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This study determined if properly and improperly fitted lacrosse helmets provide adequate stabilization of the head, and therefore the cervical spine, in the spine boarded athlete. A 3 x 3 repeated measures design was used with head to helmet range of motion (flexion/extension, side bending, and rotation) and helmet condition (properly fitted, improperly fitted and no helmet) as independent variables. Also a 2 x 2 repeated measures design was used with testing condition (improperly fitted helmet, and properly fitted helmet) and range of motion conditions (head to thorax motion and helmet to thorax). Eighteen healthy collegiate men's lacrosse players were asked to move their heads through three planes of motion after being secured to the spine board under each of the three helmet conditions. Changes in sagittal, frontal, and transverse plane motion were calculated. The head to thorax range of motion available in both the improperly and properly fitted helmet was significantly greater than the no helmet condition ($F_{(2,34)}=34.48$; $p<.001$), ($F_{(2,34)}=17.18$; $p<.001$), ($F_{(2,34)}=39.72$; $p<.001$). In the sagittal plane the range of motion was greater in the improperly fitted helmet than the properly fitted helmet. There was no difference in the helmet to thorax range of motion between helmet conditions. The head to thorax range of motion was significantly greater than the helmet to thorax range of motion in all three planes, sagittal ($F_{(1, 17)}=279.59$; $p<.0001$), frontal ($F_{(1, 17)}=184.05$; $p<.0001$), and transverse ($F_{(1, 17)}=211.43$; $p<.0001$). Thus, the cervical spine was stabilized better when the lacrosse helmet was removed. Adjusting the fit of the helmet only improved head immobilization in the sagittal plane.

EFFECTIVENESS OF CERVICAL SPINE STABILIZATION DURING SPINE BOARDING OF COLLEGIATE LACROSSE ATHLETES

by

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APPROVAL PAGE

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure 4.5. Head and helmet to thorax grand means across properly and improperly fitted helmets for all three planes of motion. 54

CHAPTER I

INTRODUCTION

Catastrophic cervical spine injury is a structural distortion of the cervical spinal column associated with actual or potential damage to the spinal cord (Neurosurgery, 2000). For many years athletic trainers and other medical professionals have been concerned with cervical spine injury and proper management of such an injury. Proper management is necessary as it is believed that improper management can lead to secondary injury and lifelong disability (Kleiner, 2001).

The primary mechanism for injury to the cervical spine involves its compression as a result of an axial load placed on the top of the head (Otis, 2000). In normal situations the compressive load is absorbed by the intervertebral disks, the bodies of the vertebrae and the surrounding musculature and ligaments. However, when the neck is in slight flexion the natural lordotic posture of the cervical spine is eliminated leaving it more vulnerable to injury from an axial load.

In the overall population there are between 150 and 500 reported cases of cervical spine injury per every 100,000 injuries and it is believed that athletics causes 25% of these (Proctor & Cantu, 2000). The National Spinal Cord Injury Research Center determined that sport produces as many as 25% of quadriplegia cases with an alarming mean age of 24 years (Clarke, 2000, Cooper, 2003). Football produces the largest number of these injuries and between 1977 and 1989 there were 128 permanent cervical cord injuries (Cantu & Mueller, 1990). The injury rate in football has been declining. In the last ten years there have been an average of 7.3 cervical cord injuries per year that have resulted in neurological damage and in some of those years, no cervical spine injuries were reported (Mueller, 2005). In ice hockey between 1982 and 1992 there were 16.8 spinal cord injuries every year and 68% of them resulted in neurological damage (Tator, 1998).

In lacrosse there have only been two spinal cord injuries reported since 1987 (Mueller, 2003). Given the nature of the sport, however, the potential for cervical injury exists due to high velocity collisions (Cantu, 2000).

Due to the potential for significant injury, it is imperative that proper emergency management techniques be used to prevent further tissue damage or secondary injury during care on the athletic field. Secondary injury can result from the inflammatory process as well as excess spinal movement (DeLorenzo, 1996, Tierney, 2003, Warren, 1998). To reduce motion and maximize space for inflammation it has been determined that the best technique for transportation to a medical facility is to immobilize the cervical spine through immobilization of the head and trunk, in a position that provides neutral alignment. (De Lorenzo, 1996, Neurosurgery, 2000)

For individuals not wearing protective equipment of the head and upper body, stabilization of the head and trunk is a relatively straightforward process that involves strapping the body to a rigid board and then securing the head with bolsters and tape. The neck is also further stabilized with a cervical collar. (Neurosurgery, 2000) However, the protective equipment athletes wear may interfere with the ability to achieve the proper immobilization. As a result, the National Athletic Trainers' Association developed a task force to research and recommend techniques for proper on field management of cervical spine injury paying special attention to equipment considerations. This Inter-Association Task Force for Appropriate Care of the Spine-Injured Athlete (IATF) made the following recommendations with regard to protective equipment. In football, ice hockey and lacrosse the helmet and shoulder pads should be left in place when immobilizing the cervical spine injured athlete. After accessing the airway by removing the face mask, the athlete should be secured to a rigid spine board with straps to stabilize the trunk and legs and bolsters and tape to secure the helmet. However, it was also recommended that the helmet or protective equipment be removed under certain circumstances. One of these circumstances includes if securing the helmet does not effectively immobilize the head either due to helmet design or fit. (Kleiner, 2001)

This presents an interesting dilemma for the athletic trainer during on field management of a cervical spine injury in an athlete who is wearing protective equipment. It is important to recognize whether the design of the helmet and the way in which the athlete wears the helmet allows for adequate spinal stabilization if spine board immobilization is necessary. It has been speculated that movement inside football, ice hockey and lacrosse helmets is minimal, but that claim has not been thoroughly researched (Waninger, 2004). Additionally, the amount of movement that is considered to be safe post cervical spine injury has yet to be established (Del Rossi, 2004). Therefore, the purpose of this study was to determine if lacrosse helmets provide adequate stabilization of the head, and therefore the cervical spine, in the spine boarded athlete.

The significance of this investigation question lies in the athletic trainer's ability to reduce secondary cervical spine injury through proper on field management. While this injury is not as common as others in sport it has much greater potential to be catastrophic.

Research questions and hypotheses

Research Question 1 - Is there a difference between cervical spine motion that occurs when an athlete is properly immobilized on a spine board while wearing a properly fitted lacrosse helmet and shoulder pads, an improperly fitted lacrosse helmet and shoulder pads, and wearing no lacrosse protective equipment?

Hypothesis 1.1 – Movements of the cervical spine (total flexion, rotation, and lateral flexion) will be significantly greater when an athlete is wearing a properly fitted lacrosse helmet and shoulder pads compared to not wearing lacrosse protective equipment while immobilized on a spine board.

Hypothesis 1.2 - Movements of the cervical spine (total flexion, rotation, and lateral flexion) will be significantly greater when an athlete is wearing an improperly fitted lacrosse helmet and shoulder pads compared to not wearing lacrosse protective equipment while immobilized on a spine board.

Hypothesis 1.3- Movements of the cervical spine (total flexion, rotation, and lateral flexion) will be significantly less when an athlete is wearing a properly fitted lacrosse helmet and shoulder pads compared to an improperly fitted lacrosse helmet and shoulder pads while immobilized on a spine board.

Research Question 2 - If there is a difference between the properly fitted lacrosse helmet and shoulder pads, the improperly fitted lacrosse helmet and shoulder pads, and the no lacrosse protective equipment conditions, is the motion a result of movement of the head inside the helmet or movement of helmet due to an inability to stabilize it?

Hypothesis 2.1 –There is no difference in the ability to stabilize the helmet between the properly and improperly fitted helmet conditions.

Hypothesis 2.2 - Increased movement of the cervical spine (total flexion, rotation, and lateral flexion) occurs as a result of increased motion of the head within the fixed properly and improperly fitted lacrosse helmet.

Assumptions/Limitations

1. Subjects were asked to move through an available range of motion. Different individuals may have put more effort into moving through that range.
2. The subjects were immobilized on the spine board three separate times. It is possible that there was some inconsistency with which the head and torso are immobilized.
3. The helmets used were the Cascade CPX. This is the helmet used by the lacrosse team in the investigation. This helmet is one size fits all and can be adjusted through insertion

of one of three pads that can be placed inside the helmet around the occiput. The helmet may not have been adjustable enough to get a proper fit on every subject.

4. The data obtained during this study is only specific to the Cascade CPX helmet used on the collegiate level athlete.

5. Measured head to thorax motion occurred in the cervical spine.

Delimitations

1. Subjects were trained prior to participation. They knew the ranges of motion in which they were to move and they were given instructions to move to the point in which they felt resistance from the equipment.

2. The helmets used were the Cascade CPX. This is the helmet used by the lacrosse team in the investigation; therefore all of the helmets tested were the same brand and style.

3. The location of the straps used to secure the head and torso were the same and the straps were tightened by the same individual. Additionally, the tension on the straps was checked between trials.

4. Every attempt was made to properly fit the helmet according to the manufacturer's suggestions.

Operational definitions

IATF – Inter-Association Task Force. A task force organized by the National Athletic Trainers' Association that reviewed the literature and provided recommendations in terms of proper on field cervical spine injury management (Kleiner, 2001).

Flexion - Movement of the head toward the chest in the sagittal plane.

Extension – Movement of the head toward the back in the sagittal plane.

Rotation – Movement of the head in the transverse plane as if looking over the shoulder.

Lateral Flexion – Movement of the head in the frontal plane touching the ear to the shoulder without lifting the shoulder.

Optimal cervical positioning – A neutral position of the cervical spine in which the head and trunk are in a position as if one is standing an looking straight ahead, radiographically 12° of extension (Schriger, 1991)

Improperly fitted lacrosse helmet – The helmet the player actually wears during practice and competition that has not been properly fitted.

Properly fitted lacrosse helmet – A helmet fitted per manufacturer's instructions.

CHAPTER II

LITERATURE REVIEW

Introduction

Catastrophic cervical spine injury can be defined as a structural distortion of the cervical spinal column associated with actual or potential damage to the spinal cord (Banerjee, 2004). Since 1931 data have been collected on the incidence of injury in athletics through the National Center for Catastrophic Sport Injury Research (Mueller, 2005). Collection started with football and then expanded to include the majority of intercollegiate sports in the National Collegiate Athletic Association (NCAA). The collection and analysis of these data have lead to concerns regarding protective equipment and overall sport safety. As a result of these concerns, changes in sporting rules and equipment have been made with subsequent positive effects on the athletic population. For example, protective equipment has been mandated or redesigned to minimize the risk of injury. Rule changes have been put into effect to remove dangerous techniques from a game while also increasing public awareness of the risk involved in participating in some athletic events. These data have therefore assisted coaches and players in knowing the risk, but more importantly serve to potentially prevent serious injury from occurring.

There is a possibility of injuring the cervical spine in most athletic competitions. Football and ice hockey are the two sports that have been studied most often due to the fact that both of these sports include high velocity collisions, which can lead to considerable injury. There have been significant rule and equipment changes in these sports in response to injury data. Lacrosse however, has not been the subject of research in this area probably because it is a relatively new sport in terms of popularity. Given the nature of the sport, the potential for cervical spine injury is apparent.

While rule and equipment changes have had a positive affect on injury rate in football and ice hockey (Mueller, 1998, Torg, 1994, Tator1998), they have potentially made on field management of injury more difficult. These equipment considerations in football, ice hockey and lacrosse have led to some debate as to proper on-field emergency management of head, neck and back injuries. Given that injury to the cervical spine will occur and the consequences of long term disability with injury to this region, proper management is essential for minimizing secondary injury.

Incidence of injury

The overall incidence of spinal injury in the entire population is estimated to be about 150 to 500 cases per 100,000 with athletics believed to cause as many as 25% of these (Proctor & Cantu, 2000). An investigation from the National Spinal Cord Injury Data Research Center determined that sport produced 15% of all spinal cord injuries and 25% of quadriplegia cases (Clarke, 2000). This makes sport the fourth leading cause of spinal cord injury behind motor vehicle accidents, violence, and falls (Cooper et al, 2003). One of the more alarming problems related to athletic spinal cord injury is that the mean age for such an injury in athletics (24 yr) is significantly lower than all the other causes (Cooper et al, 2003). It has also been observed that risk of serious head and spine injury in athletics increases as athletes mature into young adulthood. This is because as age and maturity increase the mass of the individual and the velocity of the collisions are larger, therefore potentially resulting in a greater momentum and greater force during collision (Proctor & Cantu, 2000). According to the National Center for Catastrophic Sports Injury Research the four youth sports with the highest risk of head and spine injury are football, gymnastics, ice hockey and wrestling (Cantu & Mueller, 1990).

Football

Approximately 1.8 million people play football each year and football has been associated with the largest number of catastrophic head and spine injuries (Cooper et al, 2003). Catastrophic injury in football has been studied for over 50 years. Between 1977 and 1989 there were 128 permanent cervical cord injuries. It was also determined that defensive players were at greater risk than offensive players of sustaining a cervical cord injury (Cantu & Mueller, 1990). Mueller (2000) and Torg (1990) indicated that the number of catastrophic cervical spine injuries in football has been decreasing every year since the late 1970's. They attributed this decrease to changes in the rules of the game and equipment improvements.

