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Examination of Lower Extremity Muscle Activity during an Overhand Lacrosse Shot in Females

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EXAMINATION OF LOWER EXTREMITY MUSCLE ACTIVITY 
DURING AN OVERHAND LACROSSE SHOT IN FEMALES 

By 

Brianna Marie Millard 

Bachelor of Science in Athletic Training 
California State University Northridge 
2010 

A thesis submitted in partial fulfillment 
of the requirements for the 

Master of Science in Exercise Physiology 

Department of Kinesiology and Nutrition Sciences 
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Brianna Marie Millard

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ABSTRACT

EXAMINATION OF LOWER EXTREMITY MUSCLE ACTIVITY DURING AN OVERHAND LACROSSE SHOT IN FEMALES

by

Brianna Millard

Dr. John Mercer, Examination Committee Chair
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This study intends to provide a basic biomechanical understanding of a specific movement within the sport of lacrosse, an overhand goal shot. Its purpose is to identify the different muscles of the lower extremity and the roles they perform during each phase of the lacrosse shot. Specifically, the study will compare how active muscles are between phases as well as between two different shot speeds. This research provides insight into the importance of timing muscle contractions that lead to a more accurate and faster shot.

Subjects (n=5 females, age: 21.8 ± 2 years, height: 162.56 ± 15.24 cm, mass: 63.68 ± 23.6 kg) were healthy and had at least one year of lacrosse experience. The lead leg was instrumented with electromyography (EMG) leads to measure muscle activity of the rectus femoris, biceps femoris, tibialis anterior, and the lateral and medial gastrocnemii. Subjects underwent testing for maximal voluntary isometric contraction (MVIC) for each muscle. The MVIC data was used to normalize all EMG activation amplitude data. Subjects were video recorded during five trials of a warm up speed shot (condition 1) and five trials of a game speed shot (condition 2).

Video analysis was used to identify the discrete events defining each phase and the times the events occurred. EMG data were processed by removing any zero offset,
full-wave rectifying the data, and normalizing to MVIC. The times of each discrete event were used to extract electromyography data for analysis of each phase. Data were averaged per phase for each trial. Trial data were averaged per subject and subject data were averaged per condition per muscle.

Individual subject data was analyzed using a 4 (phase) x 2 (shot) ANOVA for each muscle. Statistical analyses were completed with SPSS software version 20.0. If an interaction was observed, paired t-tests were used to compare EMG between shots for each phase. Differences were noted using $\alpha=0.05$ for all statistical tests.

The rectus femoris EMG was influenced by the interaction of phase and speed ($p<.05$). Using post hoc testing, it was determined that the rectus femoris EMG was greater during game speed (C2) than warm up speed (C1) during phases 2, 3, and 5. The rectus femoris EMG was not different between shots for phase 4. The biceps femoris EMG was not influenced by the interaction of phase and speed ($p>.05$). EMG was significantly different between the phases, regardless of shot ($p<.05$). EMG was also significantly different between shots, regardless of phase ($p<.05$). The tibialis anterior EMG was not influenced by the interaction of phase and speed ($p>.05$). There was no statistical difference between shots ($p>.05$) or phases ($p>.05$). The lateral gastrocnemius EMG was not influenced by the interaction of phase and speed ($p>.05$). There was no statistical difference between shots ($p>.05$) or phases ($p>.05$). The medial gastrocnemius EMG was not influenced by the interaction of phase and speed ($p>.05$). There was no statistical difference between phases ($p>.05$). EMG was different between shots, regardless of phases ($p<.05$). The results of this study indicate the extent to which muscles are activated during the lacrosse overhand goal shot. Although most the muscles
tested were not influenced by the interaction of phase and speed, it illustrates the
importance of timing and muscle activation that can be used as reference when designing
strengthening and or rehabilitative exercises for female lacrosse athletes.
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I greatly appreciate my boyfriend, Brian, who always believed in me. Thank you for supporting and encouraging me. Thank you for helping me with my travels back and forth, especially when moving back to California. Thank you for forcing me to read articles even when I didn’t want to, but needed to. Although you may not understand my thesis, thank you for helping me complete it!
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CHAPTER 1
INTRODUCTION

US Lacrosse, the national governing board of the game, considers it to be America’s first sport. In the 2009 article “About the Sport,” the organization states that the game was originally conceived by First Nations peoples as stickball, then named lacrosse by the French, and ultimately embraced by Canadians. Not only the oldest team sport in North America, lacrosse has also become one of the fastest growing team sports in the United States in the past decade (Hinton et al., 2005). Youth involvement has skyrocketed more than 100% since 2001, and as of 2009, the National Collegiate Athletics Association (NCAA) had 557 college teams and more than 500 college club programs, including nearly 200 women's teams (“About the Sport,” 2009). Despite lacrosse’s immense growth, there remains a disconnect between its popularity and the quantity and quality of available research.

Although it has an extensive history, specific lacrosse movements still suffer from a lack of standard terminology and thus researchers, along with coaches and players, do not share a common vocabulary. To this end, it is important to develop a description of key movements, including the goal shot, to identify the critical features that lead to success. In the act of shooting, Mercer and Nielson (2011) use some elemental lacrosse terminology. The term ‘crosse’ or ‘stick’ refers to the shooting stick. For the upper extremity, ‘bottom arm’ refers to the hand holding the distal end of the stick while ‘top arm’ refers to the hand that holds the proximal part towards the head. For the lower extremity, ‘drive leg’ refers to the planted leg that pushes the player forward while ‘lead leg’ refers to the planted leg in front of the player while shooting.
When describing the lacrosse shot, or goal shot, Mercer and Nielson (2011) name six different phases: approach, crank back minor (A), crank back major (B), stick acceleration, stick deceleration, and follow through/recovery. Using these functional terms and descriptive phases, Mercer and Nielson (2011) lay a foundation to build a model of the lacrosse shot to help identify the critical elements required to make an efficient shot.

Biomechanically, the body can be described as a kinetic link model based on the kinetic chain (Oliver, 2011). The kinetic chain describes the sequence of events that must occur in order for an athlete to perform a specific movement. The body can be looked at as having interdependent segments; the contribution of the entire body is essential during sport activities (Oliver, 2011). When looking at the biomechanics of the lacrosse shot, we look at the athlete’s ability to coordinate different physical attributes into the shape of the shot. Upon observation, the lacrosse shot builds from the ground up.

A key factor for successful lacrosse shot lower body mechanics is lead leg stabilization, which is crucial for torque and explosive, quick shots. Foot contact is important for stabilization so that the energy produced can move from the high ground reaction forces into the hip for a stronger rotation and greater speed for the shot. Oliver (2011) acknowledges the importance of the lower extremity for a more effective and faster softball pitch. Oliver (2011) also credits Putnam’s (1991, 1993) findings that the leg and trunk work sequentially in effort to accelerate the shoulder for optimal force production in upper extremity activities. Additionally, the large muscles of the hips and trunk help position the thoracic spine for functional shoulder motion (McMullen & Uhl,
It is my belief that a similar mechanism is at play in developing an effective and faster shot during lacrosse.

To understand the lacrosse shot and improve it, it is essential to understand it from the bottom up. Each parameter of the shot is dependent on leg stabilization. A grounded lead leg ensures a controlled center of mass, quick deceleration, and increases the ability to change linear motion to rotational speed. It is the stabilization of the lower extremity and core musculature, along with the efficiency of proximal segments that initiate the movement of the more distal segments and give more power to the activity. Based on the kinetic chain, the lower extremity and trunk musculature must be activated before the arm motion occurs (Oliver, 2011). Although leg stabilization has been found to be essential for efficient motion, research has neglected examining its role in lacrosse specific movements.

