Kinetics and Kinematics of the Overhand, Hybrid and Sidearm Shot of Lacrosse

Susie Renaud

This thesis is submitted to the
Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirements for the
Master of Science in Human Kinetics at the School of Human Kinetics,
Faculty of Health Science, University of Ottawa.

Abstract

Lacrosse, Canada's national summer sport, is a sport anchored in first nations' tradition. Its growing popularity in North America has not been reflected by a similar interest in the scientific literature more specifically on the biomechanics of the lumbar spine with its throwing motion. The aim of this study was to describe the motions, forces and muscle actions of the lumbar spine with the hybrid, overhand and sidearm throw. Twelve subjects were asked to throw at maximal speed while captured by a 3D motion analysis system. Flexion, extension and axial rotation angular velocities as well as positive and negative powers in the two planes were calculated. The first research question pertained to consistency in angular velocities and powers between trials of a given throwing technique. Subjects showed a fairly high variation on all variables but mostly with the angular velocities in extension and the peak positive power in flexion/extension which had high coefficient of variations (CVs). The contralateral rotation velocity and the positive rotation power had the lowest CVs. Overall the CVs for powers exceeded the angular velocities'. The second research question addressed if a difference in variables was present between the three throwing methods. A significant difference was observed in the peak negative power in flexion/extension and the peak positive power in rotation. The contralateral rotation angular velocity also showed a significant difference but the sphericity assumption failed. No other variable showed a significant difference but the observed power for those variables was also quite small. Due to the lack of power and the further need for controlling some unforeseen sources of error, this study can be used as a pilot study to further define and improve future studies in the field of lacrosse biomechanics.

Table of Contents

List of tables

List of figures

Acknowledgments

This research would not have been possible without the contribution of equipment from other facilities. Thank you to Dr. Ed Lemaire for lending Vicon cameras, increasing our total number to 6, which allowed a wider field of capture and made it possible to fully measure the fast motion that is the lacrosse throw. Thank you as well to Dr. Martin Bilodeau for providing the Delsys Bagnoli EMG system to allow us to measure muscle activation.

The author also wishes to express gratitude to the thesis committee, composed of Dr Blaine Hoshizaki and Dr Martin Bilodeau for their guidance and suggestions for the methodology of this research and analysis of the data.

The largest influence in completing this research was from Dr Gordon Robertson who went over and beyond fulfilling the duties of a thesis director. Many thanks for the hours spent teaching biomechanics theory, offering an endless well of knowledge. Thank you for finding the necessary equipment for the data collection as well as coaching the author on the proper use of the software. Without his guidance and encouragement, the biomechanics of lacrosse may have remained unstudied.

Thanks also to the subjects who volunteered their time and expertise with much enthusiasm to further the science related to their sport.

Introduction

The sport of lacrosse has been played for centuries. Developed by our first nations, it was quickly adopted by the non-indigenous population of North America. It has evolved to its current and modern versions of men's and women's field lacrosse as well as box or indoor lacrosse. Each of these categories has a different set of rules and varies in the style of play. It is widely described as the fastest sport on two feet and is an exciting game to play and watch.

As men's lacrosse is a contact sport, most of the injuries suffered by its players are of a traumatic origin. Because of the nature of the game, little can be done to prevent those injuries. As such, it is important to explain the repetitive strains that some lacrosse players seem to display. In my clinical experience as a lacrosse team therapist for 10 years, several of the players had lower back pain with various pathologies such as stress fractures and instabilities. Was it related to the recurring hits or could it possibly be due to another repetitive motion? Unfortunately, the available literature could not answer this question.

While passing, catching and running are all movements commonly executed in the sport, the highest velocity motion for the lumbar spine is possibly throwing at the net. To score, players will most likely use an overhand, sidearm or hybrid shot. These three shots are usually the most accurate shots and the ones that can develop the highest ball speed.

Logically, we could conclude that the highest velocity motion could be the most damaging to the trunk and lumbar spine. To determine how damaging the motion is, we first need to analyze it. We need to know how much motion and which specific movements occur during each of the throws. Forces applied and developed at the trunk segment as well as muscle activation patterns adapting or creating these forces with the overhand, sidearm and hybrid throw would further describe the motions.

Objectives

This research will look at the consistency of subjects when executing each of the throws. If a subject does not always use the same movement pattern or the same muscles to perform a given throw, injury could result as the body's various structures would not have a chance to adapt to the unusual and unequal forces. On the other hand, a lack of consistency may also allow for adaptation of several tissues therefore improving the body's protection against injury. This investigation will also look at the similarities or differences between each of the patterns of throwing for every subject. This will allow us to identify a potentially more damaging style of throwing but especially allow us to describe the mechanics of each motion.

Purpose

The purpose of this research was to define and compare the lacrosse overhand, sidearm and hybrid throw.

The research questions are:

1) Are there significant differences in the trial-to-trial kinetics and kinematics for the overhand, sidearm or hybrid throws within each subject, with particular emphasis at the L5/S1 joint?
2) Are there significant differences in the kinetics and kinematics among the overhand, sidearm and hybrid throws, with particular emphasis at the L5/S1 joint?

Rationale

Little scientific research has been done on lacrosse and specifically of the lacrosse throwing motion. The absence of research is unexplainable considering the interest lacrosse is stirring in North America alone. Lacrosse is Canada's national summer sport. According to the Canadian Lacrosse Association, 48 670 Canadians are currently registered in a lacrosse program. More than 40 nations are expected to compete in the 2014 Men's World Lacrosse Championships. Even though it is a widely popular sport, there has been very little published scientific research about lacrosse especially in the field of biomechanics.

The National Lacrosse League was founded in 1986 under the name Eagle Pro Box Lacrosse and currently has 9 teams in Canada and the US. The Major Lacrosse League, a professional field lacrosse league, was founded in 2001 and has 8 teams. NCAA men's lacrosse has benefited from a longstanding and glorious history with currently 296 university teams in its Division I, II and III combined. The Canadian University Field Lacrosse Association has 13 teams in Eastern Canada alone. Every four years there are senior men's world championships in box and field lacrosse as well as women's, U19 boy's and girl's world championships in field lacrosse. With all this interest in high-level lacrosse, it is a wonder that no one has looked at the biomechanics of the sport.

Even though the action of throwing in lacrosse is often described as similar to tossing a football or throwing a baseball, differences are obvious to the naked eye. There is a multitude of existing research documenting the baseball, cricket, tennis or football motions, which are all similar in some ways to the lacrosse motion. In the absence of research defining the lacrosse throw and allowing for comparison with the existing literature of the other sports, they might be partial guides in defining the lacrosse throw.

If the results of this research are valuable in that they do document and describe the efficiency of the throwing motions, it could be useful to this large population that is involved in the sport of lacrosse. The results could benefit coaches in trying to teach or improve such throwing motions. With knowledge about forces and ideal muscle activation, it could assist health professionals seeking to treat lacrosse players or to prevent such injuries from occurring.

The results of this research might also allow for further research in comparing less experienced players with more advanced players. We could also follow-up with another study to identify if players with a history of lower back pain have differences with healthy subjects. If we are able to identify flaws in some of the muscle activation patterns and can counter them with strengthening and conditioning programs, such programs might be tested in the future and implemented earlier in player development programs to prevent injuries.

Assumptions

Human movement occurs by moving segments such as the trunk or limbs around a joint. To analyze such motion, these segments are treated as rigid bodies rotating about a fixed axis of rotation (Robertson et al. 2004). This is a common assumption in biomechanics since changes in segment lengths are difficult to measure accurately. For this research, we will be interested in trunk kinetics, kinematics and muscle activation patterns and will therefore need to treat the lower leg, thigh, pelvis and trunk as rigid bodies.

To model these segments, we also assume that these rigid bodies are geometrical shapes of uniform density (Robertson et al. 2004). The various tissues composing the different segments of the human body are not homogenous nor are they exactly the same shape in every subject. However, we cannot create an individual specific model for each subject. As other authors have used this method, we will define the upper torso as a right elliptical cone; the lower torso will be described as an elliptical cylinder, the thigh, shank and foot as frusta of right circular cones (Robertson et al. 2004).

Limitations

As we are using EMG to test the pattern of activation of the trunk muscles, a certain amount of noise can falsify our data. To minimize this source of error, filtering can be applied to the data to eliminate the noise and smooth the raw data (Robertson et al. 2004). Proper methodology including proper electrode placement, proper skin preparation, minimizing the movement of wires and proper calibration of the instruments will also help reduce error. EMG being a more variable signal, averaging across trials will also be used to get a more regular pattern (Robertson et al. 2004).

The markers used for videography of the subjects can also lead to errors. As will be discussed in the methodology section, we will mostly apply markers to skin, at the exception of the pelvis markers. This will help minimize error in insuring that they are over anatomical landmarks, most likely bony, and not over loose clothing or tissue, which would likely move once movements, are initiated. The pelvis landmarks will be applied over compression shorts to minimize their movement. Force platform testing, by placing markers in each of its corners will align them with the cameras so that they can be in the same global coordinate system (Robertson et al. 2004).

Delimitations

- Using only male subjects limits the capacity to generalize this study. It is necessary to use only male subjects as women's lacrosse sticks are strung differently. Because of the difference at the level of the pocket in the women's stick, throwing will likely be different and resulting velocities would likely vary greatly. Ideally, both genders could have been assessed but due to time constraints, only males were tested.
- There is a possibility that as the subjects are throwing in a laboratory as opposed to their usual playing environment, they might modify their throwing style or velocities. As they will have to time and choreograph their throw so that both their feet land on a force platform, they might alter their usual pattern rendering it less efficient or constant than usual.
- In a laboratory setting, away from the pressures and excitement of a game, optimal performance might not be reached. It is impossible, however, to test these motions in a game setting as the equipment available to us at this time does not allow for analysis outside of the lab setting
- Our sampling method recruited players of different abilities and experience. We can expect differences that will arise from the years of experience but also from the level of lacrosse at which each player performed.