Ice Hockey

Data related to ice hockey indicate that cervical spine injuries were rare during the 1960's and 1970's but have increased significantly during the 1980's and 1990's. The average injury rate for all spinal injuries in ice hockey between 1982 and 1993 was 16.8 cases per year. (Tator et al, 1998) The majority of these injuries occurred in 16-20 year old men. Additionally, 89% of these injuries were in the cervical vertebrae and of those, 65% resulted in some neurological damage. The age range most affected by this neurological damage was 11-20 years old (Tator et al, 1998). These data suggest that cervical spine injury is a realistic concern in ice hockey. Organizations such as the Canadian Amateur Hockey Association and USA Hockey who are responsible for management and rules of ice hockey have attempted to reduce the number of injuries since the late 1980's through rule changes and increased public awareness, which has in turn decreased the number of complete spinal cord injuries (Tator, 1998).

Lacrosse

Given the nature of men's lacrosse, there is potential for serious injury. Cantu (2000) lists men's lacrosse as 11th overall in a list of sports most hazardous for the head and spine with it being the 4th intercollegiate sport on the list. However, little research was found in this area in terms of injury incidence and proper management. The few studies available have shown that concussion is more prevalent than cervical spine injury. Jordan (1998) indicated that concussion occurred in 6 of 586 players in one season. In the NCAA News (2002) it was reported that the overall injury rate in collegiate men's lacrosse was 10.8 per 1,000 athlete exposures during games and 3.2 during practices. The head, upper leg and the knee were the body parts most likely to be involved. A recent report indicated that there were two serious men's lacrosse injuries to the cervical spine in high school between 1987 and 2003 (Mueller, 2003). One resulted in death and the other in quadriplegia. While there seems to be potential for injury, lacrosse appears to have a lower incidence of injury than football and ice hockey. However, there is still a desire of the athletic trainer to know the proper management if a cervical spine injury does occur.

Equipment and rule changes as a result of injury data

Football rules and injury

The change of incidence of cervical spine injury in football is related to both the rule and equipment changes over the years. In the 1940's a plastic shelled helmet was introduced with a single bar face mask added in the 1950's. During this time (1945-1954) there were 32 fatalities as a result of spinal cord injury. Most of them occurred during games while tackling that resulted in fracture (Mueller 2000). The primary method for tackling at this time was use of the shoulder as the main contact point. However, during the end of the next decade the emphasis during tackling began to change and players began making initial contact during a tackle with the head and face instead of the shoulder. This was also the time in which the face mask increased to two bars. Between 1955 and 1964 there were 23 fatalities as a result of spinal cord injury with 70% of those occurring at the high school level (Mueller, 2000). Once again the activity that was being performed during these injuries was tackling.

The prevalence of injury began to worsen during the next decade. Wilberger (2000) stated that there were 259 cervical spine injuries in football from 1971 to 1975. This correlated to 4.1 per 100,000 players and of those, 99 cases or 1.58 per 100,000 players resulted in permanent quadriplegia. Mueller (2000) indicated an increase in cervical spine fatalities from the previously mentioned 23 to 42 during the decade of

1965-1974. The initial contact while tackling during this decade was with the head. Players were instructed to put their face into the blocker's chest essentially making the helmet and head a weapon. Also by this time players were making full contact with their heads because they were wearing full-face masks and felt as though they were well protected. Torg et al (1990) indicated that 85% of all cases of cervical spine injury from 1971 to 1975 were due to the axial loading mechanism. It is clear that requiring players to wear a helmet to reduce concussion and the design of that helmet were related to the incidence of cervical spine injury because players were tackling with their head.

Due to this dramatic increase in the number of fatalities, there were some changes that needed to occur. The NCAA and the National Federation of High School Athletic Associations changed the rules of football in 1975 so that the head could no longer be used as a weapon (Torg et al, 1990). Rules changed such that you could no longer butt block, face tackle, or spear. This changed the emphasis back to the shoulder making the initial contact during a tackle instead of the head. After this rule change the incidence of cervical spine injury started to decrease. The decline was dramatic in that it was reported that after 1978 the incidence of cervical spine injury went down to 1.3 per 100,000 and 0.4 per 100,000 resulted in quadriplegia (Torg et al, 1990). Additionally, The National Operating Committee on Standards for Athletic Equipment (NOCSAE) was developed in the late 1970's and began to develop safety standards for helmets that went into effect in 1978. The data from Mueller (2000) indicate that the frequency of fatalities related to cervical spine injury has greatly decreased with the helmet and rule changes. In 1965-1974 there were 40 fatalities as a result of spinal cord injury, 26 as a result of tackling, between 1975-1984 there were only 14, 10 as a result of tackling, and then between 1985-1994 there were only 5, all as a result of tackling. This clearly illustrates how the rules of the game have affected the incidence of this type of injury.

In a study performed by Heck (1996) analyzing two seasons of football, one prior to the spearing rule and one after, it was reported that the overall amount of spearing had not reduced even though it was against the rules. It was demonstrated that spearing had decreased in defensive lineman and independent tacklers and that linebackers and defensive backs accounted for most of the spearing that occurred. In a follow up position statement, Heck et al (2004) made several recommendations with regard to head down contact in football. They indicated that head down collisions still occur and that although the injury numbers have gone down it is still crucial to enforce rules, educate coaches and athletes of the risk in head down contact and continue to evaluate the safety standards.

Ice Hockey rules and injury

The velocity of amateur ice hockey players during skating reaches 30mph and in pee wee players 20mph (Daly et al, 1990). These speeds are enough to create significant injury (Daly et al, 1990). Through the investigation of ice hockey injury it was determined that head and face injuries could be prevented if a helmet and face mask were worn during competition. In 1978 helmets and face masks were mandated by both US and Canadian hockey leagues. However while this may be preventing injuries to the head and face, cervical spine injuries are increasing. (Reynen &Clancy, 1994) It has been theorized that this increase in cervical spine injury is due to the helmet (Reynen & Clancy, 1994). The helmet does not cause injury directly, but that it seems to be related to an increase in the aggressive play of athletes as was previously seen in football. A push or check from behind was the most often described event that lead to cervical spine injury. In most of these cases the players described being unaware of the hit and then hitting the board horizontally as to put an axial load on the spine. This type of impact with the boards created the injury in over 70% of the cases (Tator et al, 1998).

To help with this problem and prevent injury a 1985 rule that specified that there was to be no pushing or checking from behind was introduced by the Canadian Amateur Hockey Association. Additionally, in 1989 USA Hockey moved the goal line further from the boards and in 1994 made it a penalty to check someone who no longer had control of the puck. Moreover, there have been safety videos made with the intent to increase the awareness of such injury and how to prevent it. Tator et al (1998) indicated that between 1991 and 1993 the number of injuries from a push or check from behind has decreased as well as the overall number of injuries. However, in a study done on youth ice hockey injury, Reid and Losek (1999) found that the majority of spinal injuries occurred as a result of a check perceived by the coach or the player to be illegal.

SportSmart Canada also started a campaign called “Heads Up Hockey” to keep players and coaches aware of the dangers of hitting a player or the boards with the head down (Tator, 2000). While some of the attempts seem to be working, continuation of this effort will hopefully further reduce the incidence of injury. Finally in terms of management, the high velocity of the puck has lead to mandating face masks. This face mask may lead to some challenges during on field management of spinal cord injury.

Lacrosse and rule changes

There have not been significant rule changes due to the injury data in lacrosse. This is likely because it is relatively recently collected and the data do not seem to suggest a high incidence of cervical spine injury. However, there has been an attempt to redesign the helmets to assist in reducing the number of concussions. Testing of the new helmets suggests a decrease in the ability of a lacrosse helmet to dissipate force with repetitive impact forces (Caswell, 2002). It is imperative for the lacrosse community to learn from football and ice hockey and make sure that changes in helmets do not adversely affect the cervical spine.

Biomechanics of cervical spine injury

The mechanics of cervical spine injury are relatively independent of the sport. The cervical spine functions to support the head and protect the neurological structures while also allowing for enough range of motion for an individual to function. It includes seven cervical vertebrae that are categorized into upper and lower regions. The upper region includes the atlas and the axis which articulate to produce 40% of cervical flexion and extension movement and 60% of rotation (Banerjee, 2004). The lower cervical spine consists of the remaining 5 vertebrae and therefore accounts for the remainder of motion. These vertebrae are joined by ligaments and muscles that assist in stability, resist tensile and shear type of forces as well as assist in absorption of force transferred through the area. The compressive forces in each joint are absorbed primarily by the intervertebral disks and the bodies of the vertebrae. Because protection of the spinal cord is a major function of the cervical spine the bony spinal canal is large enough to allow for some movement of the spinal cord. However, between the C4 and C7 vertebral levels the spinal cord gets larger in diameter and the spinal canal becomes more narrow such that the cord fills 75% of the cross sectional area (Banerjee, 2004). The average midsagittal cord diameter is 8-9mm and canal diameter can range from 14-23mm (below 13mm is considered spinal stensosis) (Banerjee, 2004).

Normal alignment of the cervical vertebrae is in a slight lordotic curve. In this position compressive forces can be absorbed and dissipated by the supporting ligaments and musculature that surround the vertebrae as well as the interverterbal disks. The vertebral bodies can only withstand about 3Nm of energy before failing. The magnitude of energy that is transferred in sport can be 10 times that and therefore it is crucial that the musculature be in the position to absorb the majority of the force. (Otis, 2000) The spine is more resistant to flexion than to extension because the muscles on the posterior aspect of the spine are stronger and the bony arrangement does not allow for extreme motion due to the interference of the chin hitting the chest. This design allows for the spine to stay in a position that is optimal for absorbing force. (Otis, 2000)

The most common mechanism of serious cervical injury is axial loading. This type of injury occurs when a large compressive force is applied to the top of the head. Torg et al (1990) indicated that injury occurs to the cervical spine when it is compressed between the body and the rapidly decelerating head. This occurs when the cervical spine is straight (slight flexion) and the force is transmitted along the longitudinal axis of the spine creating a large compressive load on the vertebrae. The straight axial load results in a fracture with many bony fragments (Otis, 2000). Damage occurs when these fragments encroach on the spinal cord. It is more dangerous, however, when the neck is going into flexion because not only does this movement bring the spine out of its normal alignment by putting it in a straight line, but the act of flexion forces the vertebra into the spinal canal space. This is more likely to result in an unstable fracture that will be associated with spinal cord injury. This mechanism has been shown to be the primary cause of cervical fracture, dislocation, and quadriplegia with the most common vertebrae affected being C5 and C6. (Bailes, 2001, Banerjee, 2004)

Secondary injury

Although changes in sporting rules and equipment have been successful in decreasing the incidence of cervical spine injury, inevitably this injury will occur at some rate. Athletic trainers responsible for emergency care of the athlete are very interested in the proper and effective management of cervical spine injuries. If or when an injury occurs, it is important that the cervical spine be protected as not to create a secondary injury. Secondary injury is sustained due to the hemorrhage, release of vasoactive amines and edema formation (Warrren, 1998). Part of this prevention and proper management is to maintain an optimal amount of space for the spinal cord in case of swelling. The optimal space is defined as the position that gives the most amount of space inside the spinal column (De Lorenzo, 1996, Tierney, 2003).

Flexion and extension of the injured neck may result in cord deformation and elongation (DeLorenzo, 1996) According to Lennarson (2000) the spinal cord in the subaxial spine demonstrates an intolerance to small amounts of elongation and deformation. This indicates that minimizing movement in this region can be crucial to reducing secondary injury. Therefore, the overall technique in terms of management involves an immobilization procedure that places the cervical spine in the best position and limits the movement of the patient.

Optimal spinal cord space

As with every acute injury, there is inflammation associated with cervical spine injury. Due to the space constraints, it is best to put the spinal column in the ideal position so that swelling can occur with minimal risk to the spinal cord. In addition to allowing for maximal space, immobilization in the properly aligned position will further assist in protection of the spinal cord.

Several studies have attempted to determine the position of the cervical spine that allows the maximum amount of space for the spinal cord. DeLorenzo (1996) determined optimal position of the cervical spine in a supine position using MRI by looking at cross sectional area of the spinal canal versus the spinal cord. Maximal area was consistently obtained with slight flexion corresponding to raising the occiput 2cm anteriorly relative to the thorax. However, this study did not investigate equipment considerations and is also disputed by Tierney (2002) who indicated that the most amount of space was present when the occiput was not moved anteriorly. Additionally, Tierney tested a football helmet and shoulder pad condition and indicated that there was no significant difference in spinal cord space between the zero elevation without the equipment and the equipment on condition. Schriger (1991) indicated that the majority of cervical spine injuries occur with a fracture that is unstable during flexion. This would mean that placing a patient in flexion would potentially be harmful and raising the occiput would potentially put a patient in flexion. Therefore the conclusion is that leaving the shoulder pads and helmet on in football is optimal to maintain maximal cord space. (Swenson, 1997, Waninger, 2004)

For ice hockey equipment, LaPrade (2000) determined that leaving the helmet and shoulder pads on in an ice hockey player were the best choice for maintaining neutral spinal alignment. He reported that with the helmet removed and the shoulder pads remaining that the cervical spine was in a significant amount of lordosis in comparison to the helmet and the shoulder pads on or both of them off. Therefore for ice hockey the recommendation is to leave the helmet in place. This is consistent with the work of Metz (1998) who examined the angular displacement of the cervical spine when the helmet and shoulder pads were left in place in comparison to the displacement when just the helmet was removed. They determined that the greatest amount of angular displacement occurred when the head rested on the backboard with the shoulder pads still in place and the helmet off. In addition to these studies, it has been determined that removal of the helmet in football may create movement that puts the integrity of the spinal cord at risk (Donaldson 1998, Prinsen 1995). The National Athletic Trainers' Association Inter-Association Task Force for Appropriate Care of the Spine-Injured Athlete (IATF) recommendation is to keep the helmet and shoulder pads on while immobilizing the cervical spine.

