THE EFFECT OF HEADGEAR ON VISUAL AND SENSORY PERFORMANCE
OUTCOMES IN FEMALE LACROSSE PLAYERS

by

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ABSTRACT

Kathleen Anne Morrisroe: The Effect of Headgear on Visual and Sensory Performance Outcomes in Female Lacrosse Players
(Under the direction of Jason P. Mihalik)

As vision is important in injury risk and performance, understanding the effect of headgear on vision is critical for athletic safety and success. It is particularly important in women’s lacrosse, as the sport is currently debating which headgear type would optimize safety and performance for its players. The purpose of this study is to analyze the effect of headgear (no headgear, helmet, or goggles) on visual and sensory performance outcomes in college-aged female lacrosse players. Healthy participants completed the Sensory Senaptec Station assessments under three conditions: no headgear, full-helmet, and goggles. Results showed no difference in any of the visual and sensory performance measures between conditions (p>0.33). Based on these results and the overall concern that adding helmets would cause a more violent style of play, it is recommended that the sport continue its use of goggles. Future research should include a larger sample size and a broader age range.
To my family. Thank you for your never-ending support. This would not have been possible without you.
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CHAPTER I
INTRODUCTION

It is estimated that between 1.6 and 3.8 million concussions occur annually, but this is thought to be an underestimate as many people fail to seek medical attention.¹ Due in part to the high injury prevalence, attention to concussions in research and in the media has increased, which has likely contributed to a 16.5% annual increase in concussion diagnoses since 2002.¹,² As of 2016, concussions accounted for up to 9% of all sports injuries, despite new rules and mandatory concussion education that have entered the sports world in the recent years.² Although the attention surrounding concussion is on the rise, experts have yet to agree upon a standard definition of concussion due to the variance in symptoms and recovery of those sustaining the injury. However, concussions are defined by the Centers for Disease Control and Prevention as traumatic brain injuries (TBIs) that lead to a change in the mental status of the individual, and may or may not cause one to lose consciousness.³

Much of the recent work to increase safety in sport has been focused on concussions due to the increased awareness of the negative sequelae associated with concussion. Many governing bodies of sport have changed various rules in order to enhance athlete safety. Many of these proposed or instituted rule changes have been focused on protective headgear for the participating athletes, such as mandating protective eyewear in women’s lacrosse.⁴ Despite the use of headgear, it is estimated that concussions account for 6.3% of the injuries in women’s
lacrosse, while accounting for 5.6% of injuries in men’s lacrosse.\(^1\) However, while the use of helmets and other protective headgear have been shown to protect from eye and facial injuries and reduce the forces transmitted to the brain, they have not been shown to reduce one’s risk of sustaining a concussion,\(^5\) and one study even found concussion rates increased following the addition of protective headgear.\(^4\)

While the reduction of catastrophic and penetrating brain injuries are often at the forefront of headgear design, little consideration or research has focused on the way headgear may obstruct an athlete’s visual field. Vision is essential in sport performance as well as safety. The fast movements during sporting events are demanding on vision, as one must be aware of everything that is occurring on the field around them while simultaneously focusing their attention on one specific object (i.e. the ball or the goal).\(^6\) Therefore, vision is necessary to be able to see where the play is at the present moment as well as predicting where the play may go over time.\(^7\) Particular domains of vision are more closely tied to performance and safety outcomes; for example, shot accuracy in women’s lacrosse is heavily tied to visual search and balance.\(^8\) Additionally, vision is essential in sport safety because visual deficiencies make an athlete less likely to identify potentially risky scenarios during an athletic situation.\(^9\) There is a limited capacity for processing visual and sensory information in the brain, and dividing attention between two or more objects leads to decreased sensory performance compared to focusing on one object.\(^10\)

Therefore, components of full helmets, such as those worn in men’s lacrosse, or goggles, such as those worn in women’s lacrosse, could pose as visual distractors, dividing the athlete’s visual attention between the equipment and the game. The differences between full helmets and goggles are substantial. Female lacrosse regulations approve specific eyewear for the use of
athletes, which often have one bar above the athlete’s eye level, one below, and one bar down the center of the face.\textsuperscript{11} Men’s lacrosse requires hard-shelled helmets and faceguards, which typically contain three horizontal bars and one vertical bar down the center of the athlete’s face.\textsuperscript{12} However, few studies have investigated the ways in which different types of headgear influences visual outcomes.

There is a dearth of information on the effect of sport headgear on visual and sensory performance outcomes, particularly in female athletes. Females lacrosse players are more at risk for concussion than male lacrosse players and many individuals attribute this to the differences in headgear worn between the sexes.\textsuperscript{5,13} This has sparked an ongoing debate regarding whether female lacrosse athletes should be required to wear a full-faced, hard-shelled helmet rather than their protective eyewear, even though women’s lacrosse is considered a non-contact sport.\textsuperscript{14} Pro-helmet proponents argue no harm can come from the addition of more protective headgear\textsuperscript{15} and helmets can protect players from the two objects that cause the majority of head injuries in women’s lacrosse: the stick (41%) and the ball (37%).\textsuperscript{14} As ball speeds can reach in excess of 100 miles per hour,\textsuperscript{16} pro-helmet supporters argue that the addition of the helmet can protect all players, not just goalies, and reduce the possibility of catastrophic head injury.

Opponents of the change from eyewear to helmets state that they seek to preserve the sport and that they are concerned that women’s lacrosse would become more like men’s lacrosse, focused on hits and violence instead of skill and finesse.\textsuperscript{15,16} Many have titled this phenomenon the “Gladiator Effect,” arguing that with a helmet protecting their head, the women would feel more protected and therefore tend to act more violently or more aggressively.\textsuperscript{15} Other opponents have argued that since there is no standardized headgear agreed upon within the lacrosse world,\textsuperscript{17}
that these helmets would be nothing more than “costly distractions” to both the players and the spectators.\textsuperscript{18}

While much of the debate has focused on how well the goggles or the helmets diminish the forces on the athlete’s head,\textsuperscript{14} little research has examined how the different types of headgear can affect vision. Studies have indicated that anticipated collisions result in less severe impacts than anticipated collisions,\textsuperscript{19,20} so headgear with more bars (i.e. more visual distractors) may lead to more unanticipated collisions and, therefore, more severe head impacts. Hence, vision is a critical component and understanding whether full helmets or goggles are more detrimental to an athlete’s visual field is necessary to resolve this debate.

Therefore, the primary purpose of this study is to analyze how various forms of athletic headgear (no headgear, goggles, and full helmet) affects visual and sensory performance outcomes compared to no headgear in college-aged female lacrosse players.

\textbf{Research Question}

1. Is there an effect of headgear and/or headgear type (no headgear vs. goggles vs. full helmet) on visual and sensory performance outcomes as measured by the Senaptec Sensory Station for college-aged female lacrosse players?

\textbf{Research Hypothesis}

1. Visual and sensory performance outcomes of the athletes will significantly worsen when the headgear is present. Goggles will cause a significantly more detrimental effect than the full helmet to the visual and sensory performance outcomes of the athletes.
**Definition of Terms**

1. **Senaptec Sensory Station**: An objective test of visual and sensory performance that allows for analysis of many visual and sensory skills including: visual clarity, contrast sensitivity, depth perception, near far quickness, perception span, reaction time, multiple object tracking, target capture, hand-eye coordination, and go/no go.

**Operational Definitions**

1. **Healthy**: an individual with no history of a diagnosed concussion within the last year, has no known neurocognitive deficits or disorders, has no visual disorders, has no history of brain trauma that resulted in loss of activity for more than three weeks, and no history of dizziness, abnormal vestibular function or musculoskeletal abnormalities that would disturb normal range of motion.