Review of literature

EMG Studies

Electromyography (EMG) has been used repeatedly to study sports movements (Cole and Grimshaw 2008, Chow et al. 2003, Pink et al. 1993) or to study athletes and their physical dysfunctions (Renkawitz et al. 2006). While EMG cannot directly measure the strength of a given muscle, it is a valid “method of objectively assessing when a muscle is active” (Bartlett 2007). It can also provide the researcher with the sequencing of activation of a muscle (Bartlett 2007).

To acquire an EMG signal, one needs to select appropriate sites for the placement of the electrodes. SENIAM recommends that for the erector spinae, longissimus portion (ES), the electrodes be placed at 2 fingers-width from the spinous process of L1 (see Figure 1).

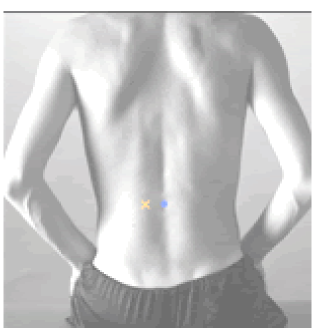


Figure 1: EMG electrode placement erector spinae

As the transversis abdominus (TA) muscle is quite deep, it can be measured in conjunction with the obliquus internus abdominis (IO). In a study by Marshall and Murphy (2003), it was found that in 9 out of 10 cadavers, the fibers from the TA were fused to fibers of the IO at the level 2 cm medial and inferior to the anterior superior iliac spine. As a result, it was found to be a valid location for electrodes to measure the activity of the TA and the IO with rapid arm movement.

In a study by Chow et al. (2003), the activity of the rectus abdominus (RA), obliquus externus abdominis (EO), IO and ES were measured during a tennis serve. The electrode placement for RA was 3 cm lateral to the umbilicus and for the EO, 15cm lateral to the umbilicus. Although this electrode placement was found to be invalid in the previous study by Marshall and Murphy, it does follow the general guidelines of electrode placement. The electrodes are away from the motor point (Robertson et al. 2004), on the muscle belly (Bartlett 2007) as well as between a motor point and a tendon and away from interfering signals from adjacent muscles (Grimshaw et al. 2007). The Noraxon website also supports this electrode placement for the rectus abdominus and the external oblique.

The normalization of an EMG signal needs to be performed to compare subjects to one another. A maximal voluntary contraction of the tested muscle is often performed to normalize the signal obtained during the motion and is widely accepted as a valid method. This has proven less efficient for dynamic motion as the maximal contraction is usually done at one angle while the motion occurs at several angles (Clarys 2000). It is also difficult to reproduce a true maximal contraction in the muscle without proper training (Grimshaw et al. 2007). It is often seen that a dynamic motion will exceed the measured maximal voluntary contraction. Using a peak of trials for each or all subjects is a better way of normalizing EMG with a dynamic motion (Robertson et al. 2004, Clarys 2000, Grimshaw et al. 2007).

Throwing Sports Studies

Even if lacrosse is a growing sport in many countries, not many studies have analyzed its motions. We could not find any kinetic, kinematic or EMG studies of lacrosse throwing other than one study by Crisco et al (2009) who looked at stick speed velocity compared to ball speed in men's and women's lacrosse sticks. They determined that measuring the velocity of the head of the stick and implying this represented the speed of the ball, introduced an error of 3.5 m/s (12.6 km/h) for men and 0.7 m/s (2.52 km/h) for women where the ball travelled faster than the head of the stick. We have been unable to find studies about how the body produces these speeds in lacrosse.

In other sports such as baseball, football, handball, cricket and javelin, as well as tennis, studies have tried to define motion, identify factors causing injury and explain how top athletes obtain better performances.

Hirashima et al. (2002) did an EMG study of the upper extremity and abdominals to determine if a sequential muscle activation pattern occurred during a throwing motion. Their 9 subjects were 3 baseball pitchers, 1 football quarterback, 2 tennis players and 3 subjects who had not ever participated in competitive overhand throwing sports. Their sample was quite small and asked to throw a ball in an overhand fashion, something the tennis players and non-athletes had no practice and possibly no motor pattern to accomplish such a task. The EMGs collected in the trunk were of the EO and RA however, the ES, MU, TA and IO were not measured but all contribute in stabilizing or rotating the spine in the throwing motion (Hodge, 1999). The authors found variations between participants, which was to be expected as they had different (or no) experience in terms of throwing or rotational motion about the spine. However, they did identify a certain pattern where the EO contralateral to the throwing arm activated before the EO ipsilateral to the throwing arm, which became active almost at foot-strike. They also found that the main activity of the RA appeared just before release. This study focused on timing of activation but did outline that variation occurred between participants doing a similar motion.

Kibler and Sciascia (2004) reviewed the literature on upper extremity kinetics to examine how the distal body segments generate and regulate forces to obtain maximal performance in throwing or rotational sports but minimized injury risk. They reported that the hip/trunk or shoulder segments developed 63 to 74% of the energy and force delivered to the hand. The force development of throwing came from the lower extremity to the contralateral IO, EO and RA then to the shoulder girdle musculature, the elbow and wrist being involved in decelerating and fine-tuning the throwing motion. We can perhaps expect similar activation of the trunk musculature for lacrosse although lumbar muscles were not discussed in this specific article.

Seroyer et al. (2010) also did a literature review on the kinetic chain in overhand pitching and how it influenced performance but also may cause injuries. They reported that the legs and trunk serve as the main force generators of the kinetic chain in throwing. We believe the same may be true for lacrosse but as baseball pitchers initiate their throw in a static position and lacrosse players do so when they are already in a forward motion (walking, hopping or running), we may not observe the same pattern for our study.

Baseball pitching has been extensively studied. Lacrosse overhand and hybrid throwing resembles the pitching motion. Fleisig et al. (2006) studied the kinetic differences between fastballs, curveballs, change-ups and sliders in baseball pitchers.

They found that when throwing curveballs, the subjects had greater forward and lateral tilt of the trunk at ball release. The curveball also had the lowest velocity. Kinetics of the trunk were not measured. As ball release is in a different position for each throw at lacrosse, kinematic data for the trunk may differ from findings from this study; however, as both activities are similar, the overhand, hybrid and sidearm throw of lacrosse might also not show significant differences in kinematics of the trunk.

Dun et al. (2008) studied 28 baseball pitchers and found that between throwing from a wind-up position or from a stretch position, kinetics or kinematics were not significantly different. The velocity of the throw, however, was slightly greater with pitching from a wind-up position. The only modification to this motion however is the starting position where the pitcher faces the plate or stands sideways to it. Shortly after initiating the motion, the pitcher produced similar movements between the two pitches. In lacrosse, the stride length might differ between the three types of throws as the wind-up and release are different.

Hong et al. (2001) found similarities between three professional baseball pitchers in the kinetics and kinematics of trunk rotation but differences in forward and side flexion. They had a small sample size, did not define the type of throw used and did not seem to account for accuracy of the throws all of which would influence the application or relevance of the study. One of their purposes, however, was to test a model in assessing the kinetics and kinematics of throwing and not to seek out differences in pitching.

Stodden et al. (2005) looked at the biomechanics of pitching and its influence on the velocity of the ball. While the focus of their article was to see if a pitcher could consistently develop high velocity ball while minimizing the risk of injury, they identified factors, which contributed significantly to the speed of the ball. In the trunk, only the forward flexion at release contributed to the ball velocity. No kinetic parameters of the trunk seemed to positively influence the speed of the ball. They did, however, find kinetic and kinematic differences within pitchers as they were asked to throw at different speeds. This is to be expected as less force is necessary to throw slower but might also indicate that overhand throwing is more consistent.

Werner et al. (2008) researched the factors affecting ball velocity in collegiate baseball pitchers. They found that pitchers of large body mass threw faster. Similar to other studies they found that increased trunk flexion at release had a positive effect on ball velocity but that increased upper trunk rotation angular velocity also increased ball speed. They did require fastballs only of their 54 subjects and recorded accuracy of the pitches, excluding from analysis throws that were off target.

Throwing in lacrosse is often described by coaches as 'the same as throwing a football'. Rash and Shapiro (1995) looked at the quarterback's throwing motion. They found similar kinematics between subjects but differences before foot-contact and during the later stages of follow-through. Several of the throws showed a different pattern of horizontal abduction possibly due to a different trunk motion, mainly increased trunk rotation. This may show that in a throwing pattern, there might be a lack of consistency, which we may observe at lacrosse even within players and within the same type of shooting. This study did not have many trials per subject and they digitized the subjects with their shirts on, leading to a certain amount of error. They measured the upper extremities only and not the trunk.

Fleisig et al. (1996) compared baseball pitching and football passing. They found that baseball pitchers had greater ball velocities, greater rotational speed of the trunk and shoulder and that during the arm deceleration phase, they also exhibited greater upper torso angular velocity. On the other hand, quarterbacks had shorter strides, less trunk flexion at ball release and greater external rotation at the shoulder at foot contact, which may indicate less trunk rotation. As no data are available for lacrosse, we cannot say yet how it will compare to both of these sports.

Javelin is another sport involving an overhand throwing technique. Gonzalez and Dietrich (2002) studied the javelin throw with cinematography to seek which factors influenced performance. As expected, they found that the distance of the throw was directly related to the speed of the javelin at release. They also explained how a summation of the joint velocities from the hip to the upper extremity contributed to the throwing motion. They only studied six subjects and do not report how many trials they recorded per subject.

