BALANCE AND NEUROPSYCHOLOGICAL PERFORMANCE FOLLOWING AN ACUTE BOUT OF SOCCER HEADING

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Context: Evidence illustrates a cumulative effect of multiple concussions or mild traumatic brain injuries. Research on the effect of an acute bout of soccer heading on brain function is not conclusive. **Objective:** To identify the effect of an acute bout of soccer heading on neuropsychological function and balance in athletes with a history of multiple concussions. **Participants:** Twenty-four NCAA Division I and III, and intramural athletes with a minimum of 4 years of competitive soccer experience composing 4 groups: subjects with a self-reported history of 1-2 concussions (EXP1), subjects with a self-reported history of 3 or more concussions (EXP2), and subjects with a self-reported history of 0 concussions randomly assigned to a control group (CON) and experimental group (EXP0). **Intervention(s):** During baseline testing, participants completed the ImPACT test, the Balance Error Score System (BESS), and the concussion symptom checklist (CSC). During session two, subjects repeated the baseline testing, and then completed 20 purposeful headers in 20 minutes. Immediately, participants repeated the ImPACT test, BESS test, and the CSC. **Main Outcome Measure(s):** Neuropsychological function as measured by the (ImPACT), balance deficiencies (BESS test), and self-reported symptom score (CSC). **Results:** On BESS test 1 (dual stance, firm surface) EXP2 had significantly (p=.046) greater errors post-heading than the other groups. For BESS test 2 (single leg stance, firm surface) EXP1 and EXP2 had

significantly (p=.008) elevated scores both pre- and post-heading. On BESS test 3 (tandem stance, firm surface), test 4 (dual stance, foam surface), test 5 (single-leg stance, foam surface), and test 6 (tandem stance, foam surface) EXP2 had significantly (p=.001) more errors both pre- and post-heading than the other groups. No significant results were found on ImPACT scores. All groups had significantly (p=.025) higher CSC post-heading scores. **Conclusions:** This study found no significance between pre- and post-heading in any groups on the BESS test, ImPACT test, and the CSC. The EXP2 group performed worse overall on the more challenging BESS tests, but their scores did not significantly worsen as was hypothesized. Further research with a larger sample size may yield better results.

BALANCE & NEUROPSYCHOLOGICAL PERFORMANCE FOLLOWING AN ACUTE BOUT OF SOCCER HEADING

SPECIFIC AIMS

No study to date has demonstrated a significant change in neuropsychological or postural sway function following an acute bout of soccer heading. [1-7] However, investigators have focused on healthy individuals without accounting for participants' history of physician-diagnosed concussion. Recent evidence has revealed that concussions can have a cumulative effect on the brain.[3, 8-11] Known as chronic traumatic brain injury (CTBI), the effect produces concussion symptoms at lower thresholds with each subsequent concussion.

An increase in the number of reported concussions, approximately 15% of all soccer injuries, indicates that there is a significant need to study the relationship between purposeful soccer heading and CTBI.[12] Understanding the extent to which soccer heading can affect the brain will help to determine if there is a need for improved safety measures, such as protective equipment, new heading techniques, or rule modifications.

The purpose of this study is to assess the effects of an acute bout of purposeful heading in soccer players with a history of concussion on measures of balance (BA) and neuropsychological (NP) test performance.

Specific Aim: The objective of this research is to assess the consequence of an acute bout of purposeful heading in soccer players on measures of BA and NP test performance. The focus of this study was to determine if the history of concussion(s) sustained by the subject affects BA and NP test functions in a subsequent session of purposeful heading in soccer.

Primary Hypothesis: There will be an increase in number of BA errors and a decrease in NP function in soccer players with a history of concussions following an acute bout of purposeful heading.

Secondary Hypothesis: Subjects with a history of 3 or more concussions will perform worse on BA and NP tests than those with 0-2 concussions.

BACKGROUND AND SIGNIFICANCE

The popularity of soccer among youth and adults in the United States has led to a rise in reported and diagnosed concussions resulting from practice and match play. Often associated with concussions, post-concussion syndrome is a condition in which an individual experiences a persistent headache (symptoms lasting more than 24 hours), feelings of depression, inability to resume professional and/or social activities, memory loss, vertigo, and other behavioral changes. [13] The National Athletic Trainers' Association (NATA) guidelines for return to play suggest that an individual must be symptom-free after exertion for at least one week.[14] These guidelines provide an opportunity for the brain to heal from the concussive event and are designed to prevent further injury and neuropsychological changes.

The accumulation of multiple concussive injuries can lead to long-term changes in neuropsychological function.[11] These changes can be caused by numerous head injuries over a period of time or by second impact syndrome, which occurs when an individual incurs a second blow to the head before a previous concussion is resolved. The residual effects of a concussion appear to increase with each subsequent injury. Symptoms can occur with multiple episodes of microtrauma as well as a single forceful impact to the head with an object.[11]

Microtrauma may result from purposeful heading, a unique part of soccer, during practice and match play. Microtrauma is the accumulation of multiple impacts to the head that accumulate to cause an injury.[15] Each individual impact may not be significant

enough to cause injury alone, but with an accumulation of many impacts, brain damage manifests over time.[15]

Pathophysiological evidence indicates a primary and secondary brain injury process. Primary brain injuries are those caused by biomechanical forces that act upon tissues of different densities resulting in an unequal movement of tissues and subsequent injury. This tissue damage may include axonal shearing and microtearing of white or gray matter causing a potassium-induced degeneration of neural membranes, depolarization of adjacent neurons, and the release of excitatory amino acids leading to neuroexcitotoxicity.[16-20] This sets off a biochemical cascade including increased ATP use and hyperglycolysis lasting up to 30 minutes in rats.[17,20] Hyperglycolysis may lead to an increased lactate levels and neuronal dysfunction.[17,19,20] Concurrently, there is an influx of calcium activating proteases that cause neuron damage and cell death.[17,20] Finally, the combination of all these reactions ends in membrane peroxidation, DNA fragmentation, and apoptosis or neural cell death.[16]

Secondary brain injury is characterized by an inflammation process which is initiated by the cell death in primary brain injury. Cell death causes an increase in the blood brain barrier permeability, resulting in microglia, macrophages specific to the brain and spinal cord, mobilizing to the injured area.[16,18,19,21] This causes adhesions to form and phagocytosis, or removal of damaged cells.[16,20,21] After 2-3 weeks a fibrillary phase begins and the dead neurons are enwrapped forming neurofibrillary tangles.[16] These tangles cause a loss of function whose nature is determined by the location and types of structures that are involved and can be considered focal or diffuse.[16,19] This insult in neural function has been shown to result in an increased susceptibility of further

injury to the involved neurons, which may explain why a cumulative effect of concussion is present, especially in individuals with three or more concussions.[17] These events help explain the pathophysiology underlying such varied symptoms expressed by individuals that have sustained concussions.

Heading is a unique aspect of soccer and has led to multiple studies testing the effects of heading on neuropsychological function in soccer players. [1,2,5-7,10,15,22,23] Short-term studies have focused on the change in postural sway of subjects after an acute bout of heading (usually consisting of 18-20 headers).[1, 5-7] Postural sway has been routinely tested using force plate technology. The majority of studies conclude there are no immediate negative effects.