The investigator has been unable to locate any research regarding optimal spinal position while wearing lacrosse equipment and therefore the assumption has been to treat it the same as ice hockey and football. The difficulty in determining this when compared to existing work is that lacrosse shoulder pads are typically thinner and therefore may not provide the torso with the amount of lift necessary in the supine position to put the cervical spine in the best position.

Current recommendation on management of cervical spine injury

Evaluation

Current proper management is designed to ensure that excessive movement does not exacerbate the initial damage done to the spine thereby reducing the chance of a secondary injury (Warren, 1998). For assessment on the field it is important to first do a primary survey checking for unconsciousness, airway, breathing, and circulation to determine that there are no life threatening injuries. If no immediate life threatening conditions are present then determining the level of consciousness of the individual and doing a neurological screening are the next step. This screening includes determining the level of consciousness of the athlete, pupillary response, pain response, and any abnormal movements. Additionally, the evaluator should be looking for neck pain, numbness or weakness. (Bailes, 2001, Banerjee, 2004) Because it may be difficult to rule out serious neurological injury while on the field, the IATF recommends that any athlete with significant neck or spine pain, diminished level of consciousness or significant neurological deficits be transported to a medical facility for a more definitive diagnosis (Kleiner et al, 2001).

Transportation and spine boarding

According to the IATF (2001) immobilization of the cervical spine should be accomplished through the use of a rigid spine board. For transport the athlete should be properly secured to the backboard in such a way that the space for the spinal cord is optimal and the airway should be accessible. This includes stabilization of the cervical spine in a neutral or in line position. To assist with in line stabilization it is recommended that every attempt be made to apply a cervical collar. Stabilization on the spine board should include straps across the shoulders, pelvis, legs and finally the head. (Kleiner, 2001)

Airway access and equipment considerations

Respiratory and cardiac arrest are rare occurrences secondary to cervical spine injury (Waninger, 2004). The most common vertebrae involved in the mechanism of sport related cervical spine injury is C5 to C7 and at these levels the respiratory system is not affected (Waninger, 2004). However, it is recommended that prior to transportation the airway be made accessible in case of respiratory distress. This is not an issue for athletes who are not wearing a helmet, but for those who are, it can be difficult to reach the airway. Modifications to helmets to improve safety have made management of the airway and gaining access to it more challenging. When football and ice hockey started requiring the use of full face masks to reduce injuries to the face, airway access became more difficult and therefore the recommendation in terms of management had to change. It was not until the most recent IATF recommendations were made that face mask removal was a priority in cervical spine injury management. The problem is that the face mask can often be difficult to remove and time consuming. Therefore removal prior to initial signs of respiratory distress ensures that time is not lost during a moment when the athlete needs immediate care. Hence the recommendation of the IATF is that the face mask of the helmet be removed before attempting to immobilize the athlete on the spine board.

There is some controversy over the best technique to perform face mask removal. The tools that are possible depend on the style and the type of helmet. All of the sports including football, ice hockey, and lacrosse have different styles and different brands of helmets with a face mask. Unfortunately these differences as well as the potential condition of the helmet have lead to difficulty in making a recommendation about the best technique for removal. The tools that are used include various types of cutting tools such as the FM extractor (Sports Medicine Concepts, Inc. Geneseo, NY) and the Trainer's Angel (Trainer's Angel, Riverside, California) as well as screwdrivers. The best tool to use is one in which the face mask can be removed as quickly as possible with the least amount of head movement. Face masks that are made of a heavy duty plastic may need to be removed with a PVC pipe cutter because the other tools used to cut the loops in a traditional set up will not work. The interesting point is that the IATF makes recommendations for how to remove the face mask of a football player, but not of either ice hockey or lacrosse. This is why it will be important for the athletic trainer to asses the equipment and have a plan prior to having to perform the skill on the field.

Transfer to the spine board

Once the athlete's face mask has been removed and the head is still being stabilized by the initial person on the scene, he or she needs to be transferred to a rigid spine board. This transfer is best accomplished using a rigid scoop stretcher that is placed under the athlete when they are lifted up about 4 to 6 inches (Kleiner et al 2001). The athlete is then lowered back down onto the spine board and strapped to it.

It is indicated that at least two straps be used to secure the torso and additional ones to secure the pelvis and legs (Kleiner et al 2001, Mazolewski et al, 1994). Mazolewski et al (1994) demonstrated that an added strap across the pelvis significantly reduced the amount of lateral motion of the torso. The recommendation is that the head be secured with towels, blankets, or commercial head immobilizers and then secured to the board with tape. The IATF's recommendation does not indicate whether tape should be used across the forehead and the chin or only the forehead. There is a concern with placing a strip of tape over the chin. While this tape may immobilize the head better, it may restrict the patient's ability to open their mouth and therefore raising the risk of aspiration (De Lorenzo et al, 1996). In situations with a helmet if the chin strap remains attached it may provide some degree of stabilization.

An additional consideration is whether or not to use a cervical collar. The current recommendation is that a cervical collar should be placed on the athlete if it can be done with the pads and helmet still in place. The best combination for head immobilization is a rigid cervical collar and supportive blocks on either side of the head with adhesive tape across the forehead (Neurosurgery 2002). This is nearly impossible with football equipment, but may be possible with lacrosse or ice hockey equipment. Waninger (2004) indicated that it was very difficult to apply a cervical collar correctly to a football, ice hockey or lacrosse player while they were wearing their equipment. If a cervical collar is going to be used it was concluded by James (2004) that a StifNeck or StifNeck Select collar be used as those collars were found to be most effective at limiting range of motion.

Once the athlete is secured to the board and strapped down body first and then head, the person stabilizing the head may remove their stabilization. At this point the transportation of the athlete is ready to occur safely.

Equipment and complications

As has previously been discussed, the evolutions of rules in sports that involve equipment such as ice hockey and football have increased the challenge of on-field management of cervical spine injury. This injury is challenging enough to handle without the added difficulty of accounting for the design of sporting equipment. The recommendation to leave the equipment in place is based on the assumption that if the helmet is stabilized the head is stabilized. Football helmets are unique in that they have been designed for a custom fit. In removal, the cheek pads need to be removed and the air bladders deflated (Waninger, 2004). However, ice hockey and lacrosse helmets are not quite as sophisticated and they may not fit the players as well which would allow for movement of the head inside the helmet. The IATF also considers movement inside the helmet as a reason for potential removal of the helmet and include the following guidelines for when it is acceptable to remove equipment.

1. "If after a reasonable time the face mask cannot be removed to gain access to the airway.
2. If the design of the helmet and chin strap is such that even after removal of the face mask the airway cannot be controlled or ventilation provided.
3. If the helmet and chin straps do not hold the head securely such that immobilization of the helmet does not also immobilize the head.
4. If the helmet prevents immobilization for transport in an appropriate position." (Kleiner et al 2001)

These are four large ifs and may be difficult to determine while trying to manage this injury on the field. Therefore, while the technology involved in making protective equipment better has reduced injury, it potentially has made it more difficult to properly secure and athlete to a spine board.

Motion analysis studies

Neck motion

Cervical spine motion has been studied a various number of ways. Early studies involved the use of hand held goniometers and radiographs, while more recent studies have incorporated more modern methods of three dimensional (3-D) motion analysis

(Pololsky, 1983, DelRossi, 2003, Waninger, 2001). These 3-D methods include using markers and video cameras as well as using electromagnetic tracking devices. When determining motion at the cervical spine these studies have utilized either the forehead (Koerhuis, 2003, James, 2004, Del Rossi, 1998) or a mouthpiece (Waninger et al, 2001) as the marker or sensor placement for the head and then the sternum to represent the thorax. The mouthpiece design was utilized when the helmet did not allow for markers or a sensor to be placed on the head (Waninger et al 2001). The sensor placement on the sternum was placed on the portion of the sternum that was not obstructed by any equipment being tested.

Electromagnetic tracking devices have been used to determine cervical range of motion (Koerhius, 2003 and Morphett, 2003). Koerhuis (2003) determined that an electromagnetic tracking device proved to be both reliable and precise in measuring both passive and active range of motion. These individuals investigated cervical range of motion in healthy adults as well as a dummy head that they moved through a range of motion to determine the accuracy of the system. They were able to measure motion with a maximal error of 2.5°. This study also compared the variability that occurred between the dummy head and the human subjects. They determined that biological variability was small and great precision could be obtained using only three trials. This indicates that cervical spine motion can be measured with accuracy in healthy human subjects. Morphett (2003) also determined the reliability of the electromagnetic tracking device for rotation, lateral flexion, and flexion and extension to be good (ICC=.94,.89,.90, respectively) in determining passive cervical range of motion. These data collectively suggest that an electromagnetic tracking device can be used to measure active or passive cervical range of motion in healthy subjects.

Immobilization and transport

Several studies have described an attempt to determine cervical spine motion during immobilization and transport (Metz, 1998, Prinsen, 1995, LaPrade, 2000, Waninger, 2001, Swenson, 1997, Tierney, 2002). Of the studies that included protective equipment, football and ice hockey equipment were the focus. It has been determined that the football helmet and shoulder pads be left in place and that the helmet does a good job stabilizing the head (Swenson, 1997, Tierney, 2002, Waninger 2004). It has also been determined that leaving the helmet and shoulder pads in place on an injured ice hockey player is the best management for maintaining spinal alignment (Metz, 1998, Prinsen, 1995, LaPrade, 2000). However, there is still some debate about whether the helmet in ice hockey would stabilize the head well enough for the cervical spine to be stabilized.

Waninger et al (2001) reported there was not a difference in rotational motion of the cervical spine in football, lacrosse, or ice hockey athletes wearing both helmets and shoulder pads while immobilized in a supine position with standard head pads and a backboard with straps. Motion in this study was induced by perturbing the backboard on its long axis 12° to simulate jostling during transportation by allowing the board to fall on the left side freely. Subjects were unaware of when this would happen. Range of motion of head inside the helmet was determined based on a difference between motion of the helmet and motion of the head ((FB – 4.8°(n=9, SD 2.1°) Lax – 6.6° (n=9, SD 1.6°) IH –

5.5° (n=12, SD 1.2°)). The limitations to this study were as follows; they did not measure motion of the head relative to the trunk, all of the equipment was properly fitted (as does not always occur in an athletic environment), and the perturbations did not involve much of a chance for inducing flexion or extension.

Poldosky (1983) tested several devices for immobilization and determined the cervical motion allowed in three planes with a hand held goniometer. They instructed subjects to move their heads into flexion, extension, rotation and lateral bending as much as they could after stabilization. The mean range of motion for each of the three planes was then compared to determine which type of immobilization was most effective. It was determined that the best way to immobilize the cervical spine was to use sandbags and tape across the forehead alone or in combination with a Philadelphia collar.

Biomechanical data reduction and analysis

The studies that explore cervical motion during various types of immobilization techniques or testing some type of device use a change in range of motion in each of the three planes to explain what is happening at the cervical spine (DelRossi, James, 2004, Podolosky, 1983). To obtain this change of motion using a 3-D analysis system the order of Euler angle rotation must be determined. The guideline is to use the plane of motion that has the most range of motion available or in some cases the motion you are most interested in and use that as the first rotation. Then the next rotation follows as the plane where there is the second greatest range of motion. The final rotation has the least amount of range of motion. In the cervical spine flexion and extension should be first, but there is some room for discussion in regard to lateral flexion and rotation. When examining the literature, James (2004) used flexion/extension, rotation, and lateral flexion and Koerhius (2003) used a rotation of flexion/extension, lateral flexion, and then rotation. However, Koerhius (2003) experienced some gimble lock and had to change their rotation to obtain lateral flexion. Thus, the better choice may be to use flexion and extension, rotation, and lateral flexion. The choice for filtering if it was done or reported is a second order Butterworth low pass filter at 10Hz (Waninger, 2001).

Summary

Through the epidemiological data it can be concluded that cervical spine injury is a possibility in athletics and that those athletes that are involved in collision type of sports may be more at risk than those not involved in collision sports. Due to the known risk, athletic trainers and medical professionals have a desire to determine the best management of a cervical spine injury. It is important to reduce the chance of secondary injury to ensure the maximum chance for a positive outcome following such an injury. This management technique may be compromised by the equipment worn by these collision sport athletes. It is therefore important to test immobilization techniques and the equipment to determine if immobilization does occur. Most of the previous research was done on football and then extrapolated to the other collision sports such as ice hockey and to a lesser extent men's lacrosse. However, equipment in these sports is different and should be tested independently. Collectively this information provides support for a further investigation of the effectiveness of cervical spine immobilization in men's lacrosse athletes.

CHAPTER III

METHODS

The purpose of this study was to determine if lacrosse helmets provide adequate stabilization of the head and therefore the cervical spine in the spine-boarded athlete. The dependent variables were changes in motion in the sagittal, frontal, and transverse plane. The independent variable was the immobilization condition (properly fitted helmet, improperly fitted helmet, and no men's lacrosse protective equipment)

Subjects

A total of 18 collegiate men's lacrosse athletes were recruited and volunteered for the investigation. This sample size was selected based on a power calculation using pilot data. A sample size of 18 subjects yielded a statistical power of at least 0.95 (Appendix A). In order to participate in this study each participant ranged in age from 18-30 and was currently actively participating in lacrosse. They had to have full, pain free neck range of motion, and have not suffered from a cervical spine or neck injury within the past six months. Additionally, they had never suffered from a cervical fracture or dislocation.