2. **Active**: an individual who completes 30 minutes of continuous exercise 3 or more days per week

**Variables**

1. **Independent**
   
a. **Headgear Condition**
   
i. No Headgear
   
ii. Goggles
   
iii. Full Helmet

2. **Dependent**
   
a. **Visual and sensory performance outcome measures (Senaptec)**
   
i. Visual clarity
   
ii. Contrast sensitivity
iii. Depth perception
iv. Near-far quickness
v. Perception span
vi. Reaction time
vii. Multiple object tracking
viii. Target capture
ix. Hand-eye coordination
x. Go/No go

Significance of the Study

This study is important because there is little understood about the effect of headgear on vision, particularly in female athletes. Because vision is so important for athletic success, and in anticipating and bracing for a hit, a decrease in visual ability could lead to more unanticipated collisions and higher magnitude forces on the athlete’s head, potentially increasing the risk of concussion. Should the headgear prove detrimental to the vision of the athlete, it would be an indication that alterations in the headgear need to be made in order to increase the athlete’s visual ability and awareness of their surroundings. This study will also help to add additional information to the ongoing debate about whether women’s lacrosse players should wear helmets or protective eyewear during practice and competition. While much of the information in the debate has been focused on the forces associated with each type of headgear, this study will examine how each type of headgear will impact the athlete’s visual and sensory performance, another important factor in sport safety.
CHAPTER II
LITERATURE REVIEW

While concussions have gained much attention in the recent years in both the research and the sport community, much has yet to be understood. Studies have shown that helmets have the capacity to reduce head impact forces, but helmets have not been shown to prevent or lessen concussion risk.\(^5\) Anticipation of impact has proven to be an important factor in reducing the forces on the head in sport;\(^{19}\) however, little is understood about the ways in which vision may prevent or reduce the risk of a concussive episode since much of the research is focused on visual deficits following concussion. Helmets are important to consider when exploring the relationship between vision and concussion because the bars that make up the face guard, which is built to protect the athlete, may in fact be impeding upon their vision.\(^{21}\)

Vision is essential in an athlete’s success and safety on the field. While previous research suggests a connection between the number of bars in a helmet’s faceguard and an athlete’s visual field,\(^{21}\) little is understood about how this deficit may impact the athlete’s other visual domains. Athletic events are incredibly demanding on the visual system and require the use of all visual domains, including depth perception and hand-eye coordination, so understanding how faceguards affect all domains of vision is crucial to create the safest equipment.\(^9\) Because there is a strong connection between headgear, vision and concussion, the purpose of this experiment is
to analyze how the type of headgear (no headgear vs. helmet vs. goggles) affects visual and sensory performance outcomes in college-aged female lacrosse players.

Concussion

The most recent definition given by the 4th International Conference on Concussion in Sport regards a concussion as a subtype of a traumatic brain injury (TBI) that affects the pathophysiological processes in the brain and is brought about by a force to the head, face, or neck.\(^5\) Because the definition has changed so drastically in the past few decades, evolving from the 1965 definition of merely losing consciousness for more than five minutes, to the present, where a concussion is described by a whole range of symptoms being presented for any amount of time, a division between the clinical and athletic understanding of the term has been shown.\(^22\) As there is no current definition of concussion that is universally agreed upon in the scientific community, the definition given by the 4th International Conference on Concussion in Sports will be used for the purposes of this study.

Pathophysiology. A concussion is an injury that disrupts the neurological functioning of the brain. Therefore, concussions are unable to be visualized by imaging technologies such as an MRI or a CT Scan and are commonly thought to be a functional, rather than structural, injury.\(^2\) After the concussive impact, the neurons and the axon membranes are stretched, leading to an influx of ions, whose movement is normally regulated by channels within the membrane.\(^23\) Because the membrane potential is no longer viable in the stretched state, ions flow in the direction of their concentration gradient, with potassium exiting the cell and calcium entering the cell.\(^2\) Glutamate, an excitatory neurotransmitter, is released and further damages the neurons by binding to molecules that cause more depolarization and more calcium ions to enter the cell.\(^23,2\)
The excess of calcium within the neuron creates mitochondrial calcium overloading, causing changes to the inner membrane and leading to dysfunction in oxidative phosphorylation and organelle swelling. The sodium-potassium pump attempts to restore proper ionic balance within the neuron; however, the active transport of sodium and potassium requires energy. With the neuron unable to synthesize energy by any means other than glycolysis, energy is quickly depleted within the cell. The lack of ATP within the cell and the mitochondrial dysfunction leads to acidosis and lack of oxidation. This dysfunction in the brain’s energy pathway is referred to as a metabolic crisis and is thought to underlie the symptoms and deficits that hallmark the concussive injury.

Incidence. It is estimated that 1.6 to 3.8 million people sustain a concussion annually; however, it is believed that this is underestimated because of the imprecise definition and the failure of individuals to seek medical attention for their concussion. Concussion incidence rates have continued to rise over the years, likely due in part to athletes being bigger, stronger, and more capable of delivering hits with much more force than in the past. However, many researchers have suggested that more concussions have been reported and diagnosed in recent years due to increased public awareness and heightened clinical understanding of concussion, rather than an increase in the number of injuries sustained. In 2012, it was found that on a collegiate level, a concussion occurred an average of 0.43 times per 1000 athletic exposures, including both practice and game situations.

Concussion in Women’s Lacrosse. In 2010, concussions were found to account for 6.3% of the injuries in women’s lacrosse, with 0.52 concussions occurring per 1000 athletic exposures. This is in contrast to men’s lacrosse, where concussions account for 5.6% of injuries, with 1.08 concussions occurring per 1000 athletic exposures. The majority of concussions in women
(65%) occurred during competition, most likely due to the excess contact that occurs in a game situation than in a practice situation.25 It has been estimated that women’s lacrosse has the highest risk of concussion during a game (14.1%) as compared to any other sport.26 Because women’s lacrosse is considered a non-contact sport, sticks hitting a player’s head represents the mechanism of injury for 41% of all concussions in women’s lacrosse and the ball causes 37% of concussions, with only 8% occurring from player-to-player contact.14 In men’s lacrosse, however, the majority of injuries to the head and face result from contact with other players, with less occurring from contact with the stick and ball.13 Concussion risk in both sexes has also been linked to experience, with a study finding that more experienced players sustained less concussions due to their expertise on how to position their bodies and avoid head contact.27 **Clinical Concussive Deficits.** Symptomology of concussions can be difficult to identify because no two injuries present in the same way,28 and because symptoms can bear incredible similarities to other conditions, such as depression, fatigue, whiplash, and other disorders.29 It is essential that the sideline concussion battery is effective in diagnosing concussion because athletes who return to play too soon after a concussion have the potential to sustain second-impact syndrome, a fatal condition where the brain swells rapidly after a second impact.30 Despite this clinical difficulty, the clinical concussion assessment battery typically evaluates three domains: symptoms, cognition, and balance.31

**Symptoms.** In the concussion assessment battery, common concussive symptoms are self-reported by the athlete.32 As shown in **Figure 1**, organizations such as the CDC have assembled checklists that enable an athletic trainer or a coach to monitor the symptoms of concussion over a specified course of time.33 This particular checklist may be more extensive than those found on the sidelines, as many of those only include nine common symptoms, such as headache, fatigue
or difficulty concentrating. Symptoms tend to be the least reliable source of information for the clinician, due to the high subjectivity of the assessment and their non-specific relationship to concussion, and therefore objective cognition and balance are often assessed during concussion evaluations.

**Figure 1.** Example of a symptom checklist from the CDC

*Cognition.* In the concussion assessment battery, the Standardized Assessment of Concussion (SAC) is most often used to measure deficiencies in neurocognitive ability. The SAC is a good indicator of cognitive function as it measures orientation (using date and time approximations), immediate memory (using word lists), concentration (using a number task in which the participant must repeat numbers back in opposite order), and delayed recall (using the same word list as was used to measure immediate memory). In the first 24 hours following a concussive episode, the largest deficits have been found in cognitive abilities, particularly relating to memory. Neurocognitive tests have also been developed, such as the Immediate Post-concussion Assessment Cognitive Test (ImPACT) computerized testing which combines processing, planning and memory and requires the participant to integrate information in a way
that has proven 79.2% effective at detecting concussion as a standalone tool. However, 17% of concussed athletes with concussion showed no abnormality in their post-concussion test.

**Balance.** The Balance Error Scoring System (BESS) is used to measure the balance deficits of concussed patients. The BESS consists of six different tests in three stances on two different surfaces. The scoring system measures the errors of the participant, and because errors can be measured differently, the BESS’s subjective scoring has led to variability amongst results. Another post-concussive balance assessment is the sensory organization test (SOT). The SOT measures 20-second intervals of 18 different conditions that manipulate different areas of the sensory system, such as somatosensory, vestibular, and visual domains. A force plate is used to measure the forces that the body produces, which produces much more objective measurements than the subjective BESS measurements. The force plates are not as clinically available as the equipment needed for the BESS. Also, because both of these assessments are scored while the patient is static, it does not allow for measurements that represent a comprehensive measurement of the system as a whole.