Currently there is an absence of valuable research on lacrosse, specifically in the area of measuring muscular activity during the lacrosse shot. This knowledge is vital to designing specific training protocols, injury prevention, rehabilitation, and improving lacrosse game play. The first step to understanding the critical features of the lacrosse shot is describing lower extremity muscle activity. There is extensive research (e.g., Oliver, 2011; Yamanouchi, 1997) that links the lower extremity as the driving force of sport specific movements. It is my supposition that the same is true for the lacrosse shot. It is therefore of paramount importance to research and understand muscle activity during the shot.
Purpose of the Study

The purpose of this research study is to describe women’s lower extremity muscle activity during the lacrosse shot. The research will look at average electromyography activity during each phase of the shot. Specifically, the study will compare how active muscles are between phases as well as between two different shot speeds.

Research Questions

How active are lower extremity muscles during the lacrosse shot, specifically the rectus femoris, bicep femoris, lateral and medial gastrocnemius, and tibialis anterior of the lead leg? How active are the specific tested muscles between phases of the shot? How active are these muscles between different shot speeds?

Significance of the Study

It is important to identify the different muscles of the lower extremity and the roles they perform during each phase of the lacrosse shot. This study will present a baseline measure of specific lower extremity muscle activity during the lacrosse shot. This research will provide insight into the importance of timing muscle contractions that lead to a more accurate and faster shot. In order to understand the kinematics of the shot with the aim of improving skill, developing training techniques, decreasing risk of injury, and implementing proper rehabilitation, the research will dissect the functional aspects of the lacrosse shot.
CHAPTER 2

REVIEW OF RELATED LITERATURE

**Brief History**

With a history spanning to the early 15th century, lacrosse is one of the oldest sports in North America. Rooted in Native American culture, ‘stickball’ was often played to resolve conflicts, heal the sick, and develop strong men and women (“About the Sport,” 2009). The evolution of the Native American game into modern lacrosse began in the 17th century by the French when they standardized the game with a set of field dimensions, limits to the number of players per team, and other basic rules that would better organize the sport (“About the Sport,” 2009). US Lacrosse states the first men’s college lacrosse team was developed in 1877 at New York University, and it was not long after that women’s lacrosse made its mark in the United States.

**Women’s Lacrosse**

Women’s lacrosse originated in the late 1800s when St. Leonard’s School in Scotland hosted the first women’s game in 1890 (“About the Sport,” 2009). Even though other universities attempted to start women's lacrosse teams in the early 1900s, it wasn’t until 1926 that the first women’s team was established at the Bryn Mawr School in Baltimore, Maryland (“About the Sport,” 2009). Men's and women's lacrosse games were played under similar rules, with no protective equipment, until the mid-1930s. It was at that time that men's lacrosse began evolving dramatically, allowing for more contact. Men’s and women’s play drastically changed in subsequent decades in terms of rules, degree of contact, number or players, field dimensions, sticks, techniques, playing strategies, body equipment, and body protection. Although the game was modified and
played under different rules, men's and women's lacrosse remain derivatives of the same, original game. With the sport rapidly growing, especially play for females, it is important to understand the sport as a whole, anatomically, kinetically, and biomechanically to better serve coaches and players for skill acquisition, strength and conditioning, and injury prevention.

The majority of sports use lower extremity musculature to some degree. It is important to focus research on this area of the body as it sets the foundation for trunk and upper extremity motion, especially in providing power and stability. It is important to establish a baseline measurement of muscle activity to better understand the lacrosse shot. To date, there is no research on lower extremity muscle activation in females within the sport of lacrosse. These results could potentially determine if recruitment patterns generate faster ball speeds, improve accuracy, improve transfer of energy, and could observe rates of injury. My research proposes an examination of other kinematics of the lacrosse shot; a comparison of other similar sports; and an assessment of types and mechanisms of injuries within the sport, as compared to other similar sports. These proposed areas of study can be used to observe how lower extremity muscle activation affects kinematics, phases of motion, and injuries.

**Kinematics**

Although previous research has hypothesized and concluded that the lower extremity generates the power behind sport specific movements, it is still important to be aware of the actual motion of the lacrosse shot. Even though it is scarce, most of the limited research on lacrosse focuses on learning the kinematics of the game. Livingston (2006) and Crisco, Rainbow, and Wang (2009) describe the kinematics of ball release
within their work. Livingston’s (2006) single subject design examining passing and Crisco et al. (2009) multiple subject coed study observing overhand shooting observed peak stick angular velocities are greater for synthetic sticks than for wooden sticks. Both Livingston (2006) and Crisco et al. (2009) learned ball speeds were greater from men’s sticks than women’s. This is most likely due to the difference in design and shape of the pocket. An important detail that both studies agreed upon was that ball speeds exceed the rate at which injury can occur if the ball makes contact with a player at an unprotected area.

**Livingston (2006)**

Given the limited research of lacrosse stick and ball kinematics, Livingston (2006) designed a study describing the kinematics of ball release from various types of sticks (crosses) during an overhand pass. The single subject design examines a young adult female with seven years of elite competitive experience. The athlete was instructed to keep one leg stationary as she stepped forward with the opposite leg to complete an overhand pass at a marked target with maximum velocity. Twenty four lacrosse stick models (6 wood, 18 synthetic) were used. For each stick, five experimental trials were taken, for a total of 120 trials. The dependent variables were stick and ball velocity for each type of crosse. This study provides key descriptive data on the kinematics of ball release from different types of crosse models. The average resultant ball release velocity was similar to radar gun estimates of a pass in game like situations. Ball velocities were greater in the synthetic crosses than the wood designs.

Benefits of the single subject design were that it allowed kinematic changes to be standard due to the model of crosse used rather than a difference in technique, skill, or
strength. These preliminary findings have observed that the material and design of the stick alters ball kinematics. Practical implications of this study were the given results of ball velocities from types of sticks used and affirmation that the ball possesses enough kinetic energy to cause injury. Livingston (2006) was influenced by a review of literature that stated there is a concerning high rate of injuries from the lacrosse balls alone in women’s lacrosse. Further research is warranted to help understand stick versus ball velocity rate, as well as ball velocity and injury rate. Livingston (2006) notes that future research should look at both genders, as well as other lacrosse specific tasks.

**Crisco (2009)**

Changes in game play, increased ball speeds, and injury rates are believed to be related to the recent changes in stick design. Structural changes have occurred, but little is currently known about how the lacrosse stick actually propels the ball. Crisco et al. (2009) developed a study focusing on the mechanics of ball release. The stick was considered to be a simple, passive extension of the hands and if this was to be correct, Crisco et al. (2009) hypothesized that the speed of the ball would equal the speed of the stick when the ball was released. The purpose of the Crisco et al. (2009) study was to measure ball speed, tip of stick speed, and 3-D kinematics during lacrosse shots.

Subjects (n=16 male and 16 female) were instructed to shoot an overhead shot toward a lacrosse goal. Four different stick models were used, two for each gender. Two conditions of three trials were examined, with each condition using different stick for that gender. Crisco et al. (2009) defined time of release as the time when the distance between the ball and stick tip was at a minimum. Kinematic variables such as ball velocity, stick tip velocity, angle of stick shaft with horizon, angle between tip velocity and stick shaft,
and angle between ball velocity and stick tip velocity were all calculated at release. Kinematic variables at the time of release were determined between the two men’s sticks and between the two women’s sticks as well.

Both the men’s and women’s shots enabled ball speeds to be faster than stick tip speeds, with men’s speeds being faster overall. It was determined that the stick itself shoots the ball faster than anticipated. Stick design and pocket depth could be possible reasons of why the men’s ball speeds were faster. Further research should examine all types of designs and their individual influences on shot kinematics, other possible variables for increases in ball shot speed, and reasons for the significantly different increase in ball shot speed with a men’s stick.

Crisco (2005)

Despite the fact that the sport of lacrosse has evolved over the years, the specifications have not, especially ball specifications which date back to 1943 (Crisco, Drewniak, Alvarez, and Spenciner, 2005). Crisco et al. (2005) observed various lacrosse balls to see if they met the dated specifications and to determine other mechanical properties of the ball that may affect ball and player performance. Ball specifications are important in establishing equal and fair play and in potentially lowering the risk of injury from balls.