Mero et al. (1994) looked at contributing body segments to javelin throwing. They filmed Olympic athletes in Barcelona but did not place any markers on them, which may have led to some level of error although the athlete’s clothing could have provided a sufficient view to allow digitizing. They found differences between throwers for the path of their grip or hand on the javelin, which reflects the path of the javelin while still in their hands. They also found a difference in the centre of gravity displacement between throwers, which would imply a different strategy to develop the final release speed between athletes.

Handball, widely popular in Europe has also been studied to define the overarm throwing motion. A study by Van den Tillaar and Ettema (2007) looked at the kinematics in handball players. Although they had no markers on the trunk they identified that faster throwers had maximal pelvic rotation earlier during their throws. As they reached greater range sooner in the movement, they have a longer time to develop a greater force throughout their segments and therefore, greater speed on release.

Cricket has also been widely studied especially throwing or “bowling” as it is called in the sport. A study by Ranson et al. (2008) looked at potentially dangerous techniques of bowling, as there are several classifications of bowlers. They did find a low variability between trials, which indicated that subjects were consistent in their form. Bowlers were classified according to a certain technique characteristics (i.e., front-on, side-on, mid-way and mixed), which is probably why their kinematic parameters did not change between trials as a given bowler always threw the same way. Lacrosse may prove to be similar within a given throwing technique but may also exhibit a lack of consistency as the same player uses more than one technique.

Another cricket study by Portus et al. (2004) looked at technique factors associated with higher ball release speed but also with injury. They found that bowlers who had a maximum hip-shoulder separation angle (defined as the difference in the orientation of the shoulders relating to the pelvis) after front foot contact had higher velocities of throwing. This showed an optimal sequence of hip and shoulder rotation, which may in turn reduce stress in the lumbar region. While this is a timing difference in the sequence, we may have similar findings to explain why lacrosse players throw faster or slower.

Crewe et al. (2013) looked at the biomechanics of the lumbopelvic joints as well as the presence of quadratus lumborum asymmetry in cricket fast bowlers. They chose to focus on the most significant motion, side flexion, for their analysis. They measured peak positive and negative power as well as total positive and negative work. Their study was designed to outline the differences in kinetics between asymmetric bowlers and the ones where the quadratus lumborum muscles were symmetric. They found that the asymmetric group could produce greater positive and negative peak powers. The focus of our study is describing the lacrosse throwing motions as well as comparing the different throws and probably will not include analysis of side flexion as it may be less significant for our movement. As Crewe et al. did, we will look at peak positive and negative powers.

As all of the above-mentioned sports use an overhand throwing technique, one needs to look at sports mimicking the sidearm shot at lacrosse. Sasakawa and Sakurai (2008) looked at the sidearm throwing motion in Ultimate players. While they only looked at the kinematics of the arm, they found smaller variations in the techniques of skilled players. Experience seemed to account for regularity in the motion; initial speed at release was not different between skilled and unskilled players. They did not include the kinematics of the trunk. By observation, one can see that the sidearm shooting in lacrosse will probably display greater trunk rotation than that of the throwing motion of a flying disc.

No one sport will be exactly like the throwing motion in lacrosse. Tennis is a sport where the athletes are required to rotate about their trunk. The serve in tennis somewhat resembles the overhand throwing motion with the addition of a jump. Gordon and Dapena (2006) found that early in the motion of the tennis serve, the trunk rotation is the greatest contributor to the speed of the racket. As in previously mentioned studies, it was to be expected that early in the motion, the trunk works to develop speed to allow distal segments to benefit from the summation of speed (Allard & Blanchi, 1996) from the legs to the upper body. They identified the twist rotation of the lower trunk as the third contributor to racket speed, the upper trunk rotation being the fourth contributor. A properly trained trunk will add to the speed of the motion and not lose the energy generated by the legs. They did, however, have a small sample with only nine subjects with only upper extremity markers.

Chow, Shim and Lim (2003) looked at EMG activity differences between types of tennis serves. They measured the RA, EO, IO and ES. There was no difference in muscle activation patterns between the flat, topspin and slice serves. They did note, however, more abdominal activity with the topspin. Once again, their sample size being five was quite small to generalize findings. Between the overhand, hybrid and sidearm shooting motions in lacrosse, lies a visible difference in starting positions and during the motion itself. We may find differences in kinetics and kinematics but we may or may not find differences in EMG such as this tennis study suggested.

While the golf swing in no way resembles a throwing motion, it does contain a large amount of lumbar rotation which is a movement seen in the lacrosse throw especially in the sidearm motion. Golf players also execute a motion while both hands are on a club just as lacrosse athletes do. Chu et al. (2010) looked at 308 golfers to better explain driving performance in the golf swing. They analyzed upper torso and pelvic rotation velocities in various phases of the golf swing. While the pelvis rotation velocity was greater in the earliest phase, the upper torso rotation velocity was greater for the remainder of the swing and twice greater than the pelvis at the time of impact with the ball. The authors of that study had started with 10 trials but analyzed only 5 of those, choosing the ones with the best performances.

Another interesting study which outlines why it is difficult to compare lacrosse with football or baseball studies was by Seay et al. (2011) where they looked at walking and running on a treadmill with and without carrying a riffle. They found that the trunk rotation was significantly greater during running with a riffle than without. As opposed to baseball and football throwing as well as cricket bowling where each upper extremity acts independently of the other, lacrosse entails that both hands will be linked to the stick the vast majority of the time and during the entire throwing motion. This may increase the trunk rotation necessary to produce an efficient and fast throw when comparing to other sports.

Inverse Dynamics Studies

All of the above-mentioned studies were done without force plates. The kinetic studies used a 'top-down' inverse dynamics where the trunk's kinetics were calculated from the release of the object (ball, football). We propose to use a 'bottom-up' technique calculating kinetics from ground reaction forces given to us by force plates (Robertson et al., 2004). Complete lower back models, incorporating all muscle actions and the contribution of intra-abdominal pressure to the kinetics of the lumbar spine, are not available for this research. We will therefore consider the motion occurring at L5-S1 as an indication of what is happening in the lumbar spine.

A study by Kawasaki et al. (2005) used similar reasoning to measure lumbar spine moments and rotation in tennis to compare one-handed and double-handed backhand strokes. They used two force plates measuring ground reaction forces for each foot independently and calculated moments at the lumbar spine at L5-S1. They also calculated rotational motion of the lumbar spine by measuring the angle of the shoulders relative to the pelvis and the pelvis to the feet. The motion required of the subjects was to hit a stationary object, limiting the capacity to generalize the results, as the motion was not exactly what happens during play. They found that the one-handed stroke had a significantly smaller extension moment before ball impact as well as smaller lateral bending and rotation moments after ball impact. They also found smaller axial rotations between the shoulders-pelvis and the pelvis-feet segments. Although their methodology is of interest to us, the results have little transferability for our study, as we will not be looking at a backhand motion in lacrosse.

Some kinetic studies, using force plates to determine moments in the lumbar spine, are related to gait. While the results of these studies do not relate to our study, they do employ similar methodology to define motion, forces and moments occurring at the lumbar spine.

A study by Khoo et al. (1995) developed a biomechanical model to determine lumbosacral loads during gait. L5-S1 was the joint under study and their model included intra-abdominal pressure (IAP). They did not measure IAP in each of their subjects but predicted it from the moment in the sagittal plane at the hip. They did not mention what the sampling frequency was for their cinematography data or their force plates. They found that during walking, loads of 1.45 to 2.07 times the subject’s body weight was applied to the L5-S1 joint.

Callaghan et al. (1999) looked at different walking speeds and two different conditions (arm swing and no arm swing) to study the forces and moments being applied at L4-L5. They used two models: the first model a rigid segment model using inverse dynamics and the second an EMG driven model. They found that forces, moments and motion of the lumbar spine increased with the increasing walking speed. Restricting arm swing also increased these values except for axial twisting and lateral bending which decreased.

Summary

Many studies have looked at the trunk’s muscle activity, kinetics and kinematics during daily activities but also while throwing. In other sports, the muscle activation pattern and motion of the trunk has been analyzed during different skills and between athletes. EMG has been used to study successfully the muscle activity during these skills. Videography and inverse dynamics have also been used to calculate the kinetics and kinematics of the studied motions. Together, these three data acquiring tools may be used to understand how the body creates the forces necessary to accomplish a task such as throwing.

As the lacrosse throwing motion has not yet been studied in biomechanics, there is no methodology proven to be most efficient for such a study. As the studies presented earlier were of similar motions, we will utilize the same methods to explain how the motion occurs but also to potentially explain the differences between the overhand, sidearm and hybrid throw as well as differences between players.

Methods

Subjects

12 males, between the ages of 25 to 30, were recruited from local lacrosse teams. Each subject met our inclusion criteria that they were a skilled lacrosse player with at least 10 years of playing experience ranging from junior to senior and professional level in box lacrosse and U19 to university level in field lacrosse. They were also healthy as defined by the absence of injuries or disease, at the time and for 2 months prior to testing. The participants' physical properties are outlined in Table 1.

Table 1. Subject description

Subject	Throwing side	Age (years)	Height (cm)	Mass (kg)
1	Left	26	177.8	90.4
2	Right	26	188.0	88.2
3	Left	26	182.9	97.5
4	Right	27	180.3	74.8
5	Right	28	172.7	119.1
6	Right	28	182.9	98.2
7	Left	25	179.1	72.1
8	Left	26	175.3	82.8
9	Right	28	182.9	93.2
10	Right	26	172.7	78.2
11	Left	30	185.2	88.2
12	Left	26	180.3	80.5

The mean age for the participants was 26.83 (±1.4) years old. The mean height was 180.1 (±4.77) cm. The mean mass was 88.6 (±12.78) kg. Half the subjects threw on the left side and the other 6 were right-handed.