Long-term, retrospective studies have tested neuropsychological function in those who have participated in soccer for an extended period of time including professional and collegiate athletes.[2, 3, 15, 24] Many of these subjects reported numerous headers performed during practices and matches as well as concussions suffered during their years of play. These studies found alterations in memory and reactive functioning with various NP tests. Despite these studies on heading and its effect on neuropsychological function and postural sway in soccer players, especially in the acute setting, few investigations have focused on soccer players with a history of concussions.

Definitions and Terminology

The American Academy of Neurology defines a *concussion* as "a trauma-induced alteration in mental status that may or may not involve loss of consciousness."[25] Symptoms commonly observed with concussion are tinnitus, dizziness, nausea, headache, an increase in BA, and a decrease in NP function among others.

Neuropsychological performance can be assessed using a computerized concussion management system (*ImPACT*) that tests subjects on multiple components (memory, reaction time to stimuli, motor control, and attention) of NP function.[26] To assess balance, the ability to maintain the body's center of mass (COM) close to the center of pressure (COP), the *Balance Error Scoring System* (BESS) examines a number of errors over time to determine an overall testing score (Table 1).[27] These errors (detailed on page 10) occur when the COM cannot be controlled in quiet standing resulting in movement of the trunk and extremities.

Review of Literature

Soccer is the most popular team sport in the world. The number of women's FIFA World Cup teams participating in preliminary competitions more than doubled between 1991 (45 teams) and 2003 (99 teams).[28] On the men's side, 194 teams competed in the preliminary competitions of the World Cup with almost 19 million fans in total game attendance during the preliminary rounds of the World Cup tournament. [29] The enthusiasm for soccer is also growing in the United States and participation among males and females in intercollegiate and interscholastic sports has increased significantly since 1981. [30] The National Collegiate Athletic Association (NCAA) reports that schools participating in women's soccer have increased from 80 in 1981 to 895 in 2003 and from 521 in 1981 to 729 in 2003 in men's soccer.[31] More women are participating in soccer than any other NCAA sponsored sport. Men's soccer has the fourth highest participation rate in men's NCAA sponsored sports. [31]

Incidence of Concussion in Soccer

Concussions have been shown to result in 4.5% of the injuries in soccer, compared to 5% in the collision sport of American football. [32] The similarity in injury rate indicates that soccer may be more of a contact/collision sport than is traditionally considered. Recent data from the NCAA reveal a continuing trend in concussions, especially in the sport of women's soccer. From 1997-2000, concussions accounted for 11.4% of all game injuries in women's soccer, as compared to just 7% in men's soccer. This increase in the number of concussions was higher than the 22-year (1982-2004) average for the sport. [31]

Negative Effects of Concussion

Sport-related concussion is a form of mild brain trauma and is associated with acute and long-term cognitive and vestibular deficits. [22,33,34] Careful consideration must be taken to avoid returning an athlete prematurely to participation following a single concussion. A second concussion sustained by an individual before resolution of the first can result in impaired playing performance, social degradation, further injury, and/or possible death.[35] Two reports released in the late 1990's suggest that purposeful heading in soccer can be comparable to repeated blows delivered to the head in boxing.[10, 36]

Acute Effects in Soccer Heading

Matser *et al.* called for the reform of heading rules in 1999, which led communities in the United States and around the world to believe that soccer heading was harmful and it should be banned. [23] However, reviewers have stated that a rule

change of this magnitude would alter the nature of the game and seemed premature before further investigation into the effects of soccer heading could be conducted. [1, 37-41]

Since that time, there have been several studies that examined the short-term effects of soccer heading using a variety of measures including NP performance, postural sway, neuroimaging, and concussion-related symptoms. [1, 5-7, 13] All of these studies have failed to find evidence of cognitive impairment. Schmitt *et al.* concluded that following an acute bout of heading (18 soccer balls during a 40-minute period), no significant impairment occurred with respect to postural sway as measured via forceplate posturography. [7] Their subjects reported a transient increase in symptoms such as headache, vertigo, and feeling fatigued. [7] Adding further support, Broglio *et al.* reported no acute changes in postural control resulting from either linear or rotational heading (20 soccer balls during a 20-minute period) in a sample of forty collegiate soccer players. [1]

Mangus *et al.* stated that an acute session of heading (20 soccer balls consecutively with 10-15 seconds rest between) did not have a negative effect on measures of balance in a sample of 10 collegiate soccer players. [5] A study by Patukian *et al.* examined the acute effects of heading (20 minutes of heading practice in 2 days) on measures of neuropsychological performance. They concluded no significant differences in test performance were apparent in an acute period of time. [6]

Gender Effects

Gender differences have been noted in neuropsychological function of normal (uninjured) subjects. Many studies have concluded that females perform better on verbal tasks while men perform better on visuospatial tasks. [42-44] Reaction time and

motor speed have also been reported as being faster in females than males [43,45,46] Specific to the ImPACT test, females outperformed males on the verbal memory measure while males performed better on visual memory scores. [47] Gender differences have also been noted in the number of concussions sustained. In a study by Covassin *et al.*, female athletes had a higher incidence of concussions during games across all sports than male athletes.[47] Women's soccer had the most concussions sustained for female sports and the incidence density ratio (injury rate per 1000 athlete-exposures) was greatest for male and female soccer players. [32]

Past studies involving soccer heading have indicated multiple concussions result in long-term declines in aspects of postural sway and NP function while short-term studies indicate no changes following an immediate heading session.[1-3,5-7,13,15,24] The proposed study will enhance our knowledge of the effect of an acute bout of soccer heading on BA and NP function in subjects with a history of multiple concussions.

Cumulative Effect of Concussion

Multiple studies have indicated a cumulative effect of concussion on neurocognitive function where a cumulative effect means a linear increase in symptoms, NP deficits, and balance errors with successive concussive blows to the head.[8-11] However, Iverson *et al.* report there is no cumulative effect on the ImPACT concussion test with only 1 or 2 previous concussions.[48] In a 2002 study, Collins *et al.* found that high school athletes with a history of 3 or more concussions had a significantly higher number of on-field reports of loss of consciousness, anterograde amnesia, and an increase in confusion than athletes with a history of 2 or fewer concussions.[49]

EXPERIMENTAL PROCEDURES

Subjects

A total of 24 soccer players (male and female, 18 – 25 years of age) were recruited from out-of-season, university-sponsored and organized soccer teams. All subjects had at least 4 years of competitive soccer experience to ensure proficiency in heading. They were divided into four groups of 6 subjects each. The groups included a control group of individuals with no history of concussion (CON), a test group of individuals with no history of concussion (EXP0), a test group with a history of 1 or 2 physician-diagnosed concussions (EXP1), and a test group of individuals with 3 or more physician-diagnosed concussions (EXP2). Subjects with no history of concussion were randomly assigned using a Latin square to the CON and EXP0 groups.