Crisco et al. (2005) tested eight balls (7 game, 1 practice). Specifications examined were mass, circumference, rebound height, ball liveliness, and ball compression rate. Specifications were graded on a pass/fail scale. Results concluded that most tests used to check these specifications were not accurate with the actual speed of lacrosse balls. Within a few of the specifications, some balls had the same values. Not
one ball model tested met all the specifications of the National Collegiate Athletic Association/ National Federation of State High Schools Association (NCAA/NFHS). Crisco et al. (2005) suggest that governing bodies update their specifications to more game accurate tests. Crisco et al. (2005) neglected to test if the different ball models were different in speed—would a faster traveling ball be more efficient than a slower traveling ball—. Crisco et al. (2005) noted that future research is needed to examine the specifications for compression loads of competitive play balls. It is possible that the current compression rate of balls can potentially enter a player’s facemask and cause injury. Further research should also observe other aspects of the sport such as specifications on contact rules and body protection equipment.

Marsh (2010)

The act of propelling an object at a target is common in sports such as a free throw shot, a baseball pitch, and a lacrosse shot (Marsh, Richard, Verre, and Myers, 2010). These actions are considered specialized movement skills because they are goal directed (Marsh et al., 2010). Accuracy is considered to be a main goal of a specialized movement skill and it is needed to be successful in sports. There are many variables that contribute to one’s accuracy. Marsh et al. (2010) examined four variables that may contribute to shot accuracy in women’s college lacrosse: balance, visual search, hand grip strength, and shoulder joint position sense. These four variables were selected based on previous research conducted on the same variables in other sports. Instrumentation included the Biodex Stability System (balance), Trail Making Test parts A and B (visual search), a hand dynamometer (hand grip strength), and an inclinometer (shoulder joint position sense). Lacrosse shot accuracy was measured using a high speed video camera
and an L shaped apparatus to determine the position of the ball in the x-y plane as it reached the target (Marsh, et. al, 2010). Shot accuracy was compared to the other variables tested in hopes that a relationship would be able to be determined.

Previous data from other sports were used to determine a relationship between accuracy and the tested variables, since there is no previous comparable data solely for lacrosse. Accuracy in most sports has a negative relationship with velocity, where Marsh et al. (2010) did not distinguish a relationship between the two. Previous research found a positive relationship between lacrosse shot error and balance stability and Marsh et al. (2010) data confirmed that subjects with greater levels of balance stability also demonstrated less lacrosse shot error. Like most specialized movement skills, the lacrosse shot is a complex whole body movement that requires optimal balance control (Marsh et al., 2010). In order to have optimal balance, one must control their center of gravity over their base of support. Imbalance during the shot can lead to excessive or compensated movements that result in poor skill execution, decreased accuracy, and even injury (Marsh et al., 2010). The relationship between visual search and accuracy illustrates the importance of attention and cognitive processing during the shot (Marsh et al., 2010). One who is more focused will have better skill acquisitions and therefore better athletic performance. There were no significant findings to make a relationship between lacrosse shot accuracy with hand grip strength or shoulder joint position sense.

Results from the variables tested and their relationship to shot accuracy can provide insight into new techniques for practice and can lead to new methods to enhance athletic performance. The results illustrate an importance of balance ability and visual search for higher lacrosse shot accuracy. Limitations of Marsh et al. (2010) study were
small sample size, controlled environment, and limited selection of variables tested. It is recommended that coaches, athletes, and health care providers desiring to enhance lacrosse shot accuracy, may do so by providing instruction and specific exercises promoting balance ability and visual search strategies that are sport specific and relate to the phases of the shot (Marsh et al., 2010).

This literature (Livingston, 2006; Crisco et al., 2005, 2009; Marsh et al., 2010) was reviewed for its relevance to the sport. Current literature has focused on lacrosse ball kinematics, stick kinematics, and shot accuracy. Further research should focus on muscle activity’s role in kinematics. EMG data can serve as another tool to evaluate efficiency of play.

**Parallel to Other Sports**

Lacrosse enjoys popularity as its own sport, but also because of the similarities to other games including hockey, soccer, basketball, baseball, and softball. When examining basic play, like many other sports, the main objective in lacrosse involves passing a ball between team members to move it downfield and ultimately score points by throwing the ball into a goal. This is a common mechanism of play that also is found in soccer and basketball, but unlike these sports, lacrosse players don't touch the ball directly. Rather, they catch and direct the ball using a stick. In this way, lacrosse is very similar to ice and field hockey. Hockey uses a stick of similar length, although it's used differently during play. Unlike hockey, lacrosse players use a net-on-a-stick to pass the ball and score. Scoring in lacrosse is similar to hockey—one goal equals one point—with a penalty point structure that allows for additional points. Lacrosse requires many skill sets that most
sports do such as speed, agility, balance, visual search, accuracy, and overall cardiovascular conditioning.

Profiling

Miller, Seegmiller, & Sharon describe the female NCAA Division 1 lacrosse athlete in the 2009 article, “Physiological Profile of Women’s Lacrosse Players.” The research outlines the increase in popularity of women’s lacrosse, and how health care professionals have become more aware of the potential work capacity, muscular strength, muscular endurance, power, flexibility, and other related fitness variables required for play. Currently, there is limited research that describes these fitness parameters and the fitness profile of a female lacrosse athlete. Miller et al. (2009) believe that data on this athlete population would provide insight for health care professionals and allow could influence future topics of research such as the susceptibility of specific injuries, injury prevention/rehabilitation programs, and strength/conditioning programs.

Miller et al. (2009) performed multiple fitness tests to determine a baseline for the basic physical fitness parameters. The physical fitness characteristics consist of cardiovascular endurance (VO₂max test and one mile run time), flexibility (sit and reach), muscular endurance (pushups, sit ups, and 60% of one repetition max (1RM) back squat until failure), muscular strength (1RM back squat and 1RM bench press), body composition (BOD POD), muscle torque (MVIC leg extension), grip strength (hand dynamometer), vertical jump (Vertec vertical column), speed (100 and 200 meter sprints), and Q-angle measurement (goniometry). Miller et al. (2009) uses descriptive statistics (mean and standard deviation) to provide the physical fitness profile.
The results demonstrate that women’s lacrosse athletes are above average, 80-90th percentile for most physiological tests as compared to athletes competing in sister sports. Evidence shows lacrosse athletes have similar fitness characteristics to women’s basketball, soccer, and track athletes. Tests of flexibility (40th percentile) and body fat percentage (just above the 50th percentile) indicate there is still room for improvement. Limitations of the study were a small sample size and that select normative data was not available for comparison. “Physiological Profile of Women’s Lacrosse Players” provides a foundation for future comparative studies for effective strength and conditioning programs.

**Lower Extremity EMG in Similar Sports**

Muscles of the lower extremity and trunk must be activated before upper extremity motion can occur in most sports. Previously, windmill softball pitch research focused solely on upper extremity muscle activity. Oliver, Plummer, and Keeley (2011) believed the lower extremity was needed to stabilize and support the upper extremity’s motions. Oliver et al. (2011) focused their research on examining upper extremity (biceps brachii, triceps brachii, rhomboid major and minor) with lower extremity (gluteus maximus and medius) muscle activity throughout the phases of the softball pitch. The 2011 design focused on specific muscle activations during the discrete events of the phases of the pitch. EMG with concurrent video analysis was used to identify muscle activity throughout the phases. MVIC data were used as the 100% normalized value of activity produced. Oliver et al. (2011) was able to quantify and describe muscle activation for the upper and lower extremities during the windmill softball pitch. Due to a
small and selective sample size, Oliver et al. (2011) suggested that further investigations need to address different population groups and muscles.

Few studies have analyzed increasing the strength of the lower extremity as a method to improve pitching abilities and preventing injury. Yamanouchi (1997) examined EMG of highly skilled pitchers (competitive baseball players) and compared it to less experienced players (high school). His intention was to use the data to potentially help prevent injury in high school baseball players. He examined the abductors, adductors, rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius for both the pivot and non-pivot leg. He concurrently recorded EMG and video of the pitch and split the footage into its respective phases. Phase one covered the first two seconds immediately prior to the landing of the non-pivot leg and phase two covered the two seconds following landing. EMG was analyzed as a percentage of the MVIC. Each of the muscles showed significantly higher activity in the skilled group for both the pivot and non-pivot leg. Yamanouchi (1997) concluded that this significant difference in muscle activity determines an importance of lower extremity strength and activation to ensure effective, accurate, and consistent pitching.