Variables

To define the muscle activation pattern of the trunk muscles, EMG signals were collected from the bilateral erector spinae, obliquus internus and externus as well as the lower portion of rectus abdominis using the Delsys Bagnoli cable telemetry system. To quantify and describe the movement of the trunk during the throwing motions, kinetics and kinematics of the lumbar spine were calculated with the data obtained from force platforms (Kistler) and the infrared cameras using the Vicon MX motion capture system.

Laboratory set-up

Six MX Vicon cameras were used in the laboratory situated at 319 Montpetit Hall at the University of Ottawa. These cameras were positioned as outlined in red in Figure 2. Three Kistler platforms also shown in grey in Figure 2 were used to accommodate right- or left-handed throwers. A canvas tarp, pictured by the curved red line, approximately 3 meters from the force plates, protected the wall and cameras from the ball. A target was outlined onto the canvas to represent the size of a field lacrosse net. The radar gun to measure the speed of the ball proved to be unreliable and was abandoned. Instead stick speed was calculated from markers attached to the stick head.

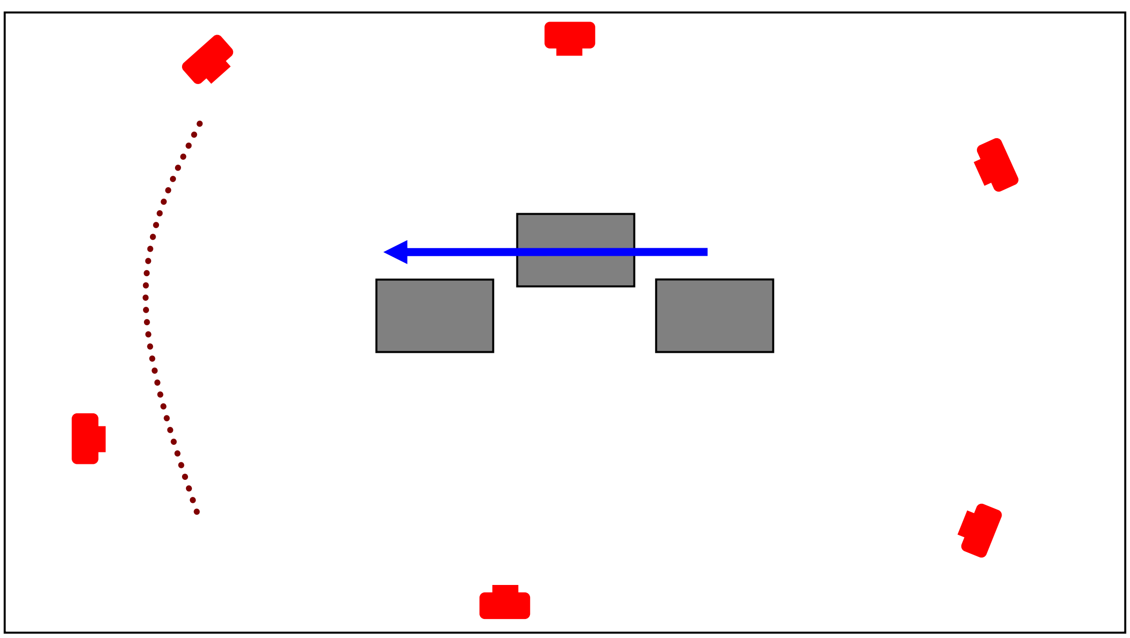


Figure 2. Top-view of laboratory setup

Protocol

Before the subject's arrival, camera orientation was checked to ensure that the entire field of view was covered. Camera calibration was performed as well as force platform zeroing and calibration. Accuracy of the cameras was ensured to always be less than 1 mm.

Subjects came to the data collection session with their own lacrosse stick and dressed in compression shorts. After explaining the procedures and obtaining written informed consent from subjects, their mass and height were measured and recorded.

Skin was shaved and washed where EMG electrodes were applied. Eight pairs of electrodes were applied in the following way (SENIAM,2010, Noraxon, 2010):

- Bilateral erector spinae on the muscle belly besides L1-L2
- Bilateral lower portion of rectus abdominis on the muscle belly next to the umbilicus
- Bilateral obliquus internus right above the inguinal ligament
- Bilateral obliquus externus above the iliac crest on the lateral portion of the trunk

A ground electrode was also applied to the sacrum. This was linked to a Delsys Bagnoli system through a wire which was set up to trail behind the subject.

Maximum voluntary contractions (MVC) were recorded for each of the muscle groups via isometric contractions against straps. Extension was measured in the prone position as the MVC for the erector spinae and flexion was measured in a half sit-up position as the MVC for the rectus abdominis. Left and right rotations were also measure in this position but resistance was applied manually by the researcher. Left rotation was the MVC for the right obliquus externus and the left obliquus internus and right rotation was the opposite. This was performed in order to allow normalization of the data for each subject. Although normalization with maximal voluntary contractions has not been proven to be ideal for trunk muscles, it is the widely accepted method.

Reflective markers were placed according to the uOttawa marker set. Markers were applied to the following anatomical landmarks: bilateral acromioclavicular joints, C7, sternal notch, xyphoid process, T12, right scapula, bilateral superior border of pelvis, bilateral greater trochanters, bilateral thighs, bilateral medial knee joint line, bilateral lateral knee joint line, bilateral lower legs), bilateral medial malleolus of the ankle, bilateral lateral malleolus of the ankle, bilateral first metatarsophalangeal joint and bilateral fifth metatarsophalangeal joint. Three markers were also attached to the lacrosse stick head. The picture below illustrates the final set up for the subjects.

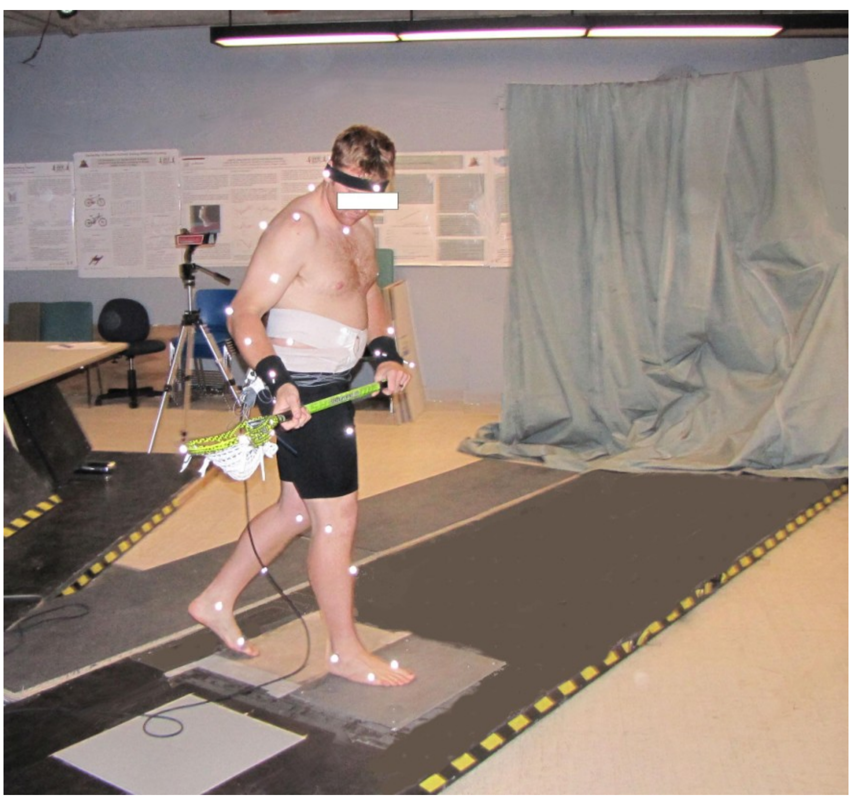


Figure 3. Markers and electrodes on subject

Subjects were then given time to familiarize themselves with the equipment. They were advised to practice shooting at the canvas and staying within the target outlined. This allowed warming up of the muscles necessary for throwing but also allowed the subjects to practice landing on the force platforms and throwing with the markers and EMG electrodes and wires. Although all subjects did not experience difficulty in hitting the target, it also allowed them to practice staying within its boundaries. Once they could consistently hit the target at a minimal speed, they were advised to try 20 shots to properly warm up their muscles.

Data collection then started. A static trial was taken with the subjects' arms outstretched at their side and their stick lying face down on a nearby table. For the dynamic trials, subjects were instructed to take 2 steps before landing on the force plates and throw as hard as they can, aiming for the target. Five subjects chose to walk these two steps while the seven others were more comfortable with a skipping/hopping approach. Shots that landed outside of the target were not counted as a valid trial.

Each subject was instructed to throw 10 sidearm shots, 10 overhand shots and 10 hybrid shots. An overhand shot was defined as having the stick in a relatively vertical position, a hybrid shot by having the stick around a 45-degree angle from the horizontal and a sidearm shot consisted of shooting while the stick was relatively horizontal (Scott 1976, Hanna 1980). Each subject was randomly placed into one of 6 groups to determine the order of the shots required. Each group consisted of four subjects. The order of the shots was as outline on Table 2.

Table 2: Throwing sequence groups

Group	***First throw***	***Second throw***	***Third throw***
A	Overhand	Hybrid	Sidearm
B	Overhand	Sidearm	Hybrid
C	Hybrid	Sidearm	Overhand
D	Hybrid	Overhand	Sidearm
E	Sidearm	Overhand	Hybrid
F	Sidearm	Hybrid	Overhand

During each of the shots, video and EMG data was recorded using Vicon Workstation software.

Sampling rates for the EMG and force platforms were 1000 Hz and for the infrared cameras, 200 Hz. Markers were labeled using Vicon Workstation software and minor gaps (less than 50 frames) were filled also using the Workstation software. More significant gaps were filled using the Vicon Polygon software. We then chose the 5 best trials per throwing method for each subject. Better trials were identified as having a complete set of markers, fewer gaps and central landings on the force platforms. Video and force platform data of those 15 trials were then used to reconstruct the subject through Visual3D to obtain angular velocity, moments of force and powers for each of the remaining trials. Maximum angular velocity, maximum moments of force and maximum powers were pulled from that data for the L5-S1 segment in flexion-extension and rotations for each of these trials. As they were not very significant values, right and left side flexion were left out of our analysis.