All participants were healthy and free from injury at the time of the study. Subjects reporting previous concussion history were free from any concussion-related symptoms for at least 2 months (most recent concussion reported was 1 year prior to testing) and must have been cleared by a physician to participate in soccer. Prior to testing, all subjects completed the approved informed consent agreement (University of Delaware HSRB # HS 06-203) and a Concussion History and Demographic (CHD) form. Subjects were asked to perform a header with a soft, foam ball tossed from a short distance (approximately 10 feet) to ensure proper heading technique.

Experimental Setup

Subjects were asked to report individually to the testing site in comfortable attire conducive to athletic performance. This included athletic shorts, t-shirt, and athletic shoes for indoor activities (no cleats). The facility was clear of all activities and distractions to create a homogeneous environment.

Procedures

The study required two testing sessions. The first session involved baseline testing and the second testing session included another battery of baseline testing, the heading protocol, and BA and NP testing. The two sessions were separated by at least 48 hours to eliminate learning effects.

Testing Session I

Testing procedures, as well as any possible side-effects of heading in the experiment, were reviewed and subjects were asked to complete the CSC. The following two measures were randomized using a Latin square (see Appendix D) to minimize learning effects.

Balance Testing

The BESS was used to determine balance (BA) function due to its portability and ease of access to reduce time between heading and secondary testing. The participant was asked to stand quietly, without shoes, in six different tests as described in Figure 1. The order of tests was randomly assigned using a Latin square (see Appendix D). Tests 1-3 were performed on a firm surface and tests 4-6 were performed on a foam balance mat. The hands were placed on the iliac crests and the subject kept his/her eyes closed

for the full 20 seconds for each trial. Each subject was asked to maintain the starting position for 20 seconds and error scores (Table 1) were compiled for each trial.

Figure 1. BESS Tests

1) Feet shoulder-width apart, hands on iliac crests, eyes closed, firm/stable surface
2) Standing on non-dominant foot with dominant foot clear of floor and non-dominant leg, hands-on iliac crests, eyes closed, firm/stable surface
3) Dominant heel in front of non-dominant toe, hands on iliac crests, eyes closed, firm/stable surface
4) Feet shoulder-width apart, hands on iliac crests, eyes closed, soft/unstable surface
5) Standing on non-dominant foot with dominant foot clear of floor and non-dominant leg, hands on iliac crests, eyes closed, soft/unstable surface
6) Dominant heel in front of non-dominant toe, hands on iliac crests, eyes closed, soft/unstable surface

Table 1 BESS Errors

Variable Name	ERRORS
Hands	Lifting hands off the iliac crests
Eyes	Opening eyes
Step	Taking a step to regain balance
30^o	Hips exceed ~30^o of flexion or abduction
Lift	Lifting heel or forefoot
5 Sec	Staying out of testing position longer than 5 seconds

This test was recorded with a digital video camera and all trials were visually inspected by the principle investigator (MBG) as well as an independent Certified Athletic Trainer (MAC) to ensure consistent scores.

Neuropsychological Testing

Neuropsychological performance was evaluated using ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing) Concussion Management (ImPACT Applications, Inc., Pittsburgh, PA) software. Participants were given a 20-minute computerized battery of tests that have been proven as sensitive in identifying neurocognitive abilities (*e.g.,* reaction time, memory, pattern recognition, etc.).[34] The test was administered to the subject in a quiet setting and test number (word group) was randomly assigned using a Latin square (see Appendix D).

The ImPACT test measures 5 variables that reflect neural functions typically impaired by brain injury. Verbal memory is the learning and retention of words and letters while visual memory incorporates memory of designs or shapes as well as memory of locations of shapes on a screen.[26] Visual motor speed is a measure of how well an individual processes through distracters and how efficiently they respond to counting problems and symbol matching.[26] Reaction time measures the speed at which a correct response is given to symbol and color matching problems.[26] Finally, impulse control is a count of incorrect distracters on a symbol matching problem and number of errors in a color matching problem.[26]

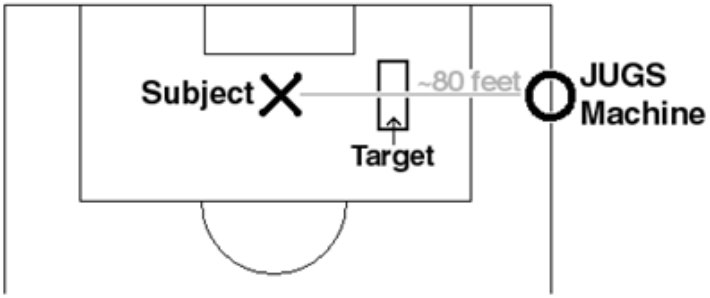
Testing Session II

Subjects repeated all baseline testing, at least 24 hours after testing session 1, with randomization of NP and BA testing and the scores from both days were averaged for a composite baseline score for each measure. After NP and BA testing, the Concussion Symptom Checklist was completed.

Heading Protocol

For the three test groups (EXP0, EXP1, EXP2), subjects were positioned 80 feet (approximately half the width of a standard soccer pitch) from a JUGS soccer machine (JUGS International, Tualatin, OR) that distributed 20 balls to the subjects over a period of 20 minutes. Participants were instructed to jump, as needed, and strike the ball as it approaches and direct it straight back towards the JUGS machine (Figure 2). A target

Figure 2 Example of Distance Used in Relation to Typical Soccer Field



was placed on the ground to reduce interference with the subjects' ability to watch the full flight of the ball. Each subject was instructed to use basic heading technique and told to aim towards the target. The JUGS machine was tested for accuracy and speed at ground contact. The average ball speed was 58.6 $\pm$ 2.7 km/h and the average distance was 11.1 $\pm$ 0.5 m (one outlier removed).

Only balls that have been purposefully redirected towards the target were counted and any other contact with the head was not considered as a header. If the ball was not properly headed, another ball was immediately sent to the subject for another attempt. The CON group performed a simulation of heading form including the jump and striking motion without making contact with the ball 20 times over a 20-minute period.

Post-heading Testing

Following completion of the heading protocol, subjects performed the NP and BA testing in a random (Latin square, See Appendix D) order and complete the Concussion Symptom Checklist.

Data Analysis

Dependent Variables

There were 12 primary dependent variables. These include each of the 6 BESS scores, the 5 ImPACT scores (Visual Memory, Verbal Memory, Visual Motor Speed, Reaction Time, and Impulse Control), and the total symptom score from the CSC.

Statistical Analysis of Data

There were four groups in the study and each group was evaluated on 2 occasions. Consequently, data were analyzed using one-way repeated measures ANOVAs for each of the 12 dependent variables. For each analysis, there were 6 subjects per group. Repeated measures ANOVAs resulted in 3 F-tests: (1) time, (2) group, and (3) group by time interaction.