Stability of the pelvis and the transfer of energy to the upper extremity requires an understanding of the role of the lower extremity muscle group as the driving force for any upper extremity movement (Oliver, 2011). Oliver (2011) credits Cordo and Nasher’s (1982) belief that for normal voluntary movement of the shoulder to occur, it is necessary for the lower extremity to be activated prior to any upper extremity movement; that it is the basis of the natural neuromuscular loop of the body. Muscle groups must work in a synergistic fashion. The lower extremity drives the position of the pelvis, torso, scapula,
and shoulder during the pitching motion. Oliver (2011), Oliver et al. (2011), and Yamanouchi (1997) stress the importance of understanding the behavior of lower extremity muscle contractions during the discrete phases of their specific activity. Oliver et al. (2011) stated that in order to understand the motion of the windmill softball pitch and its injury implications, it was imperative to understand the muscle activations throughout the pitching motion. According to Yamanouchi (1997), an efficient pitch, with a decreased risk of upper extremity injury requires key functions of the lower extremity such as the preservation of energy, controlled sway of the trunk, and deceleration of the upper part of the body. Both Oliver et al. (2011) and Yamanouchi (1997) results provide an understanding for the necessity of similarly designed research for the lacrosse shot.

It is my belief that in order to understand the motion of the lacrosse shot and the injury implications of it, researchers must find and understand the muscle activities that support the motion. In a comparable design to that of Oliver et al. (2011) and Yamanouchi (1997), EMG and video analysis during the lacrosse shot can identify discrete events of the shot and how active muscles are throughout the phases. The present study’s results along with similar studies can potentially influence future designs of lacrosse specific training programs.

**Injury**

Women’s lacrosse requires little or no protective equipment. With the exception of the goal keeper who wears more extensive gear, the players only wear a mouth guard and a faceguard or goggles. Unlike men’s play, body checking and body contact is not allowed in women’s play, so any lower extremity injuries are more likely caused by non-
contact mechanisms. According to the NCAA, an injury is defined as an event that requires a visit to the athletic trainer or physician, resulting in the player missing one or more practices or games (Matz & Nibbelink, 2004). Lacrosse play poses a unique set of injury mechanisms due to the game’s use of sticks, high ball velocity, fast pace, and quick change of direction (Hinton et al., 2005). Basic descriptive, epidemiologic data is needed to define the risks of play, mechanisms of injury, risk factors, and prevention programs.

As lacrosse has grown, researchers have found specific injury trends at both the collegiate and high school levels. Matz et al. (2004) analyzed non-head and non-face trauma, and found the highest percentage of injuries affected the ankle and knee. Hinton et al. (2005) confirm these statistics in their high school epidemiological study. Consistent with the male play, Hinton et al. (2005) found the single most common injury combination to be ankle sprains from an indirect force but with higher occurrences for females. Ankle injuries accounted for 16.1-18.1% in males and 10.4-25.4% in females (Hinton et al., 2005). The knee was the second most frequently injured body part. Female study participants endured a total of 477 injuries, 110 of which occurred at the knee alone. The most severe injuries were ligament sprains of the knee. Statistics discovered by Hinton et al. (2005) suggest that a vast majority of lower extremity injuries were due to indirect forces. Indirect force injuries can be caused by a number of factors such as a lack of stability, weak supporting muscles, muscle imbalances, and lack of eccentric control when decelerating or landing. Researchers note that although play is different between genders, boys and girls generally share priority injuries and basic injury types; those that involve ankle and knee ligament sprains occurring in noncontact situations.
These types of injuries reflect the high speed and quick direction change of the game. The injuries that Hinton et al. (2005) and Matz et al. (2004) identified in their studies are the most frequent and most restrictive of play time, suggesting that injury prevention programs should focus on the muscles of the highly injured areas.

**Risk Factors for Injury**

There are four categories of risk factors for lower extremity injuries; anatomical, hormonal, environmental, and biomechanical factors (Griffin et al., 2000; Hutchinson & Ireland, 1995). Anatomical factors include individual physical characteristics including gender, height, weight, age, Q-angle, and medical history. In females, hormonal factors may be an important aspect of ligamentous injuries, especially ACL injuries, due to the effect of hormone levels on the ligamentous tissue. In addition, research has examined the clinical significance of biomechanical movements as potential risk factors. These risk factors may influence the forces applied and increase the risk of injury to the lower extremity during dynamic tasks such as abrupt starts and stops, pivots, and side-cutting; expected movements of sports.

**Anatomical Variations**

An indication to the increase in injury rates of female athletes are gender specific anatomical variations of the lower extremity. An obvious anatomical difference is the Q-angle. The Q-angle is the angle made between the line connecting the anterior superior iliac spine and the midpoint of the patella, and the line connecting the tibial tubercle with the midpoint of the patella. Increased Q-angles in female athletes may increase valgus alignment at the knee, lead to patellar tracking abnormalities, and place an increased strain on the knee joint (Granata, Wilson, & Padua, 2002). Women tend to have an increased Q-angle due to a wider set pelvis and shorter femoral length. An abnormal Q-
angle is considered to be any angle greater than 15° in males and greater than 20° in females. Research has established a strong correlation to the increase in injury rates with differences in lower extremity alignment (e.g., Granata et al., 2002; Brophy et al., 2010; Malinzak, Colby, Kirkendall, Yu, & Garret, 2001).

Increased joint laxity may influence a female’s risk of lower extremity injury. Rozzi, Lephart, Gear, & Fu (1999) noted that healthy women possessed significantly greater knee joint laxity when compared to males. Healthy female athletes appear to apply compensatory mechanisms to achieve functional joint stabilization. This joint laxity seems to play a role in diminished joint proprioception. During six randomized trials, Rozzi et al. (1999) measured degrees of angular motion and EMG between men and women. The women took a significantly longer time to sense joint motion during knee extension. Significant gender differences in tibial lengths have also been observed; females display a decrease in the length of the tibial bone (Granata et al., 2002). The difference in tibial length can lead to possible gender differences in muscle length tension relationships and force production of the lower leg.

According to Agel et al. (2005), approximately 60-80% of severe injuries in soccer occur in the lower extremities, especially at the knee and ankle. Agel et al. (2005) concurs with the supporting research that female players face a greater risk of these injuries due to factors such as anatomical structure, lower extremity alignment, and abnormal muscle activity. Brophy et al. (2010) observed that females have different lower extremity alignments than males, specifically increased hip adduction and knee valgus. Brophy et al. (2010) also stated that females have different lower extremity muscle activation patterns, particularly in the hip flexors, abductors, knee extensors, and
flexors. The same mechanisms and injuries are thought to be true for female lacrosse players due to similar muscles involvement and similar sport specific movements.

**Biomechanical Differences**

Biomechanical differences between males and females are seen in movements such as side-step cutting maneuvers, pivoting, and quick accelerations and decelerations; which have already been established as non-contact mechanisms of injury. Gender differences in movement patterns are another possible cause for an increase in injuries of female athletes. Previous research has reported a greater risk of non-contact injury, especially that of the ACL, in females because they land and cut with greater knee valgus angles (Agel et al., 2005; Hewett, 2000). Especially while performing athletic tasks, women tend to have less knee flexion angles, more knee valgus angles, greater quadriceps activation, and lower hamstring activation (Malinzak et al, 2001). It is important to determine all factors within each sport specifically predispose females to greater risk of injury.