**Vision.** The current clinical concussion assessment battery includes three components: symptoms, cognition and balance; however, visual testing is an important component that is often missed in these tests. In the ten days post-concussion, visual function is significantly impaired, including light sensitivity, impaired antisaccades, and convergence abnormalities in 47-64% of patients. The King Devick Test is a vision test where the participant rapidly reads numbers on three cards that include saccade movements using anticipation, attention and language, which tests the brainstem, cerebellum and cerebral cortex at the same time. Another test that is directed at measuring the visual field after a concussive episode is the Vestibular/Ocular Motor Screening (VOMS) Assessment. The VOMS Assessment uses different
tasks, such as a smooth pursuit or vertical saccade task, to identify whether or not the task induces symptoms in the athlete. The VOMS Assessment has shown high internal validity as well as high sensitivity in diagnosing sport-related concussions.

_**Multimodal Concussion Assessments.**_ Due to the deficits that are present in all of the assessments, recent literature has promoted the use of a combination of different testing apparatuses in order to increase the likelihood of a proper concussion diagnosis. Through the use of many different assessments, the clinician is able to test not only the neurocognitive system, but also the vestibulo-spinal system, as well as the vestibulo-ocular system. For example, Broglio found that symptom reporting alone caught 68% of concussions, balance tests caught 61.9% of concussions and cognitive function tests caught 43.5% of concussions. However, when all three of them were performed together, over 90% of concussions were caught. Another study found that the King Devick Test alone caught 79% of concussions, the SAC and the BESS together caught 90% of concussions, and all three together caught 100% of concussions. Another study recommended a multimodal concussion assessment battery, as it was found to be about 60% more sensitive than the other measures alone. This study combined Automated Neuropsychological Assessment Metrics (ANAM) to assess neurocognitive function, Graded Symptom Checklist (GSC) to assess symptom severity, and the Sensory Organization Test (SOT) to assess postural control. Register-Mihalik emphasizes baseline testing for a point of comparison to post-injury measures in this study and states that regardless of the marketing of computerized neurocognitive tests as the only method of assessment, they should be used in conjunction with other forms of tests for a much more reliable measure of concussion.
Vision

The function of the visual system is to provide information to the brain that allows it to react to stimuli in a proper manner, with half of the circuits in the brain contributing to vision. The ventral pathways contribute to the sensory function of perceiving objects, while the dorsal pathways contribute to movement execution after the visual stimulus has been processed and decisions have been made. These pathways allow people, especially athletes, to understand their orientation in space and help to control and balance their bodies. The most basic visual functions underlying all visual system functioning include saccades, pursuits, accommodation, and convergence.

Saccadic eye movements include quick scanning of one’s surroundings and rapidly shifting one’s gaze between different objects. The frontal eye field is constantly scanning for stimuli, and once one is encountered, the superior colliculus of the midbrain and the eye field in the frontal lobe are activated, thereby activating the muscles necessary for the saccade. When the fovea shifts toward the target, the brain must control the amplitude of the movement as well as the direction, which can be done through the relaying of visual information from the occipital lobe to be processed in the parietal lobe. The activation of the superior colliculus as well as the processing of the visual information in the parietal lobe are sent to either the paramedian pontine reticular formation (the horizontal gaze center), the rostral interstitial nucleus (the vertical gaze center), or both to determine the direction in which the eyes must saccade to the target.

Visual pursuit is closely related to saccadic eye movements and is the visual field’s ability to follow slowly moving objects. Smooth eye pursuit are slow eye movements that allow the fovea to stabilize the projection of the moving target as well as adjusting eye
movements to account for any velocity error between the target and the perceiver. In the brain, this eye movement is controlled in the pons, where stimuli from the frontal eye field and the tempo-parieto-occipital junction combine to innervate the cerebellum and excite the nerves that will move the eye, particularly the abducens nerve. The eye cannot adjust to objects moving above a certain velocity threshold and tries to account for the potential of position error through the use of predictions to anticipate where the object will go. These predictions combine pursuit and saccades, especially for unpredictable targets, so that the visual system is able to catch up quickly if it falls behind, as well as track the moving object.

Accommodation and vergence are closely linked because both require the eyes to alter their shape in order to view objects at different distances or in different lightings. The Helmholtz theory of accommodation states that in an unaccommodated state, the eyes are flattened, but achieve different degrees of roundness depending on the amount of accommodation necessary for the stimulus. The curve in the eye is achieved by contracting ciliary muscles and causes the lens to curve and allows the object to focus on the retina.

Vergence is the visual system’s ability to turn the eyes inward (convergence) and outward (divergence) to fixate on objects at different depths. Studies have reported that, while this type of eye movement is the least understood, it involves the cerebro-brainstem-cerebellar pathway. Convergence requires the muscles around the eye to tense in order to focus the eye field on a near object, while the eye muscles relax and become parallel for distant objects. Two different locations exist within the frontal eye field for saccades and vergence, with vergence more anterior, however the dorsolateral prefrontal cortex (DLPFC) is involved in the anticipatory movements of both of these visual pathways.
All four of these visual domains allow for peripheral vision, by moving the eye in a way that allows the visual field to change and the objects located outside of people’s frontal eye field to be visualized. Peripheral vision is important in sport because it allows players to be aware of their surroundings without having to constantly rotate their heads to determine what is occurring in the space around them.49

Domains of Vision. The Senaptec Sensory Station allows an analysis of ten different domains of vision and was developed to help athletes assess their visual and sensory performance skills, analyze how competitive their scores are, and improve through the tools provided by the system.50 There are many domains of vision, but this literature review will focus on the following ten domains, which are measured by the Senaptec Sensory Station.

**Visual clarity.** Visual clarity is a measurement of static visual acuity (SVA), which, along with contrast sensitivity, is one of the foundations for the rest of the visual domains.51 Clinically, visual clarity is measured with Bailey-Lovie logMAR charts.52 Participants stand at a distance of 3 meters and identify letters, which start at size 0.7 (on the logarithmic scale) and each letter progresses down 0.1 log units until size -0.3 or until the participant responds incorrectly.52

A solid SVA is a critical foundation to sports vision because without it, almost all other parts of the athlete’s visual domain would be compromised.53 For example, it has been found that when SVA is not optimal, depth perception worsens as well.54 Some potential limitations to one’s visual acuity could be due to pupil size and abnormalities in the retina, cornea or lens.51 Studies have shown that when athletes choose to undergo a vision enhancement training program, SVA may be positively effected.6 Researchers have stated that visual acuity has such a great impact on sport performance that it may make the difference between winning and losing.49
For example, researchers have found that basketball players are more successful in their free throws if they are able to fixate on the hoop before shooting the ball.\(^7\)

*Contrast sensitivity.* Contrast sensitivity, or the ability to perceive characteristics about an object in different lightings,\(^53\) is the second of the two foundations for the rest of the visual domains.\(^51\) Contrast sensitivity is measured clinically by the Pelli-Robson test, where the participant stands one-meter away from a wall chart with eight lines of letters of different contrasts. The letters range from 100% contrast to 0.6% contrast, with the contrast sensitivity decreasing left to right and up to down. The result given is measured by \(1/\text{contrast}\).\(^55\) Contrast sensitivity is considered to provide a more complete description of one’s visual ability than visual acuity because it forces the eye to adapt to different lighting circumstances, as it might need to do during an athletic event.\(^51\) Studies have found that contrast sensitivity in athletes may be improved through the use of tinted lenses.\(^56\)

*Depth perception.* Depth perception, or one’s ability to judge distances between oneself and another object, is an important component in visual ability.\(^54\) Depth perception can be measured clinically using 2 apertures, with one placed behind the other and the observer must identify which is aperture is in front.\(^48\) It was found that visual deficiencies on the German national team greatly influenced performance, especially those deficiencies that affected depth perception.\(^9\) This is especially important to sports such as baseball and tennis because one must be able to estimate the distance between the bat or racket and the ball.\(^54\) Additionally, a positive relationship has also been found between depth perception and sport performance in non-equipment based sports such as rugby.\(^57\)

*Near-far quickness.* Near-far quickness is a measurement of accommodative-vergence facility, or one’s ability to accommodate for the movement of the eyes to switch between objects
near and objects far from one’s vantage point. Near-far quickness is measured by programs such as the Nike SPARQ or the Sensory Senaptec Station, or by custom programs developed by researchers. The SPARQ and Senaptec Station both measure this skill using two screens and asking the participant to respond to a stimulus that alternates between a screen about one-meter away and a screen ten-meters away. This visual domain is important in sport because players and the ball are in constant motion both close to and far from one’s position on the field. One must be able to quickly change their visual field in order to accommodate for these changes to avoid dangerous situations and perform optimally.