RESULTS

Subject Demographics

Twenty four male (n=12) and female (n=12) subjects completed testing. The following table shows the subject breakdown by group:

Table 2 Subject Demographics

	SEX	AGE	HEIGHT (cm)	MASS (kg)	YEARS OF SOCCER PLAYED	POSITION	NUMBER OF CONCUSSIONS
CON	**F=4, M=2**	**20.5**	**170.6**	**67.7**	**10.2**		**0.0**
1	F	21	154.9	61.4	10	Defender	0
2	F	22	167.6	59.1	10	Forward	0
3	F	20	162.6	58.2	15	Midfielder	0
4	F	20	165.1	56.8	17	Midfielder	0
5	M	21	195.6	97.7	4	Defender	0
6	M	19	177.8	72.7	5	Midfielder	0
EXP0	**F=4, M=2**	**20.3**	**171.5**	**67.9**	**13.7**		**0.0**
1	F	20	170.2	72.7	12	Forward	0
2	M	23	182.9	80.9	19	Defender	0
3	F	22	170.2	68.2	18	Defender	0
4	M	19	182.9	69.6	12	Forward	0
5	F	20	162.6	61.4	10	Midfielder	0
6	F	18	160.0	54.6	11	Forward	0
EXP1	**F=2, M=4**	**20.0**	**174.0**	**68.6**	**13.5**		**1.3**
1	M	18	182.9	68.2	10	Midfielder	1
2	M	21	177.8	72.7	16	Midfielder	2
3	F	21	157.5	55.9	12	Midfielder	1
4	M	21	185.4	75.0	15	Defender	1
5	M	19	175.3	75.0	11	Midfielder	1
6	F	20	165.1	65.0	17	Defender	2
EXP2	**F=2, M=4**	**21.2**	**174.4**	**69.7**	**11.0**		**3.2**
1	F	22	160.0	72.7	14	Defender	3
2	F	23	165.1	59.1	9	Defender	3
3	M	21	185.4	68.2	10	Midfielder	3
4	M	20	180.3	65.9	10	Defender	3
5	M	20	182.9	65.9	13	Defender	3
6	M	21	172.7	86.4	10	Defender	4

BESS Scores

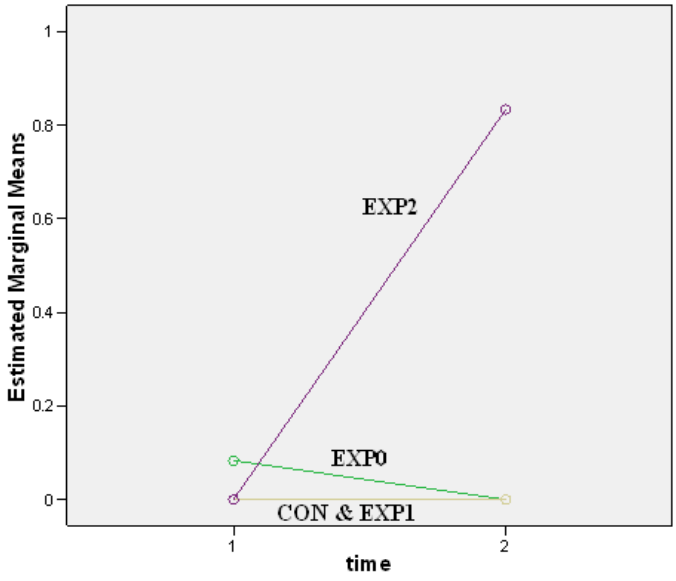
Test 1 (dual stance on firm surface)

The CON group had 0 errors, EXP0 ranged from 0-1 errors, EXP1 had 0 errors, and EXP2 ranged from 0-3 errors. The EXP2 group had significantly (p=.046) greater deficits in post-heading testing than the other three groups.

Table 3 F-Test Results for BESS Test 1

Group Effect (regardless of test session)	Time (pre-/post-heading) Effect (regardless of group)	Group x Time (pre-/post-heading) Interaction
p=.137	p=.067	p=.046*

Figure 3 Estimated Marginal Means for BESS Test 1



Test 2 (single leg stance on firm surface)

The CON group had a range of 0-15 errors, EXP0 ranged from 0-22 errors, EXP1 had 0-20 errors, and EXP2 ranged from 0-37 errors. A main group effect (p=.008) was found with the EXP1 and EXP2 group having elevated scores both pre- and post-heading.

Table 4 F-Test Results for BESS Test 2

Group Effect (regardless of test session)	Time (pre-/post-heading) Effect (regardless of group)	Group x Time (pre-/post-heading) Interaction
p=.008*	*p*=.105	*p*=.315

Table 5 Descriptive Statistics for BESS Test 2

	Group	Mean	Std. Deviation	N
BESS 2.1 (baseline)	CON	5.08	2.957	6
	EXP0	7.58	4.477	6
	EXP1	8.92	2.990	6
	EXP2	19.75	7.783	6
	Total	10.33	7.361	24
BESS 2.2 (post-heading)	CON	8.67	6.218	6
	EXP0	8.67	5.538	6
	EXP1	10.83	6.432	6
	EXP2	18.83	10.815	6
	Total	11.75	8.232	24

Test 3 (tandem stance on firm surface)

The CON group had a range of 0-8 errors, EXP0 and EXP1 ranged from 0-15 errors, and EXP2 ranged from 0-31 errors. A main group effect (*p*=.001) was found with EXP2 having higher scores on pre- and post-heading testing than the other three groups.

Table 6 F-Test Results for BESS Test 3

Group Effect (regardless of test session)	Time (pre-/post-heading) Effect (regardless of group)	Group x Time (pre-/post-heading) Interaction
p=.001*	*p*=.149	*p*=.185

Table 7 Descriptive Statistics for BESS Test 3

	Group	Mean	Std. Deviation	N
BESS 3.1 (baseline)	CON	2.08	1.715	6
	EXP0	4.50	2.915	6
	EXP1	4.67	4.320	6
	EXP2	10.75	4.896	6
	Total	5.50	4.737	24
BESS 3.2 (post-heading)	CON	3.33	2.944	6
	EXP0	6.50	3.886	6
	EXP1	2.83	2.041	6
	EXP2	15.00	9.381	6
	Total	6.92	7.071	24

Test 4 (dual stance on foam surface)

The CON group had a range of 0-2 errors, EXP0 ranged from 0-5 errors, EXP1 had 0-2 errors, and EXP2 ranged from 0-12 errors. EXP2 had elevated error scores in pre-and post-heading tests with a main group effect of p=.001.

Table 8 F-Test Results for BESS Test 4

Group Effect (regardless of test session)	Time (pre-/post-heading) Effect (regardless of group)	Group x Time (pre-/post-heading) Interaction
p=.001*	p=.757	p=.697

Table 9 Descriptive Statistics for BESS Test 4

	Group	Mean	Std. Deviation	N
BESS 4.1 (baseline)	CON	0.25	0.418	6
	EXP0	1.25	1.891	6
	EXP1	0.00	0.000	6
	EXP2	5.42	1.656	6
	Total	1.73	2.524	24
BESS 4.2 (post-heading)	CON	0.33	0.516	6
	EXP0	1.17	1.835	6
	EXP1	0.33	0.816	6
	EXP2	4.67	3.141	6
	Total	1.63	2.533	24

Test 5 (single-leg stance on foam surface)

The CON group had a range of 0-29 errors, EXP0 ranged from 0-30 errors, EXP1 had 0-28 errors, and EXP2 ranged from 0-49 errors. The EXP2 group had significantly (p=.001) more errors with single-leg balancing on the foam mat than the other three groups.