EMG data were filtered and normalized through Visual3D. The data were filtered using a linear envelope with a critically damped filter at a cut-off frequency of 6 Hz.

Once data analysis was initiated, it was decided to pursue analysis of EMG data for one subject. This was done to limit the scope of the study and offer means to support the other results instead of keeping the EMG data as a dependent variable. This meant that subject 8 was analyzed as his hybrid and overhand stick speeds were the fastest.

For the maximum angular velocities, maximum moments and maximum powers, averages for each throw, done by individual subjects, were calculated for comparisons between throws.

Statistics

For the first research question, where each subject is tested for consistency in throwing each different type of throw, data was statistically analyzed by using a coefficient of variability. For the second research question, where differences between each type of throw but within each subject are to be examined, a repeated-measures ANOVA was used for each of our 8 variables which were:

- Maximal flexion angular velocity
- Maximal extension angular velocity
- Maximal ipsilateral rotation angular velocity (so that if a player was right handed, this would be right rotation defined by the shoulders and upper torso moving towards his right hand side while his pelvis remained neutral)
- Maximal contralateral rotation angular velocity (so that if a player was right handed, this would be left rotation)
- Peak positive power for flexion-extension
- Peak negative power for flexion-extension
- Peak positive power for rotation

- Peak negative power for rotation

The means of each type of throw for each variable was calculated for each subject and then compared using the ANOVA to establish if a significant difference is present between throws.

Results

Before presenting the results, a description of the biomechanical characteristics of throwing in lacrosse is in order. All lacrosse throws consist of 3 phases: the wind-up, the acceleration phase and the follow-through. Throughout all phases, the subject holds both hands on the stick. The wind-up starts when the stick begins to move backwards and ends at maximal wind-up, when the stick is at its most posterior position or just before it begins to move forward. During this phase, some athletes will roll their stick in their hands to rotate the head of the stick and entrap the ball or have several oscillations of posterior-anterior motions with their stick prior to the definitive anterior motion of the acceleration phase. As these measures are taken to fool the opponent or to keep the ball in the stick while getting checked, we seldom observed them during our data collection but when present, they created a certain amount of trunk oscillations. During the wind-up, the upper extremities will position the stick according to which throw is being used (see Figures 4, 5 and 6).

Figure 4. Maximum wind-up hybrid

Figure 5. Maximum Wind-up Overhand

Figure 6. Maximum Wind-up Sidearm

The rear foot strikes the ground first (e.g., for a right-sided thrower the left foot strikes first) followed by the front foot so that the finished position is staggered. Next, the trunk rotates towards the dominant side (e.g., for a right-sided thrower, the shoulders rotate towards the right or clockwise on the pelvis). Weight transfer from the posterior to the anterior foot will be initiated at the end of the wind-up phase.

The acceleration phase starts at maximal wind-up and ends at ball release. During this phase, the upper extremities move the stick forward and the weight transfers from the posterior to the anterior lower extremity. The trunk then rotates in the opposite direction of the dominant side (e.g., a right-handed thrower rotates his shoulders towards the left or counterclockwise on the pelvis) and depending on the shooting style may also flex slightly (see Figures 7, 8 and 9 below).

Figure 7. Acceleration phase-hybrid

Figure 8. Acceleration phase- Overhand

Figure 9. Acceleration phase - Sidearm

The follow-through occurs after ball release and essentially consists of slowing down the upper extremities and the trunk. It starts at ball release and ends at the end of the stick swing defined as the most posterior and superior point reached on the contralateral side. The upper extremities cross in front of the body and the trunk continue to rotate in the same direction as the acceleration phase. For some subjects, the posterior foot lifts off the ground during this phase and after the end of follow-through takes a step.

As the focus of this research is the lumbar spine, an in depth description of the trunk motion is in order for each type of throw. To help assist this description, please refer to Appendices 1 through 36 where the angular velocities, moments and powers at L5-S1 for each subject and each type of throw are depicted. Appendices 1 through 21 are of subjects 1, 2, 4, 6, 7, 8 and 10 who approached the force plates with a semi-running or hopping gait. Appendices 22 through 36 are from subjects 3, 5, 8, 11 and 12 who walked onto the force plates. Examples of certain subjects' graphs accompany the text to make it easier for the reader to visualize the motion without having to constantly refer to the appendices. Included with the description are graphs from a hopping subject (HS) and a walking subject (WS) for each variable to allow comparisons. Please note that the Y axis scale is not necessarily the same for each subject as some had greater values. The X axis represents the percentage of the cycle, which was calculated from the time of first foot contact to 20 frames after ball release, and therefore does not include the complete follow-through phase but allows one to see how the subject slowed the motion. It should also be mentioned that the units for angular velocity are rad/s but deg/s have previously been reported in other tables.

For all types of throws, the wind-up portion varies greatly between subjects especially with the direction of angular velocity and powers. In a game setting, players may still be on the receiving end of body contact during this phase or be using the stick oscillations, previously described, to deceive their opponents and therefore their approach will be different each time and not as well rehearsed.

The focus of this research will be on the acceleration phase and the follow-through, which is where the greatest powers were measured and representative of how the output is produced. Maximum wind-up (MWU) and ball release (BR) were estimated from observing trials, noting the frame number at which they occurred and then transferring that information onto the graphs. It is therefore an estimation of when that event occurred to help identify the portion of the graph that represents the wind-up, acceleration and follow-through phases since the ball was not visible to the Vicon motion capture system. Note that while MWU occurred for most subjects at approximately 50% of the cycle, BR was different, rendering the acceleration phase of various lengths for each subject and between throws. Each throwing method will be discussed by separating the motion occurring in the sagittal plane (extension and flexion) and then in the transverse plane (rotation).

Description of hybrid throw

First, the flexion and extension of L5-S1 for the hybrid throwing method will be discussed. At MWU, six of the subjects had started moving into flexion and therefore had a flexion angular velocity while the other six were still moving in extension. The graphs below (Figures 10 and 11) are from subjects who were both in extension at the time of MWU. Figures 12 and 13 are from subjects who were both moving in flexion at the time of MWU

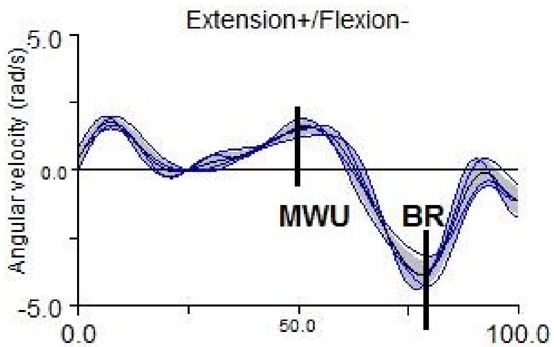


Figure 10. Subject 6 (HS) Hybrid Extension/Flexion Angular Velocity.

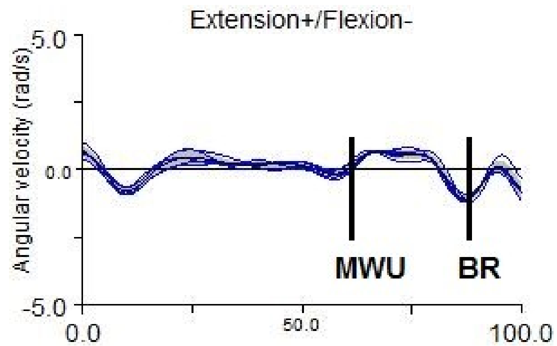


Figure 11. Subject 3 (WS) Hybrid Extension/Flexion Angular Velocity.

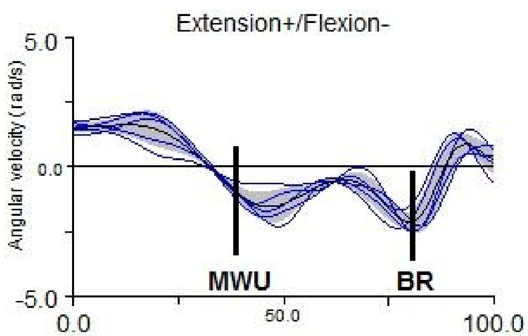


Figure 12. Subject 1 (HS) Hybrid Extension/Flexion Angular Velocity

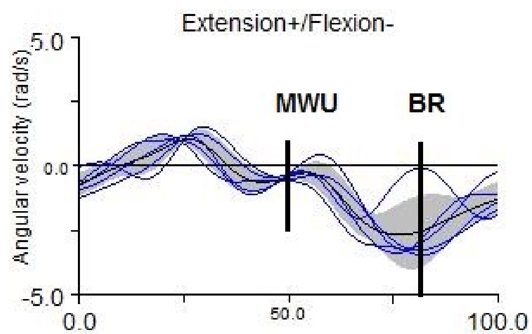


Figure 13. Subject 9 (WS) Hybrid Extension/Flexion Angular Velocity

Subjects 6 and 3 at MWU had not yet started flexing their lumbar spine, which could indicate that they initiated the motion of throwing by moving their arms before their trunks as opposed to subjects 1 and 9 who initiated flexion slightly before reaching MWU. While there is a difference in the velocity between subject 6 and 3, where the HS had greater velocity than the WS, the same difference is not reflected in the subjects that are both flexing at wind-up. As a great variety of angular velocities were seen across subjects, we may explain these individual differences by the technique used by each subject.

The moments of force contribute to better defining MWU. The majority of the subjects demonstrated an extensor moment at MWU except for one subject in each approach. Figures 14 and 15 below are of moments for extension and flexion.

