include these two testing instruments after the sideline tools. The testing order of the SCAT2, BESS, SRT, and SOT remained constant for all testing sessions.

For the third session, the subject reported back one week following the second session to complete the remaining heading task for that particular individual. The procedures were replicated exactly, with the heading intervention, followed by the immediate administration of the SCAT2 and BESS, as well as, the succeeding SRT and NeuroCom evaluation under the second headgear condition. At the very end of session three, all subjects completed a headgear satisfaction survey, assessing their overall approval of the headband. The survey consisted of five questions, which were graded on a five point Likert scale.

All neck musculature values were taken by the primary researcher to decrease bias. A secondary researcher assisted in administering SCAT2, BESS, SRT, and SOT.

Data Analysis

Data analyses were conducted using SPSS 16.0 (Chicago, IL) computer software. Totally within repeated measures analyses of covariates (ANCOVAs) were used to compare the various outcome measures across the three sessions. Neck musculature

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strength and headgear satisfaction were used as covariates in the analysis. Neck

musculature strength included normalized anterior flexor, right anterolateral flexor, left

anterolateral flexor, and total neck musculature strength. Total neck musculature was

computed by adding anterior neck musculature strength, as well as, anterolateral flexors,

cervical rotators, posterolateral extensors, and upper trapezius strength bilaterally. These

measures were used as covariates in order to determine if neck strength influenced the

outcome measures following subconcussive repetitive head impacts. Total headgear

satisfaction was a function of a headgear survey out of a possible twenty five points, with

higher numbers corresponding to more approval (Appendix 5). This variable was used as

a covariate to control for the perception of the headgear when examining the objective

outcome measures. Each individual ANCOVA was run using all five covariates at first.

In the instance where covariates did not contribute significantly to the model, these were

excluded and a repeated measures ANOVA was run. When significance was found,

Tukey post hoc was calculated to determine critical values.

The covariates did not often contribute significantly to the models. However,

overall neck strength factored into the SCAT2 total score analyses ($P = 0.023$), as well as

the concentration scores ($P = 0.012$) and SCAT2 symptom score ($P = 0.016$). The total

number of symptoms ($P = 0.023$) and the SCAT2 symptom scores ($P = 0.004$) were run

using the right anterolateral neck flexor strength. Also, headgear satisfaction was used as

a covariate during the SRT ($P = 0.00$), SCAT2 total scores ($P = 0.014$), and concentration

scores ($P = 0.043$). These eight models were the only ones in which one of the covariates

significantly contributed.

Our alpha level was set a priori to less than or equal to 0.05. An a priori power analysis examining previous studies with similar outcome measures revealed an "n" of 20 to achieve a power of 0.80. Our treatment effect was slightly less potent than previous projects, as they utilized concussed subjects. Due to the fact that the methodology of this study was unique, twenty nine subjects were used in order to guarantee proper effect size. However, we experienced one technical issue with the NeuroCom during testing, which explained the fact that there are two less subjects in all SOT calculations compared to the other dependent variables. This was attributed to the machine not functioning during one data collection section.

CHAPTER IV

RESULTS

The purpose of this study was to investigate the effects of an acute bout of soccer heading, with and without the Full90^{TM}, headband on neurocognitive and balance performance in recreational college-aged soccer players. This was accomplished through a repeated measures design where subjects were required to perform two heading bouts, one with the headband and one without. **Table 2** provides demographic information on the participants of the study.

<u>Neurocognitive Function</u>

Neurocognitive function was measured through the SCAT2 and SRT scores (**Tables 3 and 4**). We observed no significant difference in total SCAT2 scores across the heading sessions ($F_{2,52} = 1.74$, $P = 0.185$). This was also true for the immediate memory ($F_{2,56} = 0.43$, $P = 0.653$), concentration ($F_{2,52} = 0.87$, $P = 0.522$), and coordination ($F_{2,28} = 2.07$, $P = 0.161$) SAC subcomponents of the SCAT2. All subjects successfully completed the coordination during the baseline and no headgear sessions. Only two participants failed the task during the headgear session. Similarly, SAC total scores were not different across testing session ($F_{1.7,46.8} = 1.74$, $P = 0.191$). Conversely, orientation scores on the SCAT2 were different across all conditions ($F_{2,56} = 3.90$, $P = 0.026$). Scores improved from baseline ($m = 4.97$ $sd = 0.19$) to the headgear session ($m = 4.90$, $sd =$

0.31, $P = 0.017$). Delayed recall scores were notably greater during baseline than the heading sessions ($F_{1.7,47.6} = 4.46$, $P = 0.022$). Tukey post hoc analysis revealed that scores decreased from baseline ($m = 4.66$, $sd = 0.67$) to the headgear session ($m = 4.07$, $sd = 1.16$, $P = 0.010$) and no headgear session ($m = 4.28$, $sd = 0.80$, $P = 0.014$). When investigating Simple Reaction Time, a significant finding was revealed ($F_{1.8,54} = 8.45$, $P = 0.001$). Scores were improved from baseline ($m = 4258.07$, $sd = 15.98$) to the headgear condition ($m = 266.39$, $sd = 22.26$, $P = 0.008$).

Symptomatology

Symptomatology was assessed through the GSC portion of the SCAT2 (**Table 3**). A significant difference was observed in the symptom severity aspect of the SCAT2 testing instrument ($F_{2,54} = 5.78$, $P = 0.005$). Scores were lower at baseline ($m = .72$, $sd = 1.16$) to the headgear session ($m = 2.03$, $sd = 2.82$, $P = 0.01$) and no headgear ($m = 2.21$, $sd = 3.22$, $P = 0.016$). Conversely, SCAT2 symptom score ($F_{1.6,42.6} = 1.64$, $P = 0.209$) were not different between sessions. A significant finding was noticed in headache ratings ($F_{2,56} = 8.45$, $P = 0.001$). Tukey post hoc revealed baseline ratings ($m = 0.10$, $sd = 0.41$) were lower than the headgear session ($m = 0.86$, $sd = 1.13$, $P \leq 0.001$) and no headgear ($m = 0.86$, $sd = 1.30$, $P = 0.005$).

Balance Performance

The NeuroCom SOT test, as well as the firm and foam conditions of the BESS test, was used to evaluate balance performance (**Tables 4 and 5**). No difference was observed concerning composite SOT scores ($F_{1.7,44.4} = 2.63$, $P = 0.091$). Furthermore, our findings were not significant when examining the somatosensory ($F_{2,52} = 2.01$, $P = 0.144$) and vestibular ($F_{2,52} = 2.11$, $P = 0.132$) ratio scores. Conversely, visual SOT ratio scores revealed a difference ($F_{2,52} = 4.17$, $P = 0.021$). Scores improved from baseline (*m*

= 0.91, $sd = 0.05$) to the headgear session ($m = 0.94$, $sd = .06$, $P = 0.013$) and no headgear ($m = 0.94$, $sd = .06$, $P = 0.020$). Balance error scoring system (BESS) total error scores were not significantly different ($F_{1.8,49.2} = 1.18$, $P = 0.311$) across test sessions. Similarly, no significance was found when evaluating strictly firm surface errors ($F_{2,56} = 0.06$, $P = 0.945$) or foam surface errors ($F_{1.7,56} = 0.75$, $P = 0.456$) across the three testing sessions.

Headgear Satisfaction

When analyzing the headgear satisfaction survey, the average composite score was 14.72 ($sd = 4.22$) out of a total 25 points (**Table 6**). The mean scores of the questions asking subjects about not experiencing concussive symptoms and the headgear not altering heading mechanics were 3.66 ($sd = 1.37$) and 3.00 ($sd = 1.28$) respectively. The mean score produced from the statement declaring that the headband was not cumbersome was 3.10 ($sd = 1.76$). The average rating of whether the headgear was effective was 3.07 ($sd = 1.10$). When subjects were asked about considering wearing the headbands, a mean score of 1.90 ($sd = 1.01$) was produced.

Supplemental Analyses by Concussion History

We sought to better understand the potential effects that differing concussion histories may have on the dependent measures we studied across test sessions. As such, paired T-tests were run for all major outcome measures using concussion history (presence of previous concussion, absence of concussion) as the between-subject factor. Regardless of the dependent measure we analyzed, the differences in means between concussion history was not statistically significant ($P > 0.05$ for all analyses) (**Table 7**).

Table 2. Demographic Information

	Mean and Standard Deviation
Age (n = 29)	20.48 ± 1.90
Mass (kg) (n = 29)	72.13 ± 11.24
Height (cm) (n =29)	173.54 ± 8.61
Years of Soccer Experience (n = 29)	14.24 ± 3.53
Hours Per Week Dedicated to Soccer (n = 29)	8.03 ± 6.70

Table 3. Sport Concussion Assessment Tool (SCAT2) Total Score and Subcomponent Scores Means and Standard Deviations

	Baseline		Headgear		No Headgear		F value	P-value
	Mean	SD	Mean	SD	Mean	SD		
Total SCAT2 Score (n=29)	95.93	3.10	94.83	2.85	94.24	3.08	1.74	0.185
Symptom Severity (n=29)	.72	1.16	2.03	2.82	2.21	3.22	3.12	0.005*†
Total Number of Symptoms (n=29)	.48	.69	1.31	1.77	1.24	1.70	1.62	0.205
Headache Rating (n=29)	.10	.41	.86	1.13	.86	1.13	8.45	0.001*†
SCAT2 Symptom Score (n=29)	21.52	.69	20.69	1.77	20.66	1.71	2.80	0.086
SAC Orientation Score (n =29)	4.9	.19	4.90	.31	4.72	.45	3.90	0.026*
SAC Immediate Memory (n=29)	14.76	.64	14.86	.35	14.83	.47	.43	0.653
SAC Concentration (n=29)	4.07	1.25	4.34	1.01	4.00	1.16	.66	0.522
SAC Delayed Recall (n=29)	4.66	.67	4.07	1.16	4.28	.80	4.46	0.022*
Total SAC Score (n=29)	28.45	1.80	28.10	1.65	27.79	1.78	1.74	0.191

Coordination Score (n=29)	1.00	.00	.93	.26	1.00	.00	2.07	0.161

*Significant difference between baseline and headgear session (p ≤ 0.05)
†Significant difference between baseline and no headgear session (p ≤ 0.05)
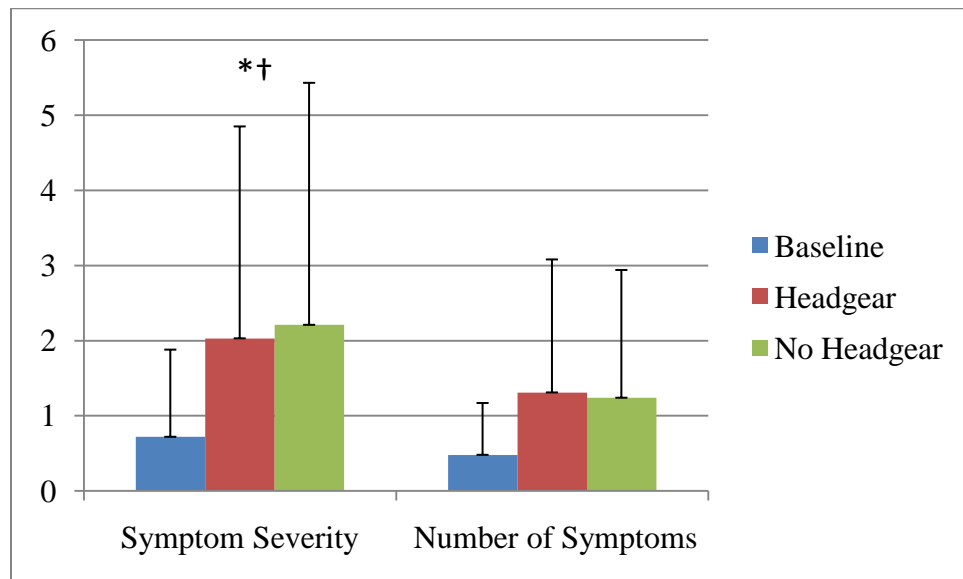
Figure 4. Symptom Severity and Number of Symptoms

*Significant difference between baseline and headgear session ($p \leq 0.05$)
†Significant difference between baseline and no headgear session ($p \leq 0.05$)

Figure 5. Headache Rating

*Significant difference between baseline and headgear session ($p \leq 0.05$)
†Significant difference between baseline and no headgear session ($p \leq 0.05$)

Figure 6. Orientation, Concentration, and Coordination Scores

*Significant difference between baseline and headgear session ($p \leq 0.05$)

Figure 7. Immediate Memory and Delayed Recall Scores

*Significant difference between baseline and headgear session (p ≤ 0.05)
†Significant difference between baseline and no headgear session (p ≤ 0.05)
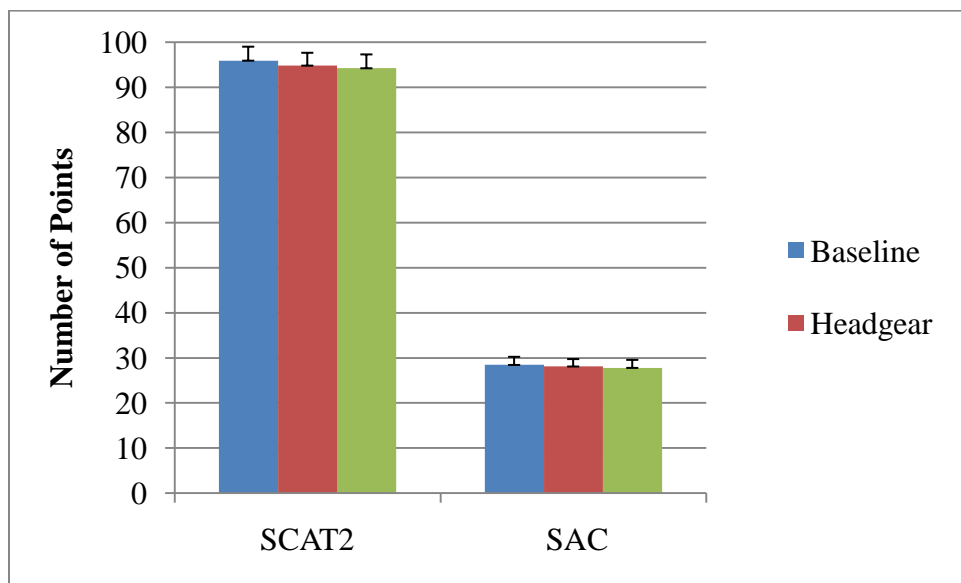
Figure 8. Sport Concussion Assessment Tool (SCAT2) and Standardized Assessment of Concussion (SAC) Total Scores

Table 4. Simple Reaction Time and Sensory Organization Test Means and Standard Deviations

	Baseline		Headgear		No Headgear		F value	*P*-value
	Mean	SD	Mean	SD	Mean	SD		
SRT Score (n=29)	258.07	15.98	266.39	22.26	264.78	29.44	8.45	0.001*
Somatosensory Ratio (SOT) (n=27)	.98	.02	.97	.03	.99	.03	2.01	0.144
Vestibular Ratio (SOT) (n=27)	.74	.10	.78	.10	.79	.10	2.11	0.132
Visual Ratio (SOT) (n=27)	.91	.05	.94	.06	.94	.06	4.17	0.021*†
Composite Score (n=29)	82.42	4.93	84.44	4.48	84.20	5.33	2.63	0.091