Table 10 F-Test Results for BESS Test 5

Group Effect (regardless of test session)	Time (pre-/post-heading) Effect (regardless of group)	Group x Time (pre-/post-heading) Interaction
p=.001*	p=.946	p=.230

Table 11 Descriptive Statistics for BESS Test 5

	Group	Mean	Std. Deviation	N
BESS 5.1 (baseline)	CON	18.67	7.181	6
	EXP0	19.58	4.488	6
	EXP1	20.83	3.488	6
	EXP2	33.00	5.235	6
	Total	23.02	7.710	24
BESS 5.2 (post-heading)	CON	16.17	5.947	6
	EXP0	20.67	4.502	6
	EXP1	19.83	4.070	6
	EXP2	35.67	5.538	6
	Total	23.08	8.968	24

Test 6 (tandem stance on foam surface)

The CON group had a range of 0-29 errors, EXP0 ranged from 0-40 errors, EXP1 had 0-26 errors, and EXP2 ranged from 0-48 errors. A main group effect (p=.001) was found with EXP2 having elevated scores on pre- and post-heading testing.

Table 12 F-Test Results for BESS Test 6

Group Interaction (regardless of test session)	Time (pre-/post-heading) Interaction (regardless of group)	Group x Time (pre-/post-heading) Interaction
p=.001*	p=.768	p=.535

Table 13 Descriptive Statistics for BESS Test 6

	Group	Mean	Std. Deviation	N
BESS 6.1 (baseline)	CON	12.17	7.250	6
	EXP0	17.83	7.033	6
	EXP1	13.83	5.145	6
	EXP2	33.00	3.391	6
	Total	19.21	10.051	24
BESS 6.2 (post-heading)	CON	13.33	6.314	6
	EXP0	16.67	4.179	6
	EXP1	12.50	4.889	6
	EXP2	35.67	7.528	6
	Total	19.54	11.088	24

ImPACT Composite Scores

No significance was found on the ImPACT test between time or group. The F-test results are listed below with group, time, and group x time interactions.

Table 14 F-Group Ranges for ImPACT Composite Scores

	Verbal Memory	Visual Memory	Visual Motor Speed	Reaction Time	Impulse Control
CON	74-100	54-98	32.2-52.1	0.73-0.50	1-15
EXP0	74-99	59-87	32.0-46.6	0.72-0.44	1-26
EXP1	71-95	61-100	31.4-53.3	0.78-0.51	0-41
EXP2	63-94	39-90	28.3-53.1	0.70-0.46	0-17

Table 15 F-Test Results for ImPACT Composite Scores

Group Effect (regardless of test session)				
Verbal Memory	Visual Memory	Visual Motor Speed	Reaction Time	Impulse Control
p =.453	p =.157	p =.726	p =.906	p =.566
Time (pre-/post-heading) Effect (regardless of group)				
Verbal Memory	Visual Memory	Visual Motor Speed	Reaction Time	Impulse Control
p=.672	p =.831	p =.166	p =.429	p =.803
Group x Time (pre-/post-heading) Interaction				
Verbal Memory	Visual Memory	Visual Motor Speed	Reaction Time	Impulse Control
p =.345	p =.961	p =.162	p =.138	p =.894

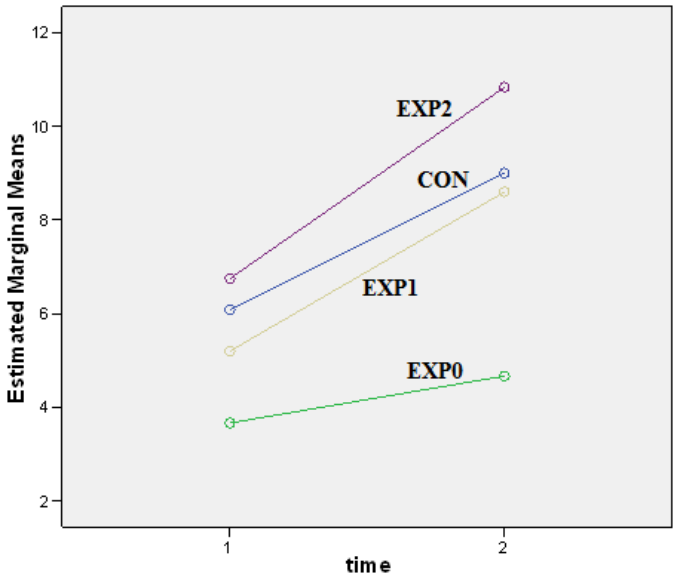
Symptom Scores from the Concussion Symptoms Checklist

The CON group had a range of 0-25 baseline symptoms and 0-19 symptoms post-heading symptoms. EXP0 ranged from 1-9 baseline symptoms and 1-12 post-heading symptoms. EXP1 had 0-14 baseline symptoms and 1-14 post-heading symptoms. EXP2 ranged from 0-20 baseline symptoms and 0-39 post-heading symptoms. A significant increase from pre-heading to post-heading sessions was found in all groups (p=.025).

Table 16 F-Test Results for Concussion Symptom Checklist

Group Effect (regardless of test session)	Tim (pre-/post-heading) Effect (regardless of group)	Group x Time (pre-/post-heading) Interaction
p =.728	*p* =.025*	*p* =.803

Figure 4 Estimated Marginal Means of CSC Scores



DISCUSSION

Main Outcomes

This study examined the effects of an acute bout of soccer heading on balance and neuropsychological function in soccer athletes. The idea that soccer players with multiple concussions may react differently to purposeful headers than individuals with no concussion history is reasonable because findings from past research suggest neurocognitive and balance changes in subjects with more than three concussions.[8-11] Recruiting athletes with more than 3 concussions who are still playing at the college level is difficult since many institutions are re-evaluating head injuries with respect to athletes participating in sports. Also, many athletes that match the criteria of the EXP2 group were unwilling to participate in this study because of their wariness to perform headers.

Balance Testing

The Balance Error Score System, as described by Riemann *et al.*, was utilized in this study to reduce the amount of time subjects had for recovery following heading as well as allowing for portability. [27] Subjects with 3 or more concussions had higher (non-significant) overall number of errors both pre- and post-heading, which supports, but does not confirm, our hypothesis that subjects with 3 or more concussions would perform worse on our tests after heading.

Participants in this study reported their most recent concussions no sooner than 2 years prior to the study. This finding indicates balance may still be affected even after other symptoms have returned to normal and the athlete has returned to competition. However, number of concussions was self-reported and may not have been treated by a physician or other medical staff. Also, concussions may have gone unreported if trauma and symptoms were minor. Therefore subjects could have had more or less concussions than reported on the Concussion History Form.

Contrary to the hypothesis, significant increases in errors were not seen between baseline and post-heading BESS scores in subjects with history of concussion. The BESS test has been shown to produce varied results based on the setting in which it is administered. [50] However, it remains a tool for athletic trainers to monitor concussion symptoms. Studies have reported a learning effect with repeated testing[51,52] however, we found no such learning effect in repeat tests on the same day.