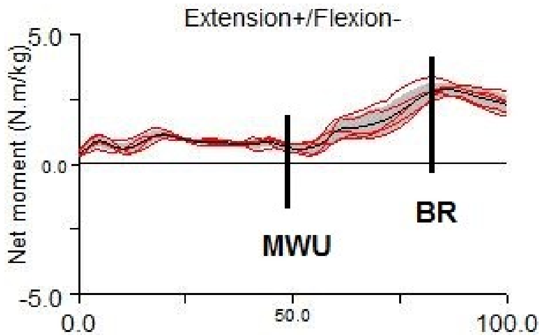


Figure 14. Subject 2 (HS) Hybrid Extension/flexion moment

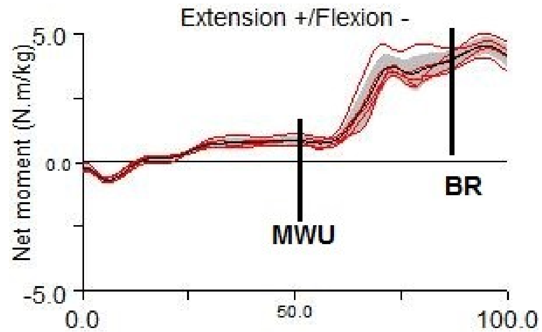


Figure 15. Subject 5 (WS) Hybrid Extension/flexion moment

Although both subjects utilized different approaches, their extension and flexion moments look similar in amplitude and direction. At MWU, while some of the subjects were moving in extension and some in flexion, almost all of them had an extension moment which means that the force applied at MWU either initiates extension or slows down the still occurring flexion. On the other hand, the power for extension and flexion at MWU was almost absent for 8 of the subjects while 2 had positive powers and 2 had negative powers. Figures 16 and 17 are the graphs of extension and flexion powers.

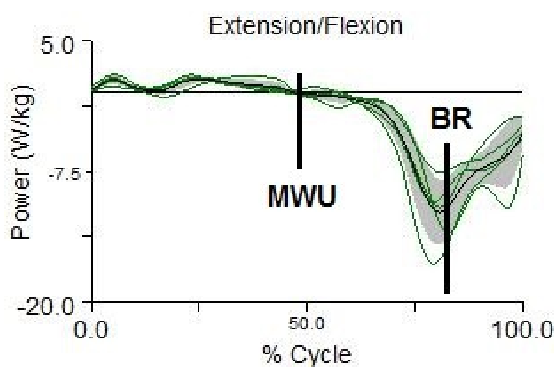


Figure 16. Subject 2 (HS) Hybrid Extension/flexion power

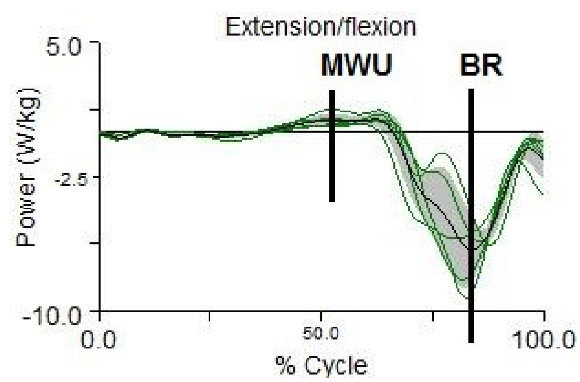


Figure 17. Subject 5 (WS) Hybrid Extension/flexion power

As the motion of winding up is not one of great speed or force, we can understand why the powers would not be significant until the acceleration phase. The player was prestretching the muscles to improve force production at the next phase. At MWU there may be some muscle activity to slow down the posterior motion of the stick but compared to the powers developed during the acceleration phase, they were not significant. At MWU for the hybrid throw, while some of the subjects were moving into flexion and some into extension, they almost inclusively demonstrated an extension moment indicating that the forces from the lumbar spine were trying to slow flexion or induce extension although the powers were relatively small.

During the acceleration phase of the hybrid throw, all of the subjects moved into flexion of their lumbar spines. In baseball and football, pitchers and quarterbacks performed similar motions during the acceleration phases of their throws (Fleisig et al. 1996). The moments of force were almost exclusively extensor indicating that the force applied controlled or opposed this flexion of the trunk. At BR, all of the subjects demonstrated an extensor moment and all except one produced negative power in both extension and flexion. These powers show that by BR, subjects had already started slowing down the motion of their lumbar spines by eccentrically controlling the induced flexion.

During follow-through of the hybrid throw, subjects moved from flexion towards extension or neutral and the extensor moment and negative power showed that the lumbar spine was slowing down the forceful flexion of the acceleration phase.

As for the rotational motion of the hybrid throw, at MWU, some subjects had already initiated the contralateral rotation of their trunk while the others were still rotating towards their dominant side. Nine of the subjects rotated their trunks towards their dominant arm at MWU while the other 3 had already initiated the opposite rotation indicating that a minority moved their lumbar spine early in the motion and prior to the acceleration phase. Figure 18 is the rotation angular velocity for subject 1 (HS and left handed=L) while figure 19 is for subject 3 (WS:L). Figure 20 is for subject 4 (HS and right handed =R) and figure 21 is for subject 9 (WS:R)

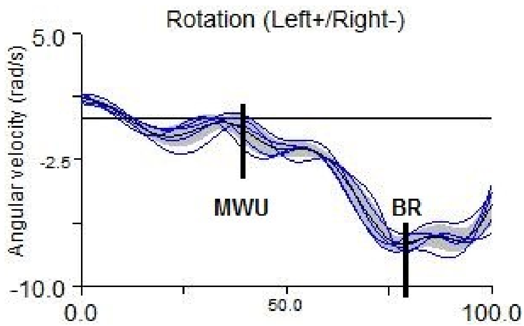


Figure 18. Subject 1 (HS:L) Hybrid Rotation angular velocity

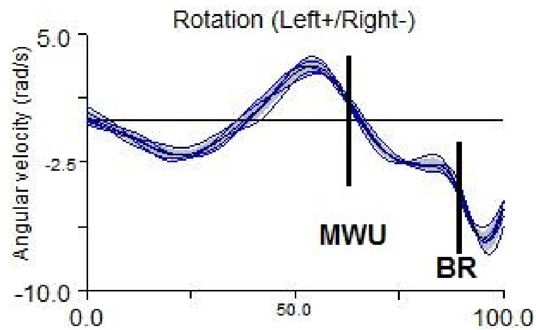


Figure 19. Subject 3 (WS:L) Hybrid Rotation angular velocity

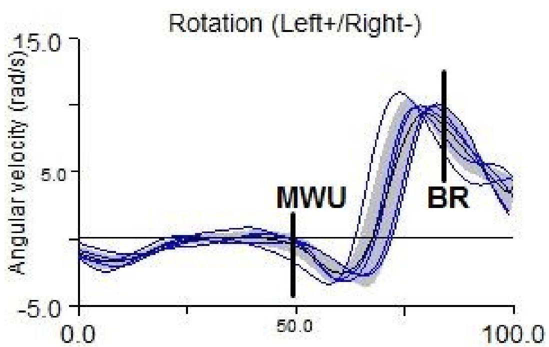


Figure 20. Subject 4 (HS:R) Hybrid Rotation angular velocity

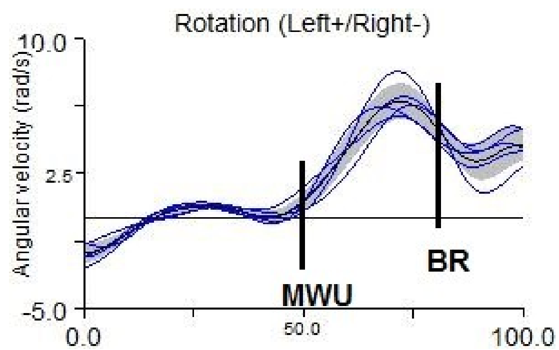


Figure 21. Subject 9 (WS:R) Hybrid Rotation angular velocity

The difference in direction of the curve between the top 2 graphs and the bottom 2 is due to the difference in dominance. The two left handed throwers rotated their shoulders left or counterclockwise during wind-up while the right handed throwers executed the reverse motion. Since spinal motion is being described, the rotation is of the L5 vertebrae on the sacrum. Therefore left rotation, which is positive in the graphs, is a counterclockwise rotation of L5 on S1 and it is assumed that the rest of the lumbar spine behaves in a similar manner. At MWU, all subjects were close to neutral in velocity which is to be expected since they have reached the necessary rotation and are on the verge of starting the opposite rotation during the acceleration phase.

All of the subjects except one demonstrated an opposite rotational moment at MWU which indicates that the forces were to rotate the spine towards the contralateral rotation of their dominant side. This force was likely to oppose the force initially applied to rotate the spine towards the dominant side during wind-up. This moment was not of great amplitude but as opposed to the flexion extension moments, shows that the rotational motion was of greater force during wind-up. The following graphs are of the net rotation moment for the hybrid throw.