*Significant difference between baseline and headgear session (p ≤ 0.05)
†Significant difference between baseline and no headgear session (p ≤ 0.05)
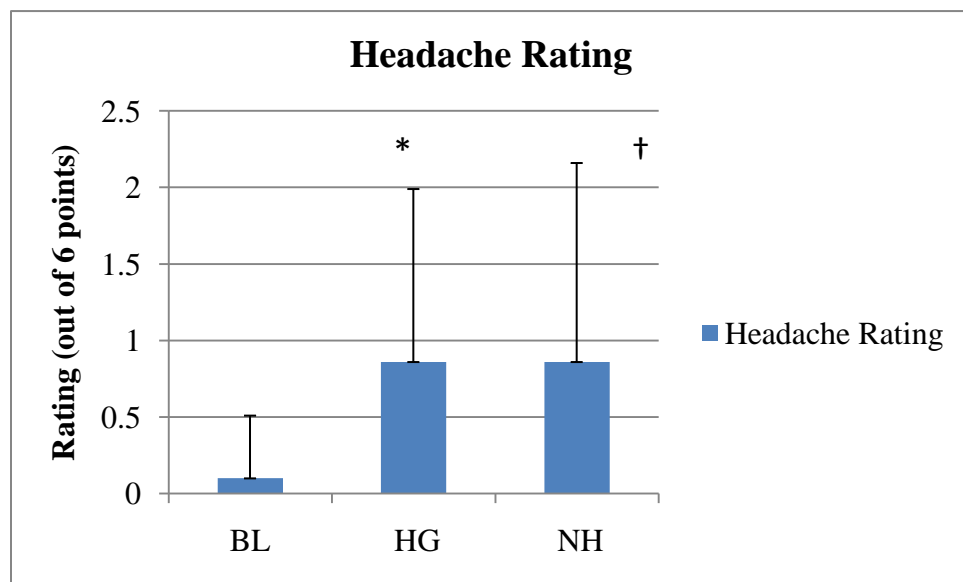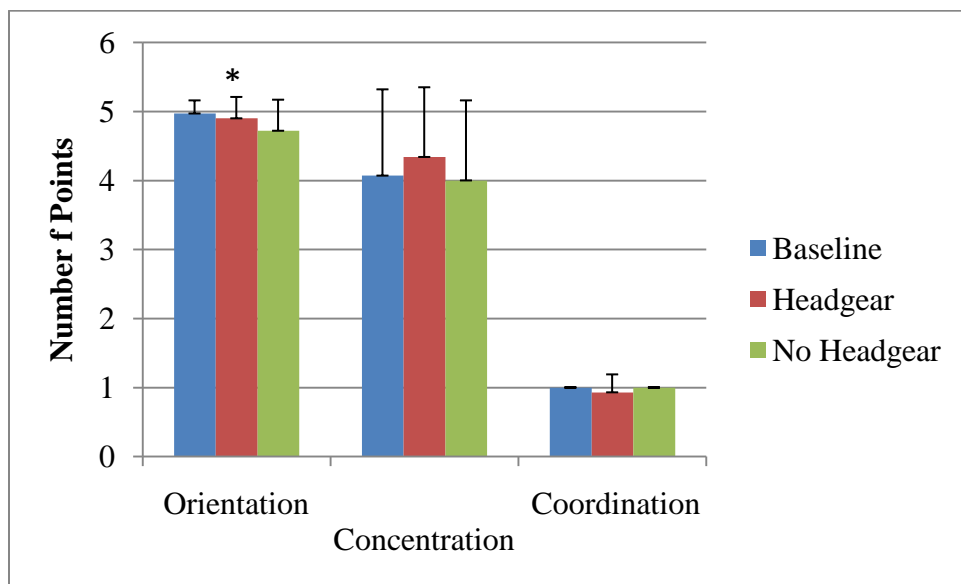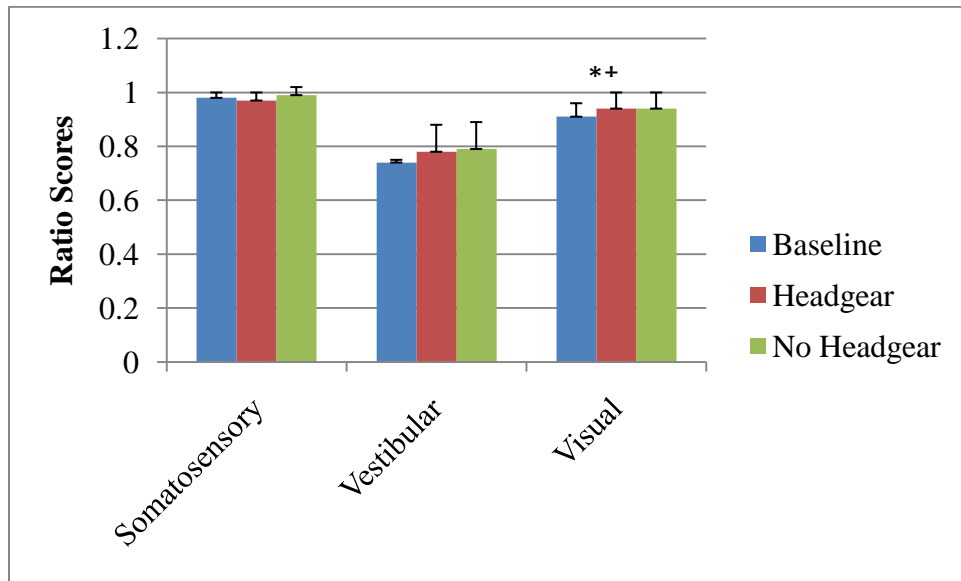
Figure 9. Sensory Organization Test (SOT) Ratio Scores

*Significant difference between baseline and headgear session ($p \leq 0.05$)
†Significant difference between baseline and no headgear session ($p \leq 0.05$)
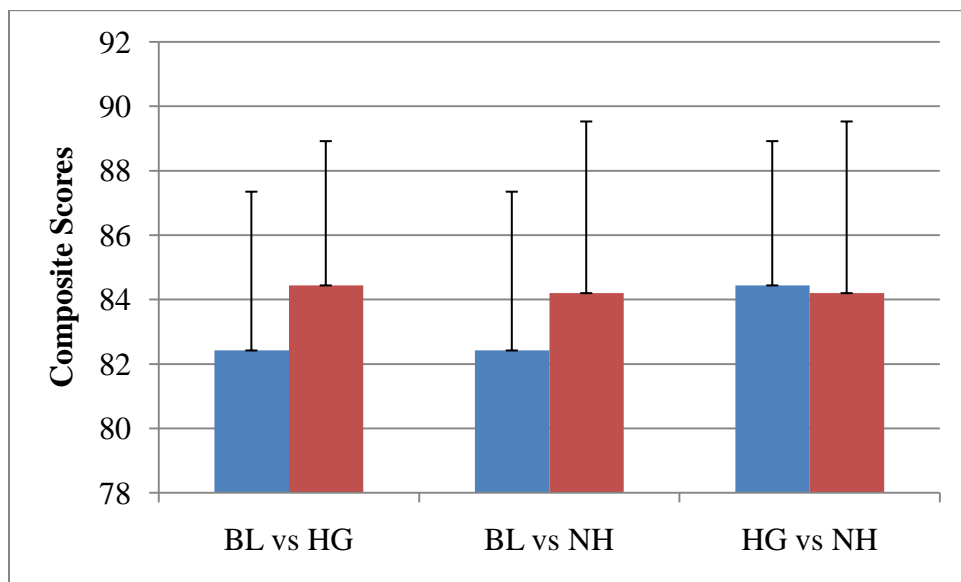
Figure 10. Composite Sensory Organization Test (SOT) Scores
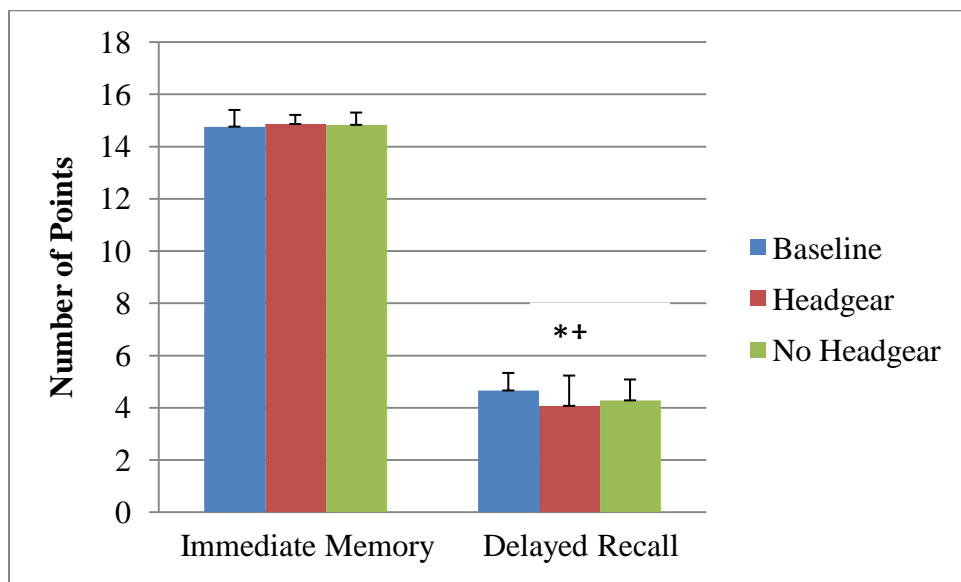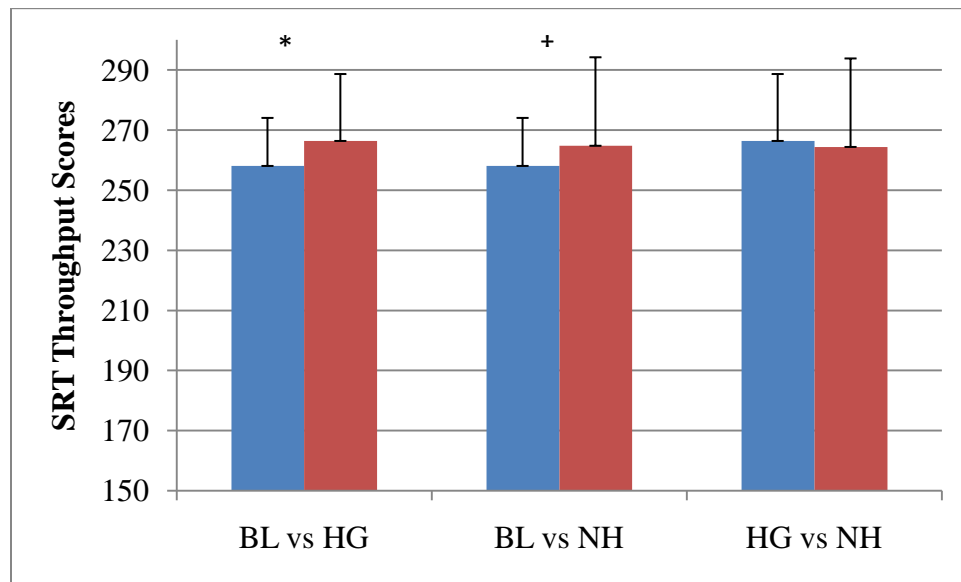
Figure 11. Simple Reaction Time Throughput Scores

*Significant difference between baseline and headgear session ($p \leq 0.05$)
†Significant difference between baseline and no headgear session ($p \leq 0.05$)

Table 5. Balance Error Scoring System Means and Standard Deviations

	Baseline		Headgear		No Headgear		F value	*P*-value
	Mean	SD	Mean	SD	Mean	SD		
BESS Firm Error Score (n=29)	2.03	2.08	2.00	2.00	2.10	2.24	.06	0.945
BESS Foam Error Score (n=29)	10.28	3.77	10.03	3.14	10.76	3.20	.75	0.456
BESS Total Error (n=29)	12.31	5.18	11.93	4.28	13.10	5.06	1.18	0.311
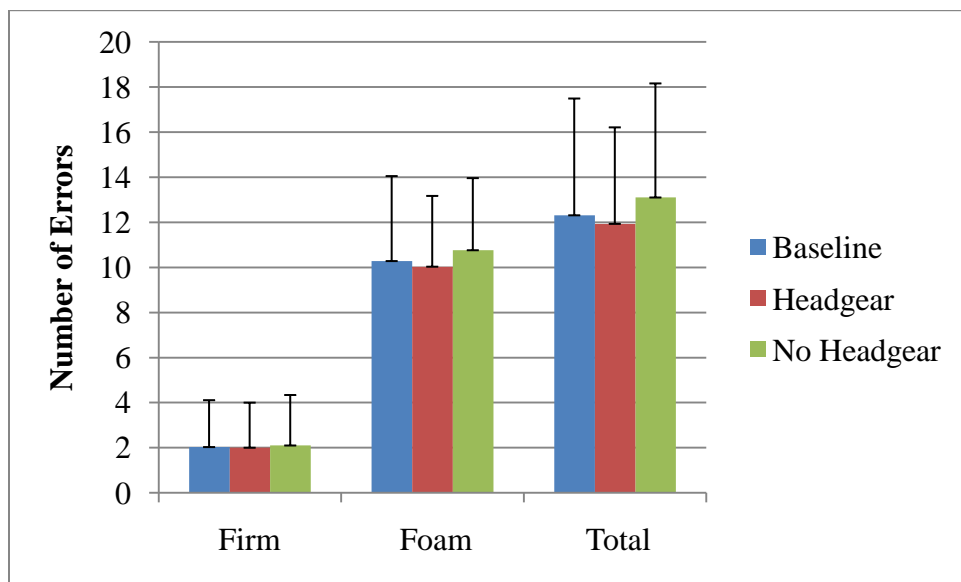
Figure 12. Balance Error Scoring System (BESS) Error Scores

Table 6. Headgear Satisfaction Survey Means and Standard Deviations

	Mean and Standard Deviation
Did not experience dizziness, lightheadedness, or headache	3.66 ± 1.37
Effective piece of equipment	3.07 ± 1.10
Did not alter heading mechanics	3.00 ± 1.28
Not cumbersome	3.10 ± 1.17
Consider wearing	1.90 ± 1.01
Overall Satisfaction	14.72 ± 4.22

Table 7. Concussion History Means and Standard Deviations for Outcome Measures

		Mean and Standard Deviations
BL SRT Score	No Con Hx (n = 22)	258.43 ± 13.40
	Con Hx (n = 7)	256.95 ± 23.70
HG SRT Score	No Con Hx (n = 22)	270.46 ± 22.22
	Con Hx (n = 7)	253.56 ± 18.24
NH SRT Score	No Con Hx (n = 22)	266.44 ± 31.29
	Con Hx (n = 7)	259.55 ± 24.01
BL SCAT2 Score	No Con Hx (n = 22)	95.73 ± 3.18
	Con Hx (n = 7)	96.57 ± 2.99
HG SCAT2 Score	No Con Hx (n = 22)	94.82 ± 2.58
	Con Hx (n = 7)	95.29 ± 2.98
NH SCAT2 Score	No Con Hx (n = 22)	94.27 ± 2.90
	Con Hx (n = 7)	94.42 ± 3.82
BL BESS Score	No Con Hx (n = 22)	13.23 ± 5.40
	Con Hx (n = 7)	9.43 ± 3.21
HG BESS Score	No Con Hx (n = 22)	12.18 ± 4.75
	Con Hx (n = 7)	11.14 ± 2.41
NH BESS Score	No Con Hx (n = 22)	13.10 ± 5.55
	Con Hx (n = 7)	13.14 ± 3.39
BL Somatosensory SOT Score	No Con Hx (n = 20)	.98 ± .02
	Con Hx (n = 7)	.98 ± .02
HG Somatosensory SOT Score	No Con Hx (n = 20)	.98 ± .03
	Con Hx (n = 7)	.96 ± .02
NH Somatosensory SOT Score	No Con Hx (n = 20)	.99 ± .03

	Con Hx (n = 7)	.98 ± .02
BL Vestibular SOT Score	No Con Hx (n = 20)	.75 ± .11
	Con Hx (n = 7)	.74 ± .04
HG Vestibular SOT Score	No Con Hx (n = 20)	.77 ± .10
	Con Hx (n = 7)	.79 ± .11
NH Vestibular SOT Score	No Con Hx (n = 20)	.80 ± .10
	Con Hx (n = 7)	.78 ± .10
BL Visual SOT Score	No Con Hx (n = 20)	.91 ± .05
	Con Hx (n = 7)	.90 ± .05
HG Visual SOT Score	No Con Hx (n = 20)	.94 ± .06
	Con Hx (n = 7)	.94 ± .05
NH Visual SOT Score	No Con Hx (n = 20)	.95 ± .05
	Con Hx (n = 7)	.92 ± .07
BL Composite SOT Score	No Con Hx (n = 20)	82.70 ± 5.33
	Con Hx (n = 7)	81.62 ± 3.80
HG Composite SOT Score	No Con Hx (n = 20)	84.78 ± 4.21
	Con Hx (n = 7)	83.47 ± 5.44
NH Composite SOT Score	No Con Hx (n = 20)	85.01 ± 4.72
	Con Hx (n = 7)	81.88 ± 6.64

CHAPTER V

DISCUSSION

Our study suggests that acute bouts of linear soccer heading using active college-aged soccer players do not lead to impairments on clinical concussion measures, which negates our initial hypothesis. We theorized that deficits would occur following the subconcussive repetitive head impacts due to the greater potency of our heading protocol compared to previous projects. Furthermore, we observed wearing protective headgear provides no further protection in this particular situation, confirming our preliminary thoughts.

Neurocognitive Function

Effects of Heading

Our study examined neurocognitive function through the administration of the Sport Concussion Assessment Tool (SCAT2), as well as the Simple Reaction Time (SRT) module of the ANAM test battery. To our knowledge, no study has used the newly published SCAT2 as a tool evaluating effects of acute bouts of soccer heading. Individual components, such as the symptom checklist, have been used previously in an isolated fashion. As our study may be the first of its kind, it suggests that an acute bout of soccer heading does not decrease neurocognitive function in recreational athletes. The conclusion was demonstrated by the lack of differences in SCAT2 and SAC total scores, as well as the concentration, coordination, and immediate memory subsets of the testing

instruments. This agrees with former studies that used alternate tools for investigating neurocognitive function and found them unaffected by soccer heading (Janke, 2006; Putukian et al., 2000). It appears that controlled linear soccer heading does not create the impact forces necessary to cause injury. Previous football data revealed that an impact speed of 9.3 ± 1.9 meters/second (20.8 ± 4.2 miles/hour) was evidenced in concussion situations with a change in head velocity of 4.0 ± 1.2 meters/second (8.9 ± 2.7 miles/hour) (Pellman et al., 2003). Although most clinical studies do not measure impact forces, it seems that soccer heading does not cause forces which reach this threshold, due to the absence of impairments on clinical testing instruments.

In opposition to the majority of non-significant results in neurocognitive function, the orientation scores were significantly depressed during the headgear session. This portion questions about the current date, day, month, year, and time. The scores were mostly likely higher during the baseline session because all subjects were notified of the date at the start of their first session in order to complete the consent form. Conversely, the participants were not given this information prior to the heading sessions. Of the total eighty seven orientation scores, there were only twelve which were not a perfect five out of five. All twelve impaired scores were the result of only the date being missed, and eleven occurred following a heading session. This most likely explains the significant difference. Also, the information demonstrates that the disparity was most likely attributed to the heading protocol, rather than the use of the headgear. Regardless of the statistical significance, the orientation scores of the SAC do not hold as much meaning clinically as other subsections. Healthcare professionals do not value orientation scores, as other sections when making assessment or return to play decisions. This may be due

to the fact that the orientation section does not challenge cognitive areas of the brain, as the concentration and delayed recall subsets do. Differences in orientation scores are largely dependent on the current point of time, and might be more reflective of the actual time rather than the degree of insult. Furthermore, the differences we found were very minimal and less than .2 out of 5 points, which is not a distinction that would ever be noticed clinically.