Equipment

Three dimensional kinematic data were collected at 50Hz using Ascension Star Hardware® (Ascension Technologies, Inc., Burlington, VT) electromagnetic motion analysis system controlled by Motion Monitor® Software(Innovative Sports Training, Inc. Chicago, IL).

A custom-built mouthpiece was used as a placement site for a sensor on the head. This mouthpiece was a rigid orthoplast device that was placed into the subject's mouth. (Figure 3.1) Between each subject it was disinfected with antibacterial soap and soaked in a 10% bleach solution for 10 minutes. It was then covered in a thermo-moldable plastic. This process ensured that each subject had a clean mouthpiece that fit into his mouth comfortably.

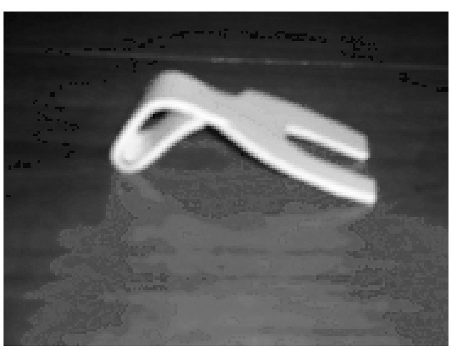

Figure 3.1. Custom mouthpiece used for sensor placement.

Participants were asked to bring the protective equipment (helmet and shoulder pads) that they would normally wear during game and practice situations. They were properly fitted with a Cascade CPX® one size fits all helmet. This helmet had three pads that could be placed around the occiput to adjust the fit. (Figure 3.2)

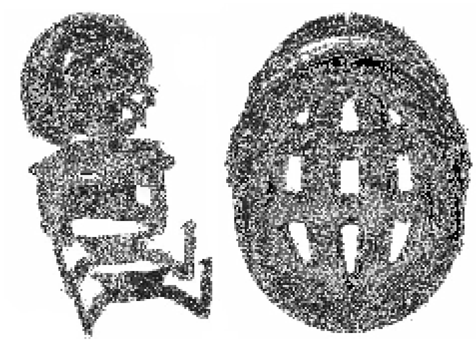

Figure 3.2. Cascade CPX helmet with the adjustment pads to insert in the helmet (www.cascadelacrosse.com)

For immobilization, a rigid spine board (Ironduck, Chicopee, Ma) was used. The participant was secured to the spine board with the Best Strap ™ System (Morrison Medical, Columbus, OH) for the torso and the Big Blue ™ Head Immobilizer (Morrison Medical, Columbus, OH) for the head . A cervical collar was used for immobilization when the athlete was not wearing protective equipment. This collar was a StifNeck® (Laerdal, Wappingers Falls, NY) collar that comes in six different sizes. (Figure 3.3)

Figure 3.3. StifNeck Cervical Collars (http://www.mhf.net/mall/catalog/0-Stores/Laerdal/stifneckreg.htm)

Protocol

When each participant entered the Sports Medicine Research Lab for testing with his helmet and shoulder pads, the following procedures were performed.

1. Each subject was informed of his risk and understood that he could discontinue participation at any time. He was then asked to read and sign an informed consent form.

2. He was properly fitted with a Cascade CPX helmet.

3. The helmet used by the player for participation was assessed.

4. The cervical collar was fitted.

5. The sensors were placed on the subject and digitized.

6. The subject was given instructions on the range of motion and practiced it.

7. The subject was secured to the spine board and testing began.

8. When all trials were completed the equipment was removed.

Helmet fitting and assessment

The Cascade CPX helmet was fitted according to the manufacturer's instructions by the primary investigator. A Cascade CPX lacrosse helmet is one size fits all with three pads that can be fit inside the helmet around the occiput to improve the fit. Once the helmet is on the head it should sit 1 inch above the eyebrow. The padding on the back of the helmet should sit firmly against the back of the head. If it does not fit against the back of the head then one of the three pads was inserted to determine which allowed for the best fit. To check the fit, the helmet was rotated from side to side and front to back. The skin on the forehead should move when this is done. If the helmet slipped the next size pad was used. The athlete then locked his fingers and placed them behind the head. He then pulled the helmet forward to make sure there was not a gap that appeared between the front liner and the head. If a gap did appear a new pad was placed inside the helmet.

The chin strap was then fitted and adjusted by holding the chin cup under the chin and adjusting the front straps first and then the back. All of the straps should have equal tension on them and sufficiently hold the helmet in place. Once the helmet was in place with the chin strap fastened the investigator performed three tests to make sure the helmet fit as best as possible.

1. The investigator pushed down on the helmet to make sure that pressure was felt evenly on top of the head. If it was only felt on the sides, the helmet was determined to be too tight.

2. The investigator moved the helmet side to side and vertically up and down to make sure that the skin on the forehead moved with the helmet.
3. The investigator asked the participant if the fit was “firm but comfortable”. If the athlete responded no to the third question then an attempt was made to adjust the helmet to best satisfy all three of the criteria.

The helmet that the participant actually wears for practice and competition was then evaluated to determine if it fit differently than the properly fitted helmet. If the padding and chin strap were adjusted in the same way as the properly fitted helmet then the participant was not eligible for the study because there was not an improperly fitted helmet to be used for comparison. If the investigator saw that the helmet was not adjusted in the same way as the properly fitted helmet the participant’s helmet was considered to be an improperly fitting helmet and the participant was eligible to be included in the study.

After the helmet had been fitted and the participant’s helmet evaluated, the face mask of both helmets was removed. This was done to allow use of the custom mouthpiece for sensor placement. The face mask on a Cascade CPX lacrosse helmet was easily removed by unscrewing the three screws that hold the face mask in place. There is one on each side and one attached to the visor (Figure 3.4).

Figure 3.4. Cascade CPX lacrosse helmet (www.cascadelacrosse.com)

<u>Fitting the cervical collar</u>

A properly fitted cervical collar allows for stabilization of the cervical spine without hyperextension. For a proper fit, the distance between the chin and the top of the shoulder was the same as the distance from the back fastener and the lower edge of the rigid plastic on the collar (Figure 3.5, Figure 3.6). This distance was measured using the fingers and then matched with the appropriate cervical collar. Once the appropriate collar was selected the collar was wrapped around the neck and fastened with the Velcro strap. This strap was tightened such that the chin rested in the chin piece (Figure 3.7).

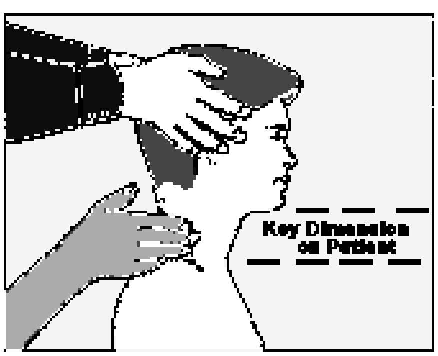

Figure 3.5. Neck dimension (http://users.stlcc.edu/cmittler/emt/ccollar.html)

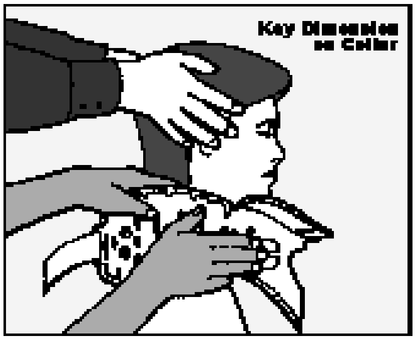

Figure 3.6. Cervical collar dimension (http://users.stlcc.edu/cmittler/emt/ccollar.html)

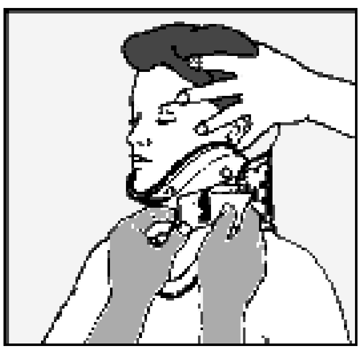

Figure 3.7. Fitted cervical collar (http://users.stlcc.edu/cmittler/emt/ccollar.html)

Motion sensor set up

Each participant was fitted with three sensors, one on the top of the helmet, one on the mouthpiece and one on the sternum near the sternal notch. Participants were asked to bite down on the mouthpiece while they had it in their mouth to make sure the movement of that sensor represented movement of the head. These sites were chosen due to the minimal movement of the soft tissue that surrounds the bony landmarks. Placing the sensor close to the sternal notch will help to minimize movement of the chest as a result of breathing. All sensors were applied to the respective sites using double sided tape.

The participants then sat in a chair with the helmet on to orient the axes and digitize the anatomical segments. To obtain the segmental axes the following points on a plane were digitized. Digitizing the head included the bridge of the nose, the middle of the chin and the occipital protuberance. Digitizing the thorax included the spinous process of T8, the xyphoid process, and the spinous process of C7. The axis for the head was the right and left temporal mandibular joint and for the thorax, C7 and the sternal notch were used. After the sensors were setup the participant was asked to test the ranges of motion.

<u>Instruction for the range of motion</u>

Prior to actual data collection each participant was given instruction and practiced moving his head in the three planes of motion, a single plane at a time. This was done first by the investigator verbally defining and visually demonstrating flexion, extension, side bending, and rotation. Flexion was defined as chin to the chest, extension was defined as looking up toward the ceiling, side bending was defined as moving the ear toward the shoulder and finally, rotation was defined as looking over the shoulder. The participant practiced these motions while watching a real-time representation of the motion on a computer screen. The participant was then asked to follow a pointer as it moved through each plane of motion. These data were then collected and graphed so the researcher could give feedback as to the proper movement. This process was done to ensure the participant understood the motion and that motion was occurring in a single plane at a time. Practice was allowed until the investigator had determined that the subject could properly perform the motions.

Securing to the spine board

Participants were secured to the spine board three times in a counterbalanced fashion, one time with no protective equipment, one time with the properly fitted lacrosse helmet and one time with the improperly fitted lacrosse helmet. Each time the participant was secured the same way. He was postioned supinely on the spine board with his head and torso stabilized according to the NATA Pre-hospital Care of the Spine injured athlete's recommendations (Kleiner, 2001). When the participant was wearing a helmet and shoulder pads, this included placing a spider strap around the torso with crossing straps in the front, stabilizing the head with bolsters on both sides, and applying athletic tape across the helmet and the chin. Four strips of tape were oriented in a crossing pattern across the helmet just over the visor and then one piece was placed across the chin strap. The chin strap of the helmet was left in place. (Figure 3.8) When the participant was not wearing protective equipment he was immobilized on the spine board with the fitted cervical collar, spider straps, bolsters on either side of the head, and tape across the forehead and chin. (Figure 3.9) It was important in both cases that the torso be immobilized first and the head second. Once the athlete was secured to the spine board data collection began.

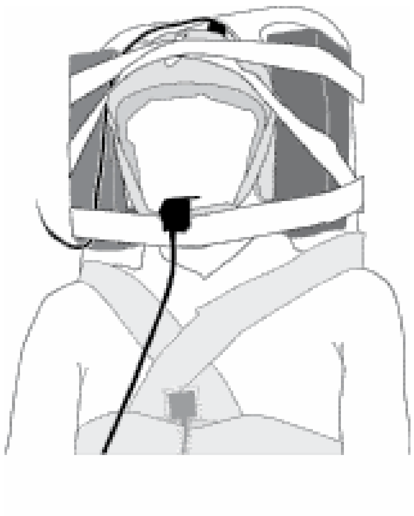

Figure 3.8. Immobilization with helmet and shoulder pads.

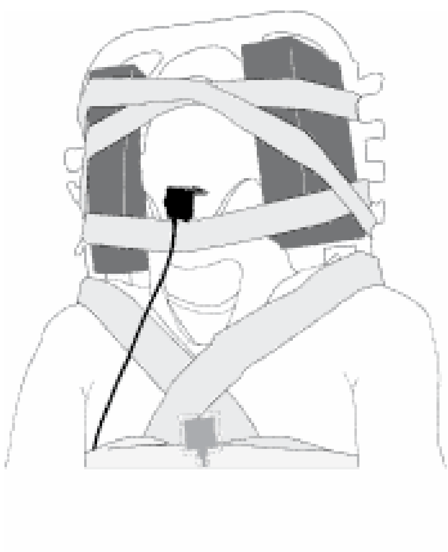

Figure 3.9. Immobilization without protective equipment.

<u>Data collection</u>

The order of testing the conditions was counter balanced as well as the order of the range of motion being tested. (Table 3.1) For each condition the participant moved into each of the three planes of motion according to the previously described instructions. To assist in movement along the plane, specific instructions were to follow a pointer with his head while the investigator moved the pointer through the three planes of motion. The participant was instructed to "move until you feel resistance and then stop". Each time the participant returned to a neutral position and told again only to move until he feels resistance. Each participant performed the task five times. Between each trial the stabilization equipment was checked to make sure that it did not come loose. The procedure was then repeated for each condition starting with stabilization on the spine board. When the data collection was completed the participant was removed from the spine board and sensors removed.

Table 3.1. Counter balanced design for data collection. 1, 2, 3 indicate if that condition is tested first second or third. F-flexion and extension, S-Side bending, R-Rotation.

