The Effect of Lacrosse Helmet Fit on Cervical Spine Movement during a Prone Log Roll

Evan Boyd Allen

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Approved by:

Meredith A. Petschauer, PhD, ATC (Advisor)

Jason P. Mihalik, PhD, CAT(C), ATC (Reader)

Joseph B. Myers, PhD, ATC (Reader)

Nina Walker, MA, CSCS, ATC (Reader)

ABSTRACT

EVAN B. ALLEN: The Effect of Lacrosse Helmet Fit Condition on Cervical Spine Movement during a Prone Log Roll

(Under the Direction of Dr. Meredith A. Petschauer)

Objective: To determine what effect lacrosse helmet fit (properly fit helmet, competition fit helmet, and helmet removed) has on movement of the cervical spine during a prone log roll. **Subjects:** Eighteen varsity male lacrosse players (age = 19.67 ± 1.33 years, height = 183.83 ± 6.60 centimeters, mass = 85.77 ± 7.47 kilograms) at The University of North Carolina at Chapel Hill. **Methods:** Head-to-thorax and helmet-to-thorax movement in the frontal, sagittal and transverse planes were recorded during a prone log roll for each helmet fit condition. Motion data was integrated and normalized to measure the total amount of sagittal, transverse, and frontal plane movement in each of the helmet fit conditions. A series of repeated measures ANOVA's were used for statistical analysis. **Results:** There was a significant difference in that amount of head-to-thorax movement that occurred in the transverse plane ($F_{2,34} = 6.00$, $p = .006$). Pair wise comparisons determined the transverse plane motion to be significantly greater in the properly fit helmet condition than in the helmet removed condition (Mean Difference = 5.19, Std. Error = 1.21, $p = .001$). A significant difference in the amount of movement between the head and helmet were found in transverse planes of the competition fit ($F_{1,17} = 11.211$, $p = .004$ Mean Difference = 5.19, Std. Error = 1.21, $p = .001$) and properly fit ($F_{1,17} = 22.005$, $p < .001$) conditions. There were no significant differences in either head to thorax motion or helmet to thorax motion in the frontal, or sagittal plane. **<u>Conclusion:</u>** The results of this study suggest that the presence of the Cascade Pro7 lacrosse helmet only causes head movement to increases in the transverse plane when the helmet is properly fit. Because the helmet is difficult to remove when the athlete is prone and most lacrosse helmets are improperly fit, it may best to leave the helmet in place until the athlete has been log rolled onto a spineboard.

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INTRODUCTION

Head and neck injuries are among the most concerning to sports medicine professionals, and it has been shown that as many as 11%-20% of all lacrosse injuries affect the head, face, or neck (Diamond & Gale, 2001; Dick, Romani, Agel, Case, & Marshall, 2007). Lacrosse has become increasingly popular across the United States with a 68% increase in the number of participants since 2001(Casazza & Rossner, 1999; US Lacrosse, 2006). The game of lacrosse is a high-speed and high-contact sport. As the number of participants in lacrosse increase, the prevalence of injury is likely to do the same. It is crucial that the individuals responsible for the emergency care of these athletes have the information needed to make the correct treatment decisions.

Men's lacrosse is a contact sport that is comparable to football and ice hockey, and with it come similar health and safety risks (Decoster, Bernier, Lindsay, & Vailas, 1999). Like these other sports lacrosse is a contact sport in which there is continuous cutting and changing direction. The athletes also wear protective helmets and shoulder pads in lacrosse, which in the case of a head or neck injury can complicate the rescue process. This is an issue because when comparing incidence of catastrophic cervical spine injuries per 100,000 participants, the rate is actually higher in college lacrosse (2.11) then it is in collegiate football (1.89) (Mueller & Cantu, 2009; Swartz, et al., 2009).

The National Center for Catastrophic Sports Injury Research database reports that there have been 11 catastrophic cervical spine injuries in collegiate lacrosse between 1982 and 2007 and 9 among high school lacrosse players (Mueller & Cantu, 2009). While the total number of catastrophic injuries remains low, given the number of injuries to the head, face, and neck, there are a large number of athletes who potently could require on-field spine injury management (Diamond & Gale, 2001; Dick, et al., 2007). It is likely that as participation, in lacrosse, continues to increase so will the number of these types of injuries.

Immobilization of the head and trunk is the most important part of management of the athlete with a suspected cervical spine injury. Stabilization is relatively uncomplicated as long as the athlete is not wearing protective equipment such as helmets and shoulder pads. However, due to the high impact nature of the sports that most commonly require cervical spine stabilization, the presence of protective head, neck, and shoulder equipment is very likely (Swartz, et al., 2009). This results in a more complicated immobilization process. Preventing secondary injury to the injured athlete by properly managing a suspected cervical spine injury is a difficult task for the athletic trainer and other medical professionals.

The National Athletic Trainers' Association organized a task force in 1998 with the goal of developing the proper techniques and guidelines for the on-field management of cervical spine injuries, in the presence of head and upper body protective equipment (A. Kleiner, Jon L., Bailes, Julian, Burruss, Pepper T., Feuer, Henry, Griffen, Letha Y., Herring, Stanley, McAdam, Connie, Miller, Dennis, Thorson, David, Watkins, Robert G., Weinstein, Stuart, 2001). The Inter-Association Task Force for Appropriate Care of the Spine Injured Athlete (IATF) recommended that in football, ice hockey and men's lacrosse the helmet and shoulder pads be left in place during the immobilization process. They suggest that equipment should only be removed once the individual is at the hospital and in a controlled environment. However, if the helmet and shoulder pads do not provide adequate support and stabilization of the head and neck they recommend they be removed immediately (Swartz, et al., 2009).

While the IATF acknowledges that the equipment in lacrosse has a different effect on the cervical alignment of the athlete (Higgins, Tierney, Driban, Edell, & Watkins, ; Sherbondy, Hertel, & Sebastianelli, 2006), there is currently not significant research available to make a recommendation specific to men's lacrosse (Swartz, et al., 2009). However, they do advocate following the principles of managing the equipment-laden athlete including that the helmet be removed if it does not prevent movement of the head inside the helmet, it prevents neutral alignment of the cervical spine or airway access, or if the facemask cannot be removed in a reasonable amount of time (Swartz, et al., 2009).

It has been well established in football that it is best for the athlete with a suspected cervical spine injury to remain in full pads as long as no complication exist (Donaldson, Lauerman, Heil, Blanc, & Swenson, 1998a; Peris, Donaldson, Towers, Blanc, & Muzzonigro, 2002). Complications that would warrant the removal of football equipment are the same as those mentioned previously. Currently, there has been little research that specifically determines the proper management of a suspected cervical spine injury in men's lacrosse. It was concluded in one study that the rotational movement seen inside an immobilized lacrosse and ice hockey helmet was not significantly different to that seen in football helmets as long as the helmet is correctly fitted (Waninger, Richards, Pan, Shay, & Shindle, 2001). Since that time, a couple of studies have resulted in different conclusions (Mihalik, Beard, Petschauer, Prentice, & Guskiewicz, 2008; Petschauer, 2010).

A study evaluating the effect an ice hockey helmet has on cervical spine movement during a prone log roll found that when the helmet was removed, there was significantly less head-to-thorax movement in the sagittal and transverse planes then when the helmet was in place, regardless of fit. Basically, the helmet removed condition resulted in less cervical flexion and rotation (Mihalik, et al., 2008). Prior to this, a study showed that significantly more head-to-thorax movement was present in athletes immobilized while wearing the Cascade CPX lacrosse helmet in comparison to the no helmet condition (Petschauer, 2010). In another study researching lacrosse equipment, Sherbondy determined that the helmet and shoulder pads worn by men's lacrosse players does not allow for neutral cervical spine alignment while immobilized and that removal of helmet alone does not affect cervical alignment (Sherbondy, et al., 2006). These findings were substantiated in a recent article which showed that while removal of the Riddell Revolution lacrosse helmet does effect the cervical-thoracic angle it does not cause any change in the space available for the spinal cord (Higgins, et al.). To our knowledge no one has investigated at the effect of lacrosse equipment on cervical spine movement prior to immobilization. Further research is needed to increase our understanding in this area. Therefore, the purpose of this study is to determine the effect of lacrosse helmet fit on cervical spine movement during a prone log roll.

Variables

Independent

Helmet fit conditions:

1. Properly Fit (PF)
2. Competition Helmet (CH)

3. Helmet Removed (HR)

Dependent

1. Head-to-thorax cervical rotation in the transverse plane
2. Head-to-thorax cervical flexion/extension in the sagittal plane
3. Head-to-thorax lateral flexion in the frontal plane
4. Helmet-to-thorax cervical rotation in the transverse plane
5. Helmet-to-thorax cervical flexion/extension in the sagittal plane
6. Helmet-to-thorax lateral flexion in the frontal plane

Research Questions

RQ_1: Is there an effect of helmet fit condition on head-to-thorax movement in the frontal, sagittal, or transverse planes during an emergency prone log roll procedure?

RQ_2: Is there an effect of helmet fit condition on helmet-to-thorax movement in the frontal, sagittal, or transverse planes during an emergency prone log roll procedure?

RQ_3: Is there an effect of helmet fit in the difference between head-to-thorax and helmet-to-thorax movement in the PF and CH conditions in the frontal, sagittal, or transverse planes during an emergency prone log roll procedure?

Hypotheses

Null

H_{01}: There is no effect of helmet fit condition on head-to-thorax movement in the frontal, sagittal, or transverse planes during an emergency prone log roll procedure.

H_{02}: There is no effect of helmet fit condition on helmet-to-thorax movement in the frontal, sagittal, or transverse planes during an emergency prone log roll procedure.

H_{03}: There is no effect of helmet on the difference between head-to-thorax and helmet-to-thorax movement in the PF and CH conditions in the frontal, sagittal, or transverse planes during an emergency prone log roll procedure.

Research Hypotheses

RH_1: There will be an effect of helmet fit condition on head-to-thorax movement during an emergency prone log roll procedure, with significantly greater motion occurring in the helmeted conditions. Specifically, movement in the CH condition will be greater than in the PF and HR condition, and motion in the PF condition will be significantly greater than in the HR condition.

RH_2: There will not be an effect of helmet fit condition on helmet-to-thorax movement during an emergency prone log roll procedure. The helmet movement in the CH condition will not be significantly different then in the PF condition.

RH_3: There will be an effect of helmet fit on the difference between head-to-thorax and helmet-to-thorax movement during an emergency prone log roll procedure. The difference between head-to-thorax and helmet-to-thorax movement will be significantly greater in the CH condition then in the PF condition.

Operational Definitions

Cervical Flexion: Movement of the head anteriorly along the sagittal plane.

Cervical Extension: Movement of the head posteriorly along the sagittal plane.

Lateral Flexion: Movement of the head along the frontal plane.

Cervical Rotation: Movement of the head along the transverse plane.

Properly Fit Helmet: Helmet is fit to the athlete as instructed by the manufacturer.

Competition (Improperly) Fit Helmet: Helmet is fit as player wears it during practice and game conditions.

Prone Log Roll: Technique used to transfer a prone athlete into a supine position for immobilization on a spine board.

Assumptions

1. The Motion Star system is reliable in measuring head movement.
2. Movement of the head relative to the thorax accurately represents cervical spine movement.
3. The subjects will follow the instructions they are given to the best of their ability.
4. The subjects and researchers will be consistent during completion of the log rolling protocol in the three separate conditions.

Delimitations

1. Only UNC varsity men's lacrosse players will be used, as this will provide the most consistency between subjects.
2. Only the Cascade Pro7 helmet will be used because this is the only helmet worn by the UNC varsity men's lacrosse team.
3. Testing will take place in a laboratory setting.
4. Only head and helmet movement relative to the thorax will be measured.

Limitations

1. The research will not be done in a real life situation.
2. There may be inconsistencies in the log roll task, from trial to trail.

3. In the properly fit helmet condition, it is possible that not all the helmets will fit exactly the same.
4. Only the Cascade Pro7 helmet will be tested, as it is the only helmet worn by the subjects of this study.