Perception span. Senaptec describes the perception span measurement as “how quickly [one] visually acquires critical information.” Perception span is measured using programs such as the Sensory Senaptec System and the Nike SPARQ, which use webs of colored circles that briefly flash in patterns that the participant must remember and recreate. The webs continuously get larger and the number of colored circles increases until the range of the perception span can be determined. This is important to the visual processes because one must be able to receive and synthesize the information that is visually presented to them in order for them to respond in an appropriate way.

Reaction time. Reaction time measures the time that it takes from the arrival of the visual stimulus to the movement initiating in response to that stimulus. It is used as a temporal measurement as to how quickly one can process information and is often used as an indicator of one’s proficiency in sport. Reaction time can be measured clinically using computer systems. For example, participants are instructed to click a mouse button as quickly as possible in response to a visual cue, and the score is measuring how quickly the participant is able to respond. Reaction time is important in sports because an athlete must be able to ascertain
information on the field and make decisions rapidly. Because of this, many athletes undergo sport performance training to enhance their reaction time and allow them to make better and quicker decisions on the field.

*Multiple-object tracking.* Multiple-object tracking is a person’s ability to acquire information about multiple objects at one time. People are typically able to track four objects at a time because the working memory is limited in the number of items that it can. Multiple-object tracking metrics must measure both tracking accuracy and precision. Therefore, measures of multiple-object tracking require the participant to watch the movements of many different objects and record their responses, both misses, false positives and correct answers. Studies have shown that in the presence of multiple objects, people tend to look centrally, between all the moving targets. This allows the person to group all the targets together as a single object so that it is not necessary for their eyes to be consistently moving. The ability to simultaneously track multiple objects is especially important in sport because there is more than one object constantly moving that the players’ eyes need to track at one time.

*Target capture.* Target capture is a measurement of dynamic visual acuity (DVA), a person’s ability to see detail when there is movement present between the observer and the object. Clinically, target capture is measured using the Sensory Senaptec Station and the Nike SPARQ. Participants are instructed to look at a central point and then respond to Landolt rings in the corners of the screen, requiring them to shift attention to different parts of the screen, process the information and respond to the stimuli. Scores on an SVA test and scores on a DVA test are not always coordinated, most likely due to the addition of movement, changing the sensory input from the retina. DVA is sometimes considered a more relevant measurement than SVA for athletes because very little is stationary during an athletic event. While static visual acuity
(SVA) is important in one’s ability to increase their DVA, it in itself is not incredibly important in visual abilities of athletes because constant and rapid movements on the athletic field are very demanding on human vision. DVA is the most important domain of vision to sport because athletes are required to detect moving targets and then fixate on it, enabling them to resolve small details in a chaotic situation. Studies have shown that the DVA measurements of elite athletes are far superior to non-athletes, suggesting that either athletes have innately better DVA skills or that sport develops these skills because they are necessary to optimal performance.

**Hand-eye coordination.** Hand-eye coordination is the connection of the visual system to the motor system. An example of a clinical test to measure hand-eye coordination is the Grooved Pegboard Test, which consists of a 5x5 matrix of keyhole shaped holes in different orientations. The participant must use one hand and manipulate the key to fit the keys into the holes, filling the holes from left to right and top to bottom. The participant’s score is the time it takes him or her to complete the entire pegboard. Hand-eye coordination allows complex movements in athletes, especially when decisions must be made and implemented quickly such as in goal-tending. Visual performance training has been shown to improve hand-eye coordination and help in body positioning during sport.5

**Go/No go.** Go/No Go tests the ability of the athlete to identify a stimulus and implement a motor plan (Go) and tests the strength of the athlete’s inhibition (No Go). Choice reaction time is clinically measured similarly to reaction time, except that depending on the color of the stimulus, the participant is instructed to either click the left or the right mouse, making their decision and clicking as quickly as possible. Choice reaction time, how long the brain takes to recognize and appropriate choose to respond or not respond to a stimulus, allows players to recognize a stimulus and implement a plan of action quickly. Studies have found that athletes,
particularly fencers and baseball players, have shorter reaction time to Go stimuli than non-athletes.\textsuperscript{58}

\textbf{Vision and Concussion.} Concussions can have a large impact on the visual field because one half of the pathways within the brain contribute to the visual system.\textsuperscript{31} All of the impairments that concussions have on executive function, attention and memory can be seen through detrimental in saccadic function including directional errors and poor spatial accuracy.\textsuperscript{31} In ten days post-concussion, studies have found that 30\% of patients exhibit saccadic dysfunction, 60\% exhibit impaired smooth pursuit function and convergence abnormalities existed in over 50\% of patients.\textsuperscript{36} Visual dysfunctions and impairments can be significant after a concussive episode, but tend to resolve within about a week.\textsuperscript{30} Eye movements are extremely sensitive to the neurological dysfunction that occurs during a concussion because the pathways that typically control them have been impaired, making vision incredibly sensitive to any abnormality.\textsuperscript{31}

While much of the concussion literature focuses on vision after a concussive episode, visual performance is also important in concussion prevention. One study revealed a significant relationship between visual performance and biomechanics of head impacts in collegiate football players, and that incorporating a visual training program into an athlete’s training can decrease the risk of having a head impact.\textsuperscript{68} Visual anticipation, or one’s ability to make a prediction with only partial visual information to predict how the target will move, has been shown to have an effect on one’s ability to anticipate hit in sport.\textsuperscript{43} Another study showed that in ice hockey players, anticipated collisions led to less severe impacts than unanticipated hits,\textsuperscript{19} and therefore with greater awareness of one’s surroundings, the athletes are better able to prepare their body to lessen the severity of the impact.\textsuperscript{20}
Headgear

Headgear has been a part of impact sports, such as football, since the early 1900s. Since then, other sports, such as lacrosse, have seen a participation increase of over 33% in the last five years, leading to heightened safety measures. Governing bodies of sport, such as the National Operating Committee on Standards for Athletic Equipment (NOCSAE), have begun to regulate the use of headgear in both contact and non-contact sports, including men’s and women’s lacrosse, especially as head injuries, including concussions, have gained more attention in the media.

Headgear and Concussion. While headgear has the capacity to decrease forces of impact to the brain and reduce the potential for other head injuries such as skull fractures and brain bleeds, it has not been shown to prevent concussions. Some studies argue that customized mandibular orthotics (CMOs) will help stabilize the temporomandibular joint, which would in turn protect the temporal lobe. Such orthotics have been found to decrease the risk of head injury by 7.67 times; however, these findings contained many study limitations and therefore more research must be done. Other tests have found that increasing the thickness of the foam padding included in helmets yields less head acceleration, leading to less severe impacts. Some potential problems with this shift in headgear are that the thickness cannot exceed 16 mm for comfort purposes of the athlete, and thicker foam allows more alterations upon each impact, making the foam softer and therefore less adept at preventing acceleration on the subsequent impact.

Some have argued that wearing headgear may in fact increase one’s risk for concussion and other injuries because it gives athletes a sense of protection and they are therefore more likely to engage in risky or dangerous behavior. This type of behavior, called the “Gladiator
Effect,” is believed to make athletes more aggressive due to their thought that they are invincible.\textsuperscript{15} Regardless of the reason, Cantu states that, “It is unlikely, given the present materials, that helmets will solve the concussion crisis,” due to the fact that headgear helps to reduce high-energy impacts, but the low impact forces that can cause concussion are not prevented.\textsuperscript{27}

\textbf{Headgear in Sport.} Over the past few decades, as head injuries have become more prevalent in the media, requirements for headgear in sport have become much stricter. For example, during the 2004-2005 lacrosse season, female lacrosse players were mandated to wear protective eyewear, to protect from eye injuries as well as skull fractures and other facial injuries resulting from blows to that region.\textsuperscript{4} Studies have found then when wearing headgear, rugby players report about half as many head injuries as those that do not wear headgear and that mouthpieces had a similar effect.\textsuperscript{4} Depending on the demands and classification of the sport, there are many options for headgear. These include (but are not limited to): mouthpieces, protective eyewear, helmets, and helmets with a full facemask.