Subject	No equipment	Properly fitted helmet	Improperly fitted helmet
1	1 (F,R,S)	2 (R,S,F)	3 (S,F,R)
2	2(F,R,S)	3(R,S,F)	1(S,F,R)
3	3(F,R,S)	1(R,S,F)	2(S,F,R)
4	1(R,S,F)	2(S,F,R)	3(F,R,S)
5	2(R,S,F)	3(S,F,R)	1(F,R,S)
6	3(R,S,F)	1(S,F,R)	2(F,R,S)
7	1(S,F,R)	2(F,R,S)	3(R,S,F)
8	2(S,F,R)	3(F,R,S)	1(R,S,F)
9	3(S,F,R)	1(F,R,S)	2(R,S,F)
10	1 (F,S,R)	3 (R,F,S)	2 (S,R,F)
11	2(F,S,R)	1(R,F,S)	3(S,R,F)
12	3(F,S,R)	2(R,F,S)	1(S,R,F)
13	1(R,F,S)	3(S,R,F)	2(F,S,R)
14	2(R,F,S)	1(S,R,F)	3(F,S,R)
15	3(R,F,S)	2(S,R,F)	1(F,S,R)
16	1(S,R,F)	3(F,S,R)	2(R,F,S)
17	2(S,R,F)	1(F,S,R)	3(R,F,S)
18	3(S,R,F)	2(F,S,R)	1(R,F,S)

Data reduction

Raw kinematic data were low pass filtered at 10Hz. To obtain the angles of motion a segmental reference system with Euler rotations was performed. The rotation sequence was such that the motion of flexion and extension was first followed by rotation and side bending. (James 2004) The angles were generated by examining the head sensor position relative to the thorax sensor position and the helmet sensor position relative to the thorax sensor position.

Once the angles were obtained from the sensor positions, the change in range of motion was calculated. Flexion, left rotation and right side bending were defined as positive ranges of motion. To obtain the change of motion the maximum number in the positive direction was subtracted from the maximum number in the negative direction. This yielded a total change in the range of motion in each plane. The joint displacements in each of the three planes were then averaged across the five trials.

Statistical analyses

An alpha level of $p<.05$ was set a priori. The dependent variables were average change in range of motion in the sagittal, frontal, and transverse planes for both head to thorax motion and helmet to thorax motion. To answer research question one, a 1-within (testing condition - no helmet, properly fitted helmet, and improperly fitted helmet) repeated measures ANOVA was performed in SPSS on each of the average ranges of motion between the head and thorax. Tukey post hoc testing was done to determine where the significance differences between conditions existed.

To answer research question two, a paired samples T-test first was done to determine significance in helmet to thorax range of motion between properly fitted and improperly fitted helmet conditions for each plane of motion. Additionally, a 2-within (testing condition - improperly fitted helmet, and properly fitted helmet; and range of motion condition - head to thorax motion and helmet to thorax) repeated measures ANOVA was performed in SPSS on each of the average ranges of motion.

CHAPTER IV

RESULTS

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. Mean and standard deviation for head to thorax range of motion when immobilized on a spine board during no helmet, properly fitted helmet, and improperly fitted helmet conditions.

	Mean	**±SD**
Sagittal Plane		
No Helmet	5.7º	2.4º
Fitted	9.5º	3.0º
Improperly Fitted	11.4º	3.1º
Frontal Plane		
No Helmet	10.2º	3.8º
Fitted	15.0º	6.2º
Improperly Fitted	15.8º	4.7º
Transverse		
No Helmet	8.8º	3.7º
Fitted	14.0º	5.0º
Improperly Fitted	15.7º	4.3º

A repeated measures ANOVA identified significant differences among the fitted helmet, improperly fitted helmet and no helmet conditions for sagittal plane motion ($F_{(2,34)}=39.72$; $p<.001$)(Appendix B). Tukey post hoc analyses were performed to identify the location of these significant differences. It was indicated by the within subjects contrasts that a linear relationship existed between these variables (Appendix B).

The sagittal plane range of motion was significantly greater during the improperly fitted helmet condition compared to the properly fitted condition (Mean difference=1.9º); and significantly greater in both the properly fitted helmet and improperly fitted helmet conditions compared with the no helmet condition (Mean differences =3.7 º & 5.7 º, respectively). These differences are illustrated in figure 4.1.

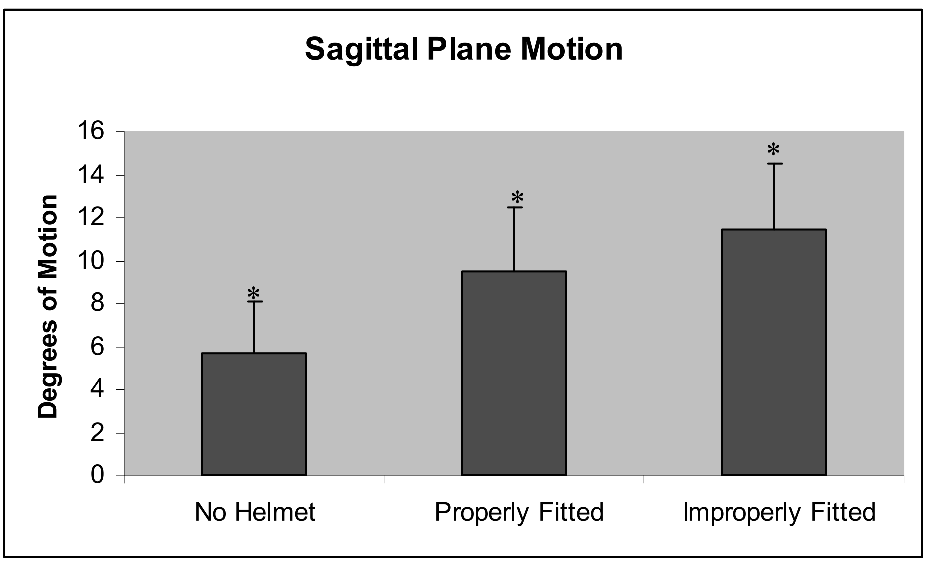

Figure 4.1. Mean sagittal plane head to thorax range of motion for no helmet, properly fitted helmet, and improperly fitted helmet conditions. (* indicates significance between each condition)

A repeated measures ANOVA identified significant differences among the fitted helmet, improperly fitted helmet and no equipment conditions for frontal plane motion ($F_{(2,34)}$=17.18; p<.001)(Appendix C). Tukey post hoc analyses were performed to identify significant differences. Range of motion in both the improperly fitted and properly fitted helmet conditions were significantly greater than the no helmet condition (Mean differences=5.6º & 4.8º, respectively). There was no difference between the improperly and properly fitted helmet conditions in frontal plane motion (Mean difference=0.8º). These differences are illustrated in figure 4.2.

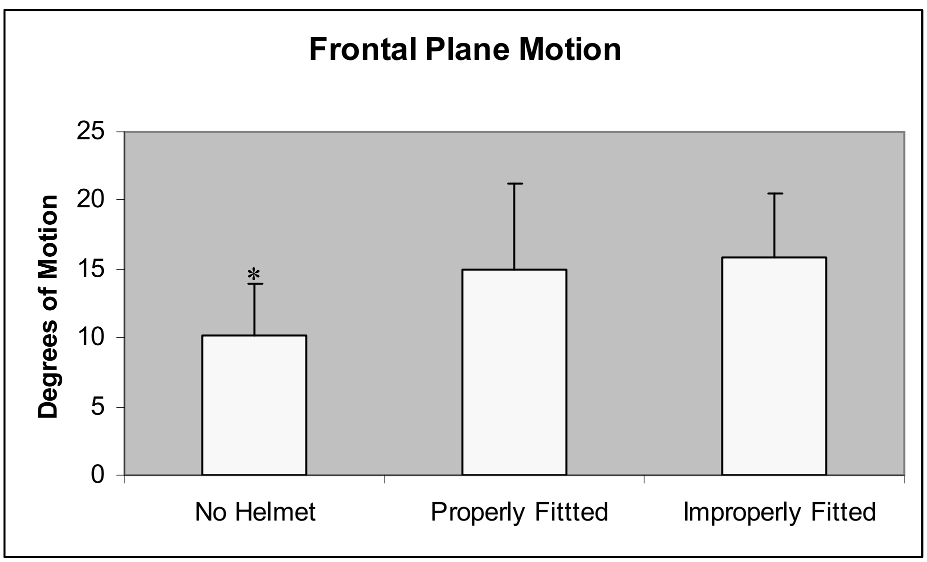

Figure 4.2. Mean frontal plane head to thorax range of motion for no helmet, properly fitted helmet, and improperly fitted helmet conditions. (* signficantly less than properly and improperly fitted conditions)

A repeated measures ANOVA also identified significant differences among the fitted helmet, improperly fitted helmet and no helmet conditions for transverse plane motion ($F_{(2,34)}=34.48$; $p<.001$)(Appendix D). Tukey post hoc analyses were performed to identify significant differences between the conditions. Range of motion in both the improperly fitted and properly fitted helmet conditions were significantly greater than the no helmet condition (Mean differences=5.2º & 6.9º, respectively). There was not a significant difference between the improperly fitted and properly fitted helmet conditions (Mean difference=1.7º). These differences are illustrated in figure 4.3.

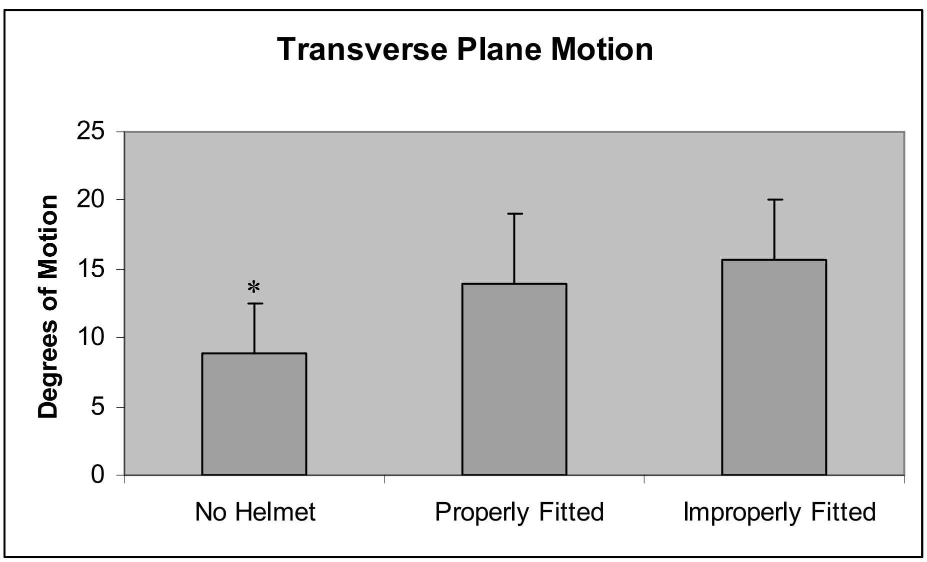

Figure 4.3. Mean transverse plane head to thorax range of motion for no helmet, properly fitted helmet, and improperly fitted helmet conditions. (*signficantly less than properly and improperly fitted conditions)

Therefore, for research question 1 – Hypothesis 1.1 was accepted in all three planes of motion as the properly fitted helmet exhibited significantly greater range of motion than the no helmet condition. Hypothesis 1.2 was accepted in all three planes of motion as the improperly fitted helmet exhibited a significantly greater range of motion than the no helmet condition. Finally, Hypothesis 1.3 was accepted in the sagittal plane where there was a significant difference between the improperly fitted and properly fitted conditions. Hypothesis 1.3 was rejected in the other two planes where there were no difference exhibited between these conditions.

Helmet to thorax range of motion

The descriptive statistics for helmet to thorax motion are presented in Table 4.2.

Table 4.2. Helmet to thorax range of motion

	Mean	**±SD**
Sagittal Plane		
Fitted	2.3º	0.9º
Improperly Fitted	2.1º	1.0º1
Frontal Plane		
Fitted	2.1º	1.2º
Improperly Fitted	2.2º	1.1º
Transverse		
Fitted	1.9º	1.1º
Improperly Fitted	2.3º	1.6º

A paired samples T-test was conducted to determine significance in helmet to thorax range of motion between properly fitted and improperly fitted helmet conditions for each plane of motion (Appendix E). There were not significant differences found between these means (p = .120, p = .630, p = .292). Therefore it can be concluded that the helmet is stabilized similarly in both conditions. (Figure 4.4)

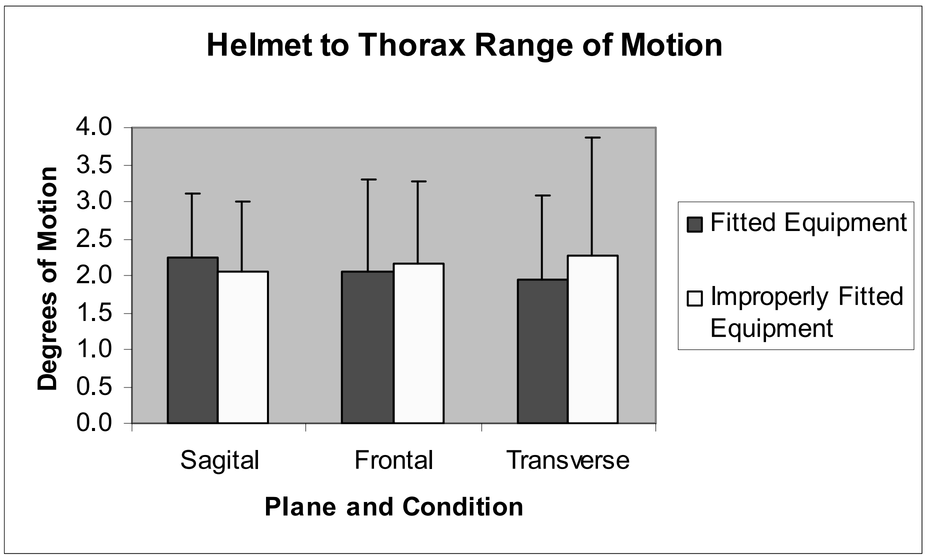

Figure 4.4. Mean helmet to thorax range of motion for both the fitted and improperly fitted helmet in the sagittal, frontal, and transverse planes of motion.