Significance

Due to the potential for cervical spine injury in men's lacrosse, it is crucial for the athletic trainer to have the necessary information on how these situations can best be managed. At this time, there has not been sufficient research looking at the effect of helmet fit on cervical spine movement to make recommendations specific to lacrosse (Swartz, et al., 2009). This study is positioned to provide the clinical research foundation that may influence official recommendations with regard to management of a men's lacrosse player with a suspected cervical spine injury.

CHAPTER II

LITERATURE REVIEW

Introduction

The sport of lacrosse continues to grow and gain popularity throughout the United States (Casazza & Rossner, 1999). Since the year 2001, the number of individuals playing competitive lacrosse has risen 68%, making it one of the fastest growing sports in the nation (US Lacrosse, 2006). It is reasonable to assume that as the numbers of lacrosse participants increases so will the number of injuries sustained by the athletes participating.

The injuries that are the most dangerous to the competitor are often a result of trauma to the head and neck. The routine collisions that are a part of all contact sports make cervical spine injuries a known risk. Due to their nature football and ice hockey, have been the subject of multiple studies investigating ways to make these sports safer for the participants. The same amount of research has not been dedicated to lacrosse despite the fact that it is also a high speed, high contact sport.

The National Center for Catastrophic Sports Injury Research database reports that there have been 11 serious cervical spine injuries between 1982 and 2007 at the collegiate level and 9 among high school athletes. While this may seem like a relatively small number there are an unknown number of times that lacrosse athletes have been immobilized and spine boarded as a precautionary measure. Additionally, the percentage of lacrosse injuries that involve the head, neck and face are estimated at 11% and 20% of all game- and practice related injuries (Diamond & Gale, 2001; Dick, et al., 2007). The number of head and neck injuries seen in lacrosse means that there is a high percentage of athletes sustaining injuries that could require cervical spine stabilization. If these situations are mishandled, the athlete is placed at an increased risk of sustaining secondary cervical spine injury. As the number of lacrosse players increases, it becomes even more important that those responsible for their well-being have the information necessary to make decisions that are in the best interest of the athlete.

Anatomy of the Cervical Spine

The cervical portion of the human spine is made up of seven vertebrae (C1-C7) that give the neck its lordotic curve. The musculature of the head and neck allow for flexion, extension, rotation, and lateral side bending of the head and cervical spinal column (Hiatt, 2002). Of the seven cervical vertebrae the two most superior are referred to as the atlas and axis, and are significantly different from the others. They are designed to support the weight of the head and allowing it to have a greater rotational range of motion (Hiatt, 2002). The first cervical vertebra (atlas) has no vertebral body. In its place is the anterior and posterior arch. These arches are connected via the left and right lateral arches, on which is located the superior and inferior articular facets. The superior facets are the attachment point for the occipital condyles while the inferior facets articulate with the axis (Bogduk & Mercer, 2000). The atlas has been referred to as the cradle because of the manner in which it articulates with the occiput. This atlanto-occipital joint is relatively deep and provides a strong union that allows only flexion and extension of the head (Bogduk & Mercer, 2000). The atlas normally allows 15˚ to 20˚ of flexion/extension. Rotation is not possible at this articulation because of the depth of the lateral arches (Swartz, Floyd, & Cendoma, 2005).

The axis is the second cervical vertebrae. It supports the head and transfers the weight to the rest of the vertebral column via the atlanto-axial joint (Swartz, Floyd, et al., 2005). The axis is similar to the other cervical vertebrae except for a tooth like projection called the dens which articulates with the anterior arch of the atlas. The dens is fixed on the anterior arch by the transverse, alar, and apical ligaments and allows the atlas to rotate on it. Normal rotation is approximately 50˚ in each direction (Swartz, Floyd, et al., 2005).

The more typical cervical vertebrae are C3-C7. Each one consists of a body, two transverse processes, pedicles, lamina, spinous process, foramen transversarium, and vertebral foramen. The vertebral foramen provides a protected passage way for the spinal cord, and the foramen transversarium houses the vertebral blood vessels. The vertebrae's increase in size is directly related to the amount of weight they support. Between each vertebra exists an intervertebral disk which protects the vertebrae from compression and helps dissipate energy as it is transmitted down the spine, and help give the cervical spine its lordotic curve (Hiatt, 2002).

Movement of the cervical spine is provided by a large number of muscles. The muscles located on the posterior aspect of the neck are responsible for extension of the head, neck, and cervical spine. The trapezius muscle mostly acts on the shoulder and scapula but also assists in pulling the head posteriorly and laterally. The splenius and rotator muscles extend and rotate the head and the cervical vertebrae. The iliocostalis, longissimus and spinalis muscles extend the head and cervical spine. The multifidi extends the cervical spine but also flexes it laterally when acting unilaterally. Musculature located on the anterior aspect of the neck is responsible for flexion. These muscles include the longus colli, sternocleidomastoid, and scalenus anterior (Hiatt, 2002).

Mechanism of Injury

An injury to the cervical spine usually takes place as the result of a compression force to the cervical spinal column due to axial loading (Swartz, Floyd, et al., 2005). Under normal conditions the cervical spine has a lordotic curve which results in slight extension of the neck. This position makes it possible for compressive forces to be absorbed and dissipated by the ligaments and musculature surrounding the vertebral column (Banerjee, Palumbo, & Fadale, 2004). If the spine is placed in approximately 30˚ of flexion the lordotic curve is eliminated. Force is then transmitted directly down the spinal column and cannot be absorbed by the surrounding structures. If the compressive force is too great for the bony structure to absorb, the impact will result in a fracture or dislocation of the vertebrae (Nightingale, Camacho, Armstrong, Robinette, & Myers, 2000; Nightingale, McElhaney, Richardson, Best, & Myers, 1996; Swartz, Floyd, et al., 2005). It has been reported that as many as 61% of all cases of cervical spine fractures occur at the C5 and C6 vertebral level. Injuries to C1 and C2 are not common in sports but in the event they do occur they are often overlooked due to the difficulty of radiographing fractures in this location (Nightingale, et al., 2000). A fracture to one of these two vertebrae results in fatality 83% of the time (Winkelstein & Myers, 1997).

The initial, and often the more critical, injury occurs within as little as 2 to 30 milliseconds following impact. This is well before motion of the cervical spine and head can be observed. The motion of the head cannot be perceived until 20-100 milliseconds after impact for flexion and extension and 150 milliseconds for rotation (Nightingale, et al., 2000; Nightingale, et al., 1996; Swartz, Floyd, et al., 2005). Fortunately in lacrosse, the players are only in this head down position when pursuing a ground ball. However, increasing participation will also result in an increased number of inexperienced, lesser skilled players. This will likely result in ground balls becoming a more common event and increase the amount of time that the athletes are in a position vulnerable to cervical spine injuries.

Evaluation and Management

The Inter-Association Task Force for Appropriate Care of the Spine-Injured Athlete (IATF) was formed by the National Athletic Trainer's Association (NATA) with the purpose of developing a protocol for the management of cervical spine injuries in the presence of protective equipment (A. Kleiner, Jon L., Bailes, Julian, Burruss, Pepper T., Feuer, Henry, Griffen, Letha Y., Herring, Stanley, McAdam, Connie, Miller, Dennis, Thorson, David, Watkins, Robert G., Weinstein, Stuart, 2001; D. M. Kleiner, 2003). The original statement has been revised based on research done since 2001 (Swartz, et al., 2009).

The NATA position statement produced a series of guidelines for the proper management of an athlete with a suspected cervical spine injury. If the victim presents with any signs or symptoms that lead the examiner to believe that an injury to the cervical spine is a possibility, the victim should be treated as though this type of injury exists. At the time of injury, the individual responding to the emergency must make a series of critical decisions. Once safety for those responding has been assured, a primary assessment can be performed in order to identify any life-threatening injuries. This includes checking for level of consciousness, airway, breathing, and circulation followed by an initial neurological screening. The neurological screening includes asking the victim if they are experiencing any numbness, tingling, or weakness in the arms and legs, neck pain, or if they are unable to feel or move their limbs (Bailes, Petschauer, Guskiewicz, & Marano, 2007). If there is any neurological involvement, the athlete should not be moved until they are properly immobilized. Immobilization should occur in a supine position, on a rigid spine board. Manual immobilization of the head and cervical spine should be maintained at all times (Swartz, et al., 2009).

Immobilization is the most important part of the pre-hospital care of an athlete with suspected cervical spine involvement. The athlete should be placed in a cervical neutral position, also known as in-line stabilization. By keeping the athlete in proper alignment, maximum space between vertebrae is ensured and decreases the probability of secondary injury (De Lorenzo, et al., 1996; Tierney, Mattacola, Sitler, & Maldjian, 2002). In an occasion where the neck is not in a neutral position a properly trained rescuer should reposition the cervical spine. The athlete should not be repositioned if movement increases signs and symptoms of a cervical spine injury, it is difficult to change the position the spine, resistance is encountered, or the athlete is apprehensive (Swartz, et al., 2009). As the spinal cord moves it changes shapes and the amount of stress placed upon it increases, raising the likelihood the victim will suffer a secondary injury. Immobilization decreases the changes in shape and amount of stress placed on the spinal cord, and places the athlete in a safer position (Tierney, et al., 2002). Additionally, secondary injury can be caused by compression of the vertebrae on the spinal cord, and keeping maximum space between the vertebrae allows more room for swelling and hemorrhaging.

Following manual immobilization of the head the IATF suggests that the helmet be left in place and the face mask removed before transportation to the hospital. The face mask should be removed even if the athlete is not experiencing respiratory difficulty or failure (A. Kleiner, Jon L., Bailes, Julian, Burruss, Pepper T., Feuer, Henry, Griffen, Letha Y., Herring, Stanley, McAdam, Connie, Miller, Dennis, Thorson, David, Watkins, Robert G., Weinstein, Stuart, 2001; D. M. Kleiner, 2003; Swartz, et al., 2009). This will allow immediate access to the athlete's airway if a respiratory problem should arises during transport. Due to the difference between helmets in football, ice hockey, and lacrosse the best method for face mask removal is difficult to determine and is unique from one helmet to the next. Often it is up to the athletic trainer to determine the safest, fastest, and most effective manner of removing the face mask.

The most commonly used tools for this are the FM Extractor (Sports Medicine Concepts, Inc, Geneseo, NY), the Trainer's Angel (Trainer's Angel, Riverside, CA), or a cordless, electric screwdriver with a Phillips head. The best choice for minimizing head movement is the screwdriver (Decoster, Shirley, & Swartz, 2005). However, it is considered unreliable at times and should not be the only means the athletic trainer has for removing the face mask (A. Kleiner, Jon L., Bailes, Julian, Burruss, Pepper T., Feuer, Henry, Griffen, Letha Y., Herring, Stanley, McAdam, Connie, Miller, Dennis, Thorson, David, Watkins, Robert G., Weinstein, Stuart, 2001).

Although the recommendation is to keep the helmet and shoulder pads in place there are some situations in which it is necessary to remove the equipment. It is recommended the helmet be removed if it is not fit in a manner that will prevent the head from moving independently of the helmet. The protective equipment should also be removed if airway and chest access cannot be achieved in a reasonable and acceptable manner (Swartz, et al., 2009).

According to the position statement given by the IATF if a football helmet is removed the shoulder pads must be removed simultaneously. If one is removed without the other, it results in increased extension of the cervical spine (Donaldson, Lauerman, Heil, Blanc, & Swenson, 1998b). However, due to the variability of the equipment in other sports, they cannot make recommendation beyond football (Swartz, et al., 2009). While the all-or-none principle is clearly appropriate for football, the protective equipment in men's lacrosse seems to have a different effect on the alignment of the cervical spine (Sherbondy, et al., 2006).