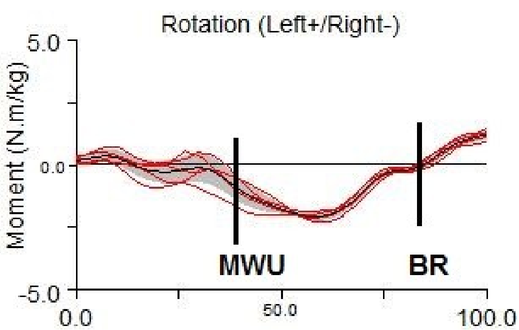


Figure 22. Subject 8 (HS:L) Hybrid Rotation moment

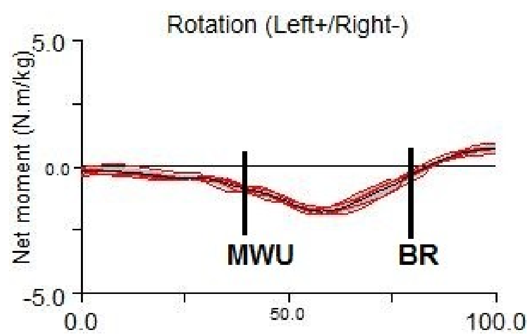


Figure 23. Subject 12 (WS:L) Hybrid Rotation moment

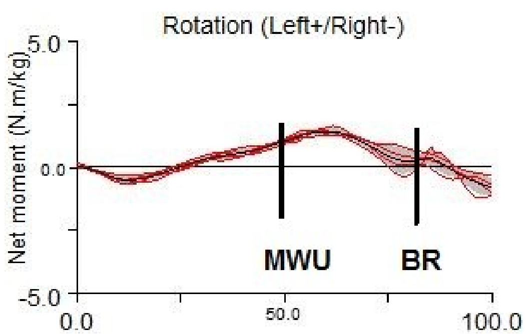


Figure 24. Subject 6 (HS:R) Hybrid Rotation moment

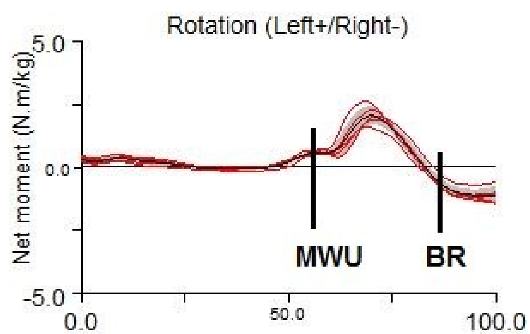


Figure 25. Subject 5 (WS:R) Hybrid Rotation moment

The rotational powers at MWU were either negative (6 subjects), absent (3 subjects) or positive (3 subjects). The following graphs are examples of the rotational powers.

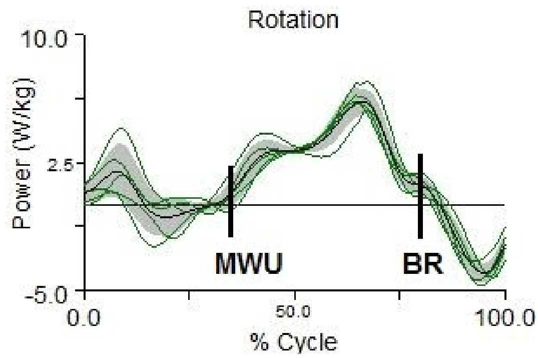


Figure 26. Subject 8 (HS) Hybrid Rotation power

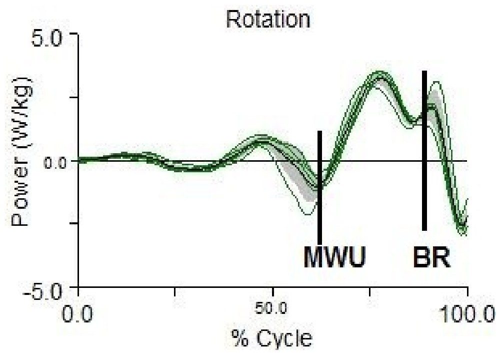


Figure 27. Subject 3 (WS) Hybrid Rotation power

This variability in powers at MWU indicates that while the majority of the subjects are eccentrically slowing down a rotational motion, a minority has already achieved the neutral and the others are still seeking to control or induce the necessary rotation to reach MWU. Once again, individual differences in technique likely explain these differences observed in power.

During the acceleration phase of the hybrid throw, all subjects rotated their lumbar spine in the contralateral rotation but the net rotational moment was not the same for all subjects. During this phase, 11 subjects had a rotational moment towards contralateral rotation while 1 subject demonstrated an ipsilateral rotational moment. At BR, 4 subjects were almost at neutral, 7 had a contralateral rotational moment and 1 had an ipsilateral rotational moment. During the acceleration phase, the vast majority of subjects were developing force to rotate their lumbar spine away from their dominant side but at ball release, some had already started to oppose that motion. The powers during the acceleration phase moved from negative to positive as the trunk is concentrically rotating and by BR, 10 subjects were still positively working their lumbar spine while one subject was almost at neutral and one had negative powers. As opposed to the extension and flexion powers, mostly negative by BR, this reflects that the trunk is still actively rotating at the end of this phase.

For the follow-through phase of the hybrid throw, all subjects continued to rotate towards their opposite side. The net moment was in ipsilateral rotation so forces applied to the lumbar spine were to control this opposite rotation which was also reflected by the powers moving from positive to negative to eccentrically slow down this rotational motion. The graphs above also show a difference in the magnitude of the powers which could be attributed to the different approach chosen as the hopping method resulting in greater initial forward velocity, would also require greater force to likely slow it down.

Description of overhand throw

Moving on to the overhand type of throwing, 8 of the subjects demonstrated an extension angular velocity at MWU while 2 were in neutral and 2 were already in flexion. As the overhand throw requires the stick to be almost perpendicular to the floor and therefore directly overhead, the amount of extension required of the lumbar spine will likely be somewhat greater than for the hybrid or the sidearm throw. Similar to the hybrid throw, the lumbar spine of most of our subjects is moving into extension at MWU so that the following phases will have the greatest range of motion available to efficiently throw the ball. The graphs below show the angular velocity in extension and flexion for the overhand throw.

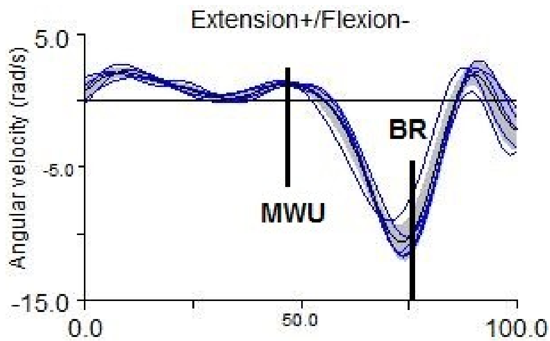


Figure 28. Subject 6 (HS) Overhand Extension/flexion angular velocity

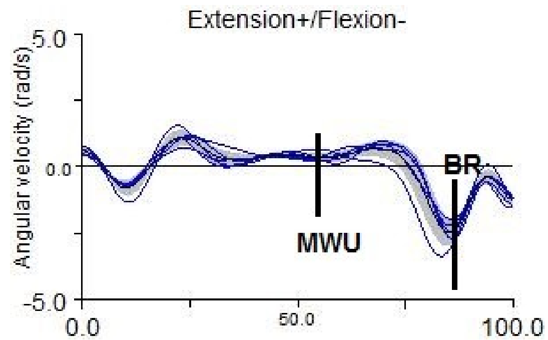


Figure 29. Subject 3 (WS) Overhand Extension/flexion angular velocity

The net moment of the sagittal plane at MWU was in extension for all subjects except 2, who were very close to neutral. As with the hybrid throw, the forces applied to the lumbar spine at the time of MWU are in the direction of extension likely to attain the maximal functional range of motion in that direction prior to the acceleration phase. At the time when subjects are about to initiate forward motion, the forces applied to their lumbar spine are still towards extension which is understandable when you factor in the motion of the upper extremities. The dominant arm is reaching into maximal flexion while their lower extremities have taken a staggered stance which means their lumbar spine has to extend for a bit longer before allowing the next phase to occur. For those subjects who demonstrated an almost zero moment, they may have already reached the right position and are ready to transition to the acceleration phase. This resembles the patterns seen for the hybrid throw as well. The graphs below are the net moment graphs in extension and flexion.

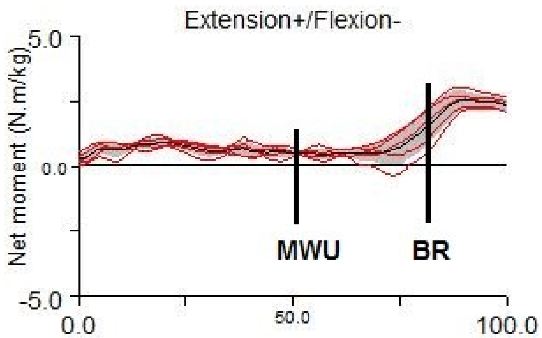


Figure 30. Subject 2 (HS) Overhand Extension/flexion moment

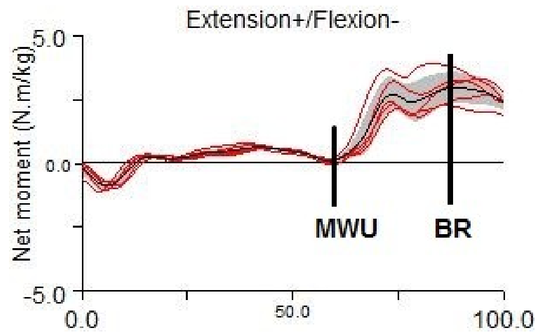


Figure 31. Subject 5 (WS) Overhand Extension/flexion moment

The powers for extension and flexion at MWU were diverse. 9 subjects were either at or very close to neutral while 2 demonstrated positive and one negative value at MWU. As the position is reached, there is less muscle action in either producing or controlling this motion as far as extensors and flexors of the trunk are concerned. Figure 32 shows the power graph for subject 1 (HS) and figure 33 is for subject 11 (WS).