The only other statistically significant score between baseline and heading sessions was the delayed recall portion of the SAC, aimed at evaluating "working memory." It has been shown to be one measure of neurocognitive function that is impacted by headache (Register-Mihalik, Guskiewicz, Mann, & Shields, 2007). Subjects in our particular study exhibited higher headache rating following both heading sessions, explaining the depressed delayed recall scores. This may be the result of the known disturbance in the chemical processes inside the brain following insult (Giza & Hovda, 2001). Research has demonstrated that head impacts cause a metabolic cascade, which would most likely affect working memory (Giza & Hovda, 2001). This metabolic cascade results in increases in K+ followed by Ca+, which alters neurotransmitters (Giza & Hovda, 2001). This, in turn, causes impairments of clinical signs, such as memory (Giza & Hovda, 2001). Although deficits were noted in the delayed recall portion of the SAC, the differences were well below one point. Clinicians would not base an assessment or return to play decision off of this disparity, in the scope of the one hundred point total of the SCAT2. This is especially the case seeing as the presence of headache is most likely the contributing factor. Despite the significance of orientation and delayed recall scores, the overwhelming majority of dependent variable measures indicated that

soccer heading was not detrimental to neurocognitive function, negating our original thoughts.

Through the SRT module, we found scores were better following the headgear conditions, when compared to baseline. This is most likely attributed to the practice effect, previously shown to occur between the first and second sessions (Kaminski, Groff et al., 2008). Scores are known to improve after the first test, and then plateau; thus creating stability after the second session (Kaminski, Groff et al., 2008). It is fitting that scores were improved after a heading condition due to this established practice effect. However, it is unusual that scores were only better following the headgear conditions, due to the counterbalanced nature of the study. The practice effect, in combination with the research design, should have yielded improved scores following both heading sessions. Despite the statistical significance between baseline and the headgear condition, our largest differences were approximately eight points on a total throughput score. Athletic trainers are not going to be concerned about these minimal discrepancies because they are not significant in a clinical environment.

Only one existing project has investigated acute bouts of soccer heading, and their possible effect on reaction time measured by a computerized program. No significant impairment was noticed following heading (Janke, 2006). The previous study may not have seen the same practice effect as we did due to the shorter amount of time between sessions. Regardless, all of the current literature appears to support the notion that soccer heading does not decrease reaction time as measured by computerized programs.

Although our study examined soccer heading in an acute sense, previous projects have investigated reaction time with regard to cumulative heading. The first of these studies looked at female interscholastic soccer players following a competitive soccer season (Kaminski, Cousino et al., 2008). This project used the Simple Reaction Time module of the ANAM battery, as we did (Kaminski et al., 2007). Researchers also found no impairments in this outcome measure (Kaminski et al., 2007). Ellemberg et al. (2007) confirmed this finding in another project investigating female university soccer players (Ellemberg et al., 2007). Simple Reaction Time, as well as Choice Reaction Time, were unaffected by heading (Ellemberg et al., 2007). All literature at this point indicates that soccer heading, whether examining acute bouts or cumulative effects, does not lead to impairments in reaction time.

Effects of Headgear

Our project also appeared to be the first of its kind to investigate the impact of soccer headgear when completing the SCAT2. The headgear did not influence total scores on the SCAT2 following acute bouts of soccer heading. This is in conjunction with a previous study that used alternate testing instruments to measure neurocognitive function (Janke, 2006). We found no individual measure of cognition to be influenced by use of the headgear.

The Simple Reaction Time (SRT) scores also did not differ between the two heading conditions, indicating that the headgear had no effect on neurocognitive function under our particular conditions. Our study seems to be the first to use this measure in association with soccer headgear. However, the results agree with a former study, which also used a computerized program to evaluate this dimension of neurocognitive function

(Janke, 2006). This project found composite reaction scores were not affected by use of soccer headgear (Janke, 2006). These researchers used three separate groups, rather than a repeated measures design, as in our study (Janke, 2006). The three groups in the previous study consisted of a no headgear group, one with the Full90^{TM}, and a final group wore a different brand of protective headgear (Janke, 2006). Each group completed the heading protocol under their condition on three consecutive days. In opposition, we required all subjects to partake in a headgear and no headgear session, rather than creating two groups where only one condition was repeated by the individual. This study, although dissimilar in design, found that headgear did not alter reaction time speeds (Janke, 2006). The researchers utilized the ImPACT (ImPACT Applications Inc., Pittsburgh, Pennsylvania) computer program to assess this variable, in contrast to the SRT module of the ANAM, as in the present study (Janke, 2006). Regardless of the different testing instrument or research design, soccer headgear did not impact reaction time scores in either case.

Symptomatology

Effects of Heading

When examining the actual symptom score yielded from the tool, we found no difference following heading tasks. However, we did find a difference in symptom severity after heading sessions. Concussive warning signs have previously been investigated Tysvaer et al. (1981) and Schmitt et al. (2004) (Schmitt et al., 2004; Tysvaer & Storli, 1981). Both of these researchers found that symptoms were more frequent and severe in nature following an acute heading task. The contradiction in our SCAT2 symptom score in our project may be attributed to the fact that the score does not assess severity of symptoms, but rather it is simply a product of the number of symptoms.

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Also, the previous studies used slightly different methodology. Tysvaer (1981)

completed his study almost thirty years ago, and was strictly based off a questionnaire

(Tysvaer & Storli, 1981). The researchers asked how often soccer players experienced a

headache following heading during games and practice sessions (Tysvaer & Storli, 1981).

Naturally, the methodology was not very precise and involved a great deal of subjectivity

and possible recall bias (Tysvaer & Storli, 1981). Schmitt's project (2004) also differed

in research design, in that it employed eighteen headers over the course of forty minutes,

in which all soccer balls were kicked by another player (Schmitt et al., 2004). Due to the

fact that the balls were not expelled from a machine, it is impossible to maintain a

consistent speed, which may have affected headache scores (Schmitt et al., 2004).

Nonetheless, there were no differences noted at the twenty four hours post injury post-

test, which agrees with our findings. All subjects in our study were completely

asymptomatic one day after they completed the heading protocol. Although our SCAT2

symptom scores negated previous research, our higher symptom severity scores

following heading tasks did confirm previous literature. This is fitting, as the former

studies investigated severity, not simply the number of symptoms, which is what is being

assessed by the SCAT2 scores. When investigating the product of number and severity

of symptoms, a much more inclusive result is created. It seems accurate that this measure

would confirm previous work in the field.

When we isolated the headache variable, we found that this symptom was more

prevalent and severe after both heading sessions, agreeing with the existing literature

(Schmitt et al., 2004; Tysvaer & Storli, 1981). This was the major significant finding in

our work, which seems to be consistent across studies. Players will commonly

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experience a headache following bouts of heading. This is sensible considering the repetitive impact that results from heading a soccer ball. The head is no different than another body part where nerves transmit a pain signal following repeated insult. It is also probable that impact from the heading triggers a mild degree of a metabolic cascade (Giza & Hovda, 2001). The imbalance in neurotransmitters may have led to the presentation of a headache (Giza & Hovda, 2001). Regardless, literature indicates that acute soccer heading bouts leads to the presence of headache (Janke, 2006; Schmitt et al., 2004; Tysvaer & Storli, 1981).

Effects of Headgear

We also found that the protective headband did not change symptom severity immediately following heading sessions. This was also true when isolating the headache rating of the GSC. The non-significant result is in opposition to previous research which reported that subjects wearing the Full90^{TM} possessed fewer and/or less severe concussive symptoms following an acute bout of soccer heading at a similar speed (Janke, 2006). Although the speed was similar in the abovementioned study, the rate of headers was twenty headers in twenty minutes, rather than the ten minutes which we employed (Janke, 2006). The subjects were also Division I athletes, which differed from the recreational soccer players in our study (Janke, 2006). It is possible that higher skilled individuals possess different control and were better able to adapt to the headband, resulting in decreased symptoms. Also, in the previous study, the number of people in each group was significantly smaller than in our study (Janke, 2006). The highest number of participants per group was twelve, which was less than half of our group numbers (Janke, 2006). Individuals' symptom scores were much more influential to the

overall results in the former study. These two points of contrast may have accounted for the differences in results regarding the impact of the headgear.

Our study also appears to contradict foundational research, which established that the headgear was effective in decreasing forces thought to cause concussive symptoms (Broglio et al., 2003). One former project consisted of launching soccer balls against a vertical forceplate to measure impact forces (Broglio et al., 2003). Granted the previous study was foundational in nature, but it was the initial design essential in testing headgear. Although we did not assess dissipation of force, it would seem that concussive symptoms would be fewer and less severe if the headbands were able to attenuate forces. Our study found that the protective headgear did not impact the presence of concussive warning signs, which seems to disagree with Broglio's work regarding impact forces. If the headbands decreased forces against a forceplate, it could be assumed that players would sustain less impact against their skull, and probably have fewer symptoms, in a clinical study.

Balance Performance

Effects of Heading

The second set of dependent variables in our study focused on balance performance. We observed no differences in the total errors of the firm or foam conditions of the Balance Error Scoring System (BESS) across heading conditions. This was also true of the total error score, which supports previous research (Broglio et al., 2004). Results confirmed a study conducted by Broglio et al., which utilized forty subjects for a heading protocol (Broglio et al., 2004). The researchers investigated center of pressure using forceplate values following an acute bout of heading (Broglio et al.,

2004). Three major differences existed between the previous study and ours. First, the former project investigated rotational and linear heading, whereas we simply examined straight heading (Broglio et al., 2004). Also, the protocol used a rate of twenty balls over twenty minutes, as opposed to ours, which utilized a rate that was twice as quick (Broglio et al., 2004). A final disparity lies in the research design, where subjects in the previous study were divided into specific heading groups (Broglio et al., 2004), dissimilar to our repeated measures design (Broglio et al., 2004). Nonetheless, our clinical examination of balance performance through the BESS coincides with the previous work using laboratory measures. Balance performance certainly appears to be unaffected by heading if studies with dissimilar designs are yielding consistent results.

Furthermore, no change was evident in the composite Sensory Organization Test (SOT) scores following the heading protocol. This was also true of the somatosensory and vestibular ratios, again supporting previous research stating that acute soccer heading bouts do not alter balance performance (Broglio et al., 2004; Mangus et al., 2004). To our knowledge, there is only one previous work that utilized the SOT, in combination with soccer heading. The researchers found no differences between pre-test and post-test scores (Mangus et al., 2004). However, this study used only ten subjects, and all soccer balls were kicked by teammates during the heading protocol (Mangus et al., 2004). Therefore, it is unreasonable to assume that all flighted balls were traveling at the same speed (Mangus et al., 2004). It is probable that players were not consistently kicking the balls at the 45 mph, the speed equivalent to corner kicks. Most likely, the players had difficulty maintaining this high velocity in a repetitive activity. Regardless, all previous

works, in conjunction with our findings, appear to assert that an acute bout of soccer heading does not affect balance performance.

Although these initial findings seem to point overwhelmingly to the idea that heading does not alter balance performance, this may not be completely accurate due to known learning and practice effects of the testing instruments. Both the BESS and SOT have been shown to exhibit improvement over time (Valovich et al., 2003; Wrisley et al., 2007). Subjects tend to become more acquainted with the testing protocol, and thus scores are higher at subsequent sessions (Valovich et al., 2003; Wrisley et al., 2007). Sensory Organization Test composite tests scores have been shown improve up until the third session, at which point the scores will then plateau (Wrisley et al., 2007). BESS scores have also been shown to improve after the initial testing session, and scores continue this upward pattern up to the fifth trial (Valovich et al., 2003). It has been established that the SOT and BESS possess practice effects, which lead to improved scores after the first testing session (Valovich et al., 2003; Wrisley et al., 2007). Previous research indicates that subjects should have scored better on both balance performance measures at the second and third sessions (Valovich et al., 2003; Wrisley et al., 2007). Due to the stratified assignment of our study, one would assume that balance performance scores would get better following heading sessions compared to baseline. Since this known improvement was not seen, it is possible that the heading task did create detriments after all. These impairments may have been masked by the practice effects of the testing instruments, which in the end, equalized one another. This led to non-significant results which suggested that there are no deficits when there is a possibility that they were simply concealed.

The visual ratio was the one dependent measure that improved following baseline. Previous literature regarding the practice effect of the SOT found that the visual ratio (Condition 4 to Condition 1) improved the greatest out of all four outcome measures from the initial testing session to the second (Wrisley et al., 2007). The sizable learning effects are most likely due to the complexity and originality of the test condition. The moving forceplate provides a task which subjects typically have never experienced. Other conditions which removed visual cues, such as Condition 5, are more familiar to people, especially after BESS trials. It is fitting that a more significant increase was noted in a condition which was novel and complex for participants.

Effects of Headgear

No balance performance variables were different between the headgear and no headgear conditions. This indicates that the headbands do not appear to have an impact on these factors following an acute soccer heading bouts with college-aged individuals. To our knowledge, our study is the only one to date which looks into this question.

Overall, we examined nineteen dependent variables, and not one yielded significant results between headgear sessions. Thus, it is fair to conclude that the headbands did not have a significant impact on neurocognitive function or balance performance following our particular heading task with our subject pool.

Headgear Satisfaction and Neck Musculature

When analyzing the headgear satisfaction survey, we found that subjects did not have a high opinion of wearing the apparatus. The average score was less than fifteen out of twenty five points when looking at all subjects. The question that asked whether subjects would consider wearing the headbands possessed a mean score of less than two

out of five. Not one of the statements yielded a mean score over 3.7 out of 5, meaning

that on average subjects did not "agree" with any of the approval statements.

The participants clearly possessed a negative attitude towards the headgear, which

may have been formulated prior to the study. This could have caused subjects to put

forth less effort when performing the heading task. For this reason, we used headgear

satisfaction scores as a covariate to control for the possibility of subjects purposefully

skewing results. It only contributed in one of the nineteen outcome measures, indicating

that overall this subjective measure did not influence the objective variables. Despite

controlling for the perception of headgear, the negative attitude towards the headgear was

substantiated by the overwhelming non-significant testing results. The fact that outcome

measures were not significant between headgear conditions legitimizes the unfavorable

opinion of the efficacy of the product in this particular situation.

Subjects also commented that the headband was uncomfortable and cumbersome.

They felt this may have altered their heading mechanics because they were not used to

the interface between their head and the ball. Therefore, participants believed they were

inclined to strike the ball differently to avoid the headband. Clinically, it seems that the

headgear caused people to feel uneasy and created a change in heading form, meaning the

players are not going to agree to wear the protective equipment. If soccer players are

unwilling to wear the headgear, it becomes very difficult to realistically endorse it, unless

a governing board mandates the use. However, rule changes will not be proposed if

research is indicating that the headbands are not beneficial in particular situations.

Along with headgear satisfaction, we also used neck musculature strength as a covariate, in order to control for the possibility of this influencing our outcome measures. Overall, we found that these strength measures did not affect our neurocognitive function and balance performance results. It appears that neck strength does not significantly contribute to results following an acute soccer heading bout using our particular subject pool. Although this was the case in our specific project, this cannot speak to the relationship between neck strength and the outcome measures using younger or lesser skilled individuals. These two groups may have poorer strength values, and may be less able to properly brace their neck for the heading task.

Clinical Application

Our project confirms the overwhelming majority of research, which indicates that acute bouts of soccer heading do not result in deficits in neurocognitive function or balance performance (Broglio et al., 2004; Janke, 2006; Putukian et al., 2000). We found no differences of clinical significance in any outcome measure. The few significant results yielded differences which would not impact an athletic trainer's assessment or return to play decision. Thus, it looks as if the concern surrounding subconcussive repetitive head impacts should be minimized. The concussion rates in soccer should no longer be attributed to this skill because the overwhelming majority of research indicates that the actual contact with the ball is not the cause. Nonetheless, this study, in addition to many others, can only speak to the skill in an acute sense with one particular subject pool.

If studies examining cumulative effects of heading yield the same results, it appears that the concern regarding the skill should be rejected. This would allow

clinicians to be confident that detriments in neurocognitive function and balance performance in soccer players are attributed to an actual injury. Soccer heading does not create these impairments at a subconcussive level, as has been previously proposed; furthermore, suggesting that protective headgear may not be warranted in this particular instance. There is no need to promote an apparatus, which protects against impairments that are not present. Additionally, this study has demonstrated that regardless of what is found regarding cumulative heading, the headband does not affect neurocognitive function or balance performance following the skill using experienced college-aged soccer players. Since its benefit was not noticed in this study, as we hypothesized, there is no need to continue to promote its use in this specific group. We cannot speak to the headband's benefit among females or youth, where it was previously thought to have increased benefit (Delaney et al., 2008).

These conclusions do not address the potential of sustaining a head injury from contact with an opponent's body or heading while unprepared for contact. These two situations have been shown to result in head injury in the sport (Boden et al., 1998; Kirkendall et al., 2001). The idea of a player striking a ball with an unprepared head should continue to warrant concern. This has been found to be the main instance where an athlete sustains a concussion from actual ball contact (Kirkendall & Garrett, 2001). Thus, it would seem that we should be more alarmed with lesser skilled individuals than younger athletes. Many youth soccer players are very experienced in heading and are capable of performing the skill with proper technique. They understand how to prepare for ball contact and strike it in a manner that reduces the likelihood of injury.

Conversely, less talented individuals, regardless of their age, are unable to brace their head and neck for the impact, which results in the chance for injury.