Once the athlete's vital signs have been determined to be stable enough for transport, the face mask has been removed, and the head is still being stabilized, the athlete should be transferred to the spine board. There has been some debate about the safest and most appropriate technique for transferring an athlete onto the spine board. Until recently the log roll has been used frequently as it is a simple and straight forward technique (Del Rossi, Horodyski, & Powers, 2003). However within the past six years the use of the log roll as the safest and most effective technique for spine boarding an athlete has been called into question. Studies are now showing that the 6-plus person lift, the lift and slide, and the motorized spine board all cause significantly less movement of the head and neck during the spine boarding process (Del Rossi, et al., 2003; Del Rossi, et al., 2008; Swartz, Nowak, Shirley, & Decoster, 2005). The recommendation to use the six-person lift instead of the log roll maneuver is a result of this research. Some of the increased head movement from the log roll is theorized to be the result of the bulky football shoulder pads that the subjects of these studies were wearing. Because lacrosse pads are much slimmer it may not be appropriate to infer these results to lacrosse. However, the six person lift is only effective on patients who are supine. If an athlete is prone, the log roll technique is recommended. The athlete should be log rolled immediately if they are unresponsive, unless the spine board is directly available. If the athlete is responsive, the log roll should be delayed until the spine board is positioned correctly so the athlete is only being moved once.

Once lowered onto the spine board the athlete should be secured with a minimum of three straps on the torso, pelvis, and legs. It has been shown that an additional strap across the pelvis may decrease the lateral movement of the torso significantly (Mazolewski & Manix, 1994). The head should then be secured to the board with tape and padding (Bailes, et al., 2007). Manual immobilization of the head seems to be the most effective method of limiting cervical spine motion (Gerling, et al., 2000). Therefore it should be maintained throughout the entire process. In order to maintain consistency of care and accuracy of information, it is important for the initial rescuer to remain with the athlete during transportation to the hospital (Swartz, et al., 2009).

Current recommendations for managing a suspected spine injury in an athlete wearing protective equipment are based on research done on football (Swartz, et al., 2009). Lacrosse equipment is significantly different from football; requiring a unique protocol based on research specifically dedicated to lacrosse. However, at this point there are very few published articles researching the effect lacrosse helmets and shoulder pads have on the cervical spine (Swartz, et al., 2009). This makes it very challenging for a clinician to design or implement emergency action plans specifically for lacrosse.

Cervical Spine Injuries in Football

When compared to other sports tackle football has the highest occurrence of fatality. While the rate of 0.22 per 100,000 players in 2007 is lower than other sports, due to the huge number of individuals participating, it has the highest number of total catastrophic cervical spine injuries (Mueller & Cantu, 2009). However, even though football does remain high on the list, the number of fatalities as a result of head and neck injuries continues to fall from its peak between the years of 1965-1974. During this time, the helmets began to provide significantly more protection than they did earlier in history. Because of the increased protection provided by the helmet, instead of leading with the shoulder, players were being taught to lead with the head. Since 1945, over 36% of fatalities (42 separate incidences) resulting from cervical spine injuries took place from 1965-1974. Since then the numbers have dropped to only 5 such cases, only 4.3% of the total number recorded since 1945 (Mueller, 1998). The decrease in frequency of fatalities because of cervical spine injuries is a result of rule changes by the National Collegiate Athletic Association (NCAA) and the National Federation of State High School Associations in 1976 (Heck, Clarke, Peterson, Torg, & Weis, 2004). At this time they made spearing, the intentional use of the top or crown of the helmet, illegal and resulted in a penalty. Axial loading is the primary mechanism for cervical spine injuries, and head-down contact is the only position in which it can result (Heck, et al., 2004). Making spearing a penalty has resulted in a significant drop in the number of fatalities as a result of cervical spine injuries (Mueller, 1998).

Because removal of the helmet without the shoulder pads results in the athlete being forced into cervical extension, it is best to leave both in place in the event of a suspected cervical spine injury (Donaldson, et al., 1998a; Peris, et al., 2002) . The neutral position allows for the greatest amount of space for the spinal cord without the dangerous movement that would result from removing the helmet and shoulder pads on the field (Tierney, et al., 2002). Since the helmet should remain in place the facemask must be removed in order to have access to the athlete's airway. When removing the facemask the side straps should be removed first and then the top straps (Swartz, et al., 2009). A cordless screwdriver is the best tool for removal of the facemask as it has been shown to cause the least amount of head movement (Decoster, et al., 2005). It is always necessary to have back up tool present that is capable of cutting the straps in case the screwdriver is not effective.

Cervical Spine Injuries in Ice Hockey

Like other contact/collision sports the risk of serious injury is present for anyone who participates in ice hockey. Even though the likelihood of suffering a spinal injury while playing ice hockey is low. Between 1943 and 1999 there were 271 such injuries recorded in Canada alone (Tator, Provvidenza, Lapczak, Carson, & Raymond, 2004). In collegiate ice hockey the incidence of catastrophic cervical spine injuries has been reported at 4.18 per 100,000 participants (Mueller & Cantu, 2009; Swartz, et al., 2009).

The research related to ice hockey has not been as extensive as what has been done in football. One study showed that the difference in cervical range of motion was not significantly different between football, ice hockey, and lacrosse players when the athletes were spine boarded with helmets and shoulder pads in place (Waninger, et al., 2001). However, a more recent study investigated the difference in cervical range of motion during a log roll. Each athlete was tested in three different conditions; properly fit, improperly (competition) fit, and helmet-removed. The results showed significantly more sagittal and transverse plane motion under both helmeted conditions than under the helmet-removed condition (Mihalik, et al., 2008).

Previous research has shown that, similar to football, the removal of the ice hockey helmet by itself causes a significant change in cervical alignment. Removal of the hockey helmet alone causes a significant increase in lordotic curve compared to subjects with no protective equipment (control), or both helmet and shoulder pads in place (Laprade, Schnetzler, Broxterman, Wentorf, & Gilbert, 2000; Metz, Kuhn, & Greenfield, 1998). In addition to increased lordosis of the cervical spine Metz et al (1998) found that even after being secured to the spine board in full pads the subjects were able to flex and extend their necks 12.9˚ when compared to the control group. This further validates the finds by Mihalik et al (2008) that ice hockey helmets do not allow for sufficient immobilization of the head. Making a recommendation on removal of the helmet is difficult because if the helmet is removed the increase in lordosis is of significant concern. On the other hand, if the helmet is left in place the head movement allowed is potentially dangerous to the athlete. So the new recommendation of the task force is to consider putting something under the head (Swartz, et al., 2009).

Cervical Spine Injuries in Lacrosse

The National Center for Catastrophic Sports Injury Research database reports 11 cervical spine injuries between 1982 and 2007 in collegiate men's lacrosse (Mueller FO, 2009). While this does not seem like a large number, it is still vitally important to have the most valid and current information available to the certified athletic trainer or medical professional that may be responding to a lacrosse player with a potential cervical spine injury.

Lacrosse equipment is very different from football and presents many different challenges. The helmets in lacrosse are much less bulky and are usually worn much looser by the athletes (Petschauer, in press). The shoulder pads are significantly thinner and tighter fitting than football pads. The equipment in lacrosse is meant mostly for protection from accidental stick, ball, and body contact and not for hitting and tackling an opposing player (Sherbondy, et al., 2006).

To date, only two published studies have researched the effect lacrosse equipment has on the movement of the cervical spine. One study compared the amount of head movement in American football, lacrosse, and ice hockey helmets after head and neck stabilization (Waninger et al., 2001). The athletes were immobilized on spine boards with straps and foam pads. Retroreflective markers were placed on the helmet and mouthpiece of the subjects. The markers were used to measure the movement of the helmet and head. Perturbation was provided by allowing the edge of the spine board to free fall to a sudden stop from a height of approximately 8.9 cm. The results showed that there was not a statistically significant difference in movement between the different types of properly fitted helmets (Waninger, et al., 2001). However, due to an apparently small sample size used in this study, it is possible that the results are lacking sufficient power. Finally this study was also limited because they did not measure head motion relative to the thorax. Instead they measured motion between the head and the helmet which does not necessarily represent motion of the cervical spine. Additionally, they did not account for the fact that in previous research, looking at lacrosse helmet fit, it was common for lacrosse athletes to wear their helmets looser than is required by the manufacturers (Petschauer, in press).

Petschauer et al, looked at the effect lacrosse helmet fit has on cervical spine movement once the athlete has been secured to a spine board. The subjects were properly secured to the spine board in each to the helmet fit conditions. Following immobilization they were instructed to actively move their head until they felt resistance from the helmet or spine board bindings. The results of this study showed that the cervical motion allowed was significantly greater in the properly fit and competition helmet then in the no helmet condition. The research also showed there to be greater head-to-thorax motion then helmet-to-thorax motion. This would suggest that head is free to move inside the helmet, and that the presence of a lacrosse helmet will not allow proper stabilization of the head on a spine board.

In a study by Sherbondy et al, the effect of lacrosse helmets and shoulder pads on cervical spine angles was investigated. The author contrasted cervical alignment between the occiput and C2, C2-C7, and the occiput and C7 in three different conditions. These conditions were no protective equipment, full equipment, and helmet removed. The no protective equipment condition was used as the control group. In this condition the subjects wore no helmet or shoulder pads. In the helmet removed condition the subjects wore only shoulder pads. When the athlete was in full equipment the results showed an increase in cervical extension of 6˚ between the occiput and C7 when compared to no equipment. When comparing the helmet removed condition to the full equipment condition he found there to an increase of 4.7˚ of cervical flexion at the occiput to C2 level. At the C2-C7 level there was a 4.4˚ increase in flexion between full equipment and no equipment. Their results also showed that there was not a significant difference, in the angular measurement of the cervical spine (occiput-C7), between the helmet removed condition and control group. This would suggest that removal of the helmet alone would not place the athlete in a more dangerous alignment. While this study produced significant results, the authors still suggested following the IATF guidelines to leave the helmet in place. This is likely the case because no research has been done on the amount of motion caused by removal of the lacrosse helmet. The findings of this study make it vital that more research be done that is dedicated specifically to lacrosse. This will allow a protocol, for handling cervical spine injuries in lacrosse, to be developed that is based on research designed to account for the differences in equipment.

Proper Fitting for Helmet

All lacrosse helmets should be approved by the National Operating Committee on Standards for Athletic Equipment (NOCSAE). Attention should be paid to ensure that the helmet fits properly by following the instructions provided by the manufacturer. The general recommendations are as follows; the proper size of helmet should be chosen, it should sit squarely on the head, with the front approximately one finger width above the eyebrows. The padding of the helmet should provide firm and consistent pressure throughout, and the four-point chin strap should be tightened so that there is no slack (US Lacrosse, 2009).

The instruction for proper fitting of the Cascade Pro7® lacrosse helmet has been set by the manufacturer. Once the helmet is in place, the front rim is positioned 1 inch above the eyebrow. The chin straps are then fastened first in the front and then in the back with equal tension on all four straps. The straps must be tight enough to hold the helmet firmly in place. In the back, the padding should be in firm, but comfortable contact with the head. If the helmet is to loose or tight, the diameter can be altered by sliding the adjust wedge at the front of the helmet. After the helmet diameter has been adjusted the facemask should clear the end of the nose by two to three finger widths. Once fitted, the helmet should be moved from side to side and up and down. If the skin on the forehead of the athlete moves with the helmet it is fit properly. A second check is performed by pushing on the back of the helmet. If a gap appears between the forehead and the front of the helmet it is still not fit properly and further adjustments should be made. Next the helmet is pushed straight down on the subjects head. If the participant feels the pressure evenly the fit is good. If pressure is felt minimally in the front and back, the helmet is too tight and should be adjusted accordingly. Finally the athlete is asked if the helmet fit is comfortable. If it is not the fitting process should be started again (Cascade Lacrosse Inc., 2004).

Motion Analysis

Various techniques for measuring movement of the cervical spine have been used over the years. Originally handheld or strap-on head goniometers and radiographs were the instruments of choice. When using the goniometer the subject was asked to position their head in a neutral position. This was considered “neutral zero.” The goniometer was then calibrated to zero and movement could be measured based on that starting neutral position. This procedure was performed to measure movement in each plane (Nilsson, Christensen, & Hartvigsen, 1996).