**Neuromuscular Control and Muscular Strength**

Neuromuscular control differences between genders include proprioception, muscular strength, muscular reaction time, and muscular recruitment (Hewett, 2000; Huston & Wojtys, 1996; Rozzi et al., 1999). After normalizing strength for body weight, Huston & Wojtyś (1996), learned both female athletes and non-athletic subjects demonstrated significantly less quadriceps and hamstring strength than male subjects. Huston and Wojtyś (1996) identified women as being quadriceps dominant upon examining the neuromuscular differences of the lower extremity between genders. They defined quadriceps dominance as the quadriceps being the first muscle to activate in
response to stress placed on the knee during selective athletic maneuvers. Huston & Wojtys (1996) learned females took significantly longer to reach peak torque of the hamstrings as compared to the male subjects. In 2000, Hewett discussed the gender differences in muscle activation timing and peak torque generation of quadriceps, hamstrings, and gastrocnemius. His research affirmed Huston & Wojtys (1996) findings, concluding that females exhibit a slower peak torque generation of hamstrings and an earlier peak torque generation of quadriceps. This study, along with others (Hewett, 2000; Rozzi et al., 1999) indicate that females tend to recruit the quadriceps and gastrocnemius muscle groups before the hamstring muscle group in reaction to anterior tibial translation. This reaction may actually increase the anterior translation force and potentially increase the risk of knee injury.

Significant differences between men and women have been revealed in studies investigating muscular force and stabilization at the knee joint. Huston & Wojtys (1996) and Hewett (2000) indicated in reaction to anterior tibial translation, females tend to recruit the quadriceps and gastrocnemius muscle groups before the hamstring muscle group. Women have a larger anterior tibial shear force placing the ACL under greater stress. This increased stress can be attributed to quadriceps dominance and the time before the hamstrings fire in opposition of the quadriceps force. In a comparison of knee joint motion patterns between men and women, Malinzak et al. (2001) observed that women tend to be put in disadvantageous situations due to the lower extremity and are at an increased risk of injury.
Hormonal Differences

There has yet to have established conclusive evidence that a relationship exists between the menstrual cycle and serious knee injury. But, body composition and hormonal physiology is another obvious difference between males and females. Women typically have a higher average body fat percentage than males. Females also tend to have a lower lean body mass, indicating less muscle mass. Having less muscle can potentially cause less stabilization of the joints and an increase in ligamentous injury. Men have greater muscle mass due to the predominant effect of androgen hormones such as testosterone, where estrogen, the predominant hormone in females, increases body fat (Liu, 1997). This difference in hormones is imperative to understanding why female athletes are more easily injured and repair more slowly than their male counterparts. Testosterone stimulates fibroblastic proliferation, whereas estrogen—especially estradiol—inhibits it (Liu, 1997). Throughout a female’s menstrual cycle, the hormones estrogen, progesterone, and relaxin levels fluctuate. These hormones are theorized to increase ligamentous laxity and decrease neuromuscular control in females (Griffin et al., 2000; Hewett, 2000). Further research is needed to establish if there is a relationship between hormone levels and type and time of injury before any speculation concerning hormone levels can be considered.

Common Injuries

Common mechanisms and types of injuries are shared among lacrosse and other sports. We can presume that field hockey’s mechanisms and types of injuries are most similar to those of lacrosse because of the similar design of play. According to Murtaugh (2001), the most frequently injured site of the body in women’s field hockey was the
lower limb—having more than half of the injuries accounted for—with the most prevalent type of injury being an ankle sprain. Common with lacrosse, most head and face injuries were caused by the ball. Like field hockey, women’s lacrosse does not have a relative high injury rate as compared to its counterpart sports soccer and hockey, but the severity of injuries is worth investigating mechanisms and developing preventive measures for injury.
CHAPTER 3

METHODS

Subjects

Subjects (n=5 females, age: 21.8 ± 2 years, height: 162.56 ± 15.24cm, mass: 63.68 ± 23.6kg, years played: 7.2 ± 14 years, hand dominance: right (5), lead leg: left (5), position: defense (3) with 1 as a midfield as well, offense (2) with 1 as a midfield as well) were healthy and had at least one year of lacrosse experience. Inclusion criteria were such that subjects were all female lacrosse players, able to throw an overhand shot, and had no injury that interfered with their ability to shoot. All subjects read and signed a university approved informed consent before participation (Appendix A).

Instrumentation

Muscle activity was measured using an 8-channel telemetry EMG system (TeleMyo 2400T, G2; Noraxon USA Inc., Scottsdale, AZ; 1500Hz). Duel electrodes (Part 242, Noraxon USA Inc. Scottsdale, AZ) were placed in line with the muscle fibers on the surface of the skin following Noraxon guidelines (Shewman, 2007) for lead placement. Video was recorded with a Panasonic Digital Video Camera Recorder (Panasonic NV-GS37, Secaucus, NJ). Speed was measured using a radar gun (Stalker Pro II, Applied Concepts, Inc. /Stalker Radar, Plano, TX).

Procedure

Subjects were instructed to wear their own shoes and comfortable practice clothing. Electromyography data were obtained by first cleaning the electrode placement sites with alcohol pads, abrading the skin, and if necessary removing any hair. Electrode
placement then occurred with dual electrodes (Ambu Blue Sensor N; Ambu Inc.
Ballerup, DK) being placed on the lead leg (left for all subjects) of the body. Muscle sites
which were instrumented included the rectus femoris, biceps femoris, medial
gastrocnemius, lateral gastrocnemius, and tibialis anterior, with a single electrode being
placed on the tibialis anterior for grounding purposes. Leads from a telemetry system
(TeleMyo 2400T, G2; Noraxon USA Inc., Scottsdale, AZ; 1500Hz) were attached to all
electrodes with extensions to allow for more movement.

Electrode placement followed manufacturer (Noraxon, USA) guidelines.
Specifically, for the rectus femoris, a pair of electrodes was placed in line with the
patellar tendon on the center of the muscle belly (Figure 1A). For the biceps femoris, a
pair of electrodes was placed on the lateral side of the posterior leg in the center of the
muscle belly (Figure 1B). For both the medial and lateral gastrocnemius, a pair of
electrodes for each head was placed at the proximal 1/3 of the lower leg, at the center of
each muscle belly (Figure 1C). For the tibialis anterior, a pair of electrodes was placed on
the proximal 1/3 of the lower leg on the center of the muscle belly. This pair of electrodes
had a third electrode that acted as a ground lead. This ground electrode was placed in line
with the other electrodes, about an inch above (Figure 1D). All leads were adhered to the
subjects’ skin in a way to prevent tension being placed on the leads during movement.
Leads were also wrapped with flexi wrap and or power flex tape to allow for more
comfortable movement of the subject (Figures 2A-2C).
Figure 1A: Rectus Femoris Electrode Placement

Figure 1B: Biceps Femoris Electrode Placement

Figure 1C: Lateral and Medial Gastrocnemius Electrode Placement
Figure 1D: Tibialis Anterior Electrode Placement