The validity of balance tests is questionable because results are influenced by many factors. These include proprioceptive deficits from past lower extremity injury or inner ear disturbances as well as unexpected distractions in the testing environment. Also, human error in administering and interpreting the balance test could skew results. Therefore, other tests such as postural sway analysis on a force plate may be utilized to determine if results have occurred from actual injury to the brain or from other factors.

Neuropsychological Testing

The ImPACT program has been proven to reliably detect changes in neuropsychological function following a concussion.[26] However, no study to date resulted in changes in NP performance using ImPACT following an acute bout of

heading. Threshold levels of type and severity of impact, as determined by ball speed and distance to head contact, for the program to detect changes have not been established. In this study, balance and symptoms were slightly affected, but NP changes were not seen. This could indicate that subjects did not receive blows significant enough to cause changes in NP function, but performing headers was great enough to challenge the balance of some subjects. However, with uncontrollable factors typical to a soccer game including type of header, opponent interference, and ball speed and direction among others removed from this testing environment a true measure of NP changes following a soccer game could not be determined.

In this study, post-heading testing commenced immediately following heading with the idea that direct changes would be seen as opposed to 24 or 48 hours after testing. However, significant changes in NP function were not seen immediately. Lovell et al found in grade 1 concussions, after an average of 36 hours post-injury, a decline in memory and reaction time.[53] Scores returned to baseline levels, or increased, following 5-10 days. [53] This delay may indicate a slower onset of symptoms than what has been traditionally thought in concussions. A postponement in testing, or the inclusion of a 36 hour follow-up test session, may indicate changes in NP function following a bout of heading that was not present in the current and past studies.

Concussion Symptom Checklist

The CSC is an effective tool in quantifying symptoms that are commonly seen in individuals with a concussion. In this study, the checklist was used to evaluate any changes in condition following heading. In most cases, headache increased immediately following heading. In some cases, dizziness also increased.

Interestingly, the symptom scores for the CON group increased between the baseline testing and the "post-heading" testing although as a control group, they did not perform any headers. The CON group sat quietly for 20 minutes without intense mental stimulation (reading, studying, and cell phones were not allowed). One possible cause for this phenomenon could be a *history effect*, meaning events that took place between testing sessions could have an effect on a subject's response to the interventions.[54] This could include hearing about concussions on the news, learning about the brain in anatomy class, or even having a family member or friend get a concussion. These outside influences could change the way a subject feels about the study and affect their responses to the CSC. Since the baseline was done twice in two different testing sessions, a low score on the first test and a high score on the second test would average lower than the final score thereby creating a significant change between testing sessions.

Another possible reason for the CON group having a significant change is the *maturation effect*.[54] This effect is seen when a subject has grown older and is typically noted in long-term studies.[54] However, a change in stress level between testing times can be considered a maturation effect. This could influence responses on the CSC since stress is characterized by an increase in headache, fatigue, trouble sleeping, irritability, poor concentration, and even nausea.

A final possibility is a *testing effect*, where subjects will answer questions differently when taking a test or questionnaire for a second or third time than they did when they initially completed it.[54] For example, a person may see an increase in IQ score when taking an intelligence test more than once. Also involved in the testing effect is the *reactivity* of the testing instrument. Any form or questionnaire with

voluntary self-descriptions by a subject, or any test that makes a subject self conscious or aware of the purpose of the study is considered a reactive measure.[54] This type of measure may have extreme variations between testing sessions because a subject becomes more aware of the testing instrument's function.[54] If a subject becomes aware of the intention of a reactive measure, they are more likely to self-report closer to the overall desired extreme even though as a control group, they may not be expected to have these variations.

A positive interaction between testing times was found where the total symptom score increased following heading. However, results can be skewed by many factors including hydration levels, stress from school or social relationships, time of day, sleeping habits, and other variables.[54,55] Due to the subjective nature of the CSC, these results may not be reliable in determining actual changes due specifically to heading as many of these symptoms change rapidly and repeatedly throughout a typical day.

Pathophysiology of Concussion

Henninger et al. found in rat models that an immediate response to head injury was a significant decrease in PO2 levels at 5 minutes compared to control rats, without a significant change in PCO2 levels.[56] This change can cause a decrease in oxygen and an increase in carbon dioxide to brain tissue resulting in cell death. A 15 second increase in mean arterial blood pressure (MABP) and a transient decrease in heart rate (HR) until 5 minutes post-injury were recorded.[56] A decrease in HR could lead to cell death and tissue damage resulting in altered symptoms and balance in the injured subject without significant changes in neurocognitive function.[56]

Grindel et al. indicate that initial calcium influx into neural tissues and cell death cause a long-term change in brain tissue that may affect brain function.[20] In this study, post-heading testing was performed immediately following the heading session. However, the acute change in calcium levels are at their peak 48 hours post-injury meaning cell death is still occurring up to 48 hours after the initial insult.[17,20] The calcium levels typically return to normal at 2 days post-injury and the calcium levels within the cells returns to normal approximately 4 days after brain injury.[17,20] Metabolism or oxidative phosphorylation of cells brought on by the calcium boost, causes damage or cell death and eventually resolves after approximately 10 days.[17,19,20] Also, glycolysis as a reaction of an increase in ATP use does not decline until 24 hours post-injury. This reaction is the catalyst for lactate levels to increase and cell death to occur.[17,20]

Understanding the inflammation process in the brain shows that an immediate significant change in NP and BA may not be seen due to the slow progression of inflammation. This swelling may not cause cell death and loss of function for up to 24 to 48 hours, especially with forces that are not severe enough to cause an actual concussion. With microtrauma, this inflammation process may take a longer period of time to be initiated because enough force must accumulate to cause a biomechanical impact to brain tissue. Therefore, immediate testing of athletes after an acute bout of soccer heading may not be adequate in understanding the entire progression of damage that heading may cause to the brain. This could indicate why our study did not show a significant effect on NP and BA testing.

Study Limitations

The design of this study was such that to have high power, 76 subjects were needed to fill out the 4 different groups. However, we were not able to retain as many subjects and ended with only 24 completing the study. This resulted in an underpowered study and hypotheses could not be adequately tested.

Research has shown a significant cumulative effect of concussion symptoms after three concussions.[49] In this study, 5 of the 6 subjects had a history of three concussions and only 1 subject had a history of four. To get a more accurate assessment of any effects of concussion following soccer heading as they relate to balance and neuropsychological function, a more varied concussion history would give a better indication of this cumulative effect.

Number of concussions was self-reported. It was impossible to confirm concussion history on each individual as we included a lifetime concussion count. Not all concussions are treated by physicians and many are unrecognized and/or unreported, resulting in possible inaccurate histories.

A measure of balance in this study was taken from the BESS, which is subjective to the grading of the person reviewing and tallying the error scores. To reduce human error as much as possible, all BESS tests were performed by the primary investigator and error scores were checked by an outside source for inaccuracy. Due to facilities, this was the best option for testing, but a postural sway analysis could have shown a more refined study of postural sway changes following heading.