In radiographic studies, the subjects would be filmed in a neutral position and then in the movement pattern the researchers were interested in. The films were then superimposed over each other and the researcher could then look at the difference in films, determine the amount of movement present, and assess where the motion occurred (Dvorak, Froehlich, Penning, Baumgartner, & Panjabi, 1988). Both of these methods have been found to be unreliable and are outdated means of collecting cervical spine motion data. Goniometery cannot measure the small motions, taking place in multiple planes that are a part of cervical movement. It can also only measure motion in one plane at a time. Radiographic studies are not practical because of the time and cost associated with them.

More recent studies have made use of three dimensional analysis technologies. This technique makes use of retro-reflective markers which are attached to the subject’s helmet and mouth piece and movement of these markers is captured by infrared cameras (Waninger, et al., 2001). Another popular method of collecting data on motion of the cervical spine is with an electromagnetic motion analysis system. With this system three separate electromagnetic receivers are attached to a mouthpiece, sternum, and the helmet (Mihalik, et al., 2008).

The electromagnetic motion analysis system has been found to be a reliable means of measuring movement of the cervical spine (Assink, et al., 2005; Koerhuis, Winters, van der Helm, & Hof, 2003). The maximum measurement error was shown to be 2.5˚ with this motion analysis system (Koerhuis, et al., 2003). The ICC values for this system is as high as 0.91 (Assink, et al., 2005). The electromagnetic tracking system has been shown to have fair to high inter-examiner reliability of ICC=0.94 for cervical rotation, 0.80 for cervical lateral flexion, and 0.78 for cervical flexion/extension. It was also shown to have high intra-examiner reliability of ICC=0.96 for cervical rotation, 0.95 for cervical lateral flexion, and 0.96 for cervical flexion/extension (Morphett, Crawford, & Lee, 2003).

The use of the electromagnetic motion analysis system seems to be a better choice than using retro-reflective markers and inferred cameras (Vicon®) for several reasons. In order for the Vicon® system to work, the cameras need to be able to see the marker the majority of the time. Given the subjects will be wearing a helmet and several people will be moving around the subject during the data collection, it is likely there will be times when one or more of the markers will be blocked. Additionally, the electromagnetic receivers can be placed directly on the sternum under the shoulder pads which provides a more accurate measurement of thorax movement than trying to place markers on the shoulder pads. The flexibility of the electromagnetic motion analysis system also allows the examiner to compare head-to-thorax, helmet-to-thorax, and head-to-helmet movement in all three planes simultaneously.

Summary

Whenever a cervical spine injury is possible it is vital for those responsible for the emergency care of the injured athlete to be prepared with the knowledge to manage the situation in the most appropriate manner. At this point, there are many unknowns when it comes to properly managing a cervical spine injury in men’s lacrosse. Very little research has been done specifically on men’s lacrosse to determine if these athletes require different immobilization techniques. The research that does exist points to the conclusion that the helmets and shoulder pads in men’s lacrosse fit differently and affect the movement of the head differently than does football equipment (Petschauer, 2006; Sherbondy, et al., 2006). The studies that have been conducted indicate that removing the lacrosse helmet would potentially provide safer and more effective immobilization of the head and neck.

CHAPTER III

METHODOLOGY

The purpose of this study was to compare the head and helmet movement of lacrosse players during a prone log roll between three different helmet conditions. This will allow us to determine if the fit of a lacrosse helmet affects the clinician's ability to properly stabilize the athlete's head and neck during in-line immobilization. This study employed a within-subject, counterbalanced, repeated measures design. The independent variables were the three helmet fit conditions: properly fit helmet (PF), competition helmet (CH) and helmet removed (HR). The dependent variables were cervical spine motion of the head and helmet relative to the thorax in the transverse, frontal, and sagittal planes.

Subjects

A total of 18 subjects were asked to volunteer for this study. This sample size was based on designs presented previously in similar studies (Mihalik, et al., 2008; Petschauer, 2006). A sample size of 18 subjects allowed for even counterbalancing of the test order within our study. Exclusion criteria for this study included lack of full, pain-free neck range of motion, currently suffering from neck pain, or previous history of a cervical fracture or dislocation. Participants in this study were required to be members of the University of North Carolina at Chapel Hill varsity men's lacrosse team who participated in practice on a daily basis, and were between the ages of 18 and 25 years. All participants in this study completed and signed an informed consent form approved by the Institutional Review Board of The University of North Carolina at Chapel Hill.

Table 3.1: Counter balanced design of data collection. CF-Competition Fit, PF-Properly Fit, HR-Helmet Removed

Subject	Testing Order		
	First	Second	Third
1,7,13	CF	PF	HR
2,8,14	CF	HR	PF
3,9,15	PF	CF	HR
4,10,16	PF	HR	CF
5,11,17	HR	CF	PF
6,12,18	HR	PF	CF

Equipment

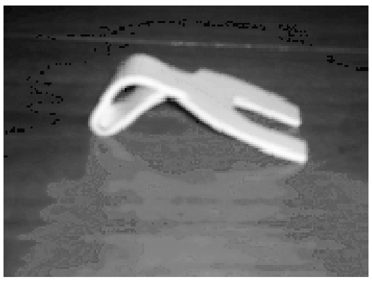
The helmet used in this study was the Cascade Pro7 (Cascade Lacrosse, Liverpool, NY). This was the only helmet worn for practice and competition by subjects of this study and represents the most recent model manufactured by Cascade. The subjects were asked to bring the helmet and shoulder pads worn during their lacrosse practices and games.

Figure 3.1. Cascade Pro7 lacrosse helmet

(www.laxzone.com)

A custom built mouth piece was used for the fixture point for the head receiver. After every subject, it was thoroughly cleaned with antibacterial soap and a new thermo-moldable plastic cover was placed over the mouth piece. This ensured that it was clean and fit comfortable for each subject

Figure 3.2. Custom mouth piece used for head receiver placement



A Motion Star (Ascension Technologies, Burlington, VT) electromagnetic motion analysis system, controlled by the MotionMonitor software (Innovative Sports Training Inc Chicago, Ill), was used to collect data. This system tracks the movements of receivers relative to a fixed electromagnetic transmitter. All receivers were secured to the skin using double-sided tape and athletic tape over the top of the receivers.

Protocol

The subjects signed up for a time to come into the Sports Medicine Research Laboratory on the campus of The University of North Carolina at Chapel Hill. Upon arrival, each subject was asked to read and sign an informed consent form stating that they understood and assumed any possible risks of participation in this study. They also completed a questionnaire addressing the exclusion and inclusion criteria, height, and weight. The subjects were then tested using a repeated measure, counterbalanced design beginning with one of the three helmet conditions. For the PF condition, a Pro7 helmet (separate from the helmet normally worn by the participant during regular competition) was fitted by the primary investigator according to the Cascade® helmet safety guidelines.

The helmet was placed on the subject's head. Once in place, the front rim was positioned 1 inch above the eyebrow. The chin straps were then adjusted and fastened first in the front and then in the back with equal tension on all four straps. The tension on the straps was great enough to hold the helmet in place. On the back of the head the padding was in firm, but comfortable contact with the head. If the helmet was to loose or tight around the circumference of the head, the wedge at the front of the helmet was adjusted accordingly. Once the wedge was adjusted, the helmet was moved side to side and up and down. A second check was performed by pushing on the back of the helmet. If the skin on the forehead of the subject moved with the padding, and if no gap appeared between the forehead and the front of the helmet, the helmet was determined to be properly fit. Next the helmet was pushed straight down on the subjects head. If the participant felt the pressure evenly the fit was good. If pressure was felt minimally in the front and back, the helmet was too tight and was adjusted accordingly. Finally the subject was asked if the helmet was fit securely on the head. If it was not secure the process was started again. The CH was also visually examined by the primary investigator to ensure a difference was present between the PF and CH conditions. If the fit of the two helmet conditions were the same, the subject's data was not collected.

Three receivers were fit to each subject, one on top of the helmet, one to the custom made mouth piece, and the third was located on the proximal sternum, inferior to the sternal notch. These positions were chosen in order to minimize motion as a result of breathing and natural movement of the skin. In order to ensure movement of the receiver on the mouthpiece represents movement of the head, the subjects were instructed to maintain a firm and constant bite at all times. After the receivers were in place, the subject was instructed to sit upright and remain motionless while anatomical landmarks were identified through a digitization process using a wooden stylus. The digitization points included the bridge of the nose, middle of the chin, occiput, T12-L1 joint, the spinous process of T8, the spinous process of C7, and the xiphoid process. After digitization the subject was moved into position to begin the log roll procedure.

The starting position for the emergency prone log roll procedure was standardized across all trials and consisted of the participants lying limp in a prone position, with their arms by their side and head turned facing their right. The subjects were instructed to remain limp at all times. They were not to assist or resist the researchers at any time during the procedure. Two certified athletic trainers (Rescuers 1 and 2) and an undergraduate athletic training student (Rescuer 3) who had been taught and practiced the proper techniques for managing on-field cervical spine injuries performed the emergency prone log roll. For all trial conditions, Rescuer 1 was responsible for immobilization of the head and neck and directing the group through the entire procedure. Rescuer 2 was in control of the subject's thorax and responsible for keeping it in line with the head and neck. Rescuer 3 controlled the legs of the subject and maintained proper alignment with the head, neck, and thorax. The second and third rescuer kneeled on a spineboard (Model #35850-BL; Iron Duck, Chicopee, MA) in order to prevent it from slipping out of position during the log roll procedure. Once the subject and rescuers were in position Rescuer 1 counted to three and then said, "Go." Data collection began on three, and on "go" the subject was rolled to his left onto the spine board, all in one motion. Once the subject had been rolled a "stop" command was given and the trial was ended.

In order to prevent learning effects from influencing our results the researchers performed the entire prone log roll procedure sixty times during pilot testing. The pilot test subject was fitted with all the lacrosse equipment and motion capturing devices that were used during official data collection. The subject was placed in position and the entire procedure was performed. Five trials were performed for each helmet condition. This procedure was done in a previous study and shown to be reliable (Mihalik, et al., 2008).

Figure 3.3. Log Roll Procedure

(Mihalik, et al., 2008)

Data Reduction

Kinematic data was collected at a sampling frequency of 144 Hz. Euler angles were used to record movement of the head and helmet relative to the receiver placed on the proximal sternum. A world axis system was established using the right-hand rule with left lateral flexion about the positive x-axis, flexion about the positive y-axis, and left rotation about the positive z-axis. Data was filtered at 10 Hz with a Butterworth low-pass filter.

Data was exported from the MotionMonitor system and reduced using a custom Matlab (The Mathworks Inc, Matick, MA) program. A trigger was used to define the beginning and end of each trial, allowing us to eliminate unwanted data before and after the trial began. To account for any difference in starting position, the average of the first 10 data points in each trial was subtracted from all the data points in that given trial. The data was than rectified and integrated in order to obtain the total amount of motion during the trial. All the data was rectified in order to make all values positive and allow us to determine the total amount of movement sustained by each subject. The data was then normalized to time in order to take into account any variation in the total amount of time needed to complete the trials. This was done for the head and helmet motions recorded in each of the three planes, allowing us to determine the total amount of movement sustained by the subjects during each condition. We also calculated the range of motion for each trial by subtracting the minimum value in each trial from the maximum. For each subject the mean across the five trials was calculated and the mean across each trial was used to determine the mean across all subjects. The datum was then analyzed and reported.

Statistical Analyses

Three repeated measures analysis of variance (ANOVA) were employed to assess significant differences in sagittal, frontal, and transverse plane head-to-thorax motion between the three helmet conditions. Three subsequent repeated measures ANOVAs assessed differences in sagittal, frontal, and transverse helmet-to-thorax motion between the CF and PF helmet conditions. Six paired-samples t-tests were performed in order to compare head-to-thorax movement and helmet-to-thorax movement between the PF and CH conditions. Our level of significance was set a priori at an alpha level of .05. In the event of a significant ANOVA, a pairwise comparison with a Bonferroni correction was to determine which conditions differed with respect to the dependent variable of interest. All statistical analyses were performed using SPSS version 16.0 (SPSS, Chicago, IL).