Along with the controlled nature of the present study, it addressed only one type of heading in soccer. The three main flighted balls in soccer are goal kicks, punts/drop kicks, and corner kicks. We simulated a situation where an opponent would head either a goal kick or punt back in the direction in which it came, attempting to advance the ball. This study did not investigate a flick, which a teammate would face the ball and direct it in a backward direction. We also did not examine directional heading at an angle, which is typically seen on corner kicks due to the nature of the positioning of the kicker and header. It is unfeasible to completely examine and measure all of these situations, but they may possess benefits from the headbands. Currently, little research has been conducted on the possibility of detriments following these alternate techniques. Due to the different locations of impact during angular heading and flicking, the headbands may provide benefit in these particular instances.

It is important to acknowledge that the headband is only designed to cover the areas of the head which should contact a ball during proper heading technique. During play when movement is not completely linear, it is more likely that the soccer ball will not come in contact with the headband compared to our controlled setting. Also, in a match, the contact with another player may not impact the headgear, but rather another portion of the head. These possibilities, combined with our strong evidence showing no benefit from the headband in our linear heading bouts with experienced individuals, should lead clinicians to be skeptical of the product's efficacy under particular conditions.

<u>Limitations</u>

There were several limitations evident in the current study. Linear heading was the only type that was tested in this study. It is important to also investigate angular heading and flicking, seeing as these skills are frequently used in soccer, especially in corner kick situations. Another limitation of the current project was we only employed experienced college-aged soccer players as subjects. Therefore, our results may not be applied across age groups or skill levels. It is possible that younger or more importantly, lesser skilled individuals, may respond differently to acute bouts of soccer heading due to their inability to effectively brace for the impact. An unprepared head and poorer neck strength may contribute to more impairment on clinical concussion measures.

We also did not measure ball impacts, which may have given greater insight into the threshold of subconcussive forces sustained during heading. Additionally, neither the researcher nor subject was blinded to the intervention during the heading protocol. Due to the nature of the research design, this would have been impossible. However, we did control for the negative preconceived notion of the headband by using this variable as a covariate in all analyses.

Also, this study focused solely on an acute bout of heading. It did not look into the cumulative effects on neurocognitive function or balance performance across a period of time. We can only draw conclusions based on subconcussive repetitive head impacts, and not the skill of heading as a whole. A final limitation of our study was we only asked about existence of previous head injury during the initial screening. We did not collect the number of concussions, in order to examine those data.

<u>Future Research</u>

Although our study confirmed previous research which found that an acute soccer heading bout did not alter neurocognitive function or balance performance, it only looked at a controlled protocol with subconcussive repetitive head impacts. Thus, future research should investigate cumulative effects through prospective studies. Also, most of the existing research utilizes college-aged individuals, which warrants upcoming projects employing youth subjects. Along with this, lower skilled participants have yet to be examined thoroughly, and should be investigated. Soccer is a sport played by masses which come from a variety of age groups and skill levels. This necessitates research that is more inclusive in nature. Lastly, directional heading should be quantified and studied to determine if changes are present when an angular component is added.

<u>Conclusions</u>

We found that heading does not result in a deterioration in neurocognitive function or balance performance under our particular conditions. Furthermore, soccer headgear does not impact these two factors following an acute heading bout. As clinicians, we ought to be aware of these two conclusions in order to understand the role of acute heading in head injury and make recommendations regarding protective equipment in the sport of soccer.

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Table 8. Data Summary Table

RESEARCH QUESTION	DATA SOURCE	METHODS

Do acute bouts of soccer heading result in mental status, simple reaction time, and balance performance deficits in college-aged competitive soccer athletes?
 	
a) Are there any deficits in SCAT2 total score, SAC total and subcomponent scores, simple reaction time throughput score, symptom severity, BESS error scores, and SOT composite and ratio scores in college-aged competitive soccer athletes following a single bout of heading?
 	
b) Does wearing the Full90™ soccer headgear during a soccer heading bout affect SCAT2 total score, SAC total and subcomponent scores, simple reaction time throughput score, symptom severity, BESS error scores, and SOT composite and ratio scores when compared to baseline scores and scores following a heading bout with no headgear in college-aged competitive
	IV:
	
	1. Headgear condition
	  *Headgear
	  *No headgear
	
	2. Test Session
	  *Baseline
	  *Heading Session 1
	  *Heading Session 2
	
	DV:
	
	composite SCAT2 scores, SAC total scores and subcomponents, SRT throughput scores, symptom severity, BESS error scores, SOT composite and ratio scores
		1 Way Totally Within Task ANCOVA
		
		Covariates
		
		1) Neck Musculature
		  *Normalized anterior neck flexor strength
		  *Normalized right anterolateral neck flexor strength
		  *Normalized left anterolateral neck flexor strength
		  *Overall neck musculature strength
		
		2) Headgear Satisfaction

soccer athletes?		

Head Anthropometric Measurements
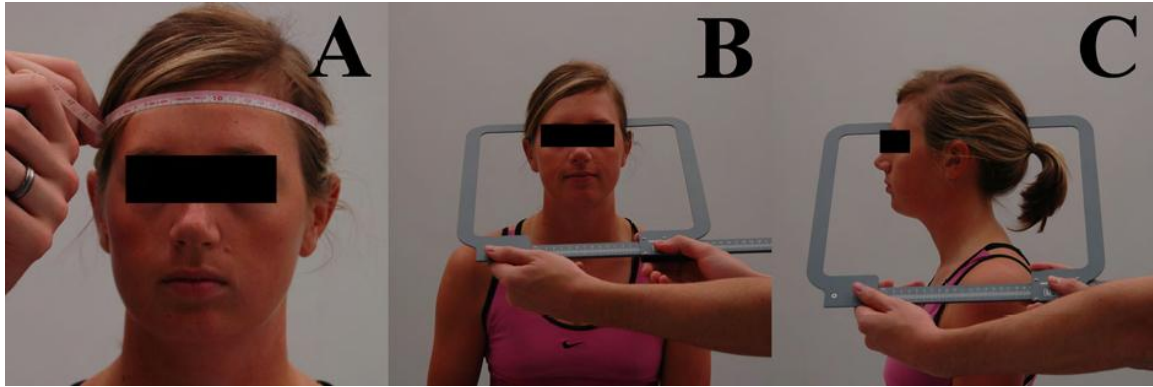
(A) Head Circumference, (B) Medial-lateral diameters, (C) Anterior-posterior

Evaluation of Anterior Neck Flexor Muscle Strength

Evaluation of Anterolateral Neck Flexor Muscle Strength

Evaluation of Cervical Rotation Muscle Strength

Evaluation of Posterolateral Neck Extensor Muscle Strength
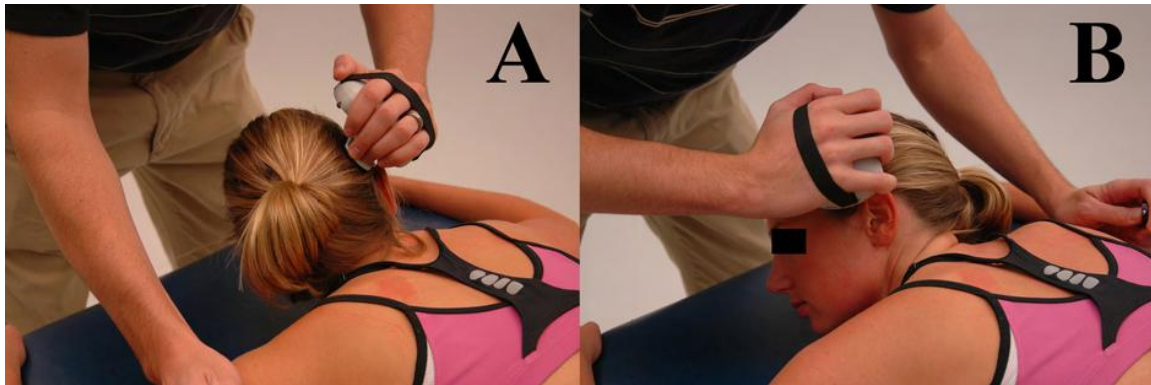
Evaluation of Upper Trapezius Muscle
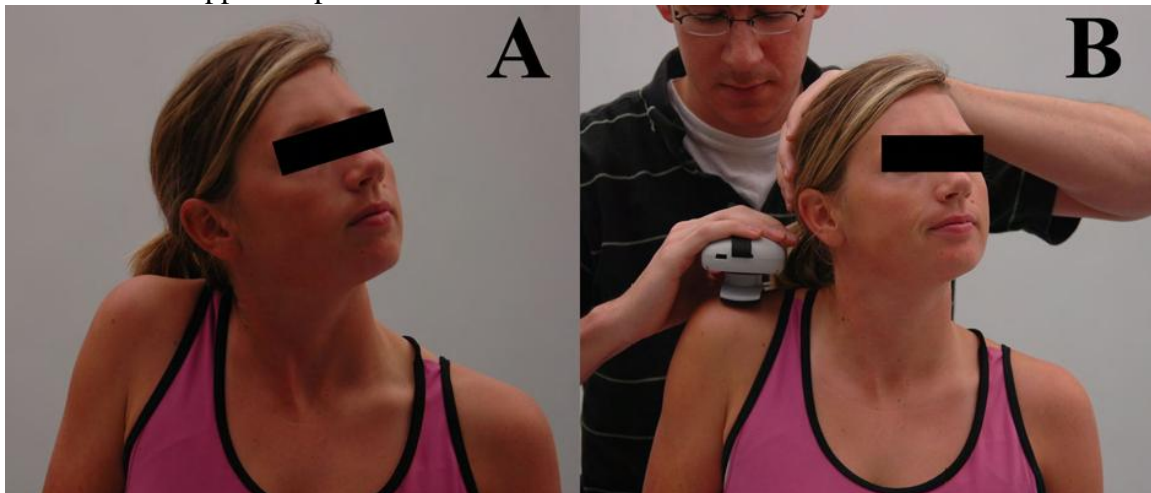
SCAT2

Sport Concussion Assessment Tool 2

Name _____

Sport/team _____

Date/time of injury _____

Date/time of assessment _____

Age _____ **Gender** ☐ M ☐ F

Years of education completed _____

Examiner _____

What is the SCAT2?[1]

This tool represents a standardized method of evaluating injured athletes for concussion and can be used in athletes aged from 10 years and older. It supersedes the original SCAT published in 2005[2]. This tool also enables the calculation of the Standardized Assessment of Concussion (SAC)[3,4] score and the Maddocks questions[5] for sideline concussion assessment.

Instructions for using the SCAT2

The SCAT2 is designed for the use of medical and health professionals. Preseason baseline testing with the SCAT2 can be helpful for interpreting post-injury test scores. Words in italics throughout the SCAT2 are the instructions given to the athlete by the tester.

This tool may be freely copied for distribtion to individuals, teams, groups and organizations.

What is a concussion?

A concussion is a disturbance in brain function caused by a direct or indirect force to the head. It results in a variety of non-specific symptoms (like those listed below) and often does not involve loss of consciousness. Concussion should be suspected in the presence of **any one or more** of the following:

- Symptoms (such as headache), or
- Physical signs (such as unsteadiness), or
- Impaired brain function (e.g. confusion) or
- Abnormal behaviour.

Any athlete with a suspected concussion should be REMOVED FROM PLAY, medically assessed, monitored for deterioration (i.e., should not be left alone) and should not drive a motor vehicle.

Symptom Evaluation

How do you feel?

You should score yourself on the following symptoms, based on how you feel now.

	none	mild		moderate		severe	
Headache	0	1	2	3	4	5	6
"Pressure in head"	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Trouble falling asleep (if applicable)	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6

Total number of symptoms (Maximum possible 22) _____

Symptom severity score
(Add all scores in table, maximum possible: 22 x 6 = 132) _____

Do the symptoms get worse with physical activity? ☐ Y ☐ N
Do the symptoms get worse with mental activity? ☐ Y ☐ N

Overall rating

If you know the athlete well prior to the injury, how different is the athlete acting compared to his / her usual self? Please circle one response.

no different	very different	unsure

Cognitive & Physical Evaluation

1 Symptom score (from page 1)
22 **minus** number of symptoms — of 22

2 Physical signs score
Was there loss of consciousness or unresponsiveness? — Y — N
If yes, how long? ____ minutes
Was there a balance problem/unsteadiness? — Y — N

Physical signs score (1 point for each negative response) — of 2

3 Glasgow coma scale (GCS)

Best eye response (E)

No eye opening	1
Eye opening in response to pain	2
Eye opening to speech	3
Eyes opening spontaneously	4

Best verbal response (V)

No verbal response	1
Incomprehensible sounds	2
Inappropriate words	3
Confused	4
Oriented	5

Best motor response (M)

No motor response	1
Extension to pain	2
Abnormal flexion to pain	3
Flexion/Withdrawal to pain	4
Localizes to pain	5
Obeys commands	6

Glasgow Coma score (E + V + M) — of 15

GCS should be recorded for all athletes in case of subsequent deterioration.

4 Sideline Assessment – Maddocks Score

"I am going to ask you a few questions, please listen carefully and give your best effort."

Modified Maddocks questions (1 point for each correct answer)

At what venue are we at today?	0	1
Which half is it now?	0	1
Who scored last in this match?	0	1
What team did you play last week/game?	0	1
Did your team win the last game?	0	1

Maddocks score — of 5

Maddocks score is validated for sideline diagnosis of concussion only and is not included in SCAT 2 summary score for serial testing.

5 Cognitive assessment
Standardized Assessment of Concussion (SAC)

Orientation (1 point for each correct answer)

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1

Orientation score — of 5

Immediate memory
"I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order."

Trials 2 & 3:
"I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before."

Complete all 3 trials regardless of score on trial 1 & 2. Read the words at a rate of one per second. Score 1 pt. for each correct response. Total score equals sum across all 3 trials. Do not inform the athlete that delayed recall will be tested.

List	Trial 1	Trial 2	Trial 3	Alternative word list		
elbow	0 1	0 1	0 1	candle	baby	finger
apple	0 1	0 1	0 1	paper	monkey	penny
carpet	0 1	0 1	0 1	sugar	perfume	blanket
saddle	0 1	0 1	0 1	sandwich	sunset	lemon
bubble	0 1	0 1	0 1	wagon	iron	insect
Total						

Immediate memory score — of 15

Concentration
Digits Backward:
"I am going to read you a string of numbers and when I am done, you repeat them back to me backwards, in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7."

If correct, go to next string length. If incorrect, read trial 2. One point possible for each string length. Stop after incorrect on both trials. The digits should be read at the rate of one per second.

			Alternative digit lists		
4-9-3	0	1	6-2-9	5-2-6	4-1-5
3-8-1-4	0	1	3-2-7-9	1-7-9-5	4-9-6-8
6-2-9-7-1	0	1	1-5-2-8-6	3-8-5-2-7	6-1-8-4-3
7-1-8-4-6-2	0	1	5-3-9-1-4-8	8-3-1-9-6-4	7-2-4-8-5-6

Months in Reverse Order:
"Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November ... Go ahead"

1 pt. for entire sequence correct

Dec-Nov-Oct-Sept-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan	0	1

Concentration score — of 5

[1] This tool has been developed by a group of international experts at the 3rd International Consensus meeting on Concussion in Sport held in Zurich, Switzerland in November 2008. The full details of the conference outcomes and the authors of the tool are published in British Journal of Sports Medicine, 2009, volume 43, supplement 1.
The outcome paper will also be simultaneously co-published in the May 2009 issues of Clinical Journal of Sports Medicine, Physical Medicine & Rehabilitation, Journal of Athletic Training, Journal of Clinical Neuroscience, Journal of Science & Medicine in Sport, Neurosurgery, Scandinavian Journal of Science & Medicine in Sport and the Journal of Clinical Sports Medicine.

[2] McCrory P et al. Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. British Journal of Sports Medicine. 2005; 39: 196-204

[3] McCrea M. Standardized mental status testing of acute concussion. Clinical Journal of Sports Medicine. 2001; 11: 176-181

[4] McCrea M, Randolph C, Kelly J. Standardized Assessment of Concussion: Manual for administration, scoring and interpretation. Waukesha, Wisconsin, USA.

[5] Maddocks, DL; Dicker, GD; Saling, MM. The assessment of orientation following concussion in athletes. Clin J Sport Med. 1995;5(1):32–3

[6] Guskiewicz KM. Assessment of postural stability following sport-related concussion. Current Sports Medicine Reports. 2003; 2: 24-30

6 Balance examination

This balance testing is based on a modified version of the Balance Error Scoring System (BESS)*. A stopwatch or watch with a second hand is required for this testing.

Balance testing

"I am now going to test your balance. Please take your shoes off, roll up your pant legs above ankle (if applicable), and remove any ankle taping (if applicable). This test will consist of three twenty second tests with different stances."

(a) Double leg stance:

"The first stance is standing with your feet together with your hands on your hips and with your eyes closed. You should try to maintain stability in that position for 20 seconds. I will be counting the number of times you move out of this position. I will start timing when you are set and have closed your eyes."

(b) Single leg stance:

"If you were to kick a ball, which foot would you use? [This will be the dominant foot] Now stand on your non-dominant foot. The dominant leg should be held in approximately 30 degrees of hip flexion and 45 degrees of knee flexion. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

(c) Tandem stance:

"Now stand heel-to-toe with your non-dominant foot in back. Your weight should be evenly distributed across both feet. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

Balance testing – types of errors

1. Hands lifted off iliac crest
2. Opening eyes
3. Step, stumble, or fall
4. Moving hip into > 30 degrees abduction
5. Lifting forefoot or heel
6. Remaining out of test position > 5 sec

Each of the 20-second trials is scored by counting the errors, or deviations from the proper stance, accumulated by the athlete. The examiner will begin counting errors only after the individual has assumed the proper start position. **The modified BESS is calculated by adding one error point for each error during the three 20-second tests. The maximum total number of errors for any single condition is 10.** If an athlete commits multiple errors simultaneously, only one error is recorded but the athlete should quickly return to the testing position, and counting should resume once subject is set. Subjects that are unable to maintain the testing procedure for a minimum of **five seconds** at the start are assigned the highest possible score, ten, for that testing condition.