Suggestions for Future Research

Further evaluation of soccer heading in athletes who have sustained multiple concussions is necessary to realize the effects of continued participation in soccer. By defining what effects, if any, heading a soccer ball after repeat concussions has on the brain; better return to play decisions can be made to reduce the incidence of long-term brain injury. To truly determine these effects, inclusion of postural sway analysis could reduce the amount of human error and increase retest reliability as opposed to the BESS test. Also, increasing the sample size may show a threshold at which soccer heading affects the brain. Testing times at 24 hours, 36 hours, 48 hours, and beyond may exhibit impaired brain function that cannot be seen immediately following the bout of heading. Furthermore, in a laboratory setting, video analysis could determine the exact ball speed and impact location and severity of each header. This information would be valuable in understanding the possible concussive force behind soccer heading.

Multiple studies have suggested that further evaluation of concussion markers such as PO2 and neurotransmitter levels may detect alterations in brain function following impact. Henninger et al. found in rats significant alterations in PO2, mean arterial blood pressure, and heart rate following a concussive blow.[56] Heegaard et al. propose theories of physical indicators including elevated neurotransmitter levels.[21] However, no study to date has been done to determine neurotransmitter levels in patients without physical symptoms. Including an examination of these markers as well as monitoring heart rate in future research could determine on a cellular level the acute response of the brain to repeated soccer heading.

All short-term studies found in literature have been performed in a laboratory setting with distractions and a normal game or practice environment removed.[1, 5-7, 13] Results from these studies can only be used to generalize about the specific heading types utilized in the study. This type of uncontested heading with a controlled ball speed, rotation, and angle of impact is rare in the sport of soccer as is perfect heading form. For a true measure of BA and NP following an acute bout of soccer heading, testing should follow a game or practice, where the typical environmental variables such as opponent interference, varied ball speeds and distances travelled, and point of impact of the ball on the head could be examined and included in testing.

Conclusion

This study found no significance between pre- and post-heading in any groups on the BESS test, ImPACT test, and the CSC. The EXP2 group performed worse on the more challenging BESS tests, but their scores did not significantly worsen as was hypothesized. A possible interaction between pre- and post-testing was indicated but due to a small sample size, the actual effect was not significantly demonstrated in our results. This potential interaction suggests our hypothesis, based on a cumulative effect of multiple concussions, that subjects with three or more concussions would perform worse on balance testing than participants with two or fewer concussions is valid and would be conducive to further research and analysis.

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Appendix A: Informed Consent Form

approved
11/29/06

University of Delaware Human Subjects Review Board
Informed Consent Form

Project Title: "Postural Sway and Neuropsychological Performance Following an Acute Bout of Soccer Heading"

Principal Investigators:
Mary Beth Gilliam
Dr. Thomas W. Kaminski
Al T. Douex, Jr.

Please read this consent form carefully before you decide to participate in this study.

Purpose of the Research Study:
Sixty male and female soccer players (minimum of 4 years competitive experience), between the ages of 18 – 25 years old, are being recruited from the University of Delaware and surrounding communities to volunteer for this study. The purpose of this study is to determine if there are any changes in balance, memory, and reaction time after a session of soccer heading among subjects with and without a prior history of concussion.

What You Will Do in the Study:
You will be asked to report to the soccer playing field for testing on four (4) separate occasions. You will be asked to complete the subject demographic (age, height, weight, playing experience, etc…) and concussion history form to determine group assignment (control, no concussions, 1-2 concussions, > 2 concussions). In addition, you will be asked to complete the Concussion Symptom Checklist form which asks questions related to symptoms that might appear following a concussion. All participants must be healthy and free from injury at the time of the study. Subjects reporting previous concussion history must be free from any concussion-related symptoms for at least 2 months and be cleared by a physician prior to participating.

Session 1:

You will be asked to complete the Concussion Symptom Checklist form which asks questions related to symptoms that might appear following a concussion.

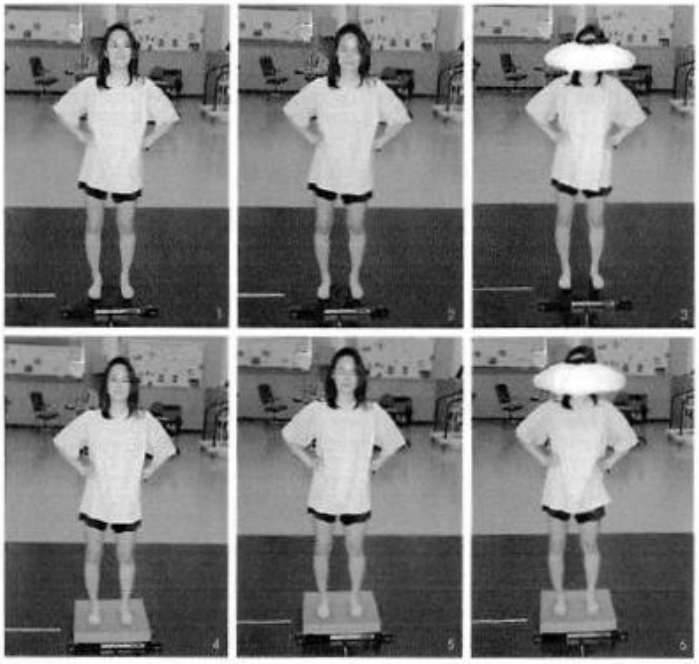
Using a coin flip you will be randomly assigned to each of the following baseline test procedures:

1. ImPACT Computerized Neuropsychological Testing - You will be given a 20-minute computerized battery of tests that have been shown to be sensitive in identifying neurocognitive abilities (i.e., reaction time, memory, pattern recognition, etc.). You will complete the tests using the computer mouse to respond to the questions. You will complete the tests while sitting alone in a quiet setting.

approved 11/29/06

2. Balance Testing – You will be asked to remove your shoes and stand with your feet shoulder-width apart on a plate that measures the forces you produce while standing (i.e "balancing"). You will be instructed to stand as still as possible with your hands on the hips for each of the conditions as described in Figure 1. Each trial will last 20 seconds.

Figure 1.



Conditions 1-3 occur directly on the force platform (firm surface) with eyes open (1), eyes closed (2), and conflict dome (3). Conditions 4-6 are performed on the Airex balance pad with eyes open (4), eyes closed (5), and conflict dome (6).

Session 2:

After 48 hours you will be asked to report back for testing again as described above. Measurements taken from both days will be used to determine your ***BASELINE*** scores.

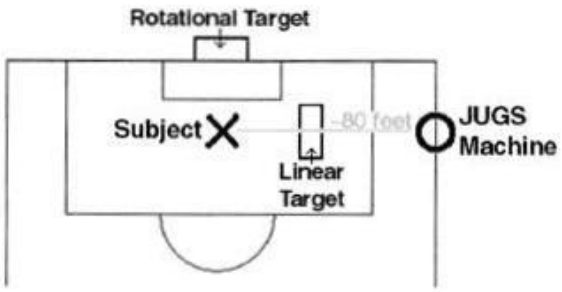
Session 3:

Following a minimum period of 48 hours, you will be asked to return again for the soccer heading session. You will be randomly assigned via a coin flip to either *rotational* or *straight on* heading. During this session you will be asked to perform 20 purposeful "headers" over a 20 minute time frame (one "header" every minute) toward a target using either a linear (straight on) or rotational (twisting) technique. A portable device ("JUGS machine") will be used to automatically send the soccer ball, at a speed and height similar to a corner or goal kick, to the subject for heading. The field will be arranged in the manner described in Figure 2. Subjects who have been assigned to the "CONTROL" group will be asked to "simulate" the heading maneuvers without actually contacting the ball.