Table 3.1: Data Analysis Table

Research Question	Data Source	Statistical Method
1. Is there an effect of helmet fit condition on head-to-thorax movement in the frontal, sagittal, or transverse planes during an emergency prone log roll procedure?	**DV:** Head-to-thorax motion in the transverse, sagittal and frontal planes. **IV:** Helmet Fit Conditions: Properly fit, Competition fit, and Helmet removed.	Three repeated measure analysis of variance (ANOVA)
2. Is there an effect of helmet fit condition on helmet-to-thorax movement in the frontal, sagittal, or transverse planes during an emergency prone log roll procedure?	**DV:** Helmet-to-thorax motion in the transverse, sagittal and frontal planes. **IV:** Helmet Fit Conditions: Properly fit, Competition fit, and Helmet removed	Three repeated measure analysis of variance (ANOVA)
3. Is there an effect of helmet fit in the difference between head-to-thorax and helmet-to-thorax movement in the PF and CH conditions in the frontal, sagittal, or transverse planes during an emergency prone log roll procedure?	**DV:** Head-to-thorax motion and Helmet-to-thorax motion in the transverse, sagittal and frontal planes. **IV:** Helmet Fit Conditions: Properly fit and Competition fit	Six paired-samples t-tests

CHAPTER IV

RESULTS

A total of eighteen subjects (age = 19.67 ± 1.33 years, height = 183.83 ± 6.60 centimeters, mass = 85.77 ± 7.47 kilograms), all participating members on the University of North Carolina at Chapel Hill men's lacrosse team, were tested. All the subjects had full and pain free cervical spine range of motions and had no history of cervical spine fracture or dislocation. Range of motion data was collected in the frontal, sagittal, and transverse planes for head-to-thorax and helmet-to-thorax movement. Differences in head-to-thorax and helmet-to-thorax movement across the three conditions in the frontal, sagittal, and transverse planes was determined using six repeated measure ANOVAs. The difference between head and helmet motion was determined using six paired-samples t-tests. These compared head and helmet motion across the competition and properly fit conditions in all three planes.

We analyzed both integrated data that was normalized to time and the total range of motion of our subject during testing. Because the results were nearly identical, and no significant differences were found in one method and not the other, only the normalized data was reported as a measure of the motion occurring throughout each trial.

Head-to-Thorax Range of Motion

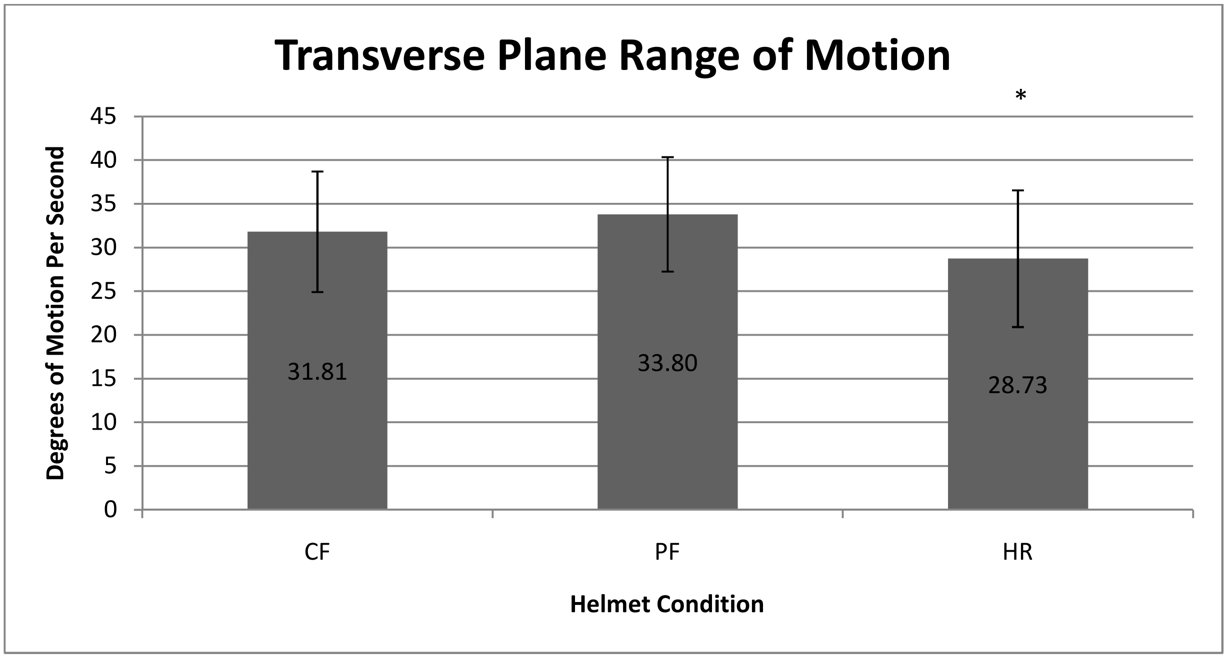
The descriptive statistics for the dependent variable range of motion between the head and the thorax are listed in Table 4.1.

Table 4.1. Descriptive and statistical results for head-to-thorax movement in each plane and helmet condition

	Mean	f-value	p-value
Sagittal Plane			
Competition Fit	$12.63^{o/s} \pm 7.20^{o/s}$	0.33	0.721
Properly Fit	$14.45^{o/s} \pm 9.07^{o/s}$		
Helmet Removed	$13.19^{o/s} \pm 6.70^{o/s}$		
Transverse Plane			
Competition Fit	$31.84^{o/s} \pm 6.83^{o/s}$	5.999	0.006
Properly Fit	$33.82^{o/s} \pm 6.59^{o/s}$		
Helmet Removed	$28.63^{o/s} \pm 7.67^{o/s}$		
Frontal Plane			
Competition Fit	$20.18^{o/s} \pm 8.63^{o/s}$	1.334	0.277
Properly Fit	$22.05^{o/s} \pm 10.08^{o/s}$		
Helmet Removed	$24.31^{o/s} \pm 10.52^{o/s}$		

A repeated measures ANOVA found a significant difference in the amount of head-to-thorax movement allowed in the transverse plane ($F_{2,34} = 6.00$, $p = .006$). Pair wise comparisons determined the transverse plane motion to be significantly greater in the properly fit helmet condition than in the helmet removed condition (Mean Difference = 5.19, Std. Error = 1.21, $p = .001$). No statistically significant differences were found between the other helmet conditions, or in the sagittal ($F_{2,34} = .330$, $p = .721$) and frontal planes ($F_{2,34} = 1.33$, $p = .277$). The significant differences that were found are illustrated in figure 4.1.

Figure 4.1. Mean transverse plane head-to-thorax range of motion for Competition Fit (CF), Properly Fit (PF), and Helmet Removed (HR) conditions. (* significantly less than properly fit condition)



Helmet-to-Thorax Range of Motion

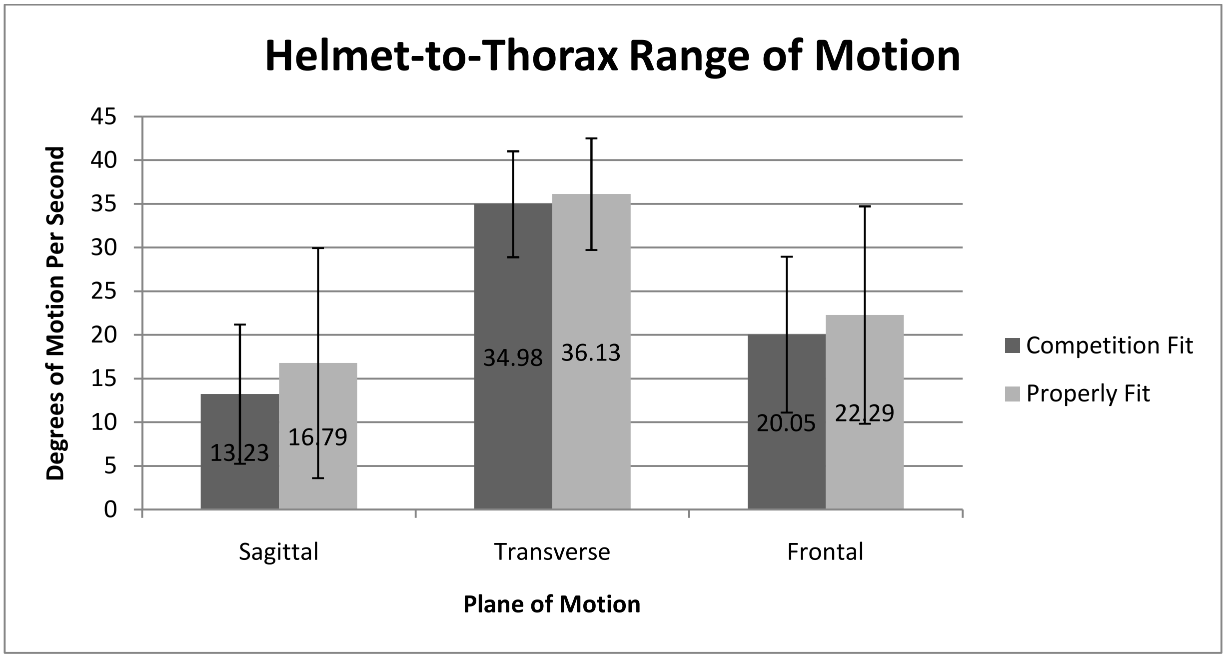
The descriptive statistics for the dependent variable range of motion between the helmet and the thorax are listed in Table 4.2.

Table 4.2. Descriptive and statistical results for helmet-to-thorax movement in each plane and helmet condition

	Mean	f-value	p-value
Sagittal Plane			
Competition Fit	$12.62^{o/s} \pm 7.79^{o/s}$	2.691	0.119
Properly Fit	$17.37^{o/s} \pm 13.35^{o/s}$		
Transverse Plane			
Competition Fit	$34.96^{o/s} \pm 6.01^{o/s}$	0.991	0.333
Properly Fit	$36.24^{o/s} \pm 5.50^{o/s}$		
Frontal Plane			
Competition Fit	$19.98^{o/s} \pm 8.93^{o/s}$	0.647	0.432
Properly Fit	$22.36^{o/s} \pm 12.61^{o/s}$		

A repeated measures ANOVA was conducted to determine significance in helmet-to-thorax range of motion between the competition fit and properly fit helmet conditions for each plane of motion. There were no significant differences found between the means in the sagittal ($F_{1,17}$ = 2.691, p = .119), transverse ($F_{1,17}$ = .991, p = .333), or frontal planes ($F_{1,17}$ = .647, p = .432). These values are illustrated in figure 4.2.

Figure 4.2. Mean helmet-to-thorax range of motion for the competition and properly fit helmet conditions in the sagittal, frontal, and transverse planes of motion



Head-to-Thorax vs. Helmet-to-Thorax Range of Motion

Six paired-samples t-tests were used to determine differences in the amount of head movement compared to helmet movement in the competition and properly fit helmet conditions. There was no significance differences found in competition fit helmet in the sagittal ($F_{1,17} < .001$, $p = .997$) or frontal planes ($F_{1,17} = .012$, $p = .915$). There was also no significant differences found in the properly fit helmet in the sagittal ($F_{1,17} = 2.103$, $p = .165$) or frontal planes ($F_{1,17} = .036$, $p = .851$). A significant difference in the amount of movement between the head and helmet were found in transverse planes of the competition fit ($F_{1,17} =$ .11.211, $p = .004$) and properly fit ($F_{1,17} = 22.005$, $p < .001$) condition. As illustrated in Table 4.3, both conditions resulted in less head movement than helmet movement.