Which foot was tested: ☐ Left ☐ Right
(i.e. which is the **non-dominant** foot)

Condition	Total errors
Double Leg Stance (feet together)	of 10
Single leg stance (non-dominant foot)	of 10
Tandem stance (non-dominant foot at back)	of 10
Balance examination score (30 **minus** total errors)	of 30

7 Coordination examination

Upper limb coordination

Finger-to-nose (FTN) task: *"I am going to test your coordination now. Please sit comfortably on the chair with your eyes open and your arm (either right or left) outstretched (shoulder flexed to 90 degrees and elbow and fingers extended). When I give a start signal, I would like you to perform five successive finger to nose repetitions using your index finger to touch the tip of the nose as quickly and as accurately as possible."*

Which arm was tested: ☐ Left ☐ Right

Scoring: 5 correct repetitions in < 4 seconds = 1

Note for testers: Athletes fail the test if they do not touch their nose, do not fully extend their elbow or do not perform five repetitions. Failure should be scored as 0.

Coordination score	of 1

8 Cognitive assessment
Standardized Assessment of Concussion (SAC)

Delayed recall
"Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order."

Circle each word correctly recalled. Total score equals number of words recalled.

List		Alternative word list	
elbow	candle	baby	finger
apple	paper	monkey	penny
carpet	sugar	perfume	blanket
saddle	sandwich	sunset	lemon
bubble	wagon	iron	insect

Delayed recall score	of 5

Overall score

Test domain	Score
Symptom score	of 22
Physical signs score	of 2
Glasgow Coma score (E + V + M)	of 15
Balance examination score	of 30
Coordination score	of 1
Subtotal	**of 70**
Orientation score	of 5
Immediate memory score	of 5
Concentration score	of 15
Delayed recall score	of 5
SAC subtotal	**of 30**
SCAT2 total	**of 100**
Maddocks Score	**of 5**

Definitive normative data for a SCAT2 "cut-off" score is not available at this time and will be developed in prospective studies. Embedded within the SCAT2 is the SAC score that can be utilized separately in concussion management. The scoring system also takes on particular clinical significance during serial assessment where it can be used to document either a decline or an improvement in neurological functioning.

Scoring data from the SCAT2 or SAC should not be used as a stand alone method to diagnose concussion, measure recovery or make decisions about an athlete's readiness to return to competition after concussion.

Athlete Information

Any athlete suspected of having a concussion should be removed from play, and then seek medical evaluation.

Signs to watch for

Problems could arise over the first 24-48 hours. You should not be left alone and must go to a hospital at once if you:

- Have a headache that gets worse
- Are very drowsy or can't be awakened (woken up)
- Can't recognize people or places
- Have repeated vomiting
- Behave unusually or seem confused; are very irritable
- Have seizures (arms and legs jerk uncontrollably)
- Have weak or numb arms or legs
- Are unsteady on your feet; have slurred speech

Remember, it is better to be safe.
Consult your doctor after a suspected concussion.

Return to play

Athletes should not be returned to play the same day of injury. When returning athletes to play, they should follow a stepwise symptom-limited program, with stages of progression. For example:

1. rest until asymptomatic (physical and mental rest)
2. light aerobic exercise (e.g. stationary cycle)
3. sport-specific exercise
4. non-contact training drills (start light resistance training)
5. full contact training after medical clearance
6. return to competition (game play)

There should be approximately 24 hours (or longer) for each stage and the athlete should return to stage 1 if symptoms recur. Resistance training should only be added in the later stages.
Medical clearance should be given before return to play.

Tool	Test domain	Time	Score			
		Date tested				
		Days post injury				
SCAT2	Symptom score					
	Physical signs score					
	Glasgow Coma score (E + V + M)					
	Balance examination score					
	Coordination score					
SAC	Orientation score					
	Immediate memory score					
	Concentration score					
	Delayed recall score					
	SAC Score					
Total	SCAT2					
Symptom severity score (max possible 132)						
Return to play			Y N	Y N	Y N	Y N

Additional comments

Concussion injury advice (To be given to concussed athlete)

This patient has received an injury to the head. A careful medical examination has been carried out and no sign of any serious complications has been found. It is expected that recovery will be rapid, but the patient will need monitoring for a further period by a responsible adult. Your treating physician will provide guidance as to this timeframe.

If you notice any change in behaviour, vomiting, dizziness, worsening headache, double vision or excessive drowsiness, please telephone the clinic or the nearest hospital emergency department immediately.

Other important points:
- Rest and avoid strenuous activity for at least 24 hours
- No alcohol
- No sleeping tablets
- Use paracetamol or codeine for headache. Do **not** use aspirin or anti-inflammatory medication
- Do **not** drive until medically cleared
- Do **not** train or play sport until medically cleared

Clinic phone number

Patient's name

Date/time of injury

Date/time of medical review

Treating physician

Contact details or stamp
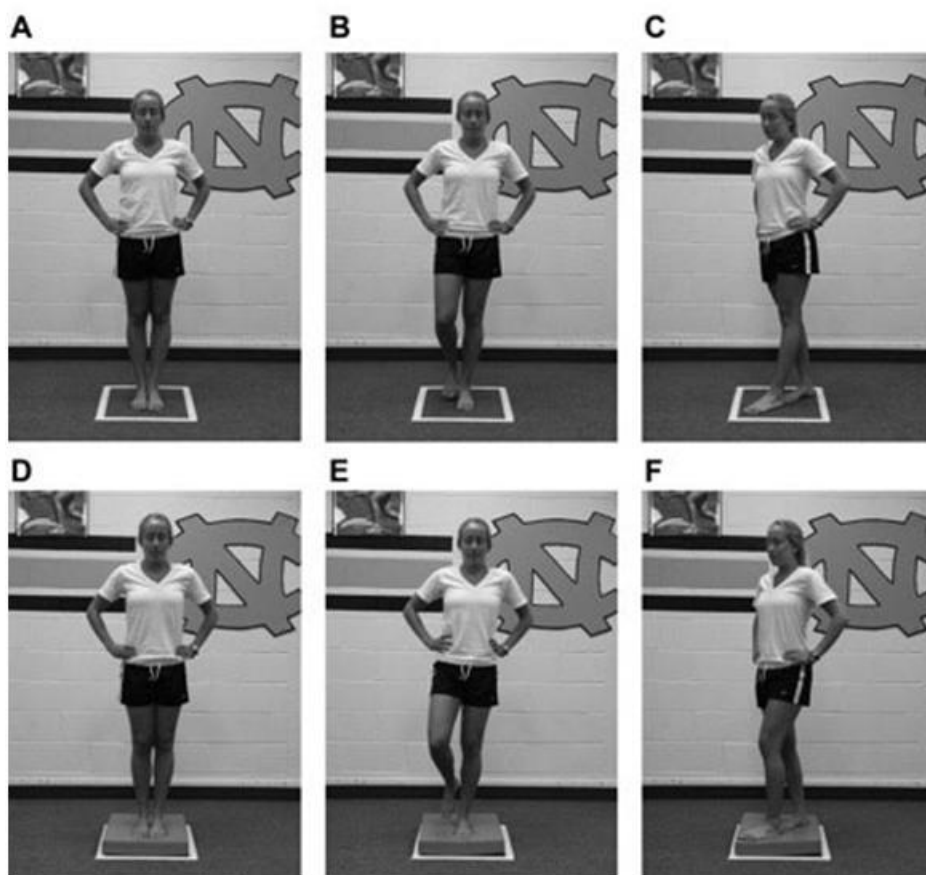
Balance Error Scoring System (BESS)
(Guskiewicz)

Balance Error Scoring System – Types of Errors
1. Hands lifted off iliac crest 2. Opening eyes 3. Step, stumble, or fall 4. Moving hip into > 30 degrees abduction 5. Lifting forefoot or heel 6. Remaining out of test position >5 sec
The BESS is calculated by adding one error point for each error during the 6 20-second tests.

SCORE CARD: (# errors)	FIRM Surface	FOAM Surface
Double Leg Stance (feet together)		
Single Leg Stance (non-dominant foot)		
Tandem Stance (non-dom foot in back)		
Total Scores:		
BESS TOTAL:		

Which **foot** was tested: ☐ Left ☐ Right
(i.e. which is the **non-dominant** foot)

Appendix 4. NeuroCom SOT
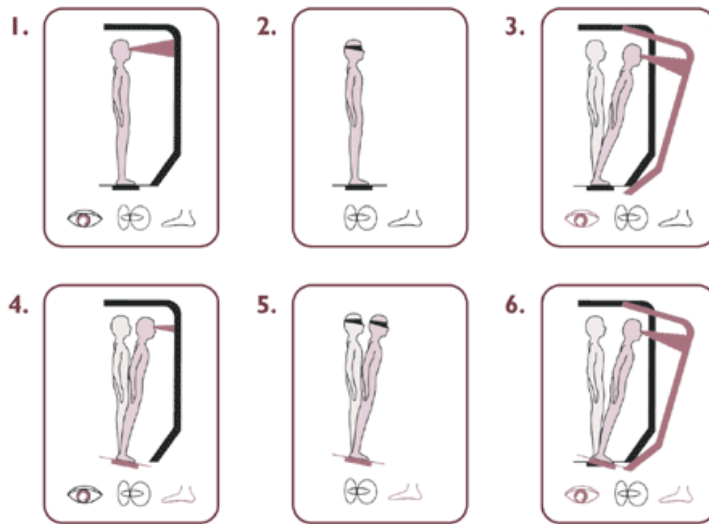
Sensory Organization Test

Appendix 5. Demographic, Heading Habits, and Headgear Satisfaction Questionnaire

I. Demographic Information

Subject #:   Date:

1) Have you ever sustained a concussion diagnosed by a doctor?

2) Have you sustained a concussion in the past 6 months diagnosed by a doctor?

2b) Have you sustained a concussion in the past 6 months that was not reported to a doctor?

3) Have you sustained a lower extremity injury in the past 3 months that has limited your participation?

>	If yes, to what extent?

>	How much time was lost due to injury?

4) Have you ever been diagnosed with vertigo, any vestibular disorder, or equilibrium deficit?

5) Have you ever been diagnosed with a learning disability, including ADHD?

6) Do you have any medical issues, such as seizures, musculoskeletal disorders, or fainting, which may impact your participation in this study?

7) Are you currently experiencing a headache, dizziness, or any other concussive symptoms?

II. Heading Habits

Years of participation in soccer:

Number of hours per week dedicated to soccer:

1) What is your primary position on the field?

2) When heading a soccer ball do you frequently feel dizzy or lightheaded?

3) Approximately, how many times per game do you head a soccer ball on average?

>	A. <5 B. 6-10 C. 11-20 D. >21

4) Approximately, how many times per practice session do you head the ball on average?

>	A. <5 B. 6-10 C. 11-20 D. >21

5) Do you consider yourself a frequent header?

6) Following a heading session, do you ever experience the presence of any of the following symptoms?

___ Dizziness

___ Lightheadedness

___ Headache

III. Headgear Satisfaction

1) Following a heading session with the headgear, I did not experience dizziness, lightheadedness, or a headache?

(5= Strongly agree, 4= Agree, 3= Unsure, 2= Disagree, 1= Strongly disagree)

___

2) Overall, the headband was an effective and comfortable piece of equipment.

(5= Strongly agree, 4= Agree, 3= Unsure, 2= Disagree, 1= Strongly disagree)

___

3) Overall, the headband did not alter my heading mechanics.

(5= Strongly agree, 4= Agree, 3= Unsure, 2= Disagree, 1= Strongly disagree)

___

4) Overall, the headband was not cumbersome in nature.

(5= Strongly agree, 4= Agree, 3= Unsure, 2= Disagree, 1= Strongly disagree)

___

5) Would you consider wearing the headgear during competition?

(5=Definitely, 4=Possibly, 3=Maybe, 2=Probably Not, 1=Definitely Not)

___

Appendix 6. Dynamic Warm-up Protocol
** Based off the thesis work of Alain Aguilar (2006)

Step 1: Jogging warm-up for 5 minutes at 12 on the RPE scale

Step 2: Dynamic Warm-up exercises

 a. Heel Toe Walks (10 steps), jog back

 b. Walking Gastroc (10 steps), jog back

 c. Russian Walk (10 steps), 50% sprint back

 d. Walking Quad Stretch (10 stretches), 50% sprint back

 e. Low-amplitude Butt Kicks (10 steps), 50% sprint back

 f. High Knee Pull (10 steps), 50% sprint back

 g. Walking Hamstring Stretch (10 steps), 50% sprint back

 h. Carioca with High Knee drive (5 cross-overs per leg), 75% sprint back

  *** Repeat and lead with opposite leg ***

 i. Walking Lunge with Transverse Reach (10 steps), 75% sprint back

 j. High Skip (10 skips), 75% sprint back

 k. Rear Leg Swing (10 steps), 75% sprint back

 l. Backward run (10 m), 90% sprint back

 m. Shuffle for Speed (10 m one leg, 10 m other)

 n. Accelerations (10 m down and back)

Step 3: Hydrate and begin test

Heel Toe Walks

Walking Gastrocnemius

Russian Walks

Walking Quadriceps

Low Amp Butt Kicks
(Backwards Butt Kicks)

High Knee Pull

Walking Hamstrings

Carioca with High Knee Drive

Lunge with Transverse Reach

High Skip

Rear Leg Swing

HEADGEAR DOES NOT IMPROVE NEUROCOGNTIVIE FUNCTION AND BALANCE
PERFORMANCE FOLLOWING ACUTE BOUTS OF SOCCER HEADING

ABSTRACT

Objective: The main objective of this study was to investigate the effects of an acute bout of

soccer heading on neurocognitive function and balance performance, as well as, the impact of the

Full90^{TM} protective headgear.

Design: This was a repeated measures study where subjects reported on a total of 3 occasions.

The first session was baseline, where neurocognitive function and balance performance was

assessed. Subjects completed a heading protocol during each of the next 2 sessions, once while

wearing headgear, and the other time without the apparatus.

Setting: Field setting (indoor Astroturf facility)

Participants: A total of 29 college-aged club and competitive division intramural athletes

Interventions: A 10 minute protocol consisting of 20 linear headers was completed twice by all

subjects.

Main Outcome Measurements: The Sport Concussion Assessment Tool (SCAT2), Balance

Error Scoring System (BESS), the Simple Reaction Time (SRT) module of the Automated

Neuropsychological Assessment Metrics (ANAM), and the Sensory Organization Test (SOT)

were used to assess mental status, reaction time, and balance performance.

Results: No detriments were observed in the SCAT2, BESS, SRT, or composite SOT scores following heading sessions ($p > 0.05$). Wearing soccer headgear during the heading activity did not influence any of the scores ($p > 0.05$).

Conclusions: This study suggests that acute bouts of heading do not lead to impairments on clinical concussion measures and wearing headgear provides no further protection in this regard.

Key Words: postural control, concussion, cognition

Word Count: 237

INTRODUCTION

Approximately 240 million people actively participate in soccer (Federation Internationale de Football Association, 2005). Among collegiate institutions, women's soccer is the most commonly added sport (Bauer et al., 2001). This game is exclusive in that it utilizes the purposeful use of the head to advance the ball during play. It has been reported that career heading totals are as high as 2000 (Tysvaer & Storli, 1981). The average velocity of a flighted soccer ball is approximately 45 miles per hour during a punt or corner kick, and 55 miles per hour during a goal kick or drop kick (Kirkendall & Garrett, 2001). These seemingly high speeds, coupled with the considerable heading totals, have raised concern about head injuries in the sport.

A concussion is defined as a change in mental status resulting from trauma or rotational force to the brain, with or without loss of consciousness (McCrory et al., 2005). The characteristic symptoms reported by an individual range from headache, to vision related problems, and amnesia (Guskiewicz et al., 2004; Maroon et al., 2000; McCrory et al., 2005;

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Piland et al., 2003). The United States Olympic athletes reported a 50% and 22% risk of sustaining a concussion for males and females respectively during their career (Barnes et al., 1998). Specifically in women's collegiate soccer, head injuries represent 13.8% of all injuries (Covassin et al., 2003). Considerable thought has examined neck musculature as a contributor to the sex discrepancy in concussion incidence. Males have been shown to possess greater isometric strength, neck girth, as well as head-neck segment mass and length (Mansell et al., 2005).

The high concussion statistics have sparked research regarding the possible detriments from acute bouts of heading. Past studies have shown conflicting results (Broglio et al., 2004; Putukian et al., 2000; Schmitt et al., 2004). In response to the possibility of balance or neurocognitive impairments, manufacturers created soccer headbands, designed to attenuate the forces sustained from heading. Foundational research has provided inconsistent results regarding their ability to reduce forces. A study implementing headgear found that the apparatus did not improve neurocognitive function, as measured through the ImPACT computer program (Janke, 2006). Conversely, concussive symptoms were reduced following an acute bout of heading with the headband (Janke, 2006).

Researchers have begun to investigate potential deficits from heading, in both an acute and chronic sense. Currently, a need exists to evaluate an acute bout of heading, in conjunction with soccer headgear, to establish trends in neurocognitive function and balance performance. Thus, the purpose of this study was to investigate the effects of an acute soccer heading bout with and without the Full90[TM] headband on neurocognitive and balance performance in recreational college-aged soccer players.