Subject Initials: _____
Date: _____
HSRB 4/06

approved 11/29/06 DW

Figure 2.



Field layout for header testing

Immediately upon concluding the heading session, you will be asked to again perform the baseline test procedures described above.

Session 4:

After 7 days have passed, you will be asked to return for one final heading session. The other type of heading (*rotational* vs. *straight on)* that was not performed during Session 3 will be performed in the manner described above. Immediately following the heading session both the neuropsychological and balance testing will be performed a final time. Additionally, you will be asked to complete the Concussion Symptom Checklist form.

Time Required:
Testing on four separate occasions with each session lasting approximately 1.5 hours.

Risks:
There are no known physical risks in completing the computerized tests. The tests do require active attention, concentration, and mental effort and have in some cases caused mental frustration (particularly when completed following mild brain trauma or concussion). If severe mental frustration is apparent, testing will be discontinued.

As with any activity performed in an uncontrolled environment, there is some risk of injury (to muscle, bone, and joint) similar to a soccer practice or match. To date there are no studies that have reported harmful effects associated with an acute bout of soccer heading. It is important however, that you complete the Concussion Symptom Checklist honestly and without reservation, especially after each heading session.

In the event of an acute injury, you will receive immediate first aid from a certified athletic trainer; however any follow-up care will be at your own expense.

Subject Initials: _____
Date: _____
HSRB 4/06

Approved 1/15/06

Benefits/Compensation:
There are no direct benefits to you for your participation in this study. Nor is there any compensation for you for participating in this research study.

Confidentiality:
All data will be kept confidential. Your information will be assigned a code number. The list connecting your name to this code number will be kept in a locked file. When the study is completed and the data have been analyzed, that list will be destroyed, however the data will be stored indefinitely. Your name will not be used in any report whatsoever.

Voluntary Participation:
Your participation in the study is completely voluntary. There is no penalty for not participating.

Right to Withdraw from the Study:
You have the right to withdraw from the study at anytime without penalty.

Payment:
You will receive no payment for participating in this study.

Who to Contact if You Have Questions About the Study:
Mary Beth Gilliam, (513) 382-4525, Dr. Thomas W. Kaminski, (302) 831-6402, or Al T. Douex, Jr. (302) 831-0001

Who to Contact About Your Rights in the Study:
Chair of the Human Subjects Review Board, (302) 831-2136 Office of the Vice Provost for Research University of Delaware

Agreement:
I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

Participant:_____ **Date:**_____

Principal Investigator:_____ **Date:**_____

Appendix B: Concussion History and Demographic

UNIVERSITY OF DELAWARE – SOCCER HEADING STUDY

Concussion / General Health History Questionnaire

(All information is fully confidential and will not be shared with anyone at your school.)

Section I: Demographic Information

Name:_____ Year In School: _____

Height: _____ Weight: _____ Age: _____

Email Address: _____

Primary Position: (If more than one, place a 1 next to primary position, and a 2 next to secondary position)
? Goalkeeper ? Defender ? Midfielder ? Forward

How many years have you played organized soccer? (Club or School sponsored): _____

SECTION II: INJURY HISTORY. During the past 6 months, have you had an injury to any of the following body parts that caused you to miss participation for the defined time periods? Check box indicating time lost due to each injury.

Body Part	Missed Less than 7 Days	Missed 8-21 Days	Missed 22 or More Days
Head			
Neck			
Shoulder			
Arm, Elbow			
Wrist, Hand, Fingers			
Trunk			
Hip, Thigh			
Knee			
Lower Leg – Ankle, Foot, Toes			

SECTION III: CURRENT INJURIES. *Are you currently being treated for any of the following body parts that is causing you to miss participation or a limitation on your participation in activities? Check box indicating the area of your injury and describe it in the space provided*

Body Part	Injury?	Injury Description
Hip, Thigh		
Knee		
Lower Leg – Ankle; Foot; Toes		

SECTION IV: HISTORY OF CONCUSSION, PART 1: SPORT RELATED

Have you had a concussion from participation in sports? ☐ No (go to Part 2) ☐ Yes (continue below)

Time Period of Injury (please list each injury only once-)	*Competition Level*		***Did your concussion cause a time loss from participation for one practice or more?***		Medical Care Please mark the care you received for your concussion. Check all that apply			
	Pre-College	College	Yes	No	Hospital	Physician	Athletic Trainer	Self/Parent
In last 2 months								
3-6 months ago								
7-11 months ago								
1 year ago								
2 years ago								
3 years ago								
4 years ago								
5 or more years ago								

HISTORY OF CONCUSSION, PART 2: NON-SPORT RELATED

Have you had a concussion that was not sports related? ☐ No (end questions) ☐ Yes (continue below)

Time Period of Injury (please list each injury only once-)	Cause of Injury					***Did your concussion cause a time loss from participation for one practice or more?***		Medical Care Please mark the care you received for your concussion. Check all that apply			
	Motor Vehicle Accident	Bike Accident	Fall	Fight	Other	Yes	No	Hospital	Physician	Athletic Trainer	Self/ Parent
In last 2 months											
3-6 months ago											
7-11 months ago											
1 year ago											
2 years ago											
3 years ago											
4 years ago											
5 or more years ago											

Appendix C: Concussion Symptom Checklist

University of Delaware
Soccer Heading Study
Concussion Symptom Checklist

ID No. _____

Scoring Index:
Score each item from 0 to 6; 0 = none, 6 = worst ever experienced)

Symptom	***Baseline 1***	***Baseline 2***	***Post-Heading***
	0 1 2 3 4 5 6	***0 1 2 3 4 5 6***	***0 1 2 3 4 5 6***
Headache			
Nausea			
Vomiting			
Dizziness			
Poor Balance			
Sensitive to Noise			
Ringing in the Ears			
Sensitive to Light			
Blurred Vision			
Poor Concentration			
Memory Problems			
Trouble Sleeping			
Drowsy/Sleepy			
Fatigued			
Sad/Depressed			
Irritable			
Neck Pain			
TOTAL SCORE:			

Appendix D: Latin squares

1. Assignment of subjects to CONC and EXP0 groups (2x2)

1	2
2	1

2. Assignment of balance and neuropsychological testing order (2x2)

1	2
2	1

3. Assignment of BESS condition order (6x6)

1	2	3	4	5	6
2	3	6	1	4	5
3	6	5	2	1	4
6	5	4	3	2	1
5	4	1	6	3	2
4	1	2	5	6	3

4. Assignment of ImPACT test order (4x4)

1	2	3	4
2	4	1	3
4	3	2	1
3	1	4	2