Figure 2: Illustration of the setup to record muscle activity

Figure 2A: Posterior View  Figure 2B: Anterior View  Figure 2C: Lateral View
Prior to testing, subjects completed a 5-second maximal voluntary isometric contraction (MVIC) for each muscle. The MVIC data were used to normalize all EMG data. Throughout all testing, EMG data were sampled at a rate equal to 1,500 Hz. The following positions were used for MVIC testing: The rectus femoris was tested with the subject in a seated position with both of her legs extending off of the table and flexed at the knee to 90°. The researcher stabilized the thigh to be tested (lead leg) by placing one hand on the distal, anterior aspect of the thigh. The researcher’s other hand grasped the anterior aspect of the participant’s lower leg just proximal to the malleoli. The subject was then instructed to attempt to fully extend her knee as the researcher applied downward force and was coached to not let the researcher push her leg back. The biceps femoris was tested with the subject in the prone position with the lead leg flexed at the knee to 90° and the drive leg lying flat on the table. The researcher stabilized the lead leg by placing one hand on the distal, posterior aspect of the thigh. The researcher’s other hand grasped the posterior aspect of the same leg’s heel. The subject was instructed to attempt to pull her heel in towards her gluteal muscles as the researcher resisted the motion. The medial and lateral gastrocnemii were tested simultaneously with the subject standing and completing a single leg heel raise stance. No additional force was provided. The tibialis anterior was tested with the subject sitting upright with both legs extended forward. The researcher supported the lead leg at the distal lower leg, just above the ankle. The subject was instructed to dorsiflex and invert the foot. Force was applied from the researcher against the medial, dorsal surface of the foot in the direction of plantar flexion and eversion of the foot. A zero offset was obtained prior to performance of maximal voluntary isometric contraction testing of each muscle.
After MVIC tests were completed, subjects were allowed to do their own warm up. All subjects used their own stick and shot with their dominant side. Each subject was instructed from what distance to shoot an overhand shot. The camera was placed at an angle such that the anterior and lateral view of the subject could best be recorded. This position was selected as the best view of the discrete events of the whole shot. Video was sampled at a standard rate of 30 frames per second. Subjects completed two throwing conditions: a warm up speed (C1) and a game speed (C2). Trials were considered valid for the specific condition being tested as long as the speed was within 2.2 m/s (5mph) of the previous shot and within a 4.5 m/s (10mph) range. All trials were included. Each condition consisted of 5 trials, for an overall total of 10 trials per subject. Conditions were not blind or randomized and always commenced with warm up speed. For each trial, data collection began before the subject initiated their shot and continued until the completion of their follow through of the shot. As soon as video data were compressed, the subject completed the next trial.

**Data Reduction**

Data from electromyography and video were saved on a flash drive and transferred to a personal computer for analysis. Electromyography data were converted to be readable and analyzed in Microsoft Excel (2007, Redmond, WA). Video records were evaluated through Microsoft Media Player (2007, Redmond, WA).

The video record was used to identify the discrete events defining each phase and the times the events occurred. These phases have been described by Mercer and Nielson (2011) as: (1) approach (2) crank back minor (3) crank back major (4) stick acceleration (5) stick deceleration (6) follow through and recovery (Figure 3). The phases are defined
by specific discrete events (Mercer & Nielson, 2011). The approach phase is the start of the movement and concludes with drive foot contact. Crank back minor is from drive foot contact to lead foot contact. Crank back major is from lead foot contact to maximum elbow flexion of the top arm. Stick acceleration commences with maximum elbow flexion until ball release. Stick deceleration is starts from ball release to maximum elbow extension of the top arm. Follow through is from maximum elbow extension to terminal trunk rotation (Figure 3). For the purpose of this study, the phases that were analyzed were (2) crank back minor, (3) crank back major, (4) stick acceleration, and (5) stick deceleration.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Discrete Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approach</td>
<td>Start of the movement</td>
</tr>
<tr>
<td>Drive foot contact</td>
<td></td>
</tr>
<tr>
<td>Crank Back Minor (A)</td>
<td></td>
</tr>
<tr>
<td>Lead foot contact</td>
<td></td>
</tr>
<tr>
<td>Crank Back Major (B)</td>
<td>Maximum elbow flexion of the top arm</td>
</tr>
<tr>
<td>Stick Acceleration</td>
<td>Ball release</td>
</tr>
<tr>
<td>Stick Deceleration</td>
<td>Maximum elbow extension top arm</td>
</tr>
<tr>
<td>Follow Through</td>
<td>End trunk rotation</td>
</tr>
<tr>
<td>Recovery</td>
<td></td>
</tr>
</tbody>
</table>

(Mercer, J. & Nielson, J., 2011)

Figure 3: Phases of the Lacrosse Shot
Electromyography data were processed by removing any zero offset, full-wave rectifying the data, and normalizing to MVIC (Figure 5). The times of each discrete event were used to extract electromyography data for analysis of each phase. Data were averaged per phase for each trial from the raw data (Figure 5A). Zero offset was removed by subtracting the average of the raw data from all individual EMG values (Figure 5B). Absolute value of the zero offset raw data was performed in full wave rectification (Figure 5C). Figure 5D illustrates the calculating of the average EMG within each phase. The width of the red columns represents the length of time of each phase, while the height is the average EMG. After the averages were computed, they were then normalized to MVIC data. Trial data were averaged per subject and subject data were averaged per condition per muscle. A detailed description and illustration of this process can be found in Appendices C and D.
Figure 5: Illustration of data processing steps.

Figure 5A: Raw Data

Figure 5B: Zero Offset Removal

Figure 5C: Full Wave Rectifying

Figure 5D: Normalizing to MVIC

Statistical Analysis

The Average EMG for each muscle; rectus femoris, biceps femoris, tibialis anterior, lateral and medial gastrocnemii, were each analyzed using a 4 (phase) x 2 (shot) ANOVA. Statistical analyses were completed with SPSS software version 20.0. If an interaction was observed, paired t-tests were used to compare EMG between shots for each phase. Differences were noted using α=0.05 for all statistical tests.
CHAPTER 4

RESULTS

The mean and standard deviations of the shot speeds were 33.96 ± 9.64mph for the warm up speed (C1) and 42.76 ± 9.52mph for the game speed (C2).

The rectus femoris electromyography (EMG) was influenced by the interaction of phase and speed (p<.05). Using post hoc testing, it was determined that the rectus femoris EMG was greater during game speed (C2) than the warm up speed (C1) during phases 2, 3, and 5 (p<.05), but rectus femoris EMG was not different between shots for phase 4 (p>.05).

Figure 6: Rectus Femoris Average Electromyography (EMG) during each phase (Phase 2-5) and for each shot speed (C1: Warm-up; C2: Game). EMG data were normalized to the Maximal Voluntary Isometric Contraction (MVIC). EMG was greater during C2 vs. C1 (p<.05) at phases 2, 3, and 5, but there was no difference between phase 4.
The biceps femoris EMG was not influenced by the interaction of phase and speed (Figure 7, p>.05). EMG was significantly different between the phases, regardless of shot (p<.05). EMG was also significantly different between shots, regardless of phase (p<.05).

*Figure 7*: Biceps Femoris Average Electromyography (EMG) during each phase (Phase 2-5) and for each shot speed (C1: Warm-up; C2: Game). EMG data were normalized to the Maximal Voluntary Isometric Contraction (MVIC). EMG was different between phases (p<.05) and was greater during C2 vs. C1 (p<.05).
The tibialis anterior EMG was not influenced by the interaction of phase and speed (Figure 8, p>.05). There was no statistical difference between shots (p>.05) or phases (p>.05).

*Figure 8:* Tibialis Anterior Average Electromyography (EMG) during each phase (Phase 2-5) and for each shot speed (C1: Warm-up; C2: Game). EMG data were normalized to the Maximal Voluntary Isometric Contraction (MVIC). EMG was not different between phase or shot speed.
The lateral gastrocnemius EMG was not influenced by the interaction of phase and speed (Figure 9, p>.05). There was no statistical difference between shots (p>.05) or phases (p>.05).

*Figure 9:* Lateral Gastrocnemius Average Electromyography (EMG) during each phase (Phase 2-5) and for each shot speed (C1: Warm-up; C2: Game). EMG data were normalized to the Maximal Voluntary Isometric Contraction (MVIC). EMG was not different between phase or shot speed.
The medial gastrocnemius EMG was not influenced by the interaction of phase and speed (Figure 10, p>.05). There was no statistical difference between phases (p>.05). EMG was different between shots regardless of phases (p<.05).

*Figure 10*: Medial Gastrocnemius Average Electromyography (EMG) during each phase (Phase 2-5) and for each shot speed (C1: Warm-up; C2: Game). EMG data were normalized to the Maximal Voluntary Isometric Contraction (MVIC). EMG was greater during C2 vs. C1 (p<.05)
CHAPTER 5

DISCUSSION

An important aspect of this study is that it is the first study to measure EMG of the lower extremity muscles for each phase during a lacrosse shot for women. By analyzing EMG during each phase for a warm up and game speed shot, it was interesting to observe the individual muscle activity throughout the phases. An important observation was that the rectus femoris, biceps femoris, and medial gastrocnemius muscles were more active when shot speed increased, while the tibialis anterior and lateral gastrocnemius were not influenced by shot speed.