MATERIALS AND METHODS

Subjects

A total of 29 subjects (13 female and 16 male) college-aged soccer players (age = 18-25 years old, 20.48 ± 1.90) from a university setting were used (Table 1). All participants were recruited from the club or competitive division intramural teams at the institution, and were informed of all study procedures. They were notified of all inherent risks, and were asked to read and sign an informed consent form.

Subjects were excluded if they were under the age of 18, or if they suffered a concussion in the past 6 months. Participants who sustained a lower extremity injury within the past 3 months were also excluded. Additionally, subjects were prohibited from participating if they possessed known medical conditions such as vertigo, equilibrium disorders, vestibular deficits, or diagnosed learning disabilities, including Attention Deficit Hyperactivity Disorder (ADHD).

Procedures

Subjects reported to the Sports Medicine Research Laboratory for three separate testing sessions, all separated by 1 week. The first meeting established baseline on all 4 testing instruments, and two subsequent sessions with a heading protocol ensued.

Test Session 1

During the baseline session, neck and head circumference, as well as neck musculature strength measurements were taken. Strength of the anterior neck flexors, anterolateral neck flexors, cervical rotators, posterolateral extensors, and upper trapezius was assessed using a hand-held dynamometer (HHD) (Lafeyette Manual Muscle Test System Model Number 01163)

(Kendall, 2005). The peak strength bilaterally was averaged into a single value and normalized to the subject's body weight.

All subjects then partook in baseline testing of the Sport Concussion Assessment Tool 2 (SCAT2), Balance Error Scoring System (BESS), Simple Reaction Time (SRT) module, and Sensory Organization Test (SOT; NeuroCom ® International; Clackamas, OR).

Test Session 2 and 3

One half of the participants completed the first intervention (session 2) with the Full90^{TM} Select headgear (Full90 Sports, Inc, San Diego, CA), and the other half without the apparatus (Table 2). All athletes wearing the headband were fitted properly by the investigator according to the manufacturers' guidelines. Headgear condition testing order (no headgear vs. headgear) was counterbalanced across subjects. During the second and third test sessions, subjects completed all measures assessed at baseline with the exception of muscle strength assessment. Following the third session, subjects completed a headgear satisfaction survey exploring their overall contentment with the apparatus. The survey produced a score out of a possible 25 points, with higher numbers corresponding to more approval.

The heading intervention for both heading sessions consisted of 20 headers, (Broglio et al., 2004; Putukian et al., 2000; Schmitt et al., 2004). All soccer balls travelled at a speed of 72.42 kph (45 mph), from a distance of 24.384 meters (80 feet), all agreement with previous literature (Broglio et al., 2004; Putukian et al., 2000; Schmitt et al., 2004). The heading was performed at a rate of 1 every 30 seconds with the use of a calibrated Gold Medal Soccer Tutor (Sports Tutor Inc., Burbank, California, USA). The rate was twice as fast as previous studies,

which employed one header per minute, and observed no acute deficits (Broglio et al., 2004; Janke, 2006)

The protocol began with each subject catching five practice trials with their hands to become acquainted with the distance, speed, and rate. Participants were told to head all soccer balls for maximum distance in a linearly back towards the calibrated Soccer Tutor machine. In order for a trial to be counted, the initial flight of the ball following head contact was required to be in a forward direction. When soccer balls did not initially move forward or contact was not made, a retrial occurred immediately following the mistrial.

All soccer balls used in this study were size 5 balls inflated to 0.70 bars of pressure, which met manufacturer's guidelines. The balls were checked prior to each session, in order to ensure proper pressure.

Immediately following the 20th header, the SCAT2 was administered to the subject at the testing location, followed by the foam conditions of the BESS, in order to generate a total BESS score. Subsequent to this test battery, the subject was escorted to the Research Laboratory where they completed the SRT followed by the SOT. For the first run through of the SOT, each of the 6 conditions was performed in condition order (1-6). The second and third runs were conducted in a randomized order.   The testing order remained constant from baseline to all testing sessions.

Instrumentation

SCAT2

The SCAT 2 was used to assess mental status, cognitive ability, and postural control. The mental status portion examined orientation through five standard questions; immediate

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memory by evaluating recall of five dissimilar words; delayed recall by assessing the same five words; and concentration by asking the athlete to repeat a string of numbers in reverse order.

The Graded Symptom Checklist (GSC) section utilized a 7 point Likert grading scale in order to permit subjects to report a range of 22 concussive symptoms. The SCAT2 yielded a composite score out of 100 points based on all domains of the instrument.

Balance Error Scoring System

The BESS protocol involved a total of 6 trials, using combinations of 3 stances and 2 surfaces. The double leg, single leg, and tandem stances were used in conjunction with a firm and foam surface. The testing position required a subject to place their hands on their hips for 20 second trials, with their eyes closed (Figure 1). Under the single leg conditions, the nondominant leg was used for weight bearing. (Guskiewicz, 2001; Register-Mihalik et al., 2008; Valovich McLeod et al., 2006)

Simple Reaction Time

The SRT task is one module from the Automated Neuropsychological Assessment Metrics. The computer module required participants to click a computer mouse when a stimulus appears, at different time intervals, challenging reaction time. The throughput score was a product of accuracy and speed of performance.

Sensory Organization Test

The SOT (NeuroCom International, Clackamas, OR) is an instrument designed to disrupt the selection sensory process of an individual in a systemic manner. This was achieved by adjusting the amount of somatosensory information, visual information, or both, and subsequently, measuring the subject's ability to reduce postural sway. The protocol for this

instrument was comprised of 18 total trials, broken down into 6 conditions, each lasting 20

seconds, performed 3 times each (Figure). The SOT used a forceplate system measuring vertical

ground reaction forces which were created as the participant's center of gravity deviated around

a fixed base of support (Guskiewicz, 2001). The overall calculations and procedures followed

the protocol of previous studies (Guskiewicz, 2001)

There are a total of 3 unique visual conditions (eyes open, eyes, closed, sway-referenced

visual surround), which are matched up with 2 different surface types (fixed, sway referenced).

The testing instrument yields a composite equilibrium score, as well as, somatosensory,

vestibular, and visual ratio scores (Guskiewicz, 2001; Register-Mihalik et al., 2008)

Statistical Analysis

Data analyses were conducted using SPSS 16.0 (Chicago, IL) computer software.

Separate totally within repeated measures analysis of covariates (ANCOVAs) were used for each

outcome measure across the 3 sessions. Neck musculature strength and headgear satisfaction

were used as covariates in the analysis. Neck musculature strength included normalized anterior,

right anterolateral, left anterolateral, and total neck musculature strength. Total neck

musculature was computed by adding anterior neck musculature strength, as well as,

anterolateral, cervical rotators, posterolateral, and upper trapezius strength bilaterally. Total

headgear satisfaction was a function of a survey out of a possible 25 points, with higher numbers

corresponding to more approval. Each individual ANCOVA was first run using all 5 covariates.

In the instance where covariates did not contribute significantly to the model, these were

excluded and the test was run again. When significance was found, Tukey post hoc was

calculated to determine critical values. In addition the influence of concussion history group

(yes/no) on each outcome measure was assessed using independent samples t-test. Our alpha level was set a priori to less than 0.05.

The covariates did not often contribute significantly to the models. Overall neck strength factored into the SCAT2 total score analysis (p = 0.023), and SCAT2 symptom score (p = 0.016). The total number of symptoms (p = 0.005), and the SCAT2 symptom score (p = 0.004) were run using the right anterolateral neck flexor strength. Headgear satisfaction was used as a covariate during the SRT (p = 0.00) and SCAT2 total scores (p = 0.014). In cases where no covariates contributed, a 2-way totally within repeated measures ANOVA was used.

RESULTS

Neurocognitive Function

Neurocognitive function was measured using the SCAT2 and SRT in this study (**Tables 3 and 4**). We observed no significance in total SCAT2 scores across heading sessions ($F_{2,52}$ = 1.74, p = 0.185). Similarly, SAC total scores were not different across testing session ($F_{1.7,46.8}$= 1.74, p = 0.191). When investigating Simple Reaction Time, a significant finding was revealed ($F_{1.8,54}$ = 8.45, p = 0.001), with scores improving from baseline to the headgear condition.

Symptomology

Symptomology was assessed through the GSC portion of the SCAT2 (**Table 3**). A significant difference was observed in the symptom severity aspect of the SCAT2 testing instrument ($F_{2,54}$ = 5.78, p = 0.005). Scores were lower at baseline than the heading sessions. Conversely, SCAT2 symptom score ($F_{1.6,42.6}$= 1.64, p = 0.209) were not different between sessions. A significant finding was noticed in headache ratings ($F_{2,56}$= 8.45, p = 0.001), with Tukey post hoc revealing baseline ratings lower than heading sessions.

Balance Performance

The SOT, as well as, the firm and foam conditions of the BESS was used to evaluate

balance performance **(Table 3)**. No difference was observed concerning composite SOT scores

($F_{1.7,44.4}$ = 2.63, p = 0.091). Furthermore, our findings were not significant when examining the

somatosensory ($F_{2,52}$ = 2.01, p = 0.144) and vestibular ($F_{2,52}$ = 2.11, p = 0.132) ratio scores.

Conversely, visual SOT ratio scores revealed a difference ($F_{2,52}$ = 4.17, p = 0.021), with scores

improving from baseline to heading sessions.

BESS total error scores were not significantly different ($F_{1.8,49.2}$ = 1.18, p = 0.311) across

test sessions. Similarly, no significance was found when evaluating firm ($F_{2,56}$ = .06, p = 0.945)

or foam ($F_{1.7,56}$ = .75, p = 0.456) surface errors.

Headgear Satisfaction

When analyzing the headgear satisfaction survey **(Table 5)**, the average composite score

was 14.72 out of a total 25 points. The mean scores of the questions asking subjects about not

experiencing concussive symptoms and the headband not altering heading mechanics were 3.66

and 3.00 respectively. The mean score produced from the statement declaring that the headband

was not cumbersome was 3.10. The average rating of whether the headgear was effective was

3.06. When subjects were asked about considering wearing the headbands, a mean score of 1.90

was produced. Concussion history (yes/no) did not appear to influence any of our outcome

measures following heading. **(Table 6)**.

DISCUSSION

Our study suggests that repetitive subconcussive head impacts do not lead to detriments

in clinical concussion measures and wearing headgear provides no further protection in this

regard. The overwhelming majority of variables assessed indicated neurocognitive function and

balance performance were not impaired following acute heading bouts, agreeing with previous studies (Broglio et al., 2004; Janke, 2006; Mangus et al., 2004; Putukian et al., 2000). Furthermore, concussion history did not influence outcome measures, suggesting that this factor did not affect the result of acute subconcussive head impacts.

Improvement was seen in simple reaction time scores, as well as, visual SOT ratio scores. The improvement in SRT scores during headgear sessions was likely credited to the known practice effect of the tool (Kaminski, Groff et al., 2008). It was unexpected that only visual SOT scores improved when investigating all balance performance measures. However previous literature, examining practice effects of the SOT, found that the visual ratio increased the greatest amount out of all 4 outcome measures following the initial testing session (Wrisley et al., 2007). This task is complex and unnatural to subjects, which explains the large improvement.

Although results seem to point overwhelmingly to no deficits in balance performance, this may not be completely accurate due to the nonexistence of practice effects. Both the BESS and SOT have been shown to exhibit improvements on the second and third trials, which may have been masked by detriments from heading (Valovich et al., 2003; Wrisley et al., 2007).

Our differing results between the SCAT2 symptom and symptom severity scores may be attributed to the fact that the former score is not as inclusive as the latter. The symptom severity score is a product of the number and intensity of symptoms. The higher scores in this area following heading tasks, are in accordance with former studies examining acute heading bouts (Schmitt et al., 2004; Tysvaer & Storli, 1981). Despite the elevated symptom severity and headache scores after heading, they were not impacted by the headbands. This contradicts the

only previous study that investigated symptoms in relation to headgear, which is most likely explained by the difference in timing between testing sessions (Janke, 2006).

Overall soccer heading, particularly in our controlled linear setting, may not produce enough force to bring about head injury. The overwhelming majority of research, using a variety of outcome measures and methodology, indicates that the skill is not detrimental in an acute sense. Acute linear heading bouts do not appear to be potent enough to reach the threshold for impact forces or head accelerations seen in concussive events. Longer duration activities or higher velocity collisions are more apt to create these impairments. In a controlled setting, players are able to prepare for the blow, as opposed to impacts sustained during competition. In anticipation of the contact, the athlete contracts neck musculature making the head and neck a rigid segment. This decreases head accelerations, and reduces the chance for injury.

Soccer Headgear

The protective headgear did not provide significant benefit in any outcome measure using our particular protocol and subject pool. This is in conjunction with a former study which possessed slightly dissimilar methodology, yet found no impact of the headgear on neurocognitive function or reaction time (Janke, 2006).

It is important to acknowledge that headbands are only designed to cover the areas of the head contacting a ball during proper heading technique. During play when movement is not completely linear, it is more likely that the soccer ball will not come in contact with the headband. Also, in a match, the contact with another player may not impact the headgear, but rather another portion of the head. These possibilities, combined with our evidence showing no

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benefit in our controlled environment, should lead clinicians to be skeptical of the product's efficacy under particular conditions.

Headgear Satisfaction and Neck Musculature

When analyzing the headgear satisfaction survey, we found that subjects did not have a high opinion of wearing the apparatus. Participants reported they would not be willing to wear the headgear during competition. The subjects clearly possessed a negative attitude towards the headgear, which may have caused subjects to offer less effort during the heading task. Accordingly, we used headgear satisfaction scores as a covariate to control for the possibility of subjects purposefully skewing results. It only contributed in one of the 19 outcome measures, indicating that overall this subjective measure did not influence the objective variables.

Subjects commented that the headband was uncomfortable and cumbersome. They felt this may have altered their heading mechanics because they were not accustomed to the interface between their head and the ball. Therefore, participants believed they were inclined to strike the ball differently to avoid the headband. Clinically, the headgear caused people to feel uneasy and created a change in heading form, meaning the players are not going to agree to wear the protective equipment. If soccer players are unwilling to wear the headgear, it becomes very difficult to realistically endorse it, unless a governing board mandates the use. However, organizations will not propose rule changes without research confirming its efficacy.

Along with headgear satisfaction, we also used neck musculature strength as a covariate, and again found that these measures did not affect neurocognitive function or balance performance using our particular subject pool and heading protocol. This cannot speak to the relationship between neck strength and the outcome measures using younger or lesser skilled

individuals. These two groups may have poorer strength values, and may be less able to properly brace their neck for the heading task.

Clinical Application

Our project confirms the overwhelming majority of research, which indicates that acute bouts of soccer heading do not result in deficits in neurocognitive function or balance performance (Broglio et al., 2004; Janke, 2006; Putukian et al., 2000). Thus, it looks as if the concern surrounding subconcussive repetitive head impacts should be minimized. Nevertheless, this study, in addition to many others, can only speak to the skill in an acute sense.

If studies examining cumulative effects of heading yield the same results, it appears that the concern regarding the skill should be reconsidered. However, this study has demonstrated that regardless of what is found regarding heading over time, the headband does not affect neurocognitive function or balance performance following the skill using experienced college-aged soccer players.

Limitations

The present study did not address angular heading or the cumulative effect of soccer heading on clinical measures. Due to the different location of impact during angular heading and flicking, the headbands may provide benefit in these particular instances. It is necessary to investigate this to establish a realistic gauge of dangers associated with all aspects and dimensions of the skill. Actual ball impacts were not measured during the protocol, which may have given greater insight into subconcussive forces. A final limitation is our sample was limited to skilled college aged individuals. Future studies should focus on youth and lower skilled players.

Conclusions

We found that acute bouts of soccer heading do not result in deterioration in neurocognitive function or balance performance and soccer headgear does not impact these clinical concussion measures using experienced soccer players. As clinicians, we ought to be aware of these conclusions to understand the role of acute heading in head injury and make recommendations regarding protective equipment in soccer.

REFERENCES

1.   Federation Internationale de Football Association. Federation Internationale de Football Association (FIFA) Survey. Accessed September 19, 2005.

2.   Bauer JA, Thomas TS, Cauraugh JH, Kaminski TW, Hass CJ. Impact forces and neck muscle activity in heading by collegiate female soccer players. *J Sports Sci.* Mar 2001;19(3):171-179.

3.   Tysvaer A, Storli O. Association football injuries to the brain. A preliminary report. *Br J Sports Med.* Sep 1981;15(3):163-166.

4.   Kirkendall DT, Garrett WE, Jr. Heading in Soccer: Integral Skill or Grounds for Cognitive Dysfunction? *J Athl Train.* Sep 2001;36(3):328-333.

5.   Practice parameter: the management of concussion in sports (summary statement). Report of the Quality Standards Subcommittee. *Neurology.* Mar 1997;48(3):581-585.

6.   Piland SG, Motl RW, Ferrara MS, Peterson CL. Evidence for the Factorial and Construct Validity of a Self-Report Concussion Symptoms Scale. *J Athl Train.* Jun 2003;38(2):104-112.

7.   Guskiewicz KM, Bruce SL, Cantu RC, et al. National Athletic Trainers' Association Position Statement: Management of Sport-Related Concussion. *J Athl Train.* Sep 2004;39(3):280-297.

8.   McCrory P, Johnston K, Meeuwisse W, et al. Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. *Br J Sports Med.* Apr 2005;39(4):196-204.