Table 4.3. Descriptive and statistical results for head-to-thorax and helmet-to-thorax movement in each plane and helmet condition

	Mean		f-value	p-value
Sagittal Plane				
	Head-to-Thorax	**Helmet-to-Thorax**	**Head-to-Helmet**	**Head-to-Helmet**
Competition Fit	$12.63^{o/s} \pm 7.2^{o/s}$	$12.62^{o/s} \pm 7.79^{o/s}$	> 0.001	0.997
Properly Fit	$14.45^{o/s} \pm 9.07^{o/s}$	$17.37^{o/s} \pm 13.35^{o/s}$	2.103	0.165
Transverse Plane				
Competition Fit	$31.83^{o/s} \pm 6.83^{o/s}$	$34.96^{o/s} \pm 6.01^{o/s}$	11.211	0.004
Properly Fit	$33.82^{o/s} \pm 6.59^{o/s}$	$36.24^{o/s} \pm 6.50^{o/s}$	22.005	> 0.001
Frontal Plane				
Competition Fit	$20.18^{o/s} \pm 8.63^{o/s}$	$19.98^{o/s} \pm 8.93^{o/s}$	0.012	0.915
Properly Fit	$22.05^{o/s} \pm 10.08^{o/s}$	$22.36^{o/s} \pm 12.61^{o/s}$	0.904	0.851

Figure 4.3. Head and helmet-to-thorax movement for all three planes of motion in the competition fit condition. (* indicates significant difference in movement within the plane)

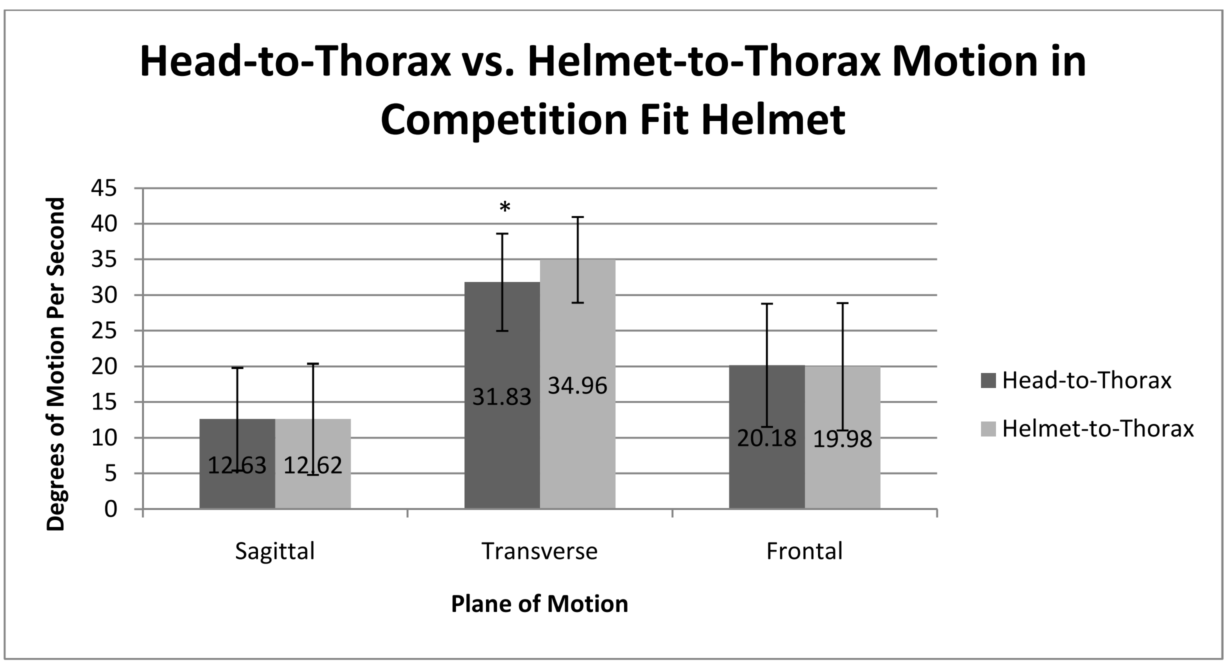
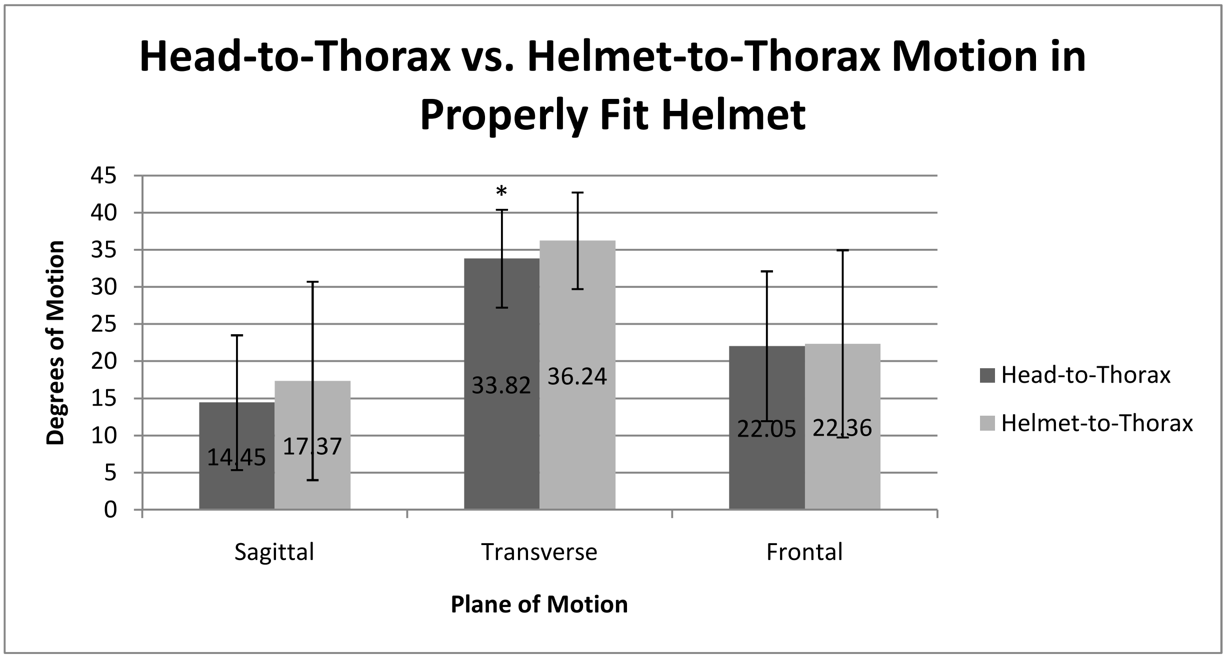


Figure 4.4. Head and helmet-to-thorax movement for all three planes of motion in the properly fit condition. (* indicates significant difference in movement within the plane)



CHAPTER V

DISCUSSION

Head-to-Thorax Range of Motion

The primary finding of this study was that the majority of the movement allowed in the three different helmet fit conditions was not significantly different during a log roll of a men's lacrosse player. We did find that there was significantly more transverse head movement in the properly fit helmet than in the helmet removed condition. This indicates that cervical rotation is more effectively controlled and limited when the athlete is not wearing a helmet. However, the transverse motion is the only plane in which there was a statistically significant difference. The lack of other significant differences between the helmet conditions would indicate that helmet fit does not have a substantial effect on cervical range of motion during a log roll in a Cascade Pro7 helmet.

We originally hypothesized that there would be significantly more cervical motion in both helmeted conditions than in the helmet removed condition. We also said that more head motion would take place in the competition helmet than in the properly fit helmet. This proved not to be the case as differences in head-to-thorax movement in the three conditions were insignificant in the frontal and sagittal planes. No difference in cervical range of motion was seen between the competition and properly fit conditions in any of the three planes.

According to the NATA position statement on how best to manage an athlete suspected of suffering a cervical spine injury, the helmet and shoulder pads should not be removed unless the helmet does not properly stabilize the head (Swartz, et al., 2009). They also suggest that if the helmet is removed, the shoulder pads must be removed as well. These recommendations are mostly a result of research done on football equipment and generalized to all equipment intensive sports. Some research has shown that lacrosse helmets may have a different effect on cervical spine alignment and available motion (Higgins, et al., ; Petschauer, 2010; Sherbondy, et al., 2006). While others suggest that football, hockey, and lacrosse helmets all sufficiently stabilize the head following spine boarding (Waninger, et al., 2001). Waninger found that there was not a significant difference in the amount of head motion allowed by the three different helmet types when subjecting participants to a perturbation by dropping the left edge of the spine approximately 8.9 cm (Waninger, et al., 2001). By doing this he attempted to simulate the jostling that can occur during transport of an athlete with a suspected cervical spine injury. Petschauer, on the other hand, determined that even when immobilized with a properly fit lacrosse helmet, significantly more head motion was available than when the helmet was removed (Petschauer, 2010).

Our results seem to agree more closely with the findings of Waninger, who showed that fit of the Sport Cascade lacrosse helmet does not have a significant effect on head-to-thorax motion. A possible explanation for why our results do not align with what Petschauer found is that we measured passive range of motion, as Waninger did, instead of active range of motion (Waninger, et al., 2001). We also looked exclusively at the Cascade Pro7 helmet, instead of the Cascade CPX. The Pro7 is Cascade's newest helmet model, and could provide better security for the head. A proper fit of the Pro7 can be obtained through adjustment of the chin strap, ear pads, and slide bar. This is used to adjust the diameter of the helmet. With the CPX the only way to make this adjustment was to change an occiput pad in the back of the helmet. Our lack of significant findings outside of the transverse plane could also be explained because a prone log roll is mostly a rotational movement. There is not a lot of frontal and sagittal plane motion in a log roll so the fit of the helmet should not greatly affect how much the head moves.

To this point all the lacrosse specific research has been done on subjects immobilized in a supine position, or have looked determined cervical alignment following helmet removal (Higgins, et al., ; Petschauer, 2010; Sherbondy, et al., 2006; Waninger, et al., 2001). Unfortunately it is not uncommon for an athlete to fall prone after being hit. To our knowledge this is the first study to investigate the effect of lacrosse equipment on an athlete found in a prone position and must be rolled supine for proper cervical stabilization.

Helmet-to-Thorax Range of Motion

Prior to beginning data collection we hypothesized that the fit of the lacrosse helmet would not have a significant effect the range of motion that occurred between the helmet and thorax in the sagittal, frontal, or transverse planes. Analysis of the data showed this to be the case. These results are important because they indicate that we were consistently moving the helmet through the same range of motion. Helmet fit should not have a significant effect on how much the helmet is moving during a prone log roll. While we cannot make generalizations to all rescuers who may be required to perform this procedure, our results would suggest that a properly trained sports medicine professional can consistently and effectively control the helmet regardless of fit. These finding correspond with results in hockey research which showed helmet fit did not affect their ability to consistently perform a prone log roll (Mihalik, et al., 2008). It has also been shown that training does not have a significant effect on the amount of cervical movement resulting from a log roll (Del Rossi, et al., 2003). This indicates that rescuers should be equally effective in stabilizing the helmet no matter how extensive their experience is.

Head-to-Thorax vs. Helmet-to-Thorax Range of Motion

In the transverse plane there was a significant difference between head-to-thorax and helmet-to-thorax range of motion. In both the CF and PF conditions the head rotated less than the helmet. As the subject was rolled onto the spineboard and the helmet was brought into a neutral position, the head does not move through the same range of motion. This suggests that the head is moving independently of the helmet. In a study looking at the effect of lacrosse helmet fit on active head motion after stabilization, they found that the head moves significantly more than the helmet in both conditions (Petschauer, 2010), which is the originally hypnotized. We thought the head would move significantly more than the helmet and that head movement in the CF helmet would be greater than that found in the PF helmet. Once again possible explanations for the differences in the results are that we measured passive range of motion and our subjects wore a different model helmet. A significant difference in head-to-helmet movement has also been shown in research performed on football helmets (Toler, et al.). Despite the different results and helmet types, the outcomes indicate a similar trend. The head and helmet are not moving as a unit. This could be a serious issue if an athlete was stabilized in a helmeted condition and something caused an uncontrolled rotation of the head.