\textit{Women’s Lacrosse Goggles.} Women’s lacrosse, as a non-contact sport, uses protective eyewear as its headgear.\textsuperscript{14} Approved eyewear varies, but one model consists of one horizontal bar above eye level and one below, as well as three vertical bars – one down the middle and two on either side, as illustrated by the US Lacrosse-approved goggles in Figure 2.\textsuperscript{11} All hard helmets are considered illegal in women’s lacrosse,\textsuperscript{14} which has sparked much debate regarding what the required headgear should be for the sport.
Figure 2. Under Armour Illusion 2 Lacrosse Goggles

_{Men’s Lacrosse Helmets.} The required protective headgear in men’s lacrosse is full-faced helmet with a hard outer shell and padding on the inside to absorb much energy. Faceguards are required on the helmets, which typically consist of three horizontal bars and one vertical bar down the middle, as illustrated by the Cascade helmet in Figure 3. The helmets must be properly fitted so that each player is able to be looking through the space between the bar and the top of the helmet.

Figure 3. Cascade CS-R helmet

_Headgear and Vision._ Vision is essential, not only in the athlete’s success on the field, but also in preventing head injuries. There is a limited capacity for processing visual and sensory
information in the brain, and that dividing attention between two or more objects leads to decreased sensory performance than just focusing on one object.\textsuperscript{10} Therefore, the bars that make up the sports helmet or goggles could pose as visual distractors, dividing the athlete’s visual attention between two different targets. One study found that the more advanced the design was for football helmets, meaning the type and amount of protective bars, the larger the visual deficit was for the athlete, particularly in the inferior, peripheral area of the visual field.\textsuperscript{21}

Studies have indicated that anticipated collisions tend to result in less severe impacts than anticipated collisions, because the athlete is more aware of their surroundings and is able to position their body in a way that would lessen the impact forces.\textsuperscript{19,20} Should the bars on athletes’ headgear be dividing their attention and worsening their ability to analyze their surroundings, it would lead to more unanticipated collisions and therefore more severe head impacts. However, studies have analyzed the impact on the visual field of sports goggles, but only those used to protect the eyes in basketball and other sports, that are clear and do not have the protection of bars.\textsuperscript{74}

**Methodology**

This study chooses to evaluate visual and sensory performance outcomes using the Sensory Senaptec System. This system will allow for the measurement of all ten tested domains of vision and will give the researchers a holistic view of the athlete’s visual abilities. This will be tested in female collegiate lacrosse athletes under conditions of no headgear, goggles, and full helmet to allow a comparison of visual and sensory performance between the three conditions.
Summary

Currently, there is great debate in the women’s lacrosse world regarding the use of headgear for athlete safety. While previous research has shown that headgear leads to a decrease in the forces and acceleration that a head experiences during an impact, there is no research to support that helmets reduce concussion incidence. Research has also shown that addition of more than one object to a person’s visual field decreases their ability to focus and identify objects within that field and, therefore, changes to the type of headgear worn by lacrosse players may influence their visual abilities. Without the ability to visualize all of one’s surroundings, and with the bars on the facemask or goggles posing as potential visual distractors, an athlete’s performance as well as his/her safety may be compromised. However, much of the current research fails to take into account the connection between the visual field and headgear. Therefore, this study seeks to investigate whether different types of headgear (helmet or goggles) differentially affect visual outcomes in female collegiate lacrosse players compared to an unequipped condition.
CHAPTER III  
METHODOLOGY

Participants

This study included a sample of 16 healthy, female participants (Age: 20.44±1.01 years, Height: 163.35±5.19 cm, Weight: 60.87±11.59 kg) who currently play or have a history of playing lacrosse for at least one year at a varsity level (high school or college). Participants were recreationally active, performing 30 minutes of exercise at least three times per week, and between 18 and 25 years old. Participants were excluded if they were diagnosed with a concussion within the last year, had any known neurocognitive deficits, had a previous injury to the brain that resulted in a loss of activity for more than three weeks, or had a history of psychological conditions. Participants with history of permanent vision loss, strabismus, previous corrective eye surgery, or color blindness, as well as those with a history of dizziness, abnormal vestibular function, or musculoskeletal abnormalities that would disturb normal range of motion were also excluded from this study.

Instrumentation

The Senaptec Sensory Station was used. The Senaptec Sensory Station is a computer-based system designed to evaluate multiple domains related to vision and sensory performance. Although little information regarding the psychometric properties of the Senaptec Sensory Station is available,
other computer-based visual and sensory performance assessments have been shown to be highly valid and reliable. The Senaptec Sensory Station assessed ten different visual and sensory performance skills of the participants: visual clarity, contrast sensitivity, depth perception, near-far quickness, perception span, reaction time, multiple-object tracking, target capture, hand-eye coordination, and go/no go. The Senaptec Sensory Station incorporates the use of a Motorola touch-screen-phone, which acts as a response device for some of the tests, an android touch-screen tablet, and a 50-inch, height-adjustable screen. The following domains were tested using the Senaptec Sensory Station:

1. Visual Clarity – Participant’s were given a Motorola touch screen phone and asked to stand a distance of 10 feet from the tablet screen. A Landolt ring (circular ring with a gap at either the top, bottom, left, or right side) appeared on the screen, with the gap appearing at a random direction at predetermined sizes. The participant is asked to swipe on the phone in the direction of the gap on the Landolt ring. The Landolt rings decrease in size until the participant can no longer correctly identify the direction of the gap. At this point, the Landolt rings increase in size until the correct direction is identified. These reversal points continue until the smallest size at which the participant can still accurately determine the direction of the Landolt ring gap is determined. The dominant and non-dominant eyes are evaluated separately, using an eye occluder, as well as together in a condition using both eyes.

2. Contrast Sensitivity – The participant remains 10 feet from the tablet and continues to respond using the Motorola touch screen phone. Four circles appear on the tablet screen in a diamond configuration. One of the circles displays a set of concentric circles that vary in brightness. The participant is asked to swipe the phone in the direction of the
circle that contains the concentric circle pattern. With each correct response, the concentric circles continue to get fainter, making the appropriate response more difficult to discern. Similar to visual clarity, reversal points are used until the faintest level at which the participant can correctly identify the concentric rings is found. Contrast sensitivity was assessed at 2 spatial frequencies of 6 cycles per degree and 18 cycles per degree.

3. Depth Perception – Participants remain 10 feet from the tablet during the depth perception assessment, which requires a pair of red-blue glasses and the Motorola phone to continue interacting with the screen. The tablet displays four rings in a diamond shape pattern, with one of the rings appearing to float in front of the screen (appears closer to the participant). The participant is asked to swipe on the phone in the direction of the ring that is floating out of the screen. The differences between the rings in the background and the ring in the foreground become less pronounced until the subtlest difference that the participant can identify is determined. Participants complete this assessment looking over their right shoulder, their left shoulder, and looking straight ahead.

4. Near-Far Quickness – Participants continue to stand 10 feet from the tablet screen and use the cell phone to interact with the system. Landolt rings, whose size depends on the participant’s results from the visual clarity section, appear alternatingly on the cell phone and the tablet screen. The participant must alternate their gaze from the cell phone to the tablet screen, always swiping on the phone in the direction of the gap of the Landolt ring. This is the first assessment in the Senaptec Sensory Station battery where speed matters; the test continues for 30 seconds and the participants tries to correctly identify as many Landolt ring gaps as possible.
5. Perception Span – The participant stands at an arm’s length (approximately two feet) from the tablet screen and directly interacts with the tablet. Participants focus on a central dot in the center of a grid pattern. Then, a pattern of dots, which are pseudorandomized to prevent recognizable shapes, flash in the grid pattern for 100ms. Once the pattern disappears, the participant is asked to select the dots necessary to recreate the pattern. The pattern continues to get larger and the increase in difficulty as long as the participant achieves at least 75% accuracy. The difficult levels range from six circles with 2 or 3 dots highlighted, to thirty circles with 7 to 10 dots flashing. After two failed attempts (less than 75% accuracy) at the same level, the test ends.