A two within repeated measures ANOVA using the improperly fitted and properly fitted conditions as one level and the helmet to thorax motion and head to thorax motion as the second level indicated a significant main effect for helmet to thorax motion and head to thorax motion in the sagittal ($F_{(1, 17)}$=279.59; p<.001), frontal ($F_{(1, 17)}$=184.05; p<.001), and transverse ($F_{(1, 17)}$=211.43; p<.001) planes(Table 4.3, Figure 4.5)(Appendix F,G,H). This indicated that there was a greater range of motion available between the head and the thorax regardless of the fit of the helmet. Therefore it can be concluded that the motion seen between the head and thorax is a result of the head moving inside the helmet and not the helmet and the head acting as a unit to move together. Hypothesis 2.1 is accepted there was not a difference in the ability to stabilize the properly and improperly fitted helmet. Hypothesis 2.2 is accepted as increased movement of the cervical spine occurred as a result of increased motion of the head within the fixed properly and improperly fitted lacrosse helmet.

Table 4.3. Grand means for types of range of motion across the properly and improperly fitted helmet conditions.

	Mean	**Std Error**
Sagital Plane		
Head to Thorax	10.4°	0.6°
Helmet to Thorax	2.2°	0.2°
Frontal Plane		
Head to Thorax	15.4°	1.2°
Helmet to Thorax	2.1°	0.3°
Transverse		
Head to Thorax	14.9°	1.0°
Helmet to Thorax	2.1°	0.3°

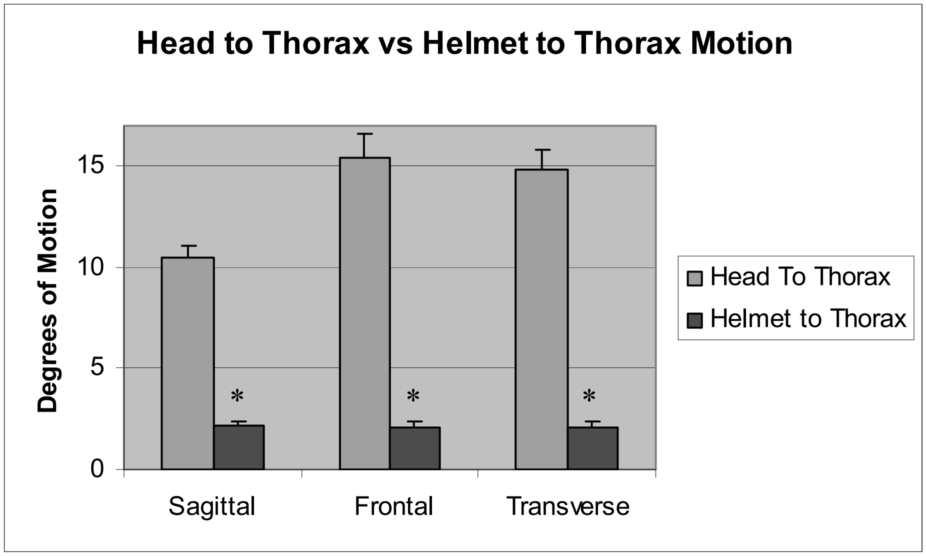

Figure 4.5. Head and helmet to thorax grand means across properly and improperly fitted helmets for all three planes of motion. (* indicates significance between conditions within the planes)

CHAPTER V

DISCUSSION

Head to helmet movement

The most important finding of this study was that while secured to a spine board wearing a men's lacrosse helmet and shoulder pads, subjects experience greater range of motion in the cervical spine compared to not wearing a helmet and shoulder pads. Head to thorax motion in all three planes was greater with the head inside the helmet. This indicates the cervical spine is stabilized more effectively without the helmet and shoulder pads in place.

According to the IATF pre-hospital guidelines for care of the cervical spine injured athlete, the helmet and shoulder pads should be left in place when securing the athlete to the spine board unless the helmet does not sufficiently stabilize the head (Kleiner, 2001). The results of this study indicate that the lacrosse helmet did not stabilize the head inside the helmet as well as when the athlete wore no protective equipment. This indicates that the athlete may be at a greater risk when the helmet is left in place, contradicting the recommendations of the IATF.

These results also dispute those of Waninger (2001) who determined the lacrosse helmet did sufficiently stabilize the head during cervical spine immobilization. He compared football, lacrosse, and ice hockey helmets and indicated there was not a difference in head range of motion. However, Waninger (2001) only determined passive rotational movement when the athlete was jostled which is not indicative of the total available range of motion and did not include a comparison to a no helmet condition. The active range of motion that was included in this study is important in that it represents the worst possible scenario. While it is unlikely that an individual will move to his or her full available motion while having a spine injury, it is possible to have a combative patient and motion that may occur as a result of transport can be very unpredictable. Therefore if the patient can actively move, the stabilization procedure is not truly immobilizing them. This does not help to prevent secondary injury. Additionally, Waninger (2001) did not include flexion and extension which is potentially the most damaging range of motion in the cervical spine injured patient (Del Rossi, 2004, Tierney, 2002, Torg, 1990). Therefore, given the design differences of this investigation, it is not surprising that the results are different from Waninger (2001).

Helmet to thorax motion

It is indicated by this study that there is not a problem with the ability to stabilize the helmet and secure it to the spine board. The motion of the stabilized helmet that occurred (helmet to thorax) was very small (range of 1.9-2.3º) in comparison to the range of motion that was available at the head (head to thorax) (range of 5.7-15.8º). Therefore the head motion that was measured was not motion of the helmet, but motion that was mainly of the head inside the helmet. Additionally the motion of the helmet relative to the thorax was not significantly different between helmet conditions, which indicated that the helmet was stabilized in the same way between fit conditions. The conclusion can be made that stabilization of the helmet is not a problem. The difficulty lies in the ability to stabilize the head inside the helmet.

Helmet fitting

All of the lacrosse players in this study were currently participating with a helmet that was not fitted according to the manufacturer's instructions. This was an inclusion criterion. If the player's helmet was found to fit the same as the properly fitted helmet the player was excluded from the study. However, no players were turned away because their helmet was currently fitted properly. All subjects wore the chin strap too loose (18/18) and 14 of the 18 needed occipital padding added to make the helmet fit properly.

The addition of the padding and correctly fitting the chin strap likely resulted in the significant difference between the properly fitted and improperly fitted conditions in the sagittal plane. The manner by which these helmets are fitted allows for padding to be placed on the posterior aspect of the head just inferior to the occiput. The padding under the occiput could possibly prevent some flexion and extension, but would not affect the additional planes of motion. (Figure 3.2) This indicates that properly fitting the helmet may offer better stabilization when trying to limit flexion and extension.

Given that the other two planes of motion were not affected, properly fitting the helmet may not be enough to provide satisfactory stabilization. While fitting the helmet did reduce some motion, significantly less available range of motion was exhibited in all three planes when the helmet and shoulder pads were removed. This indicates that removing the helmet may be the best treatment plan until a helmet that properly stabilizes the head can be designed.

When discussing fitting instructions with the manufacturer it was indicated that the face mask was part of the fit of the helmet as it closes the helmet in toward the temporal area of the head. Clinical observation reveals that some athletes actually bend the face mask so that the helmet fits tighter. If the current guidelines generated by the IATF are followed (removal of the face mask) this potentially disturbs the fit of the helmet, which then affects its ability to limit movement of the cervical spine during spine boarding. This means is that even if the athlete has a helmet that fits well with the face mask in place, it may not fit as well when removed. Therefore, it is debatable that if by removing the facemask we are actually reducing the possibility of maintaining a stable neutral cervical spine.

Finally, it is necessary to educate the lacrosse community as to the importance of wearing a properly fitted helmet. It was demonstrated that properly fitting the helmet will improve the stabilization of the cervical spine in the sagittal plane. However, this is a challenging task. The culture in lacrosse tends to be nonconformist. It will be necessary to educate coaches and younger players as well as parents to the importance of a properly fitted helmet. While this education will take time as it did in both football and ice hockey, hopefully with some persistence the lacrosse community will get the message and the players will wear their helmets with the safest fit.

Cervical collar

A cervical collar was not used in this investigation in the helmeted athlete conditions due to the fact that one could not be used on every athlete. The lacrosse helmet protrudes posteriorly. (Figure 3.4) If an athlete has a short neck or his head is structured in such a way that the helmet sits lower on his head, a cervical collar cannot be properly applied. Waninger (2001) indicated that it was very difficult to properly apply a cervical collar with football, lacrosse, or ice hockey equipment on. However, in some cases, it may be possible given the individual's anatomy and fit of a helmet to apply a cervical collar. Podolsky (1983) and James (2004) indicated a reduction in all ranges of motion when using a rigid type of cervical collar. Poldolsky (1983) reported a reduction of 11º in flexion, 11º in extension, 3º in lateral bending and 26º of rotation when comparing a Philadelphia collar to no immobilization. Likewise, James (2004) determined a 28º reduction in total angular displacement when a StifNeck collar was used compared to a softer vacuum immobilizer. Therefore, if a cervical collar can be applied then its use is indicated (James 2004, Neurosurgery, 2002, Podolsky, 1983).

Clinical significance

The available ranges of motion in the cervical spine during spine board immobilization determined by this investigation could be significant in the cervical spine injured men's lacrosse player. Given that the goal of immobilization is to reduce the risk of secondary injury to the cervical spine, it may be necessary to remove the helmet.

According to the IATF the helmet should be left in place. The task force made this recommendation without supporting research. These data suggest the men's lacrosse helmet did not stabilize the head. If the head is not stabilized inside the helmet, then immobilizing the helmet will not prevent secondary injury by limiting cervical spine motion. It is possible that the IATF needs to amend the recommendation for men's lacrosse helmets. Additionally, the men's lacrosse players in this study did not wear the helmet fitted properly. Even with a properly fitted helmet cervical motion was not limited as effectively as the no helmet condition, but as previously stated athletic trainer's educating athletes as to the importance of proper fit will help limit some motion.

The amount of cervical motion that is required for secondary injury to occur is unknown, but the current line of thinking is to limit range of motion as much as possible (Del Rossi, 2004). When trying to speculate about how much motion is too much difficulty arises because of the normal biomechanics of the spine when flexing and extending. According to Swartz (2005) "each vertebrae may experience its greatest flexion and extension before the cervical column itself is fully flexed or extended". Additionally not all of the vertebrae are moving in the same direction at the same time. There are instances in which during flexion C6 and C7 are actually extending. During this time the available space for the spinal cord varies. (Swartz, 2005) Tierney (2002) indicated that the sagittal column space was greatest when the occiput was in a neutral position when compared to lifting it 2mm and 4mm. This lifting in theory would generate flexion. If a generalization about what happens to this space is possible it could be speculated that as flexion continued or as the occiput was raised the space would decrease. However, according to Tierney (2002) the lowest space was determined to be with the 2mm elevation which indicates as you go into flexion the space changes are not predictable. Finally, the diameter of the spinal cord itself changes as motion of the cervical spine occurs. The spinal cord folds and unfolds in response to tension and compression (Tierney 2002). This change in sagittal diameter of the spinal cord means that even if the sagittal column space were predicable the diameter of the cord is not. Therefore given the changes and instability that could result from injury it is difficult to make any conclusions about the type or amount of motion that is potentially damaging.

While there are not many injuries to the cervical spine that occur in men's lacrosse it is important for the certified athletic trainer to be prepared. When an injury does occur it can potentially be catastrophic, therefore proper immobilization and management is crucial. When athletic trainers are on the field there is comfort in knowing how to handle an injury when it occurs. It is the job of an athletic trainer to provide the athlete with best possible medical care. This study indicates a need for separating the guidelines between types of sporting equipment and to clearly establish guidelines for athletic trainers to follow.

Limitations

It was possible to have slight differences in immobilization which would lead to differences in motion. During immobilization every attempt was made to consistently secure the subject to the spine board and all subjects where immobilized by the principle investigator.

It was also possible that every athlete would attempt to move through the range of motion differently and with a different level of force. All the subjects were instructed in how to perform each of the three planes of motion and allowed to practice. Additionally any trial in which the planes of movement were not clear was repeated. Subjects were instructed to move to the point where they felt resistance and then return to the neutral position.

It appeared as though some subjects moved their trunk more than others. Their trunk was secured tightly and they were instructed not to move it, but it is inevitable that some motion will occur when trying to move the head.

The researcher could not control the size and shape of an individual's head. Some helmets fit better simply because the head was a better match to the helmet. The helmets were all fit according to the manufacturer's instructions.

To be consistent the current investigation evaluated only the Cascade CPX helmet which is considered to be one of the top helmets in men's lacrosse. This is just one type of helmet and therefore more research needs to be conducted on several types of lacrosse helmets at various age groups to determine if the stabilization of the head inside the helmet is a problem with other helmets.