Helmet Fit

As has been the case in previous research (Petschauer, 2010), all of our subjects were currently practicing and competing in a helmet that is improperly fit. If they had reported for data collection with a properly fit helmet they would have been excluded, because participating in an improperly fit helmet was one of our criteria. Of the eighteen subjects that reported for testing all of them brought in a helmet that fit them too loosely. Thirteen of them had to have the chin straps and slide bar tightened and larger ear pads inserted. Four of them had to have the chin straps and slide bar tightened, and one subject required only the chin straps be tightened.

While we did not find significant differences between CF and PR conditions it is important to emphasize the helmet does more than stabilize the head during cervical spine immobilization. Therefore, it is still important to educate all lacrosse players on the importance of wearing a properly fit helmet. The lacrosse helmet is designed to decrease head, eye, and other facial injuries and it will defeat the design if the helmet is not fitted properly (Lincoln, Hinton, Almquist, Lager, & Dick, 2007). While the value of wearing a properly fit helmet still needs further research, it would be reasonable to assume that a tighter fitting helmet would provide better protection for the head and face. Wearing the helmet properly fit would also make lacrosse specific research more straightforward. Not dealing with the variable of an improperly fit helmet would make it easier to determine the effect a lacrosse helmet has on the head and neck, therefore making recommendations easier to determine. More importantly, dealing with improperly fit helmets complicates the decision making process for the clinical athletic trainer. They have no idea what type of helmet fit they will be encountering on the field. When faced with a helmet that does not fit correctly the rescuer must make a quick decision whether or not to leave the helmet in place. Serious consequences can result if the wrong judgment is made.

Unfortunately, the desire for change is not present in the lacrosse culture. Many of the athletes are more concerned with comfort and their image and look on the lacrosse field then they are with increasing the safety of the game. Lacrosse is not as violent and does not have as many collisions as football and ice hockey, so the athletes do not have a fear of being hit and injured on every play. A concerted effort needs to be made to educate coaches, officials, and athletes that head and neck injuries are a real possibility. Wearing a helmet that fits well is beneficial because it ensures the helmet is in a good position to protect the athlete from concussions, eye and facial injuries. Additionally, if the helmet became dislodged during competition it would expose the athlete to more serious head and facial injuries. A properly fit helmet could go a long way in eliminating or minimizing the severity of some of these injuries (Lincoln, et al., 2007).

Clinical Significance

Our research attempted to help answer the question of how best to manage a men's lacrosse athlete lying prone. The results of this study suggest that fit of the Cascade Pro 7 helmet does not have an effect on the movement of the athlete's head as they are being log rolled from a prone position. While it is a small range of motion the head does move independently from the helmet, in the transverse plane, whether the helmet is fit according to the manufactures' specifications or not. Additionally, the position of the athlete's head when lying prone could make it extremely difficult to safely remove the helmet while maintaining proper cervical alignment. These factors lead to the conclusion that it is in an athlete's best interest to leave the helmet in place until they have been moved into a supine position.

Once in a supine position, the question of whether or not to remove the helmet has still not been answered. Waninger showed that the range on motion inside a properly fit lacrosse helmet is the same as in a football helmet (Waninger, et al., 2001). However, more recent research has suggested that a lacrosse helmet, no matter how it is fitted, allows more active head motion than no helmet (Petschauer, 2010). Two separate studies have shown removing the helmet alone does not have a significant effect on cervical alignment and leaving it on does not put the athlete in the best position (Higgins, et al., ; Sherbondy, et al., 2006).

The NATA position statement states clearly whenever there is a suspected cervical spine injury the facemask should always be taken off. If this cannot be done in a timely or efficient manner the entire helmet should be removed (Swartz, et al., 2009). Due to the multiple screws, small plastic clasps, and the fact that the chin guard is riveted to the helmet makes removal of the facemask alone, on the Pro7, is very difficult. As stated previously, it also suggests a helmet should be removed if it does not fit in a manner that provides stabilization of the head (Swartz, et al., 2009). The results of the most recent research suggest that it would be best to remove the helmet after log rolling, but before immobilizing an injured athlete. More research is needed before a definite recommendation can be made.

Cervical spine injuries in men's lacrosse are not extremely common; however, head and facial injuries do occur regularly (Diamond & Gale, 2001; Dick, et al., 2007; Mueller & Cantu, 2009). Every injury to the head or face represents a potential catastrophic cervical spine injury. For this reason it is vital for the certified athletic trainer to have as much information as possible on how to best handle an emergency situation. The certified athletic trainer needs to be comfortable and confident in the decisions and techniques to be used.

Due to the differences lacrosse helmets and shoulder pads have on cervical alignment and range of motion, it seems clear that there needs to be recommendations specific to lacrosse and potentially to the type of helmet being worn.

Limitations

It is likely for there to the some variability in the movement caused by the log rolling procedure. Though the log roll was practiced repeatedly and every attempt was made to perform the procedure the same from one trial to the next some inconsistency is inevitable. However, because there was no significant difference in helmet movement we are confident in the consistency of the log rolls.

The same specifications were used to fit each of the helmets and each subject was fitted individually by the primary investigator. This was done to ensure that each subject was fitted to the same specifications and the helmet was custom fit to their head. Despite these procedures the size and shape of the subject's heads varied and the helmet fit some subjects better than others.

The testing was conducted in a research laboratory and not in a real life situation. The effect of the outdoor environment or an on-field emergency, on the results is unknown.

Our sample was taken from uninjured lacrosse players and it is difficult to know if the athletes tightened their cervical musculature at any point during the log roll. Each subject was reminded repeatedly to remain completely relaxed and not to fight or help the researchers in any way.

In order to be consistent and because the Cascade Pro7 is the only helmet worn by our subjects, it was the only helmet tested. Therefore, we cannot generalize our results to other helmets and how they might affect cervical range of motion during a prone log roll.

Future Research

The amount of cervical range of motion that is allowed before an injured athlete will suffer secondary injuries is still unknown (Del Rossi, et al., 2003). Until we know how much movement can safely take place it must be the goal of any rescuer to limit head and neck motion as much as possible. Future research needs to done to determine the effect of other lacrosse helmets on cervical range of motion during a prone log roll. In the case of the Cascade Pro7 our results suggest that it is best to leave the helmet in place until after the log roll. This may not be the case in other brands of lacrosse helmets or Cascade models. Determining the feasibility of removing the facemask in a timely manner and the amount of head movement it causes needs to be investigated. Due to the different designs and manner in which the facemasks are attached, this should be done in all current brands and models of lacrosse helmets. The amount of cervical motion caused by removal of the helmet is also vital information that we do not have.

Conclusion

The presence of protective equipment has a significant effect on how an athletic trainer will choose to manage a cervical spine injury. In many cases the helmet and shoulder pads make the situation more complicated. It is critical that the rescuer know what effect the equipment will have on the management of the injured athlete. This study investigated the effect lacrosse helmet fit has on cervical motion during a prone log roll. It showed that significantly more rotation was allowed in the PF condition when compared to the HR condition. A significant difference was also seen between head and helmet rotation in both CF and PF helmets. No significance was found between the three conditions in the frontal or sagittal planes, and no significant difference between head and helmet movement was found in the frontal or sagittal planes. Therefore, based on these results and that removal of the helmet while in a prone position could prove difficult, we suggest that helmet be left in place until the athlete has been log rolled into supine position.

APPENDIX A

University of North Carolina
Department of Exercise and Sports Science
Research Questionnaire

SID:________________________________

Subject #:___________________________

Height:__________kg

Weight:_________cm

Previous History of Cervical Fracture/Dislocation:________

Suffering from Current ROM Limiting Neck Pain:_________

Helmet Corrections:

Change Ear Pads:_________

Adjust Chin Strap:________

Adjust Slide Bar:_________

Notes:

APPENDIX B

University of North Carolina
Department of Exercise and Sports Science
Manuscript

ABSTRACT

EVAN B. ALLEN: The Effect of Lacrosse Helmet Fit Condition on Cervical Spine Movement during a Prone Log Roll

(Under the Direction of Dr. Meredith A. Petschauer)

Objective: To determine what effect lacrosse helmet fit (properly fit helmet, competition fit helmet, and helmet removed) has on movement of the cervical spine during a prone log roll. **Subjects:** Eighteen varsity male lacrosse players at The University of North Carolina at Chapel Hill. **Methods:** Head-to-thorax and helmet-to-thorax movement in the frontal, sagittal and transverse planes were recorded during a prone log roll for each helmet fit condition. Motion data was integrated and normalized to measure the total amount of sagittal, transverse, and frontal plane movement. A series of repeated measures ANOVA's were used for statistical analysis. **Results:** There was a significant difference in the amount of head-to-thorax movement that occurred in the transverse plane ($F_{2,34}$ = 6.00, p = .006). Pair wise comparisons determined the transverse plane motion to be significantly greater in the properly fit helmet condition than in the helmet removed condition (Mean Difference = 5.19, Std. Error = 1.21, p = .001). A significant difference in the amount of movement between the head and helmet were found in transverse planes of the competition fit ($F_{1,17}$ = .11.211, p = .004) and properly fit ($F_{1,17}$ = 22.005, p < .001) conditions. There were no significant differences in either head to thorax motion or helmet to thorax motion in the frontal, or sagittal plane. **Conclusion:** The results of this study suggest that the presence of

the Cascade Pro7 lacrosse helmet only causes head movement to increases in the transverse plane when the helmet is properly fit. Because the helmet is difficult to remove when the athlete is prone and most lacrosse helmets are improperly fit, it may best to leave the helmet in place until the athlete has been log rolled.

Key Words: cervical spine, prone log roll, lacrosse, helmet

Introduction

Head and neck injuries are among the most concerning to sports medicine professionals, and it has been shown that as many as 11%-20% of all lacrosse injuries affect the head, face, or neck (Diamond & Gale, 2001; Dick, Romani, Agel, Case, & Marshall, 2007). Lacrosse has become increasingly popular across the United States with a 68% increase in the number of participants since 2001(Casazza & Rossner, 1999; US Lacrosse, 2006). The game of lacrosse is a high-speed and high-contact sport. As the number of participants in lacrosse increase, the prevalence of injury is likely to do the same.

Men's lacrosse is a contact sport that is comparable to football and ice hockey, and with it come similar health and safety risks (Decoster, Bernier, Lindsay, & Vailas, 1999). The athletes also wear protective helmets and shoulder pads in lacrosse, which in the case of serious injury, can complicate the rescue process. This is an issue because when comparing incidence of catastrophic cervical spine injuries per 100,000 participants, the rate is actually higher in college lacrosse (2.11) then it is in collegiate football (1.89) (Mueller & Cantu, 2009; Swartz, et al., 2009).

The National Athletic Trainers' Association organized a task force in 1998 with the goal of developing the proper techniques and guidelines for the on-field management of cervical spine injuries, in the presence of head and upper body protective equipment (Kleiner, 2001). The Inter-Association Task Force for Appropriate Care of the Spine Injured Athlete (IATF) recommended that in football, ice hockey and men's lacrosse the helmet and shoulder pads be left in place during the immobilization process. They suggest that equipment should only be removed once the individual is at the hospital and in a controlled environment. However, if the helmet and shoulder pads do not provide adequate support and stabilization of the head and neck, the IATF recommends they be removed immediately (Swartz, et al., 2009).

These recommendations are based primarily on research done in football. Studies specific to the effect of protective equipment on cervical spine alignment and in-line stabilization in men's lacrosse and have shown different results than what is seen in football (Higgins, Tierney, Driban, Edell, & Watkins, 2010 ; Petschauer, 2010; Sherbondy, Hertel, & Sebastianelli, 2006). Removal of only the helmet has been shown not to have a significant effect on cervical alignment or the space available for the spinal cord (Higgins, et al., 2010; Sherbondy, et al., 2006). It has also been shown that after being secured to a spine board, active cervical range of motion was greater when a lacrosse helmet was in place compared to when it was removed (Petschauer, 2010). More research is needed in order to make recommendations specific to lacrosse on how best to manage an athlete with a suspected cervical spine injury. To our knowledge, no one has investigated the effect of lacrosse equipment on cervical spine movement prior to immobilization. Therefore, the purpose of this study was to determine the effect of lacrosse helmet fit on cervical spine movement during a prone log roll.