6. Reaction Time – The participant continues to stand at an arm’s length from the tablet screen. Two sets of concentric rings appear on each side of the screen, with the participant placing their index finger of each hand on the inner most circles. Two, three, or four seconds later, one of the concentric circles turn red. The participant is instructed to remove that hand’s index finger as quickly as possible, while leaving their other index finger in place. This task is completed seven times, in a pseudorandom order to avoid anticipation effects on the right and left sides. If a trial was performed at slower than two standard deviations of their mean performance, the trial could be repeated (two total trials could be repeated, for a maximum number of nine total trials). Reaction time, in milliseconds, is calculated as an average score, and for both the dominant and non-dominant hands.

7. Multiple-Object Tracking – The participant is instructed to stand at an arm’s length away from the tablet screen and focus on a central dot. Multiple pairs of dots (between 2 and 8 pairs based on participant performance) appear on the screen, with the participant asked
to follow one of the two dots from each pair. The dot to be tracked by the participant is illuminated red for one second at the beginning of each trial. Each pair of dots begins to separately rotate in different directions for five seconds. After the dots complete their rotations, the participant must choose which dot within each pair was illuminated in the beginning. A total of ten trials are completed, with the number of pairs as well as the speed of rotation varying during the assessment.

8. Target Capture – Participants are now asked to stand 10 feet away from the 50-inch screen raised to eye level, using the cell phone to interact with the visual stimuli. With the participant focusing on the center of the screen, a Landolt ring briefly appears in one of the four corners of the big screen. Participants are instructed to find the Landolt ring, identify the direction of the gap, and swipe their finger in the direction of the gap on the Motorola touch screen. The time the Landolt ring appears on the screen decreases with each correct answer.

9. Hand-eye Coordination – Participants stand at an arm’s length distance (approximately 2 feet) from the 50-inch display. The screen shows an 8x10 matrix of 80 circles, with one circle illuminated green. Participants are instructed to touch the illuminated circle as quickly possible. As soon as the circle was selected, a different circle will illuminate green. The process continues through a series of 80 pseudorandomized circles. Although the illuminated circles appear random to the participants, they are controlled to avoid clusters or recognizable sequences that may impact performance.

10. Go/No Go – The Go/No Go assessment is similar to the Hand-Eye Coordination assessment, with the added difficulty of decision-making. Participants continue to stand at an arm’s length distance from the 50-inch display. The screen displays the same 8x10
matrix of circles, but now circles are either illuminated green or red. The participant is
instructed to touch the green circles as quickly and accurately as possible but to avoid all
the red circles. Each circle, both green and red, is only illuminated for 500ms before a
new circle is illuminated. The same pseudorandomized procedures used in the Hand-Eye
Coordination are used for this assessment. The outcome from this assessment is the
number of green dots correctly hit minus the number of red dots incorrectly selected, with
25% credit given to green dots that were hit late (within 500ms of the illumination
disappearing).

Procedure

Prior to study participation, all individuals signed an informed consent document
approved by the University’s Institutional Review Board. Once consent was obtained,
participants were fit for appropriately sized lacrosse helmet and goggles. Participants completed
one testing session with three headgear conditions: no headgear, helmet, and goggles.
Participants completed all 10 Senaptec Sensory Stations assessments during each condition, with
the assessments on the station always following the same pre-determined order: 1) visual clarity,
2) contrast sensitivity, 3) depth perception, 4) near-far quickness, 5) perception span, 6) reaction
time, 7) multiple object tracking, 8) target capture, 9) hand-eye coordination, and 10) go/no go.
However, each condition (no headgear, helmet, or goggles) was randomized to minimize the
potential for learning or fatigue effects (Table 1).
### Table 1. Randomization schedule.

<table>
<thead>
<tr>
<th>Ordering Condition</th>
<th>Order of Headgear Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A B C</td>
</tr>
<tr>
<td>2</td>
<td>A C B</td>
</tr>
<tr>
<td>3</td>
<td>B A C</td>
</tr>
<tr>
<td>4</td>
<td>B C A</td>
</tr>
<tr>
<td>5</td>
<td>C A B</td>
</tr>
<tr>
<td>6</td>
<td>C B A</td>
</tr>
</tbody>
</table>

Legend: A – no headgear; B – helmet; C - goggles

Conditions were randomized in blocks of six, such that for every six participants completing the study, each potential order of conditions was completed once. The only difference between each condition was the presence or type of headgear used. All testing was completed in one, two-hour test session.

### Data Analysis

All data were analyzed using SAS and one-way analyses of variance (ANOVAs) were conducted. The independent variable manipulated was the type of headgear and the dependent variables measured were the visual and sensory performance outcomes. The Senaptec Sensory Station outputs all outcome variables of interests for this study for each of the 10 assessments, which are summarized in “outcome variable” column in Table 2. All outcomes of interest were analyzed using separate, repeated-measures ANOVAs, looking at within subject factors (Table 3).

### Power Analysis

Previous work looking at the effect of various sport helmets on visual and sensory performance in male athletes was used to determine the effect size and correlation between...
measures on the Senaptec Sensory Station. The effect size and correlation for each Senaptec assessment was averaged over all ten outcome measures and these values were used to calculate the required sample size. Using the following parameters ($\alpha = 0.05$, Power$= 0.80$, Number of groups$= 1$, Number of measurements$= 3$, Effect size$= 0.305$, Correlation among repeated measures$= 0.394$, and Nonsphericity correction$= 1$ (sphericity assumption is met)), it was determined that 23 subjects were needed to adequately power the study. Since this study uses blocked randomization with block sizes of six to account for the different potential order of conditions (see Table 1), a total of 24 subjects will be recruited for this study. At the time of submission, 16 participants have been tested, however data collection is ongoing to satisfy this power analysis.
Table 2. Testing Procedures and Data Reduction

<table>
<thead>
<tr>
<th>Domain</th>
<th>Test Measure</th>
<th>Outcome Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Clarity</td>
<td>Measures how well one can see distant details</td>
<td>logMAR (20/20 vision = value of 0)</td>
</tr>
<tr>
<td>Contrast Sensitivity</td>
<td>Measures how well one can judge contrast differences</td>
<td>log CS = -log(1/threshold)</td>
</tr>
<tr>
<td>Depth Perception</td>
<td>Measures how well one can judge depth and distance</td>
<td>Arcseconds*</td>
</tr>
<tr>
<td>Near-Far Quickness</td>
<td>Measures how rapidly and precisely one can shift their gaze between near and far distances</td>
<td>Number of cycles that the participant completed</td>
</tr>
<tr>
<td>Perception Span</td>
<td>Measures the scope of one’s visual field and how well one acquires visual information</td>
<td>Number of correctly identified circles</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>Measures how quickly one is able to react in response to a visual stimulus</td>
<td>Time (ms)*</td>
</tr>
<tr>
<td>Multiple-Object Tracking</td>
<td>Measures how well one is able to divide attention between moving objects and track them at different speeds</td>
<td>Maximum number of tracked circles Maximum rotation speed</td>
</tr>
<tr>
<td>Target Capture</td>
<td>Measures how quickly one is able to shift their gaze and recognize a target in their periphery (Dynamic Visual Acuity)</td>
<td>Response time (ms)*</td>
</tr>
<tr>
<td>Hand-Eye Coordination</td>
<td>Measures how rapidly and accurately one is able to respond to changing targets</td>
<td>Time to complete task (ms)*</td>
</tr>
<tr>
<td>Go/No Go</td>
<td>Measures how rapidly and accurately one is able to make a decision about a target and respond to the changing targets</td>
<td>Number of correct hits Number of incorrect hits Correct hits – incorrect hits</td>
</tr>
</tbody>
</table>

* Indicates a lower score is indicative of better performance
### Table 3. Data Analysis Measures