Future research

It is still unknown how much motion in the cervical spine is too much and creates secondary injury. Del Rossi, 2004 stated "The magnitude of angular motion that the cervical spine can tolerate before neurological injury has not yet been determined." It was stated that it is clear that the less motion available the better the outcome. (Del Rossi, 2004) Additionally it was indicated that individuals with cervical spine injury and therefore instability are at potentially a greater risk when movement occurs. Due to the ethical implications of attempting to determine the amount of motion that is unsafe for a spine injured individual we may never know the answer to this question. Sophisticated computer modeling may be the best approach to help answer this important question of how well must an athlete be immobilized.

There are other aspects of this area that necessitate further study that will hopefully contribute to the future management of cervical spine injury. Many studies have been done to determine the optimal positioning of the cervical spine following injury (DeLorenzo,1996; LaPrade, 2000; Metz, 1998; Tierney, 2002) however, these have failed to explored lacrosse equipment. It has been assumed that alignment is the same for lacrosse as it is for ice hockey and football. Radiographic studies using lacrosse equipment to determine optimal spinal cord alignment would help determine if the alignment of the cervical spine is better with or without the helmet in place.

As is suggested by this research if the helmet is to be removed, there needs to be some research conducted in the area of removal of lacrosse helmets. In a study that is being prepared for publication it was determined that removing the lacrosse helmet took less time and created less motion than leaving it on and removing the face mask. (Delano, 2005 in submission) This type of study needs to be conducted on several different types of helmets to determine if this is true across more than one helmet.

Finally, the designers of lacrosse helmets should consider stabilization of the injured athlete. More research on the design of a helmet that would limit motion as well as design of a face mask that could be removed quickly without compromising the integrity of the helmet would assist in care of the spine injured athlete. Lacrosse equipment design is certainly in its infancy and more research needs to be done in multiple areas.

Conclusion

The purpose of this study was to evaluate the ability of a Cascade CPX men's lacrosse helmet to properly stabilize the head inside the helmet in properly fitted and improperly fitted helmet conditions. According to the results of this investigation, the helmet does not effectively stabilize the head in either condition.

It is important to recognize that men's lacrosse helmets and shoulder pads are not the same as football and ice hockey and therefore should not be assumed to be treated the same during a cervical spine injury. As was illustrated by this study, the helmet does not do a sufficient job in stabilizing the head and if the goal during immobilization on a spine board is to stabilize the head it is not being accomplished by leaving the lacrosse helmet in place. Additionally it was found that there is some benefit to fitting the helmet properly when trying to limit motion in the sagittal plane. The current players used in this investigation (division I lacrosse athletes) were found not to not wear the equipment in a properly fitted manner. Thus if a helmet was designed that would stabilize the head the players would need to be educated as to the importance of properly fitting their helmets. Finally more research needs to be done on lacrosse equipment to further assist in the education of certified athletic trainers and emergency medical personal to give the spine injured athlete the best possible chance of reducing secondary injury.

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APPENDIX A: PILOT TESTING

The methods were designed and pilot testing performed on two subjects to anticipate difficulties and calculate effect size. The pilot testing was performed following the procedures outlined in the methods chapter using only one helmet condition and the no equipment condition. Means and standard deviations were calculated along with the effect size to determine the number of subjects needed for a power of 0.8 with an alpha of <0.05. (Table A.1)

	Mean NE degrees	Mean E degrees	Largest StDev degrees	Effect Size	Subject #
Lax/Sag	5.48	12.14	4.99	-1.33	5.12
Lax/Tran	10.24	19.12	2.30	-3.86	2.28
Lax/Front	11.95	15.70	2.62	-1.43	4.69

Table A.1 – Mean for the change in range of motion for the helmet condition and the no equipment condition for each of the three planes of motion. The largest standard deviation between trials of either the helmet or no equipment condition, effect size and number of subjects need for a power of 0.8 at an alpha of <0.05.

APPENDIX B: SAGITTAL PLANE ANOVA

Repeated measures ANOVA comparisons for Sagittal plane motion

Within-Subjects Factors

Measure: MEASURE_1

rom	Dependent Variable
1	FlexFE
2	FlexUE
3	FlexNE

Descriptive Statistics

	Mean	Std. Deviation	N
FlexFE	9.4561	2.95176	18
FlexUE	11.3939	3.05089	18
FlexNE	5.7217	2.35548	18

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
rom	Sphericity Assumed	299.251	2	149.625	39.724	.000	.700	79.449	1.000
	Greenhouse-Geisser	299.251	1.903	157.238	39.724	.000	.700	75.602	1.000
	Huynh-Feldt	299.251	2.000	149.625	39.724	.000	.700	79.449	1.000
	Lower-bound	299.251	1.000	299.251	39.724	.000	.700	39.724	1.000
Error(rom)	Sphericity Assumed	128.064	34	3.767					
	Greenhouse-Geisser	128.064	32.354	3.958					
	Huynh-Feldt	128.064	34.000	3.767					
	Lower-bound	128.064	17.000	7.533					

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	rom	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
rom	Linear	125.515	1	125.515	37.809	.000	.690	37.809	1.000
	Quadratic	173.736	1	173.736	41.233	.000	.708	41.233	1.000
Error(rom)	Linear	56.435	17	3.320					
	Quadratic	71.629	17	4.213					

a. Computed using alpha = .05

Estimates

Measure: MEASURE_1

rom	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	9.456	.696	7.988	10.924
2	11.394	.719	9.877	12.911
3	5.722	.555	4.550	6.893

Pairwise Comparisons

Measure: MEASURE_1

(I) rom	(J) rom	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	95% Confidence Interval for Difference[a] Upper Bound
1	2	-1.938*	.716	.045	-3.839	-.036
	3	3.734*	.607	.000	2.122	5.347
2	1	1.938*	.716	.045	.036	3.839
	3	5.672*	.611	.000	4.049	7.295
3	1	-3.734*	.607	.000	-5.347	-2.122
	2	-5.672*	.611	.000	-7.295	-4.049

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

APPENDIX C: FRONTAL PLANE ANOVA

Repeated measures ANOVA comparisons for frontal plane motion

Within-Subjects Factors

Measure: MEASURE_1

rom	Dependent Variable
1	SBFE
2	SBUE
3	SBNE

Descriptive Statistics

	Mean	Std. Deviation	N
SBFE	14.9783	6.22516	18
SBUE	15.8000	4.69445	18
SBNE	10.1583	3.76698	18

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
rom	.858	2.456	2	.293	.875	.968	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: rom

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
rom	Sphericity Assumed	334.416	2	167.208	17.180	.000	.503	34.360	.999
	Greenhouse-Geisser	334.416	1.751	191.004	17.180	.000	.503	30.080	.999
	Huynh-Feldt	334.416	1.936	172.779	17.180	.000	.503	33.252	.999
	Lower-bound	334.416	1.000	334.416	17.180	.001	.503	17.180	.974
Error(rom)	Sphericity Assumed	330.908	34	9.733					
	Greenhouse-Geisser	330.908	29.764	11.118					
	Huynh-Feldt	330.908	32.904	10.057					
	Lower-bound	330.908	17.000	19.465					

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	rom	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
rom	Linear	209.092	1	209.092	16.493	.001	.492	16.493	.969
	Quadratic	125.324	1	125.324	18.463	.000	.521	18.463	.981
Error(rom)	Linear	215.517	17	12.677					
	Quadratic	115.391	17	6.788					

a. Computed using alpha = .05

Estimates

Measure: MEASURE_1

rom	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	14.978	1.467	11.883	18.074
2	15.800	1.106	13.466	18.134
3	10.158	.888	8.285	12.032

Pairwise Comparisons

Measure: MEASURE_1

(I) rom	(J) rom	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.822	1.062	1.000	-3.642	1.999
	3	4.820*	1.187	.002	1.669	7.971
2	1	.822	1.062	1.000	-1.999	3.642
	3	5.642*	.841	.000	3.410	7.874
3	1	-4.820*	1.187	.002	-7.971	-1.669
	2	-5.642*	.841	.000	-7.874	-3.410

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

APPENDIX D: TRANSVERSE PLANE ANOVA

Repeated measures ANOVA comparisons for transverse plane motion

Within-Subjects Factors

Measure: MEASURE_1

rom	Dependent Variable
1	RotFE
2	RotUE
3	RotNE

Descriptive Statistics

	Mean	Std. Deviation	N
RotFE	13.9889	4.97332	18
RotUE	15.7150	4.30728	18
RotNE	8.8150	3.65687	18

Mauchly's Test of Sphericity[b]

Measure: MEASURE_1

					Epsilon[a]		
Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Greenhouse-Geisser	Huynh-Feldt	Lower-bound
rom	.933	1.118	2	.572	.937	1.000	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

b.
Design: Intercept
Within Subjects Design: rom

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
rom	Sphericity Assumed	464.152	2	232.076	34.479	.000	.670	68.959	1.000
	Greenhouse-Geisser	464.152	1.874	247.733	34.479	.000	.670	64.600	1.000
	Huynh-Feldt	464.152	2.000	232.076	34.479	.000	.670	68.959	1.000
	Lower-bound	464.152	1.000	464.152	34.479	.000	.670	34.479	1.000
Error(rom)	Sphericity Assumed	228.849	34	6.731					
	Greenhouse-Geisser	228.849	31.851	7.185					
	Huynh-Feldt	228.849	34.000	6.731					
	Lower-bound	228.849	17.000	13.462					

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: MEASURE_1

Source	rom	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
rom	Linear	240.922	1	240.922	45.661	.000	.729	45.661	1.000
	Quadratic	223.229	1	223.229	27.272	.000	.616	27.272	.998
Error(rom)	Linear	89.697	17	5.276					
	Quadratic	139.152	17	8.185					

a. Computed using alpha = .05

Estimates

Measure: MEASURE_1

rom	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	13.989	1.172	11.516	16.462
2	15.715	1.015	13.573	17.857
3	8.815	.862	6.996	10.634

Pairwise Comparisons

Measure: MEASURE_1

(I) rom	(J) rom	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-1.726	.960	.270	-4.275	.823
	3	5.174*	.766	.000	3.141	7.207
2	1	1.726	.960	.270	-.823	4.275
	3	6.900*	.858	.000	4.623	9.177
3	1	-5.174*	.766	.000	-7.207	-3.141
	2	-6.900*	.858	.000	-9.177	-4.623

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
FlexFE	18	3.89	15.04	9.4561	2.95176
FlexUE	18	6.26	16.41	11.3939	3.05089
FlexNE	18	1.43	10.56	5.7217	2.35548
FlexFHel	18	.57	3.82	2.2550	.85913
FlexUHel	18	.55	4.51	2.0506	.95791
SBFE	18	5.43	28.50	14.9783	6.22516
SBUE	18	6.29	25.95	15.8000	4.69445
SBNE	18	2.27	16.22	10.1583	3.76698
SBFHel	18	.61	4.93	2.0556	1.23297
SBUHel	18	.52	4.25	2.1550	1.11044
RotFE	18	5.84	25.39	13.9889	4.97332
RotUE	18	6.69	21.74	15.7150	4.30728
RotNE	18	2.39	14.95	8.8150	3.65687
RotFHel	18	.57	4.23	1.9372	1.13913
RotUHel	18	.63	5.99	2.2811	1.59374
Valid N (listwise)	18				

Tukey Critical Value Calculation

The critical value for the sagittal plane was calculated using $q_{3,34,.05}$=3.49 and determined to be 1.597. In the frontal plane the critical value was determined to be ($HSD_{3,34,.05}$=2.566). In the transverse plane the critical value was determined to be ($HSD_{3,34,.05}$=2.314)

APPENDIX E: T-TEST

T-Test output

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	FlexFHel	2.2550	18	.85913	.20250
	FlexUHel	2.0506	18	.95791	.22578
Pair 2	SBFHel	2.0556	18	1.23297	.29061
	SBUHel	2.1550	18	1.11044	.26173
Pair 3	RotFHel	1.9372	18	1.13913	.26850
	RotUHel	2.2811	18	1.59374	.37565

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	FlexFHel & FlexUHel	18	.836	.000
Pair 2	SBFHel & SBUHel	18	.735	.001
Pair 3	RotFHel & RotUHel	18	.561	.015

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	FlexFHel - FlexUHel	.20444	.52935	.12477	-.05880	.46769	1.639	17	.120
Pair 2	SBFHel - SBUHel	-.09944	.86120	.20299	-.52771	.32882	-.490	17	.630
Pair 3	RotFHel - RotUHel	-.34389	1.34169	.31624	-1.01110	.32332	-1.087	17	.292

APPENDIX F: SAGITTAL PLANE 2-WITHIN ANOVA

2-Within ANOVA for the sagittal plane

Within-Subjects Factors

Measure: MEASURE_1

howfit	location	Dependent Variable
1	1	FlexFE
	2	FlexFHel
2	1	FlexUE
	2	FlexUHel

Descriptive Statistics

	Mean	Std. Deviation	N
FlexFE	9.4561	2.95176	18
FlexFHel	2.2550	.85913	18
FlexUE	11.3939	3.05089	18
FlexUHel	2.0506	.95791	18