Subjects

A total of 18 subjects (ht = 183.83 ± 6.60 cm, mass = 85.77 ± 7.47 kg) were asked to volunteer for this study. Exclusion criteria for this study included lack of full, pain-free neck range of motion, currently suffering from neck pain, or previous history of a cervical fracture or dislocation. Participants in this study were required to be members of the University of North Carolina at Chapel Hill varsity men's lacrosse team who participated in practice on a daily basis, and were between the ages of 18 and 25 years.

Equipment

A Motion Star (Ascension Technologies, Burlington, VT) electromagnetic motion analysis system, controlled by the MotionMonitor software (Innovative Sports Training Inc Chicago, Ill), was used to collect data at a sampling frequency of 144Hz. This system tracks the movements of receivers relative to a fixed electromagnetic transmitter. They were attached to the subject using double-sided tape and athletic tape over the top of the receivers. One was attached to the top of the Cascade Pro7 helmet (Cascade Lacrosse, Liverpool, NY), the second to the proximal sternum, inferior to the sternal notch, and the third to a custom built orthoplast mouthpiece covered in a thermo-moldable plastic cover. The subjects were log rolled onto a rigid spine board (Ironduck, Chicopee, Ma).

Protocol

The subjects reported to the Sports Medicine Research Laboratory on the campus of The University of North Carolina at Chapel Hill for testing where they read and signed an informed consent form. They completed a questionnaire addressing the exclusion and inclusion criteria, height, and weight. Subjects were then tested using a repeated measure, counterbalanced design beginning with one of the three helmet conditions. For the PF condition, a Pro7 helmet (separate from the helmet normally worn by the participant during regular competition) was fitted by the primary investigator according to the Cascade® helmet safety guidelines and checked for proper fit.

The CH was examined by the primary investigator and subjects were only included in the study if the CH was not determined to be properly fit. If the helmet did not require tightening of the chin straps, changing of the ear pads, or adjustments to the slide bar the subject was not included in data collection.

The three receivers were then secured to each subject. In order to ensure movement of the receiver on the mouthpiece represented movement of the head, the subjects were instructed to maintain a firm and constant bite at all times. After the receivers were in place, the subject was instructed to sit upright and remain motionless while anatomical landmarks were identified through a digitization process. The digitization points included the bridge of the nose, middle of the chin, occiput, T12-L1 joint, the spinous process of T8, the spinous process of C7, and the xiphoid process. The starting position for the emergency prone log roll procedure was standardized across all trials and consisted of the participants lying limp in a prone position, with their arms by their side and head turned facing their right. The subjects were instructed to remain limp at all times. Two certified athletic trainers (Rescuers 1 and 2) and an undergraduate athletic training student (Rescuer 3) who had been taught and practiced the proper techniques for managing on-field cervical spine injuries performed the emergency prone log roll. For all trial conditions, Rescuer 1 was responsible for immobilization of the head and neck and directing the group through the entire procedure. Rescuer 2 was in control of the subject's thorax and rescuer 3 controlled the legs of the subject. Once the subject and rescuers were in position Rescuer 1 counted to three and then said, "Go." Data collection began on three, and on "go" the subject was rolled to his left on to the spine board, all in one motion. Once the subject had been rolled a "stop" command was given and the trial was ended. A total of five trials were completed for each of the three helmet conditions.

Data were exported from the MotionMonitor system and reduced using a custom Matlab (The Mathworks Inc, Matick, MA) program. A trigger was used to define the beginning and end of each trial. To account for any difference in starting position, the average of the first 10 data points in each trial was subtracted from all the data points in that given trial. The data were then rectified, integrated and, normalized to time.

Statistical Analyses

Three repeated measures analysis of variance (ANOVA) were employed to assess significant differences in sagittal, frontal, and transverse plane head-to-thorax motion between the three helmet conditions. Three subsequent repeated measures ANOVAs assessed differences in sagittal, frontal, and transverse helmet-to-thorax motion between the CF and PF helmet conditions. Six paired-samples t-tests were performed in order to compare head-to-thorax movement and helmet-to-thorax movement between the PF and CH conditions. Alpha level was set a priori at 0.05. In the event of a significant ANOVA, a Bonferroni correction was employed to produce a pairwise comparison. All statistical analyses were performed using SPSS version 16.0 (SPSS, Chicago, IL).

Results

In the transverse plane there was significantly greater head to thorax motion between the properly fit helmet condition and the helmet removed condition ($F_{2,34} = 6.00$, $p = .006$) (Mean Difference = 5.19, Std. Error = 1.21, $p = .001$). No statistically significant differences were found between the other helmet conditions, or in the sagittal ($F_{2,34} = .330$, $p = .721$) and frontal planes ($F_{2,34} = 1.33$, $p = .277$).

There were no significant differences found in the amount of helmet-to-thorax movement between the means in the sagittal ($F_{1,17} = 2.691$, $p = .119$), transverse ($F_{1,17} = .991$, $p = .333$), or frontal planes ($F_{1,17} = .647$, $p = .432$).

Six paired-samples t-tests were used to determine differences in amount of head movement compared to helmet movement in the competition and properly fit helmet conditions. There were no significance differences found in competition fit helmet in the sagittal ($F_{1,17} < .001$, $p = .997$) or frontal planes ($F_{1,17} = .012$, $p = .915$). There were also no significant differences found in the properly fit helmet in the sagittal ($F_{1,17} = 2.103$, $p = .165$) or frontal planes ($F_{1,17} = .036$, $p = .851$). A significant difference in the amount of movement between the head and helmet were found in transverse planes of the competition fit ($F_{1,17} =$ .11.211, $p = .004$) and properly fit ($F_{1,17} = 22.005$, $p < .001$) condition.

Discussion

The primary finding of this study was that the majority of the movement allowed in the three different helmet fit conditions was not significantly different during a log roll of a men's lacrosse player. We did find that there was significantly more transverse head movement in the properly fit helmet than in the helmet removed condition. This indicates that cervical rotation is more effectively controlled and limited when the athlete is not wearing a helmet. However, the transverse motion is the only plane in which there was a statistically significant difference. The lack of other significant differences between the helmet conditions would indicate that helmet fit does not have a substantial effect on cervical range of motion during a log roll in a Cascade Pro7 helmet.

Our results seem to agree more closely with the findings of Waninger, who showed that fit of the Sport Cascade lacrosse helmet does not have a significant effect on head motion. A possible explanation for why our results do not align with what Petschauer found is that we measured passive range of motion, as Waninger did, instead of active range of motion. We also looked exclusively at the Cascade Pro7 helmet, instead of the Cascade CPX. The Pro7 is Cascade's newest helmet model, and could possibility provide better security for the head. Our lack of significant findings outside of the transverse plane could also be explained because a prone log roll is mostly a rotational movement. There is not a lot of frontal and sagittal plane motion in a log roll so the fit of the helmet should not greatly affect how much the head moves in these planes.

Helmet fit did not have a significant effect on the range of motion that occurred between the helmet and thorax in the sagittal, frontal, or transverse planes. These results are important because they indicate that we were consistently moving the helmet through the same range of motion. Helmet fit should not have a significant effect on how much the helmet is moving during a prone log roll. While we cannot make generalizations to all rescuers who may be required to perform this procedure, our results would suggest that a properly trained sports medicine professional can consistently and effectively control the helmet regardless of fit. These findings correspond with results in hockey research which showed helmet fit did not affect their ability to consistently perform a prone log roll (Mihalik, Beard, Petschauer, Prentice, & Guskiewicz, 2008). It has also been shown that training does not have a significant affect the amount of cervical movement resulting from a log roll (Del Rossi, Horodyski, & Powers, 2003). This indicates that rescuers should be equally effective in stabilizing the helmet no matter how extensive their experience is.

In the transverse plane there was a significant difference between head-to-thorax and helmet-to-thorax range of motion. In both the CF and PF conditions the head rotated less than the helmet. As the subject was rolled onto the spineboard and the helmet was brought into a neutral position, the head does not move through the same range of motion. This suggests that the head is moving independently of the helmet. In a study looking at the effect of lacrosse helmet fit on active head motion after stabilization, Petschauer, 2010 found that the head moves significantly more than the helmet in both conditions. Once again possible explanations for the differences in the results are that we measured passive range of motion, our subjects wore a different model helmet, and rotation is the primary motion in a log roll. A significant difference in head-to-helmet movement has also been shown in research performed on football helmets (Toler, et al.). Despite the different results and helmet types, the outcomes indicate a similar trend. The head and helmet are not moving as a unit. This could be a serious issue if an athlete was stabilized in a helmeted condition and something caused an uncontrolled rotation of the head.

It is likely for there to the some variability in the movement caused by the log rolling procedure. Though the log roll was practiced repeatedly and every attempt was made to perform the procedure the same from one trial to the next some inconsistency is inevitable. However, because there was no significant difference in helmet movement we are confident in the consistency of the log rolls.

The same specifications were used to fit each of the helmets and each subject was fitted individually by the primary investigator. This was done to ensure that each subject was fitted to the same specifications. Despite these procedures the size and shape of the subject's heads varied and the helmet fit some subjects better than others.

Our sample was taken from uninjured lacrosse players and it is difficult to know if the athletes tightened their cervical musculature at any point during the log roll. Each subject was reminded repeatedly to remain completely relaxed and not to fight or help the researchers in any way.

In order to be consistent and because the Cascade Pro7 is the only helmet worn by our subjects, it was the only helmet tested. Therefore, we cannot generalize our results to other helmets and how they might affect cervical range of motion during a prone log roll.

Clinical Significance

Our research attempted to help answer the question of how best to manage a men's lacrosse athlete lying prone. The results of this study suggest that fit of the Cascade Pro 7 helmet does not have an effect on the movement of the athlete's head as they are being log rolled from a prone position. While it is a small range of motion head does move independently from the helmet, in the transverse plane, whether the helmet is fit according to the manufactures' specifications or not. Additionally, the position of the athlete's head when lying prone could make it extremely difficult to safely remove the helmet while maintaining proper cervical alignment. These factors lead to the conclusion that it is in an athlete's best interest to leave the helmet in place until they have been moved into a supine position.

Cervical spine injuries in men's lacrosse are not extremely common; however, head and facial injuries do occur regularly (Diamond & Gale, 2001; Dick, et al., 2007; Mueller & Cantu, 2009). Every injury to the head or face represents a potential catastrophic cervical spine injury. For this reason it is vital for the certified athletic trainer to have as much information as possible on how to best handle an emergency situation. The certified athletic trainer needs to be comfortable and confident in the decisions and techniques to be used. Due to the differences lacrosse helmets and shoulder pads have on cervical alignment and range of motion, it seems clear that there needs to be recommendations specific to lacrosse and potentially to the type of helmet being worn.

The amount of cervical range of motion that is allowed before an injured athlete will suffer secondary injuries is still unknown (Del Rossi, et al., 2003). Until we know how much movement can safely take place it must be the goal of any rescuer to limit head and neck motion as much as possible. Future research needs to done to determine the effect of other lacrosse helmets on cervical range of motion during a prone log roll. In the case of the Cascade Pro7 our results suggest that it is best to leave the helmet in place until after the log roll. This may not be the case in other brands of lacrosse helmets or Cascade models. Determining the feasibility of removing the facemask in a timely manner and the amount of head movement it causes needs to be investigated. Due to the different designs and manner in which the facemasks are attached, this should be done in all current brands and models of lacrosse helmets. The amount of cervical motion caused by removal of the helmet is also vital information that we do not have.

The presence of protective equipment has a significant effect on how an athletic trainer will choose to manage a cervical spine injury. In many cases, the helmet and shoulder pads make the situation more complicated. It is critical that the rescuer know what effect the equipment will have on the management of the injured athlete. This study investigated the effect lacrosse helmet fit has on cervical motion during a prone log roll. Based on the results and that removal of the helmet while in a prone position could prove difficult, we suggest that helmet be left in place until the athlete has been log rolled into supine position.

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