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Comparison</th>
<th>Data Source</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a. Is there an effect of headgear (no headgear vs. full helmet) on visual and sensory performance outcomes?</td>
<td>No headgear vs. full helmet</td>
<td>Independent Variable: • Headgear type</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dependent Variable: • Sensory and performance outcomes</td>
<td></td>
</tr>
<tr>
<td>1b. Is there an effect of headgear (no headgear vs. goggles) on visual and sensory performance outcomes?</td>
<td>No headgear vs. goggles</td>
<td>Independent Variable: • Headgear type</td>
<td>Repeated-measures ANOVA (within factors)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dependent Variable: • Sensory and performance outcomes</td>
<td></td>
</tr>
<tr>
<td>1c. Is there an effect of headgear (full helmet vs. goggles) on visual and sensory performance outcomes?</td>
<td>Full helmet vs. goggles</td>
<td>Independent Variable: • Headgear type</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dependent Variable: • Sensory and performance outcomes</td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER IV
MANUSCRIPT

Introduction

Concussions continue to account for 9% of all sports injuries (up to 3.8 million injuries per year)\(^1\) despite new rules and mandatory education designed to prevent injury.\(^2\) Many governing bodies of sport have instituted new rules to protect athletes based on the prevalence of concussions and head injuries in sport over the past years, such as the addition of goggles in women’s lacrosse to reduce head and face injuries.\(^4\) Headgear may protect against catastrophic injury, but helmets and other protective headgear do not necessarily reduce an individual’s risk of concussion.\(^5\) In women’s lacrosse, concussions remain a large risk, accounting for 6.3% of injuries sustained in the sport.\(^1\)

Reduction of catastrophic brain injuries is the primary concern in helmet design. Current helmet testing standards largely fail to evaluate the way headgear can affect an athlete’s vision, which is critical to sport performance and safety. An athlete must be able to visually identify potential risks in the rapid and ever-changing sport environment in order to avoid or anticipate these dangerous situations.\(^9\) With limited capacity for the processing of visual and sensory performance in the brain,\(^10\) components of headgear could pose as visual distractors that are dividing the athlete’s attention between the equipment and the game. The substantial differences between full helmets and goggles, specifically the number and position of bars, could lead to different visual and sensory capabilities for athletes in these different types of headgear.
Female lacrosse players have a higher risk of concussion than their male counterparts. Many attribute this to the headgear worn during play.\textsuperscript{5,13} This has sparked an ongoing debate regarding whether female lacrosse players should be required to switch to a full helmet or if the current protective goggles are sufficient.\textsuperscript{14} Much of this debate regarding headgear in women’s lacrosse is centered on how each type of headgear can dissipate the forces that are exerted on the athlete’s head during an impact,\textsuperscript{14} while little has focused on how various headgear types can influence visual capabilities, athlete safety, and sports performance. As studies have indicated that anticipated collisions result in less severe impacts than unanticipated collisions,\textsuperscript{19} visual capabilities in headgear is a critical component in resolving this debate.

Therefore, the purpose of this study is to analyze how headgear affects visual and sensory performance in college-aged female lacrosse players. It was hypothesized that headgear would cause a detriment and that goggles would cause more of a detriment than a helmet. Headgear was hypothesized to cause a decrement in performance because the bars of both types of headgear could pose as visual distractors to the visual and sensory processing areas of the brain. Goggles were hypothesized to be worse because they have bars closer to the eyes than a helmet and therefore may take up larger parts of the visual field when attempting to process visual and sensory information.

\textbf{Methods}

\textbf{Participants.}

Sixteen participants between the ages of 18 and 25 who had a history of playing lacrosse for at least one year at the varsity level, and being currently recreationally active (\geq 30 minutes of exercise, three times per week). Participants were excluded if they were diagnosed with a
concussion within the last year, had any known neurocognitive deficits, had a previous injury to the brain that resulted in a loss of activity for more than three weeks, or had a history of psychological conditions. Participants with history of permanent vision loss, strabismus, previous corrective eye surgery, or color blindness, as well as those with a history of dizziness, abnormal vestibular function, or musculoskeletal abnormalities that would disturb normal range of motion were also excluded from this study. All participants gave informed consent.

Procedures.
Participants completed the ten Senaptec Sensory Station assessments under three conditions (no headgear, helmet, and goggles) during one, two-hour testing session. Participants were randomized to condition order in block sizes of six, so that for every six participants completing the study, each potential order of conditions was completed once. The Senaptec Sensory Station assessments include ten assessments of visual and sensory performance and assessments were always completed in the same order. Outcome variables of each task are outlined in Table 4.

Statistical Analyses.
All data was analyzed using SAS Version 9.4 (Cary, North Carolina). Separate one-way repeated-measures ANOVAS were run to analyze the effect of headgear on visual and sensory performance outcomes. The independent variable analyzed was headgear condition and the dependent variables were the visual and sensory performance outcome measures from the Senaptec Sensory Station.
Table 4. Senaptec Sensory domains and outcome measures

<table>
<thead>
<tr>
<th>Domain</th>
<th>Test Measure</th>
<th>Outcome Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Clarity</td>
<td>Measures how well one can see distant details</td>
<td>logMAR (20/20 vision = value of 0)</td>
</tr>
<tr>
<td>Contrast Sensitivity</td>
<td>Measures how well one can judge contrast differences</td>
<td>log CS = −log $\frac{1}{\text{threshold}}$</td>
</tr>
<tr>
<td>Depth Perception</td>
<td>Measures how well one can judge depth and distance</td>
<td>Arcseconds*</td>
</tr>
<tr>
<td>Near-Far Quickness</td>
<td>Measures how rapidly and precisely one can shift their gaze between near and far distances</td>
<td>Number of cycles that the participant completed</td>
</tr>
<tr>
<td>Perception Span</td>
<td>Measures the scope of one’s visual field and how well one acquires visual information</td>
<td>Number of correctly identified circles</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>Measures how quickly one is able to react in response to a visual stimulus</td>
<td>Time (ms)*</td>
</tr>
<tr>
<td>Multiple-Object Tracking</td>
<td>Measures how well one is able to divide attention between moving objects and track them at different speeds</td>
<td>Maximum number of tracked circles Maximum rotation speed</td>
</tr>
<tr>
<td>Target Capture</td>
<td>Measures how quickly one is able to shift their gaze and recognize a target in their periphery (Dynamic Visual Acuity)</td>
<td>Response time (ms)*</td>
</tr>
<tr>
<td>Hand-Eye Coordination</td>
<td>Measures how rapidly and accurately one is able to respond to changing targets</td>
<td>Time to complete task (ms)*</td>
</tr>
<tr>
<td>Go/No Go</td>
<td>Measures how rapidly and accurately one is able to make a decision about a target and respond to the changing targets</td>
<td>Number of correct hits Number of incorrect hits Correct hits – incorrect hits</td>
</tr>
</tbody>
</table>

*Indicates a lower score is indicative of better performance
Results

The study included sixteen healthy, female participants (Age: 20.44±1.01 years, Height: 163.35±5.19 cm, Weight: 60.87±11.59 kg). On average, participants played lacrosse for 6.56 years. Seven participants were actively playing lacrosse at the time of testing and there was a maximum of four years since playing lacrosse. Lacrosse experience varied from nine participants designating high school varsity as their highest level, six competing at the collegiate club level and one participant competing at the collegiate varsity level. Participants were asked about their perceived discomfort in a helmet and those that reported not having participated in a sport requiring a helmet (n=13), reported an average comfort of 2.53 out of 5, indicating slight discomfort. Two participants reported playing the goalie position of women’s lacrosse, which requires a full helmet, and one participant reported playing softball with a full facemask in addition to her lacrosse experience. These participants (n=3) reported an average comfort of 4.67 out of 5, indicating high comfort in a helmet.

Means and standard errors for each visual and sensory performance outcome are listed in the table below for each of the headgear conditions (Table 5). Our analysis revealed no significant differences in the visual and sensory performance metrics across any headgear condition (p>0.05).