9.   Maroon JC, Lovell MR, Norwig J, Podell K, Powell JW, Hartl R. Cerebral concussion in athletes: evaluation and neuropsychological testing. *Neurosurgery.* Sep 2000;47(3):659-669; discussion 669-672.

10.   Barnes BC, Cooper L, Kirkendall DT, McDermott TP, Jordan BD, Garrett WE, Jr. Concussion history in elite male and female soccer players. *Am J Sports Med.* May-Jun 1998;26(3):433-438.

11.   Covassin T, Swanik CB, Sachs ML. Sex Differences and the Incidence of Concussions among Collegiate Athletes. *J Athl Train.* Sep 2003;38(3):238-244.

12. Mansell J, Tierney RT, Sitler MR, Swanik KA, Stearne D. Resistance training and head-neck segment dynamic stabilization in male and female collegiate soccer players. *J Athl Train.* Oct-Dec 2005;40(4):310-319.

13. Putukian M, Echemendia RJ, Mackin S. The acute neuropsychological effects of heading in soccer: a pilot study. *Clin J Sport Med.* Apr 2000;10(2):104-109.

14. Broglio SP, Guskiewicz KM, Sell TC, Lephart SM. No acute changes in postural control after soccer heading. *Br J Sports Med.* Oct 2004;38(5):561-567.

15. Schmitt DM, Hertel J, Evans TA, Olmsted LC, Putukian M. Effect of an acute bout of soccer heading on postural control and self-reported concussion symptoms. *Int J Sports Med.* Jul 2004;25(5):326-331.

16. Janke LM. *The Effect of Headgear on Symptoms and Neurocognitive Impairment after Purposeful Heading*: Kinesiology, California State University, Fullerton; 2006.

17. Kendall FM, E; Provance, P; Rodgers, M; Romani, W. *Muscles Testing and Function with Posture and Pain*. 5th ed. Baltimore: Lippinocott Williams and Wilkins; 2005.

18. Guskiewicz KM. Postural stability assessment following concussion: one piece of the puzzle. *Clin J Sport Med.* Jul 2001;11(3):182-189.

19.   Valovich McLeod TC, Barr WB, McCrea M, Guskiewicz KM. Psychometric and

        measurement properties of concussion assessment tools in youth sports. *J Athl Train.*

        Oct-Dec 2006;41(4):399-408.

20.   Register-Mihalik JK, Mihalik JP, Guskiewicz KM. Balance deficits after sports-related

        concussion in individuals reporting posttraumatic headache. *Neurosurgery.* Jul

        2008;63(1):76-80; discussion 80-72.

21.   Mangus BC, Wallmann HW, Ledford M. Analysis of postural stability in collegiate

        soccer players before and after an acute bout of heading multiple soccer balls. *Sports

        Biomech.* Jul 2004;3(2):209-220.

22.   Kaminski TW, Groff RM, Glutting JJ. Examining the stability of Automated

        Neuropsychological Assessment Metric (ANAM) baseline test scores. *J Clin Exp

        Neuropsychol.* Dec 28 2008:1-9.

23.   Wrisley DM, Stephens MJ, Mosley S, Wojnowski A, Duffy J, Burkard R. Learning

        effects of repetitive administrations of the sensory organization test in healthy young

        adults. *Arch Phys Med Rehabil.* Aug 2007;88(8):1049-1054.

24.   Valovich TC, Perrin DH, Gansneder BM. Repeat Administration Elicits a Practice Effect

        With the Balance Error Scoring System but Not With the Standardized Assessment of

        Concussion in High School Athletes. Mar. Available at:

http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=12937472 Accessed 1, 38.
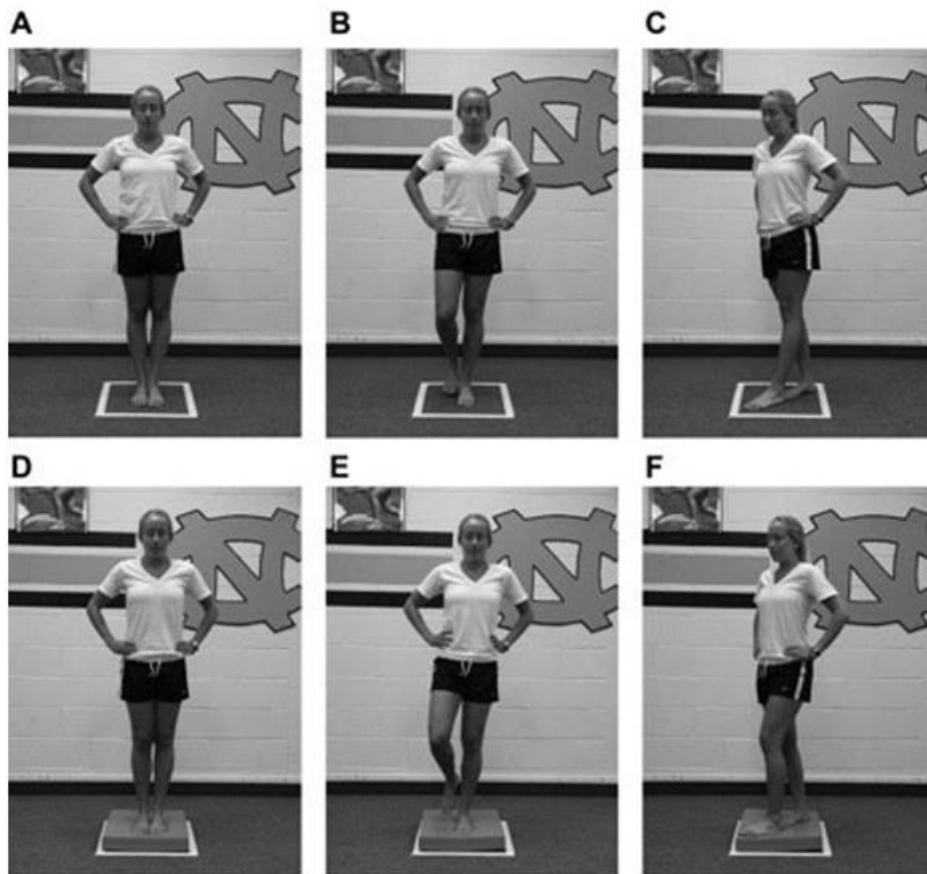
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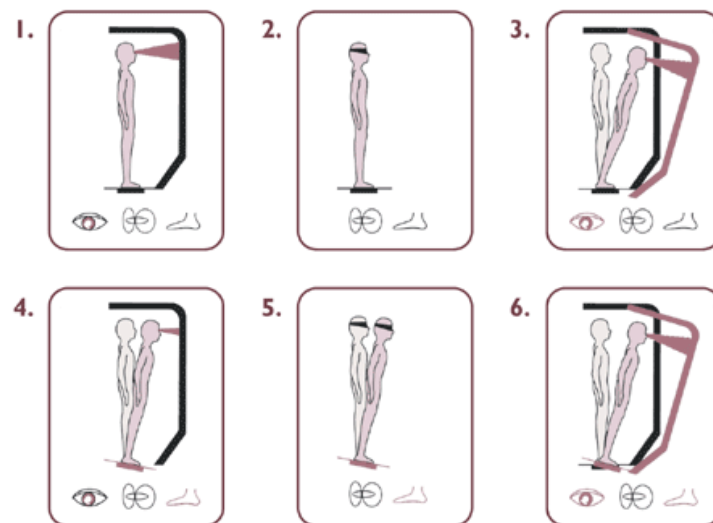
Sensory Organization Test

Table 1. Demographic Information

	Mean and Standard Deviation
Age (n = 29)	20.48 ± 1.90
Mass (kg) (n = 29)	72.13 ± 11.24
Height (cm) (n =29)	173.54 ± 8.61
Years of Soccer Experience (n = 29)	14.24 ± 3.53
Hours Per Week Dedicated to Soccer (n = 29)	8.03 ± 6.70

Table 2 Testing Order for Subjects

	1st Heading Intervention	**2nd Heading Intervention**
Baseline (all 29 subjects)	Headgear = 15 subjects No headgear = 14 subjects	Headgear = 14 subjects No Headgear = 15 subjects

Table 3. SCAT2 Total Score and Subcomponent Scores Means and Standard Deviations

	Baseline		Headgear		No Headgear		F value	*P*-value
	Mean	SD	Mean	SD	Mean	SD		
Total SCAT2 Score (n=29)	95.93	3.10	94.83	2.85	94.24	3.08	1.74	0.185
Symptom Severity (n=29)	.72	1.16	2.03	2.82	2.21	3.22	3.12	0.005*†
Total Number of Symptoms (n=29)	.48	.69	1.31	1.77	1.24	1.70	1.62	0.205
Headache Rating (n=29)	.10	.41	.86	1.13	.86	1.13	8.45	0.001*†
SCAT2 Symptom Score (n=29)	21.52	.69	20.69	1.77	20.66	1.71	2.80	0.086
Total SAC Score (n=29)	28.45	1.80	28.10	1.65	27.79	1.78	1.74	0.191

*Significant difference between baseline and headgear session
†Significant difference between baseline and no headgear session

Table 4. Simple Reaction Time, Sensory Organization Test, and Balance Error Scoring System
Means and Standard Deviations

	Baseline		Headgear		No Headgear		F value	*P*-value
	Mean	SD	Mean	SD	Mean	SD		
SRT Score (n=29)	258.07	15.98	266.39	22.26	264.78	29.44	8.45	0.001*
Somatosensory Ratio (SOT) (n=27)	.98	.02	.97	.03	.99	.03	2.01	0.144
Vestibular Ratio (SOT) (n=27)	.74	.10	.78	.10	.79	.10	2.11	0.132
Visual Ratio (SOT) (n=27)	.91	.05	.94	.06	.94	.06	4.17	0.021*†
BESS Firm Error Score (n=29)	2.03	2.08	2.00	2.00	2.10	2.24	.06	0.945
BESS Foam Error Score (n=29)	10.28	3.77	10.03	3.14	10.76	3.20	.75	0.456
BESS Total Error (n=29)	12.31	5.18	11.93	4.28	13.10	5.06	1.18	0.311

*Significant difference between baseline and headgear session
†Significant difference between baseline and no headgear sessions

Table 5. Headgear Satisfaction Survey Means and Standard Deviations

	Mean and Standard Deviation
Did not experience dizziness, lightheadedness, or headache	3.66 ± 1.37
Effective piece of equipment	3.06 ± 1.10
Did not alter heading mechanics	3.00 ± 1.28
Not cumbersome	3.10 ± 1.17
Consider wearing	1.90 ± 1.01
Overall Satisfaction	14.72 ± 4.22

Table 6. Concussion History Means and Standard Deviations for Outcome Measures

		Mean and Standard Deviations
BL SRT Score	No Con Hx (n = 22)	258.43 ± 13.40
	Con Hx (n = 7)	256.95 ± 23.70
HG SRT Score	No Con Hx (n = 22)	270.46 ± 22.22
	Con Hx (n = 7)	253.56 ± 18.24
NH SRT Score	No Con Hx (n = 22)	266.44 ± 31.29
	Con Hx (n = 7)	259.55 ± 24.01
BL SCAT2 Score	No Con Hx (n = 22)	95.73 ± 3.18
	Con Hx (n = 7)	96.57 ± 2.99
HG SCAT2 Score	No Con Hx (n = 22)	94.82 ± 2.58
	Con Hx (n = 7)	95.29 ± 2.98
NH SCAT2 Score	No Con Hx (n = 22)	94.27 ± 2.90
	Con Hx (n = 7)	94.42 ± 3.82
BL BESS Score	No Con Hx (n = 22)	13.23 ± 5.40
	Con Hx (n = 7)	9.43 ± 3.21
HG BESS Score	No Con Hx (n = 22)	12.18 ± 4.75
	Con Hx (n = 7)	11.14 ± 2.41
NH BESS Score	No Con Hx (n = 22)	13.10 ± 5.55
	Con Hx (n = 7)	13.14 ± 3.39
BL Somatosensory SOT Score	No Con Hx (n = 20)	.98 ± .02
	Con Hx (n = 7)	.98 ± .02
HG Somatosensory SOT Score	No Con Hx (n = 20)	.98 ± .03
	Con Hx (n = 7)	.96 ± .02

NH Somatosensory SOT Score	No Con Hx (n = 20)	.99 ± .03
	Con Hx (n = 7)	.98 ± .02
BL Vestibular SOT Score	No Con Hx (n = 20)	.75 ± .11
	Con Hx (n = 7)	.74 ± .04
HG Vestibular SOT Score	No Con Hx (n = 20)	.77 ± .10
	Con Hx (n = 7)	.79 ± .11
NH Vestibular SOT Score	No Con Hx (n = 20)	.80 ± .10
	Con Hx (n = 7)	.78 ± .10
BL Visual SOT Score	No Con Hx (n = 20)	.91 ± .05
	Con Hx (n = 7)	.90 ± .05
HG Visual SOT Score	No Con Hx (n = 20)	.94 ± .06
	Con Hx (n = 7)	.94 ± .05
NH Visual SOT Score	No Con Hx (n = 20)	.95 ± .05
	Con Hx (n = 7)	.92 ± .07
BL Composite SOT Score	No Con Hx (n = 20)	82.70 ± 5.33
	Con Hx (n = 7)	81.62 ± 3.80
HG Composite SOT Score	No Con Hx (n = 20)	84.78 ± 4.21
	Con Hx (n = 7)	83.47 ± 5.44
NH Composite SOT Score	No Con Hx (n = 20)	85.01 ± 4.72
	Con Hx (n = 7)	81.88 ± 6.64

References

Andersen, T. E., Arnason, A., Engebretsen, L., & Bahr, R. (2004). Mechanisms of head injuries in elite football. *Br J Sports Med, 38*(6), 690-696.

Barnes, B. C., Cooper, L., Kirkendall, D. T., McDermott, T. P., Jordan, B. D., & Garrett, W. E., Jr. (1998). Concussion history in elite male and female soccer players. *Am J Sports Med, 26*(3), 433-438.

Barth, J. T., Freeman, J. R., Broshek, D. K., & Varney, R. N. (2001). Acceleration-Deceleration Sport-Related Concussion: The Gravity of It All. *J Athl Train, 36*(3), 253-256.

Bauer, J. A., Thomas, T. S., Cauraugh, J. H., Kaminski, T. W., & Hass, C. J. (2001). Impact forces and neck muscle activity in heading by collegiate female soccer players. *J Sports Sci, 19*(3), 171-179.

Bleiberg, J., Halpern, E. L., Reeves, D., & Daniel, J. C. (1998). Future directions for the neuropsychological assessment of sports concussion. *J Head Trauma Rehabil, 13*(2), 36-44.

Boden, B. P., Kirkendall, D. T., & Garrett, W. E., Jr. (1998). Concussion incidence in elite college soccer players. *Am J Sports Med, 26*(2), 238-241.

Broglio, S. P., Guskiewicz, K. M., Sell, T. C., & Lephart, S. M. (2004). No acute changes in postural control after soccer heading. *Br J Sports Med, 38*(5), 561-567.

Broglio, S. P., Ju, Y. Y., Broglio, M. D., & Sell, T. C. (2003). The Efficacy of Soccer Headgear. *J Athl Train, 38*(3), 220-224.

Broglio, S. P., Macciocchi, S. N., & Ferrara, M. S. (2007). Sensitivity of the concussion assessment battery. *Neurosurgery, 60*(6), 1050-1057; discussion 1057-1058.

Broglio, S. P., Sosnoff, J. J., Rosengren, K. S., & McShane, K. (2009). A comparison of balance performance: computerized dynamic posturography and a random motion platform. *Arch Phys Med Rehabil, 90*(1), 145-150.

Broglio, S. P., Tomporowski, P. D., & Ferrara, M. S. (2005). Balance performance with a cognitive task: a dual-task testing paradigm. *Med Sci Sports Exerc, 37*(4), 689-695.

Brown, C. N., Guskiewicz, K. M., & Bleiberg, J. (2007). Athlete characteristics and outcome scores for computerized neuropsychological assessment: a preliminary analysis. *J Athl Train, 42*(4), 515-523.

Cantu, R. C. (2003). Recurrent athletic head injury: risks and when to retire. *Clin Sports Med, 22*(3), 593-603, x.

Cernich, A., Reeves, D., Sun, W., & Bleiberg, J. (2007). Automated Neuropsychological Assessment Metrics sports medicine battery. *Arch Clin Neuropsychol, 22 Suppl 1*, S101-114.

Collie, A., Maruff, P., Darby, D. G., & McStephen, M. (2003). The effects of practice on the cognitive test performance of neurologically normal individuals assessed at brief test-retest intervals. *J Int Neuropsychol Soc, 9*(3), 419-428.

Collie, A., McCrory, P., & Makdissi, M. (2006). Does history of concussion affect current cognitive status? *Br J Sports Med, 40*(6), 550-551.

Collins, M. W., Lovell, M. R., Iverson, G. L., Cantu, R. C., Maroon, J. C., & Field, M. (2002). Cumulative effects of concussion in high school athletes. *Neurosurgery, 51*(5), 1175-1179; discussion 1180-1171.

Covassin, T., Swanik, C. B., Sachs, M., Kendrick, Z., Schatz, P., Zillmer, E., et al. (2006). Sex differences in baseline neuropsychological function and concussion symptoms of collegiate athletes. *Br J Sports Med, 40*(11), 923-927; discussion 927.

Covassin, T., Swanik, C. B., & Sachs, M. L. (2003). Sex Differences and the Incidence of Concussions Among Collegiate Athletes. *J Athl Train, 38*(3), 238-244.

Delaney, J. S., Al-Kashmiri, A., Drummond, R., & Correa, J. A. (2008). The effect of protective headgear on head injuries and concussions in adolescent football (soccer) players. *Br J Sports Med, 42*(2), 110-115; discussion 115.