Although there are no current research studies on EMG of the lacrosse shot for female players, the results of this study are very similar to other studies that have investigated EMG during throwing. For example, there is previous research on lower extremity EMG during softball and baseball pitching. Oliver et al. (2011) focused their research on examining upper extremity EMG with lower extremity EMG during softball windmill pitch. Oliver et al. (2011) recorded EMG concurrently with video analysis to analyze the pitch and divide its movements into phases, similar to the present study. Oliver et al. (2011) reported that there was consistent activation of lower extremity muscles throughout phases of the pitch between subjects in order to stabilize the upper extremity motions. Based upon an analysis of the results, Oliver et al. (2011) concluded that there is a need of lower extremity muscles to consistently fire in order to stabilize the body and generate torque to propel the upper extremity motion. Oliver et al. (2011) speculated that the greater ground reaction forces reported in windmill pitchers are because of the posting of the plant leg during phase 4 of the pitching cycle and
throughout ball release. They also reported that during this time, the dominant gluteal muscles display great activity in attempt to stabilize the pelvis while on a single leg support. The present study showed similar patterns of activity within a synergist muscle of the glutes, the biceps femoris. In both warm up speed and game speed, the biceps femoris (Figure 7) appears to be most active in phase 4 (C1: 33.6 ± 6.9% and C2: 86 ± 16.7%). Similar to the softball pitch’s weight shift where activation of the gluteals is required, there is a weight shift between lead leg contact and max top arm elbow flexion. Thus activation of the gluteals along with the hamstring group muscles, primarily the bicep femoris, is required.

Results of the present study are also very similar to Yamanouchi (1997) who examined lower extremity muscle contraction during a baseball pitch using EMG and video analysis. He compared EMG of skilled players to non skilled players of the pivot and non pivot leg. He analyzed the pitch as two phases: the first covered the two seconds prior to the landing of the non pivot leg, while the second covered the following two seconds immediately after the landing of the non-pivot leg. EMG of both the pivot and non-pivot leg of the skilled players was significantly higher than that of non skilled group. Yamanouchi (1997) observed that the non-pivot leg quadriceps showed higher and more significant activity (48% MVIC) in phase 1, while the biceps femoris showed higher activity in phase 2 (50% MVIC). The present study demonstrated a similar pattern of muscle activity of the rectus femoris and biceps femoris across phases to that reported by Yamanouchi (1997) during a baseball pitch. The rectus femoris was most active at both speeds (C1: 45.9± 5.5%, 84.5± 14.1% and C2: 131± 14.3%, 176.3± 23.9%) during phases 2 and 3, which is the shift from drive leg to lead leg contact during a lacrosse shot.
The biceps femoris was most active during phase 3’s lead leg contact and phase 4’s ball release (C1: 27.6± 6.5%, 33.6± 6.8% and C2: 58.9± 11.8%, 86.2± 16.7%).

In the present study, there were some confounding factors and limitations to recognize. For example, a confounding factor included experience and skill. Even with a small sample size, there was a large range of experience and skill levels between subjects. Future research is needed to determine how experience and skill influences muscle activity. Another confounding factor was shooting style of each subject. Each subject had somewhat of a unique style which made identifying discrete events difficulty. For example, the discrete event for the phases of follow through and recovery is end of trunk rotation. Some subjects had no or very little trunk rotation. In terms of lead and drive leg contact, some subjects had a single leg balance during lead leg contact where others still had the drive leg in contact with the ground while shooting. Further research is needed to better identify if specific discrete events should be used for analyzing a women’s lacrosse shot. Fatigue may have been a confounding factor. However, the impact of fatigue was likely minimal because the task was not hard and plenty of rest was provided between shots as well as between conditions. A limitation was the differences between the EMG sampling rate and the camera frame rate per second. EMG was measured at 1,500Hz while the video recorded at 30fps, therefore possibly altering discrete event times by 1/30th of a second.

It was a challenge to illicit MVIC’s for all muscles. It was noted that for the gastrocnemiii, the percent to MVIC was consistently larger than the tested MVIC values in all subjects. When testing MVIC for all other muscles, an external force
was applied to the limb to resist movement. But for the gastrocnemii, no external force was applied. This methodological approach may have limited the ability of subjects to achieve a true MVIC for the gastrocnemius. Further examination should be done in order to see if different ways of measuring MVIC for the gastrocnemii make a significant difference in MVIC and percentage of activity values. Another confounding factor was that subjects did not warm up before the MVIC procedures. A warm up before the MVIC test could have elicited a smaller or larger maximal value. However, no literature was found relating warm up to MVIC. Further research would need to be done implementing this idea in order to establish if there is any statistical difference between testing with or without a warm up. That being said, since the study design was repeated measures, the issue of MVIC is not critical for statistical comparison.

The present study was very specific in selecting sex, leg, muscles tested, and level of play. An obvious limitation is because only females were tested, these results could not be applied to men’s shooting since the technique and equipment are unique to their sex. An investigation of both dominant and non dominant lower extremity muscles could provide a better insight into how active muscles are. The study was also limited due to the number of subjects tested. A small sample size means that no definitive answers can be given, but this research is important because it provides some insight as to how active muscles are during the overhand lacrosse shot.

Considering the confounding factors and limitations, by having subjects shoot using two speeds (warm up, game), it was determined that the rectus femoris EMG was
influenced by the interaction of phase and speed (p<.05). Rectus femoris EMG was greater during game speed (C2) than the warm up speed (C1) during phases 2, 3, and 5 (p<.05), but rectus femoris EMG was not different between shots for phase 4 (p>.05). Phase 3 held recorded the largest EMG (Figure 6) activity for the rectus femoris (C1: 84.5 ± 14.1%, C2: 176 ± 23.9%). The rectus femoris was most active at the initial lead leg contact. It is at this part of the phase where the leg holds the most knee flexion throughout the shot. The lead leg falls from the most flexion into full extension by the end of the phase.

The biceps femoris EMG was not influenced by the interaction of phase and speed (Figure 7, p>.05). EMG was also significantly different between shots, regardless of phase (p<.05). For example, within phase 4, the bicep femoris was most active in both conditions (C1: 33.6 ± 6.9% and C2: 86 ± 16.7%), yet at significantly different levels. Phase 4 was measured from maximum elbow flexion of the top arm to the discrete event of ball release. The biceps femoris is most active here because within the mechanics of the shot, it is responsible for multiple things such as assisting with single leg balance while extending the knee and hip and stabilizing the pelvis. EMG was significantly different between the phases, regardless of shot (p<.05). Although EMG was different between phases, it was consistently highly active throughout the entire shot. From an injury perspective, having more active knee extensors puts female athletes at a lower risk of injury. When women land, decelerate, or pivot, they have an increase in knee instability due to commonly found neuromuscular imbalances that put them at a higher risk of injury. There is an abundance of data that supports that these neuromuscular imbalances are the primary underlying mechanisms for the increased incidence of knee
injuries in female athletes (e.g., Liu, 1997; Colby et al., 2000; Malinzak et al., 2000). A common imbalance is quadriceps dominance (increased quadriceps recruitment and decreased hamstring strength and recruitment, which is related to the extended knee position component of the injury mechanism). Having increased hamstring recruitment decreases the risks of injury. Subjects in the present study appear to demonstrate a strong eccentric control. Although this cannot be generalized for all female lacrosse athletes, the present study demonstrates that this could quite possibly mean that female lacrosse athletes would be putting themselves at less risk of injury while shooting.

The tibialis anterior EMG was not influenced by the interaction of phase and speed (Figure 8, p>0.05). There was no statistical difference between shots (p>0.05) or phases (p>0.05). During phase 2 at foot strike, the tibialis anterior (C1: 87±20.4% and C2: 143.8±42.3%) activates because the foot is dorsiflexed upon heel contact. This is where we see the initial movements of the lead leg, with the lower leg muscles receiving contact first, therefore needing to contract first to support the rest of the movement.