Table 5. Means and standard error for Senaptec Sensory Station tasks

<table>
<thead>
<tr>
<th>Senaptec Outcomes</th>
<th>No Headgear</th>
<th></th>
<th>Goggles</th>
<th></th>
<th>Full Helmet</th>
<th></th>
<th>F-value</th>
<th></th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>(2,30)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual Clarity</td>
<td>-0.067</td>
<td>0.12</td>
<td>-0.064</td>
<td>0.19</td>
<td>-0.074</td>
<td>0.098</td>
<td>0.02</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>Contrast Sensitivity</td>
<td>1.66</td>
<td>0.37</td>
<td>1.59</td>
<td>0.31</td>
<td>1.71</td>
<td>0.29</td>
<td>0.60</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Depth Perception</td>
<td>109.06</td>
<td>93.99</td>
<td>141.12</td>
<td>99.16</td>
<td>127.75</td>
<td>96.35</td>
<td>0.45</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>Near-Far Quickness</td>
<td>27.31</td>
<td>5.83</td>
<td>26.13</td>
<td>7.46</td>
<td>28.00</td>
<td>6.24</td>
<td>0.34</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>Perception Span</td>
<td>39.75</td>
<td>13.89</td>
<td>42.56</td>
<td>13.87</td>
<td>41.31</td>
<td>12.02</td>
<td>0.18</td>
<td>0.84</td>
<td></td>
</tr>
<tr>
<td>MOT Proportion Score</td>
<td>0.72</td>
<td>0.11</td>
<td>0.75</td>
<td>0.12</td>
<td>0.76</td>
<td>0.098</td>
<td>0.65</td>
<td>0.53</td>
<td></td>
</tr>
<tr>
<td>Reaction Time</td>
<td>375.00</td>
<td>27.97</td>
<td>369.75</td>
<td>24.26</td>
<td>376.75</td>
<td>28.67</td>
<td>0.29</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>Target Capture</td>
<td>228.13</td>
<td>95.25</td>
<td>231.25</td>
<td>140.68</td>
<td>182.81</td>
<td>43.51</td>
<td>1.15</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>Eye-Hand Coordination</td>
<td>53283</td>
<td>6138.67</td>
<td>51584</td>
<td>3959.27</td>
<td>52273</td>
<td>4280.57</td>
<td>0.49,</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>Go/No Go</td>
<td>4.25</td>
<td>3.75</td>
<td>4.44</td>
<td>3.81</td>
<td>3.94</td>
<td>3.66</td>
<td>0.07</td>
<td>0.93</td>
<td></td>
</tr>
</tbody>
</table>
Discussion

In a sample of sixteen healthy, college-aged, female lacrosse players, no significant differences were found across headgear conditions in any visual and sensory performance tasks. We did not find any detriment in visual and sensory performance when participants wore either type of headgear. This finding contradicts the hypothesis that performance would be diminished in the presence of headgear. Results from the visual clarity and contrast sensitivity tasks suggest the bars of the goggles or the helmet are not posing any obstruction to the visual field. Results from depth perception, near-far quickness, perception span, multiple object tracking, reaction time, target capture, eye-hand coordination and go/no go suggest that headgear does not interfere in participants’ abilities to use full visual and cognitive function to complete the tasks.

Although many sources in the literature indicate that there is a limited capacity for visual information at one time,\textsuperscript{10} this study’s findings showed no difference in the visual and sensory performance markers with the presence of bars in the participant’s visual field. Studies have shown that individuals can selectively determine which visual and sensory information is relevant to the current task or behavior.\textsuperscript{10} Our sample consisted of experienced female lacrosse players (6.56 years of average playing experience) and it is possible that the participants are habituated to filtering out the bars of this headgear. Studies have shown that the plasticity of the central nervous system includes “experience-dependent plasticity,” which leads to a decreased response to the same stimulus over a period of time.\textsuperscript{76} The way in which attention is distributed depending on retinal input can also change over time as one undergoes perceptual grouping, in which the visual system is able to organize different inputs into objects that are either relevant or irrelevant.\textsuperscript{77}
Other theories explaining visual adaption center around visual attention. Studies have determined that the competition for attention within the visual system occurs in the ventral stream of visual processing and top-down processing leads to the proper stimuli being suppressed in processing. Therefore, since the central nervous system was already aware of its goal in the Senaptec Sensory Station task, as it would be in a sport situation, the visual input of the bars from the headgear were able to be properly suppressed such that it did not affect visual and sensory performance. The literature suggests a short-term and long-term habituation component to stimuli in the visual-attention system, which offers an explanation as to why the habituation to the bars in the headgear was still present despite participants not having played lacrosse in an average of 1.78 years.

In addition to the goggles, we found no differences in visual and sensory performance outcomes in helmeted conditions. Goaltenders are currently the only female lacrosse players mandated to wear full helmets. However, the bars used in full lacrosse helmets are similar to those used in goggles. The same habituation aiding in the goggles findings could be transferred to the helmeted conditions, thus aiding in the ability to filter out the distraction of the helmet bars. Therefore, despite the goggles consisting of fewer bars that are closer to the face than the helmets, the participants were able to classify that visual stimulus as irrelevant based on their prior experience with the goggle bars.

Limitations. This study’s largest limitation was a small sample size. With only 16 participants, the effects of the helmet and goggles may not truly be representative of the population of female, college-aged lacrosse players. The limited age-range included within the study fails to account for a large portion of the women’s lacrosse population, as US Lacrosse has rules denoted from ages six and up. Younger players may be more affected by headgear, as they have not played
long enough for this habituation to occur. Little head movement and use of peripheral vision occurs in the majority of the tasks of the Senaptec Sensory Station. These limitations affect the generalizability of the results as there is ample head movement throughout a lacrosse game. The full helmet or goggles may potentially impede more of the peripheral field of vision, which was not accounted for in most of the tests. Finally, there are many different brands and types of goggles approved by US Lacrosse, so some of the participants may have been more comfortable in the one set of goggles that were provided to them than others. Similarly, there were only three sizes of helmet available for the participants. While they were fit to the best of the researcher’s ability, the helmets and goggles worn by players in lacrosse games may be better suited or better fit to the individual’s head such that it would be more comfortable. Therefore, further research should include a larger sample size, take into account a wider age range, and have participants provide their own fitted goggles and helmet.

Significance. With the literature suggesting that vision is an important component in sports safety, these findings suggest that vision is preserved regardless of headgear condition. Therefore, this adds to the current debate in women’s lacrosse regarding whether helmets or goggles should be worn because most of the debate has focused on forces that are applied to the head or the implementation of new rules. This study provides previously unknown information regarding how different types of headgear affect visual and sensory performance.

Conclusions. The preservation of visual and sensory performance between conditions suggests no difference in an athlete’s visual and sensory performance while wearing no headgear, helmet, or goggles. Studies have shown vision to be an important component of sports safety, allowing athletes to anticipate and respond to hits or other dangerous situations in sports. The results of this study suggest that athletes should be able to see and respond equally as well in helmets or
goggles. Many are concerned about the “Gladiator Effect” in women’s lacrosse, where athletes are more aggressive when they feel more protected, and that the addition of helmets would lead to a change in the women’s game from skill and finesse to violence.¹⁵

The results of this study suggest that there is no detriment to the athlete’s visual and sensory performance abilities between helmet and goggles conditions. However, as the current trajectory of women’s lacrosse seems wishes to remain a non-contact sport, we recommend the continuation of goggles as protective headgear. The participant’s general feeling of discomfort toward wearing a helmet further supports this, and we recommend that lacrosse governing bodies continue to implement rule changes to further decrease the number of concussions on the field.

Future Directions in this Research Line. The debate on the most advantageous headgear is ongoing in women’s lacrosse. While the results of this study suggest the continuation of goggles as protective headgear, future studies should continue to explore this research area to provide the most up-to-date information and continue to prioritize athlete safety. Future studies should attempt to replicate this study is various ages and experience levels. Should a similar study find that there is a larger decrement in a goggled condition, there is a potential that women’s lacrosse may benefit from helmets and this implementation should begin at younger ages of play to increase playing comfort. Should the study find that goggles are better or that there is no difference in headgear throughout all age ranges, it would be recommended that women’s lacrosse continue the use of goggles. Additional studies should evaluate the effect of headgear on the peripheral aspects of vision. There is a potential that this was not properly accounted for in the Senaptec Sensory Station because many of the tasks require little movement of the head and targets that are straight in front of one’s visual field. Peripheral vision is incredibly important in one’s ability to perceive dangers on the field during a game situation. Should this study find that
goggles or helmets inhibit the peripheral field of vision more, there is a potential that this information would contribute further to the discussion of headgear in women’s lacrosse. Finally, the most informative study would be the implementation of helmets in one league of women’s lacrosse while continuing the use of goggles in another similar league, and track the injuries in both populations. This would allow a better understanding of how the helmet would change the game of women’s lacrosse and if those concerned about the “Gladiator Effect” were correct in their concern of the addition of violence to the game.
REFERENCES