Delaney, J. S., & Drummond, R. (1999). Has the time come for protective headgear for soccer? *Clin J Sport Med, 9*(3), 121-123.

Delaney, J. S., Lacroix, V. J., Leclerc, S., & Johnston, K. M. (2002). Concussions among university football and soccer players. *Clin J Sport Med, 12*(6), 331-338.

Duma, S. M., Manoogian, S. J., Bussone, W. R., Brolinson, P. G., Goforth, M. W., Donnenwerth, J. J., et al. (2005). Analysis of real-time head accelerations in collegiate football players. *Clin J Sport Med, 15*(1), 3-8.

Ellemberg, D., Leclerc, S., Couture, S., & Daigle, C. (2007). Prolonged neuropsychological impairments following a first concussion in female university soccer athletes. *Clin J Sport Med, 17*(5), 369-374.

Federation Internationale de Football Association. (2005). Federation Internationale de Football Association (FIFA) Survey.   Retrieved September 19, 2005

Field, M., Collins, M. W., Lovell, M. R., & Maroon, J. (2003). Does age play a role in recovery from sports-related concussion? A comparison of high school and collegiate athletes. *J Pediatr, 142*(5), 546-553.

FIFA. (2008/2009). Laws of the Game.   Retrieved January 21, 2009, from http://www.fifa.com/mm/document/affederation/federation/81/42/36/lotg_en.pdf

Fuller, C. W., Junge, A., & Dvorak, J. (2005). A six year prospective study of the incidence and causes of head and neck injuries in international football. *Br J Sports Med, 39 Suppl 1*, i3-9.

Funk, J. R., Cormier, J. M., Bain, C. E., Guzman, H., & Bonugli, E. (2008). Relationship between linear and rotational head acceleration in various activities. *Biomed Sci Instrum, 44*, 207-212.

Gardiner, M., Smith, M. L., Kagstrom, E., Shohami, E., & Siesjo, B. K. (1982). Influence of blood glucose concentration on brain lactate accumulation during severe hypoxia and subsequent recovery of brain energy metabolism. *J Cereb Blood Flow Metab, 2*(4), 429-438.

Giza, C. C., & Hovda, D. A. (2001). The Neurometabolic Cascade of Concussion. *J Athl Train, 36*(3), 228-235.

Green, G. A., & Jordan, S. E. (1998). Are brain injuries a significant problem in soccer? *Clin Sports Med, 17*(4), 795-809, viii.

Guskiewicz, K. M. (2001). Postural stability assessment following concussion: one piece of the puzzle. *Clin J Sport Med, 11*(3), 182-189.

Guskiewicz, K. M. (2003). Assessment of postural stability following sport-related concussion. *Curr Sports Med Rep, 2*(1), 24-30.

Guskiewicz, K. M., Bruce, S. L., Cantu, R. C., Ferrara, M. S., Kelly, J. P., McCrea, M., et al. (2004). National Athletic Trainers' Association Position Statement: Management of Sport-Related Concussion. *J Athl Train, 39*(3), 280-297.

Guskiewicz, K. M., Marshall, S. W., Bailes, J., McCrea, M., Cantu, R. C., Randolph, C., et al. (2005). Association between recurrent concussion and late-life cognitive impairment in retired professional football players. *Neurosurgery, 57*(4), 719-726; discussion 719-726.

Guskiewicz, K. M., Marshall, S. W., Bailes, J., McCrea, M., Harding, H. P., Jr., Matthews, A., et al. (2007). Recurrent concussion and risk of depression in retired professional football players. *Med Sci Sports Exerc, 39*(6), 903-909.

Guskiewicz, K. M., McCrea, M., Marshall, S. W., Cantu, R. C., Randolph, C., Barr, W., et al. (2003). Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. *Jama, 290*(19), 2549-2555.

Guskiewicz, K. M., Mihalik, J. P., Shankar, V., Marshall, S. W., Crowell, D. H., Oliaro, S. M., et al. (2007). Measurement of head impacts in collegiate football players: relationship between head impact biomechanics and acute clinical outcome after concussion. *Neurosurgery, 61*(6), 1244-1252; discussion 1252-1243.

Guskiewicz, K. M., Ross, S. E., & Marshall, S. W. (2001). Postural Stability and Neuropsychological Deficits After Concussion in Collegiate Athletes. *J Athl Train, 36*(3), 263-273.

Hislop, H. M., J. (1986). *Daniels and Worthingham's Muscle Testing: Techniques of Manual Examination*: Elsevier Science

Ingersoll, C. D., & Armstrong, C. W. (1992). The effects of closed-head injury on postural sway. *Med Sci Sports Exerc, 24*(7), 739-743.

Janke, L. M. (2006). *The Effect of Headgear on Symptoms and Neurocognitive Impairment after Purposeful Heading.* California State University, Fullerton.

Jordan, B. D. (1996). Acute and chronic brain injury in United States National Team Soccer Players. *Am J Sports Med, 24*(5), 704-705.

Kaminski, T. W., Cousino, E. S., & Glutting, J. J. (2008). Examining the relationship between purposeful heading in soccer and computerized neuropsychological test performance. *Res Q Exerc Sport, 79*(2), 235-244.

Kaminski, T. W., & Dede, D. E. (2002). A retrospective examination of purposeful heading in a group of female collegiate soccer players. *Medicine and Science in Sports and Exercise, 34*(S-2).

Kaminski, T. W., Groff, R. M., & Glutting, J. J. (2008). Examining the stability of Automated Neuropsychological Assessment Metric (ANAM) baseline test scores. *J Clin Exp Neuropsychol*, 1-9.

Kaminski, T. W., Wikstrom, A. M., Gutierrez, G. M., & Glutting, J. J. (2007). Purposeful heading during a season does not influence cognitive function or balance in female soccer players. *J Clin Exp Neuropsychol*, 1-10.

Kane, R. L., & Kay, G. G. (1992). Computerized assessment in neuropsychology: a review of tests and test batteries. *Neuropsychol Rev, 3*(1), 1-117.

Kendall, F. M., E; Provance, P; Rodgers, M; Romani, W. (2005). *Muscles Testing and Function with Posture and Pain* (5th ed.). Baltimore: Lippinocott Williams and Wilkins.

Kirkendall, D. T., & Garrett, W. E., Jr. (2001). Heading in Soccer: Integral Skill or Grounds for Cognitive Dysfunction? *J Athl Train, 36*(3), 328-333.

Kirkendall, D. T., Jordan, S. E., & Garrett, W. E. (2001). Heading and head injuries in soccer. *Sports Med, 31*(5), 369-386.

Majerske, C. W., Mihalik, J. P., Ren, D., Collins, M. W., Reddy, C. C., Lovell, M. R., et al. (2008). Concussion in sports: postconcussive activity levels, symptoms, and neurocognitive performance. *J Athl Train, 43*(3), 265-274.

Mangus, B. C., Wallmann, H. W., & Ledford, M. (2004). Analysis of postural stability in collegiate soccer players before and after an acute bout of heading multiple soccer balls. *Sports Biomech, 3*(2), 209-220.

Mansell, J., Tierney, R. T., Sitler, M. R., Swanik, K. A., & Stearne, D. (2005). Resistance training and head-neck segment dynamic stabilization in male and female collegiate soccer players. *J Athl Train, 40*(4), 310-319.

Maroon, J. C., Lovell, M. R., Norwig, J., Podell, K., Powell, J. W., & Hartl, R. (2000). Cerebral concussion in athletes: evaluation and neuropsychological testing. *Neurosurgery, 47*(3), 659-669; discussion 669-672.

Matser, J. T., Kessels, A. G., Jordan, B. D., Lezak, M. D., & Troost, J. (1998). Chronic traumatic brain injury in professional soccer players. *Neurology, 51*(3), 791-796.

McCaffrey, M. A., Mihalik, J. P., Crowell, D. H., Shields, E. W., & Guskiewicz, K. M. (2007). Measurement of head impacts in collegiate football players: clinical measures of concussion after high- and low-magnitude impacts. *Neurosurgery, 61*(6), 1236-1243; discussion 1243.

McCrea, M. (2001). Standardized Mental Status Testing on the Sideline After Sport-Related Concussion. *J Athl Train, 36*(3), 274-279.

McCrea, M., Kelly, J. P., Randolph, C., Kluge, J., Bartolic, E., Finn, G., et al. (1998). Standardized assessment of concussion (SAC): on-site mental status evaluation of the athlete. *J Head Trauma Rehabil, 13*(2), 27-35.

McCrory, P., Ariens, T., & Berkovic, S. (2000). The nature and duration of acute concussive symptoms in Australian football. *Clin J Sport Med, 10*(4), 235-238.

McCrory, P., Johnston, K., Meeuwisse, W., Aubry, M., Cantu, R., Dvorak, J., et al. (2005). Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. *Br J Sports Med, 39*(4), 196-204.

McCrory, P., Meeuwisse, W., Johnston, K., Dvorak, J., Aubry, M., Molloy, M., et al. (2009). Consensus statement on concussion in sport: the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. *J Athl Train, 44*(4), 434-448.

McIntosh, A. S., McCrory, P., Finch, C. F., Chalmers, D. J., & Best, J. P. (2003). Rugby headgear study. *J Sci Med Sport, 6*(3), 355-358.

Mehnert, M. J., Agesen, T., & Malanga, G. A. (2005). "Heading" and neck injuries in soccer: a review of biomechanics and potential long-term effects. *Pain Physician, 8*(4), 391-397.

Mihalik, J. P., Bell, D. R., Marshall, S. W., & Guskiewicz, K. M. (2007). Measurement of head impacts in collegiate football players: an investigation of positional and event-type differences. *Neurosurgery, 61*(6), 1229-1235; discussion 1235.

Miller, J. R., Adamson, G. J., Pink, M. M., & Sweet, J. C. (2007). Comparison of preseason, midseason, and postseason neurocognitive scores in uninjured collegiate football players. *Am J Sports Med, 35*(8), 1284-1288.

Naunheim, R. S., Ryden, A., Standeven, J., Genin, G., Lewis, L., Thompson, P., et al. (2003). Does soccer headgear attenuate the impact when heading a soccer ball? *Acad Emerg Med, 10*(1), 85-90.

Naunheim, R. S., Standeven, J., Richter, C., & Lewis, L. M. (2000). Comparison of impact data in hockey, football, and soccer. *J Trauma, 48*(5), 938-941.

Newman, J. A., Beusenberg, M. C., Shewchenko, N., Withnall, C., & Fournier, E. (2005). Verification of biomechanical methods employed in a comprehensive study of mild traumatic brain injury and the effectiveness of American football helmets. *J Biomech, 38*(7), 1469-1481.

Pellman, E. J., Viano, D. C., Tucker, A. M., & Casson, I. R. (2003). Concussion in professional football: location and direction of helmet impacts-Part 2. *Neurosurgery, 53*(6), 1328-1340; discussion 1340-1321.

Piland, S. G., Motl, R. W., Ferrara, M. S., & Peterson, C. L. (2003). Evidence for the Factorial and Construct Validity of a Self-Report Concussion Symptoms Scale. *J Athl Train, 38*(2), 104-112.

Powell, J. W., & Barber-Foss, K. D. (1999). Traumatic brain injury in high school athletes. *Jama, 282*(10), 958-963.

Putukian, M., Echemendia, R. J., & Mackin, S. (2000). The acute neuropsychological effects of heading in soccer: a pilot study. *Clin J Sport Med, 10*(2), 104-109.

Rabadi, M. H., & Jordan, B. D. (2001). The cumulative effect of repetitive concussion in sports. *Clin J Sport Med, 11*(3), 194-198.

Register-Mihalik, J., Guskiewicz, K. M., Mann, J. D., & Shields, E. W. (2007). The effects of headache on clinical measures of neurocognitive function. *Clin J Sport Med, 17*(4), 282-288.

Register-Mihalik, J., Mihalik, J., & Guskiewicz, K. (2008). Balance deficits after sports-related concussion in individuals reporting posttraumatic headache. *Neurosurgery, 63*(1), 76-80; discussion 80-72.

Riemann, B., Guskiewicz, K., & Shields, E. (1999). Relationship Between Clinical and Forceplate Measures of Postural Stability. *Journal of Sport Rehabilitation, 8*, 71-82.

Riemann, B. L., & Guskiewicz, K. M. (2000). Effects of Mild Head Injury on Postural Stability as Measured Through Clinical Balance Testing. *J Athl Train, 35*(1), 19-25.

Rowson, S., McNeely, D., & Duma, S. (2007). Lateral bending biomechanical analysis of neck protection devices used in football. *Biomed Sci Instrum, 43*, 200-205.

Rutherford, A., Stephens, R., & Potter, D. (2003). The neuropsychology of heading and head trauma in Association Football (soccer): a review. *Neuropsychol Rev, 13*(3), 153-179.

Schmitt, D. M., Hertel, J., Evans, T. A., Olmsted, L. C., & Putukian, M. (2004). Effect of an acute bout of soccer heading on postural control and self-reported concussion symptoms. *Int J Sports Med, 25*(5), 326-331.

Schneider, & Zerniche. (1988). Computer simulation of head impact: estimation of head injury risk during soccer heading. *Int J Sports Biomech, 4*, 258-271.

Scott Delaney, J., Puni, V., & Rouah, F. (2006). Mechanisms of injury for concussions in university football, ice hockey, and soccer: a pilot study. *Clin J Sport Med, 16*(2), 162-165.

Shehata, N., Wiley, J. P., Richea, S., Benson, B. W., Duits, L., & Meeuwisse, W. H. (2009). Sport concussion assessment tool: baseline values for varsity collision sport athletes. *Br J Sports Med, 43*(10), 730-734.

Sports, F. (2009). F90 Premier Headguard.   Retrieved March 20, 2009, from http://www.full90.com/products/protect/premier/

Stalnacke, B. M., Ohlsson, A., Tegner, Y., & Sojka, P. (2006). Serum concentrations of two biochemical markers of brain tissue damage S-100B and neurone specific enolase are increased in elite female soccer players after a competitive game. *Br J Sports Med, 40*(4), 313-316.

Stalnacke, B. M., Tegner, Y., & Sojka, P. (2004). Playing soccer increases serum concentrations of the biochemical markers of brain damage S-100B and neuron-specific enolase in elite players: a pilot study. *Brain Inj, 18*(9), 899-909.

Stephens, R., Rutherford, A., Potter, D., & Fernie, G. (2005). Neuropsychological impairment as a consequence of football (soccer) play and football heading: a preliminary analysis and report on school students (13-16 years). *Child Neuropsychol, 11*(6), 513-526.

Stratford, P. W., & Balsor, B. E. (1994). A comparison of make and break tests using a hand-held dynamometer and the Kin-Com. *J Orthop Sports Phys Ther, 19*(1), 28-32.

Takahashi, H., Manaka, S., & Sano, K. (1981). Changes in extracellular potassium concentration in cortex and brain stem during the acute phase of experimental closed head injury. *J Neurosurg, 55*(5), 708-717.

Tierney, R. T., Higgins, M., Caswell, S. V., Brady, J., McHardy, K., Driban, J. B., et al. (2008). Sex differences in head acceleration during heading while wearing soccer headgear. *J Athl Train, 43*(6), 578-584.

Tysvaer, A. (1992). Head and neck injuries in soccer. Impact of minor trauma. *Sports Med, 14*(3), 200-213.

Tysvaer, A., & Storli, O. (1981). Association football injuries to the brain. A preliminary report. *Br J Sports Med, 15*(3), 163-166.

Valovich McLeod, T. C., Barr, W. B., McCrea, M., & Guskiewicz, K. M. (2006). Psychometric and measurement properties of concussion assessment tools in youth sports. *J Athl Train, 41*(4), 399-408.

Valovich, T. C., Perrin, D. H., & Gansneder, B. M. (2003, Mar). Repeat Administration Elicits a Practice Effect With the Balance Error Scoring System but Not With the Standardized Assessment of Concussion in High School Athletes. *J Athl Train* Retrieved 1, 38, from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=12937472

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

Withnall, C., Shewchenko, N., Gittens, R., & Dvorak, J. (2005). Biomechanical investigation of head impacts in football. *Br J Sports Med, 39 Suppl 1*, i49-57.

Withnall, C., Shewchenko, N., Wonnacott, M., & Dvorak, J. (2005). Effectiveness of headgear in football. *Br J Sports Med, 39 Suppl 1*, i40-48; discussion i48.

Witol, A. D., & Webbe, F. M. (2003). Soccer heading frequency predicts neuropsychological deficits. *Arch Clin Neuropsychol, 18*(4), 397-417.

Wrisley, D. M., Stephens, M. J., Mosley, S., Wojnowski, A., Duffy, J., & Burkard, R. (2007). Learning effects of repetitive administrations of the sensory organization test in healthy young adults. *Arch Phys Med Rehabil, 88*(8), 1049-1054.

Yang, M. S., DeWitt, D. S., Becker, D. P., & Hayes, R. L. (1985). Regional brain metabolite levels following mild experimental head injury in the cat. *J Neurosurg, 63*(4), 617-621.

Zetterberg, H., Hietala, M. A., Jonsson, M., Andreasen, N., Styrud, E., Karlsson, I., et al. (2006). Neurochemical aftermath of amateur boxing. *Arch Neurol, 63*(9), 1277-1280.

Zetterberg, H., Jonsson, M., Rasulzada, A., Popa, C., Styrud, E., Hietala, M. A., et al. (2007). No neurochemical evidence for brain injury caused by heading in soccer. *Br J Sports Med, 41*(9), 574-577.