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
howfit	Sphericity Assumed	13.520	1	13.520	6.162	.024	.266	6.162	.648
	Greenhouse-Geisser	13.520	1.000	13.520	6.162	.024	.266	6.162	.648
	Huynh-Feldt	13.520	1.000	13.520	6.162	.024	.266	6.162	.648
	Lower-bound	13.520	1.000	13.520	6.162	.024	.266	6.162	.648
Error(howfit)	Sphericity Assumed	37.299	17	2.194					
	Greenhouse-Geisser	37.299	17.000	2.194					
	Huynh-Feldt	37.299	17.000	2.194					
	Lower-bound	37.299	17.000	2.194					
location	Sphericity Assumed	1231.734	1	1231.734	279.584	.000	.943	279.584	1.000
	Greenhouse-Geisser	1231.734	1.000	1231.734	279.584	.000	.943	279.584	1.000
	Huynh-Feldt	1231.734	1.000	1231.734	279.584	.000	.943	279.584	1.000
	Lower-bound	1231.734	1.000	1231.734	279.584	.000	.943	279.584	1.000
Error(location)	Sphericity Assumed	74.895	17	4.406					
	Greenhouse-Geisser	74.895	17.000	4.406					
	Huynh-Feldt	74.895	17.000	4.406					
	Lower-bound	74.895	17.000	4.406					
howfit * location	Sphericity Assumed	20.651	1	20.651	8.061	.011	.322	8.061	.763
	Greenhouse-Geisser	20.651	1.000	20.651	8.061	.011	.322	8.061	.763
	Huynh-Feldt	20.651	1.000	20.651	8.061	.011	.322	8.061	.763
	Lower-bound	20.651	1.000	20.651	8.061	.011	.322	8.061	.763
Error(howfit*location)	Sphericity Assumed	43.551	17	2.562					
	Greenhouse-Geisser	43.551	17.000	2.562					
	Huynh-Feldt	43.551	17.000	2.562					
	Lower-bound	43.551	17.000	2.562					

a. Computed using alpha = .05

1. howfit * location

Measure: MEASURE_1

howfit	location	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	9.456	.696	7.988	10.924
	2	2.255	.202	1.828	2.682
2	1	11.394	.719	9.877	12.911
	2	2.051	.226	1.574	2.527

2. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
6.289	.382	5.483	7.095

3. howfit

Estimates

Measure: MEASURE_1

howfit	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	5.856	.426	4.958	6.753
2	6.722	.415	5.847	7.597

Pairwise Comparisons

Measure: MEASURE_1

(I) howfit	(J) howfit	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.867*	.349	.024	-1.603	-.130
2	1	.867*	.349	.024	.130	1.603

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

4. location

Estimates

Measure: MEASURE_1

location	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	10.425	.610	9.138	11.712
2	2.153	.205	1.720	2.586

Pairwise Comparisons

Measure: MEASURE_1

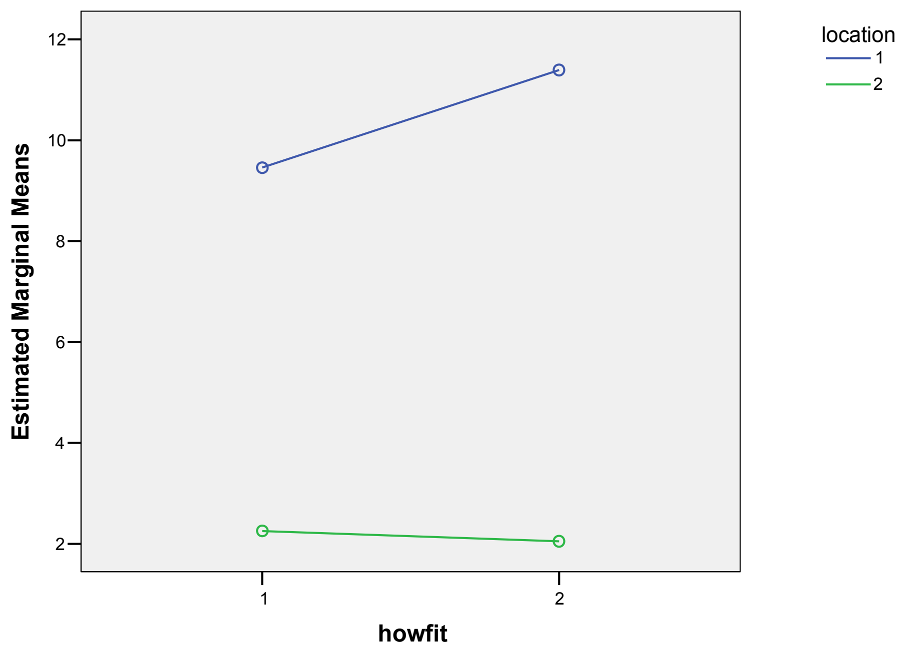
(I) location	(J) location	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	8.272*	.495	.000	7.228	9.316
2	1	-8.272*	.495	.000	-9.316	-7.228

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Estimated Marginal Means of MEASURE_1



APPENDIX G: FRONTAL PLANE 2-WITHIN ANOVA

2-Within ANOVA for the frontal plane

Within-Subjects Factors

Measure: MEASURE_1

howfit	location	Dependent Variable
1	1	SBFE
	2	SBFHel
2	1	SBUE
	2	SBUHel

Descriptive Statistics

	Mean	Std. Deviation	N
SBFE	14.9783	6.22516	18
SBFHel	2.0556	1.23297	18
SBUE	15.8000	4.69445	18
SBUHel	2.1550	1.11044	18

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
howfit	Sphericity Assumed	3.818	1	3.818	.660	.428	.037	.660	.120
	Greenhouse-Geisser	3.818	1.000	3.818	.660	.428	.037	.660	.120
	Huynh-Feldt	3.818	1.000	3.818	.660	.428	.037	.660	.120
	Lower-bound	3.818	1.000	3.818	.660	.428	.037	.660	.120
Error(howfit)	Sphericity Assumed	98.318	17	5.783					
	Greenhouse-Geisser	98.318	17.000	5.783					
	Huynh-Feldt	98.318	17.000	5.783					
	Lower-bound	98.318	17.000	5.783					
location	Sphericity Assumed	3176.311	1	3176.311	184.048	.000	.915	184.048	1.000
	Greenhouse-Geisser	3176.311	1.000	3176.311	184.048	.000	.915	184.048	1.000
	Huynh-Feldt	3176.311	1.000	3176.311	184.048	.000	.915	184.048	1.000
	Lower-bound	3176.311	1.000	3176.311	184.048	.000	.915	184.048	1.000
Error(location)	Sphericity Assumed	293.388	17	17.258					
	Greenhouse-Geisser	293.388	17.000	17.258					
	Huynh-Feldt	293.388	17.000	17.258					
	Lower-bound	293.388	17.000	17.258					
howfit * location	Sphericity Assumed	2.347	1	2.347	.495	.491	.028	.495	.102
	Greenhouse-Geisser	2.347	1.000	2.347	.495	.491	.028	.495	.102
	Huynh-Feldt	2.347	1.000	2.347	.495	.491	.028	.495	.102
	Lower-bound	2.347	1.000	2.347	.495	.491	.028	.495	.102
Error(howfit*location)	Sphericity Assumed	80.692	17	4.747					
	Greenhouse-Geisser	80.692	17.000	4.747					
	Huynh-Feldt	80.692	17.000	4.747					
	Lower-bound	80.692	17.000	4.747					

a. Computed using alpha = .05

1. howfit * location

Measure: MEASURE_1

howfit	location	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	14.978	1.467	11.883	18.074
	2	2.056	.291	1.442	2.669
2	1	15.800	1.106	13.466	18.134
	2	2.155	.262	1.603	2.707

2. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
8.747	.705	7.260	10.234

3. howfit

Estimates

Measure: MEASURE_1

howfit	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	8.517	.855	6.713	10.321
2	8.978	.650	7.606	10.349

Pairwise Comparisons

Measure: MEASURE_1

(I) howfit	(J) howfit	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-.461	.567	.428	-1.656	.735
2	1	.461	.567	.428	-.735	1.656

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

4. location

Estimates

Measure: MEASURE_1

location	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	15.389	1.186	12.887	17.891
2	2.105	.257	1.563	2.648

Pairwise Comparisons

Measure: MEASURE_1

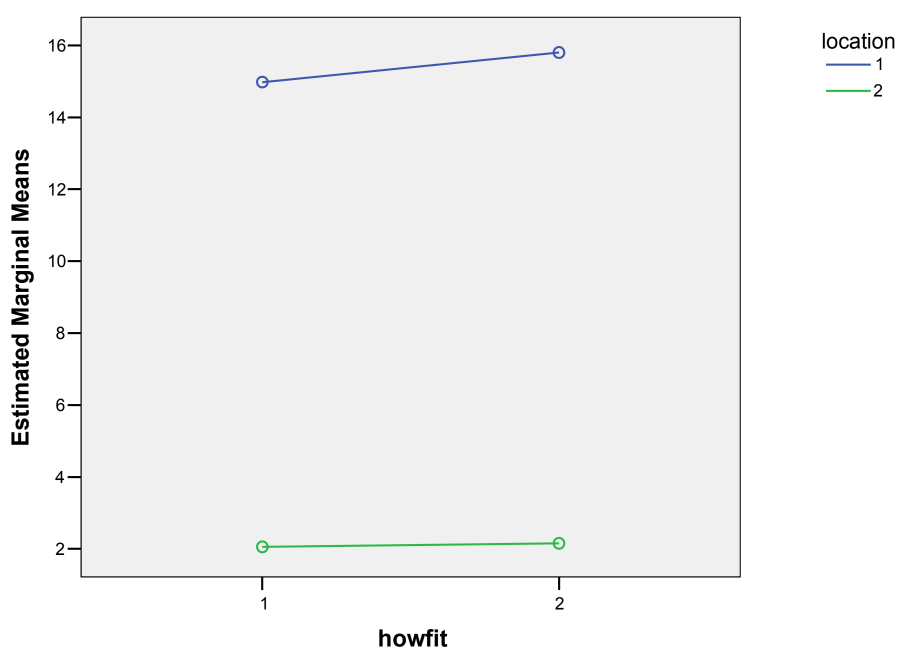
(I) location	(J) location	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	13.284*	.979	.000	11.218	15.350
2	1	-13.284*	.979	.000	-15.350	-11.218

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Estimated Marginal Means of MEASURE_1



APPENDIX H: TRANSVERSE PLANE 2-WITHIN ANOVA

2-Within ANOVA for the transverse plane

Within-Subjects Factors

Measure: MEASURE_1

howfit	location	Dependent Variable
1	1	RotFE
	2	RotFHel
2	1	RotUE
	2	RotUHel

Descriptive Statistics

	Mean	Std. Deviation	N
RotFE	13.9889	4.97332	18
RotFHel	1.9372	1.13913	18
RotUE	15.7150	4.30728	18
RotUHel	2.2811	1.59374	18

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
howfit	Sphericity Assumed	19.282	1	19.282	3.701	.071	.179	3.701	.442
	Greenhouse-Geisse	19.282	1.000	19.282	3.701	.071	.179	3.701	.442
	Huynh-Feldt	19.282	1.000	19.282	3.701	.071	.179	3.701	.442
	Lower-bound	19.282	1.000	19.282	3.701	.071	.179	3.701	.442
Error(howfit)	Sphericity Assumed	88.577	17	5.210					
	Greenhouse-Geisse	88.577	17.000	5.210					
	Huynh-Feldt	88.577	17.000	5.210					
	Lower-bound	88.577	17.000	5.210					
location	Sphericity Assumed	2922.811	1	2922.811	211.430	.000	.926	211.430	1.000
	Greenhouse-Geisse	2922.811	1.000	2922.811	211.430	.000	.926	211.430	1.000
	Huynh-Feldt	2922.811	1.000	2922.811	211.430	.000	.926	211.430	1.000
	Lower-bound	2922.811	1.000	2922.811	211.430	.000	.926	211.430	1.000
Error(location)	Sphericity Assumed	235.009	17	13.824					
	Greenhouse-Geisse	235.009	17.000	13.824					
	Huynh-Feldt	235.009	17.000	13.824					
	Lower-bound	235.009	17.000	13.824					
howfit * location	Sphericity Assumed	8.597	1	8.597	2.156	.160	.113	2.156	.283
	Greenhouse-Geisse	8.597	1.000	8.597	2.156	.160	.113	2.156	.283
	Huynh-Feldt	8.597	1.000	8.597	2.156	.160	.113	2.156	.283
	Lower-bound	8.597	1.000	8.597	2.156	.160	.113	2.156	.283
Error(howfit*location	Sphericity Assumed	67.792	17	3.988					
	Greenhouse-Geisse	67.792	17.000	3.988					
	Huynh-Feldt	67.792	17.000	3.988					
	Lower-bound	67.792	17.000	3.988					

a. Computed using alpha = .05

1. howfit * location

Measure: MEASURE_1

howfit	location	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
1	1	13.989	1.172	11.516	16.462
	2	1.937	.268	1.371	2.504
2	1	15.715	1.015	13.573	17.857
	2	2.281	.376	1.489	3.074

2. Grand Mean

Measure: MEASURE_1

Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
8.481	.579	7.260	9.701

3. howfit

Estimates

Measure: MEASURE_1

howfit	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	7.963	.681	6.526	9.400
2	8.998	.592	7.750	10.247

Pairwise Comparisons

Measure: MEASURE_1

(I) howfit	(J) howfit	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-1.035	.538	.071	-2.170	.100
2	1	1.035	.538	.071	-.100	2.170

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

4. location

Estimates

Measure: MEASURE_1

location	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	14.852	.986	12.772	16.932
2	2.109	.286	1.506	2.712

Pairwise Comparisons

Measure: MEASURE_1

(I) location	(J) location	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	12.743*	.876	.000	10.894	14.592
2	1	-12.743*	.876	.000	-14.592	-10.894

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Estimated Marginal Means of MEASURE_1