The gastrocnemii begin a loading response at foot strike, preparing to completely fire as it falls from heel to toe contact (stance phase) into phase 3. Although the lateral gastrocnemius EMG was not influenced by the interaction of phase and speed (Figure 9) and there was no statistical difference between shots or phases, it appeared to be extremely active (C1: 203.5 ± 79.8% and C2: 322 ± 141.9%) as the foot went from heel strike into pronation. As the foot supinated, the medial gastrocnemius (C1: 110 ± 24.4% and C2: 138 ± 30%) fired and became extremely active within the phase. Although the medial gastrocnemius EMG was not influenced by the interaction of phase and speed
(Figure 10 and there was no statistical difference between phases, EMG was different between shots regardless of phases.

The knowledge of muscle activity during a lacrosse shot may be helpful to the development of proper injury preventative and rehabilitative muscle strengthening programs. Understanding how active specific muscles are can influence exercise design protocols, identifying an importance to include more strength based exercises for the more involved muscles. The data could also be used to design muscle and sport specific prehab and warm up exercises that could be implemented before practices and games. In addition, clinicians will be able to incorporate exercises that mimic the timing of maximal muscle activation most used during the shot phases. Exercises for strengthening specific muscles used within sport specific movements continue to be recommended and used even though there is no numerical data on the muscle strengths and requirements needed to fulfill a task.

The most important aspect of this study is that it is the first study to measure EMG of the lower extremity muscles for each phase during a lacrosse shot for women. There is now a numerical set of data that describes muscle activity during the different phases of the lacrosse shot at two different speeds. It was interesting to observe that the rectus femoris, biceps femoris, and medial gastrocnemius muscles were more active when shot speed increased, while the tibialis anterior and lateral gastrocnemius were not influenced by shot speed. This research has now provided insight into the importance of timing muscle contractions that can lead to a more efficient shot. Dissecting the functional aspects of the lacrosse shot in such an approach can help us to better understand the kinematics of the shot with the aim of improving skill and decreasing the
risk of injury through developing training techniques and implementing appropriate rehabilitation.
TITLE OF STUDY: Lower Extremity Muscle Activity during an Overhand Lacrosse Shot

CONTACT INFORMATION
If you have any questions or concerns about the study, please contact:

Dr. John Mercer 702-895-4672
Brianna Millard, ATC 818-259-7230

Purpose of the Study

The purpose of this research study is to describe lower extremity muscle activity during the lacrosse shot in females. This study is being conducted by Brianna Millard, a graduate student at the University of Nevada Las Vegas under the supervision of Dr. John Mercer, Ph.D., associate professor of Biomechanics.

Participants

You are invited to participate because you are a female lacrosse player. You will not be allowed to participate if you have any current injury that interferes with your ability to shoot.

Procedure

If you decide to participate, you will be asked to shoot many times on goal with your own crosse. You will wear your own shoes and comfortable practice clothing. However, we ask that you wear shorts so we can place some special instruments on your thighs and legs. The instruments will measure how active muscles are when shooting. Many small stickers (about the size of a quarter) will be placed on your skin – to make the instrument
work well, we may need to shave any hair and rub the skin clean. Prior to shooting, you will be asked to maximally contract each muscle being tested. We will also be videotaping your shot for the purpose of analyzing the data and recording your shot speed with a sports radar gun. During the test, you will have time to rest in between shots. It will take about one hour to get everything ready, have you shoot, and then unhook you from the instruments.

**Benefits of Participation**

There may or may not be direct benefits to you as a participant in this study. By being part of the study, you will see how research is conducted. You will have an idea of how active your muscles are during a shot as compared to your max activation. You will have an understanding of how active specific muscles are during the shot, which you can use as a tool to improve muscular strength or skill.

**Risks of Participation**

There are risks involved in all research studies. This study may include only minimal risks. You may be sore after taking so many shots. You may need to have your body hair shaved and you may experience skin irritation or rashes from the shaving or instruments. Sometimes, taking the instruments off the skin can be painful – sort of like taking a band-aid off. You can stop the test at any time for any reason.

**Cost /Compensation**

There will not be financial cost to you to participate in this study. You will not be compensated for your time.

**Contact Information**

If you have any questions, please feel free to contact, Brianna Millard at (818) 259-7230 or by email: bremillard87@yahoo.com. You may ask questions now, or if you have any additional questions later, the faculty advisor, Dr. John Mercer, Ph.D. at (702) 895-4672 or by email: john.mercer@unlv.edu will be happy to answer them. For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted you may contact the UNLV Office of Research Integrity at 702-895-2794.

**Voluntary Participation**

Your participation in this study is voluntary. If at any time you do not want to continue, please let us know and the test will stop. We want you to ask any questions you may have about the study prior to signing this document. If you participate in the study, we will provide copies of this form.

**Confidentiality**

Any information obtained in connection with this research study that can be identified with you will be disclosed only with your permission; your results will be kept confidential. In any written reports or publications, no one will be identified or identifiable and only group data will be
presented. All identifiable information that will be collected about you will be labeled by a code. All records will be stored in a locked facility at UNLV for 3 years after completion of the study and identifiable information destroyed thereafter.

**Consent**

You are making a decision whether or not to participate. Your signature indicates that you have read this information and your questions have been answered. Even after signing this form, please know that you may withdraw from the study at any time.

_I consent to participate in the study and I agree to be videotaped_

________________________________________
Signature of Subject Date

________________________________________
Printed Name of Subject Date

________________________________________
Signature of Researcher Date

*Participant Note: Please do not sign this document if the Approval Stamp is missing or is expired.*
APPENDIX B
Data Collection Sheet

Lower Extremity Muscle Activity of the Lacrosse Shot in Females

<table>
<thead>
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<table>
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<td>Shot speed/Notes</td>
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## Appendix C

### Phase, Time, and Cell Data Sheet

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<td>Stick Deceleration</td>
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<tr>
<td>Follow Through</td>
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<tr>
<td>Recovery</td>
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</table>
APPENDIX D

Data Reduction

All recorded data was averaged for each muscle at each trial (found the average from time 0 to last time recorded). Zero offset was then removed from the raw data.

Zero offset data was then rectified. Average per phase per muscle was then calculated by finding the specific absolute value cell that correlated with the specific start and end time of the phase being measured.
MVIC data was then fully rectified. First zero offset was removed and then the signal was fully rectified. Data normalization occurred by calculating the greatest one second average for each muscle when performing maximum voluntary isometric contractions and by relating muscle activity to 100% of the MVIC.
The final stage of analyzation consisted of finding each subject's individual average per muscle, per phase. Values for each muscle for all trials at each condition per phase were averaged. Basically, the “average of the averages” were found.

Then, a group average response per muscle per phase was found. For example, the average for the biceps femoris in subjects 1, 2, 3, 4, and 5 of phase 2 condition 1 were averaged and then graphed.
Standard error bars were added to the columns in the graph. Standard error was found by first finding the standard deviation of each averaged phase per subject in its pertaining column. Standard error was found using the following equation: \( SE = \frac{SD}{\sqrt{n}} \), with \( n=5 \), the total number of subjects. This was then repeated for all muscles tested, at each phase, and for both conditions.
APPENDIX E
Data Tables and SPSS Output

Rectus Femoris

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Tests of Within-Subjects Effects

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Paired Samples Statistics

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Tests of Within-Subjects Effects

Measure: MEASURE_1

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## Tibialis Anterior

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### Tests of Within-Subjects Effects

Measure: MEASURE_1

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# Lateral Gastrocnemius

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## Tests of Within-Subjects Effects

**Measure:** MEASURE_1

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Medial Gastrocnemius

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Tests of Within-Subjects Effects

Measure: MEASURE_1

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References


Hinton, R. Y., Lincoln, A. E., Almquist, J. L., Douoguih, W. A., & Sharma, K. M.


VITA

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University of Nevada, Las Vegas

Brianna Millard

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Thesis Dissertation Examination Committee:
Chairperson, John Mercer, Ph. D.
Committee Member, Dick Tandy, Ph. D.
Committee Member, Janet Dufek, Ph. D.
Graduate Faculty Representative, Carolee Dodge-Francis, Ph. D.