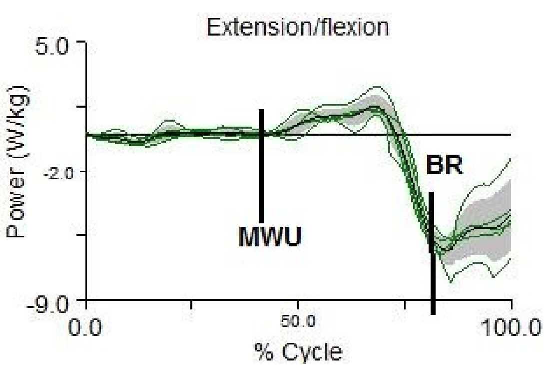


Figure 32. Subject 1 (HS) Overhand Extension/flexion power

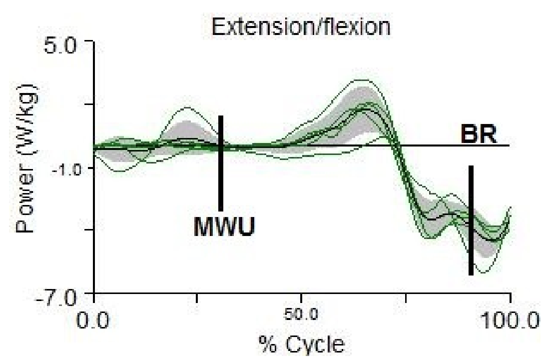


Figure 33. Subject 11 (WS) Overhand Extension/flexion power

At MWU, most subjects were still moving into extension, which was also reflected by a mostly extension moment although the powers demonstrated were negligible.

During the acceleration phase of the overhand throw, subjects went from an extension angular velocity to a flexion one. As the arms are reaching overhead and forward towards BR, the lumbar spine flexes to accommodate that motion. At BR, the 12 subjects had reached an extensor moment, with one subject being almost at neutral. The forces acting on the lumbar spine are therefore to counteract the flexion that is occurring. Powers at BR were also mostly negative except for one subject, which show that the musculature is already working eccentrically to stop or control the flexion movement at the time that the ball leaves the stick. This could also be a mechanism to transfer the energy from the movement achieved by the lumbar spine to the next segments in the kinetic chain. By stopping motion in the lumbar spine, the other segments can take the force produced in the lumbar spine and further contribute force to throw as fast as possible.

During the follow-through phase of the overhand method, subjects moved from the flexed position of BR towards neutral or into slight extension as reflected by the angular velocities. The moment of force was exclusively an extensor moment and most of the subjects had negative powers. Once the ball leaves the stick, subjects returned towards a neutral posture after having developed forces to oppose the flexion of their lumbar spine and eccentrically control the slowing down of motion. Those that demonstrated a positive power at the end of the cycle were likely actively resuming a standing posture. Since only 20 frames after BR were analyzed, this recovery just occurred faster for some subjects.

For the rotational movement of the lumbar spine during the overhand throw, at MWU, 9 subjects had an angular velocity towards their dominant side while the other 3 were already rotating towards the opposite side. Just as with the hybrid, the trunk reached its maximum rotation prior to the acceleration phase or, for a minority of subjects, had already started rotating prior to the upper extremities being in their maximal wind-up position. The following graphs show the rotational angular velocity. In this instance, a slight difference in angular velocity was present between the two right-handed subjects but not between the two left-handed throwers.

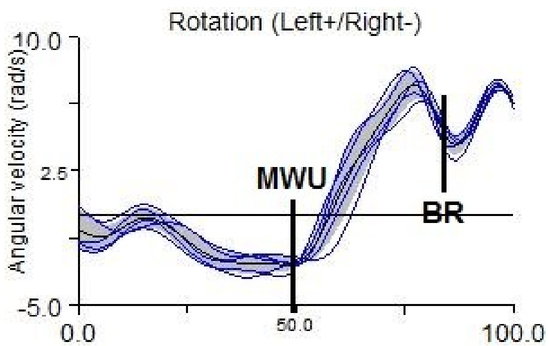


Figure 34. Subject 2 (HS:R) Overhand Rotation angular velocity

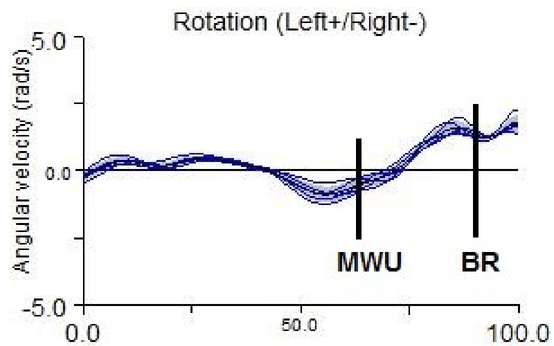


Figure 35. Subject 5 (WS:R) Overhand Rotation angular velocity

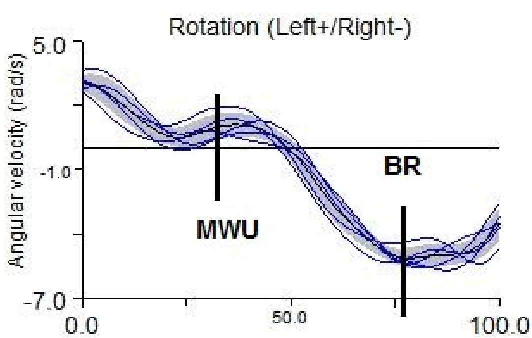


Figure 36. Subject 7 (HS:L) Overhand Rotation angular velocity

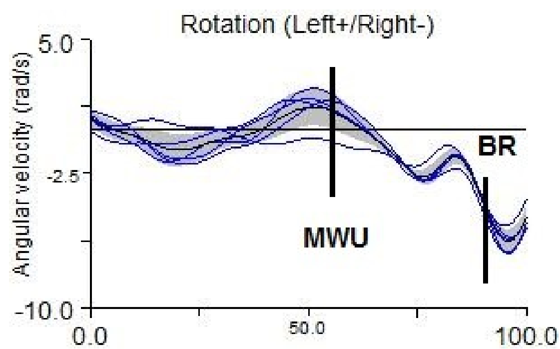


Figure 37. Subject 3 (WS:L) Overhand Rotation angular velocity

At MWU all of the subjects except one demonstrated an opposite rotational net moment which means that the forces applied were all aiming to rotate the spine in the opposite direction of the dominant side. This occurs to oppose the rotation occurring for wind –up. The moments at MWU for the hybrid throw were more varied than with the overhand. The overhand throw probably relies less on rotational motion to achieve MWU and therefore possibly leaves a smaller possibility of using different strategies to reach

MWU as far as rotation is concerned. The following graphs are examples of the rotation moments.

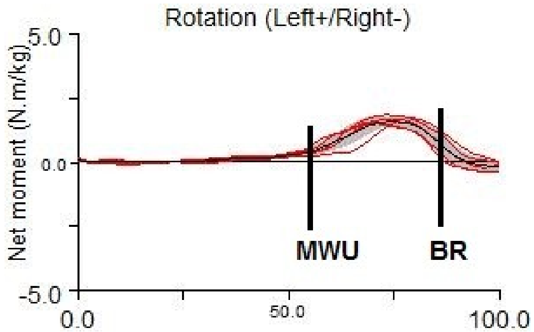


Figure 38. Subject 4 (HS:R) Overhand Rotation moment

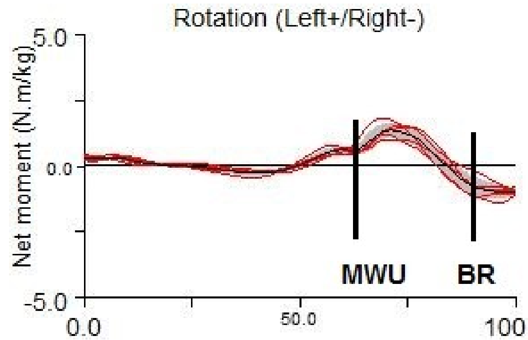


Figure 39. Subject 5 (WS:R) Overhand Rotation moment

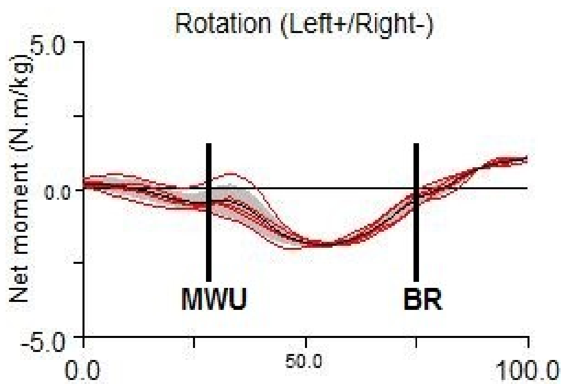


Figure 40. Subject 8 (HS:L) Overhand Rotation moment

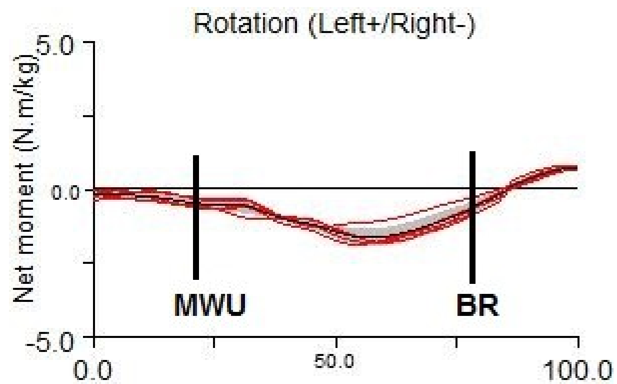


Figure 41. Subject 12 (WS:L) Overhand Rotation moment

There isn't a big difference between the hopping and the walking approach or between the right and left handed subjects, in the magnitude of the moments.

The powers present at MWU were at zero for 3 subjects, positive for 1 subject and negative for the remainder of our sample. This is congruent with the moments observed as the muscle action is eccentrically stopping a motion, hence the rotation towards the dominant side or, for a minority of subjects, has already quieted down awaiting the next phase. The following graphs are the powers for a hopping subject and a walking subject.

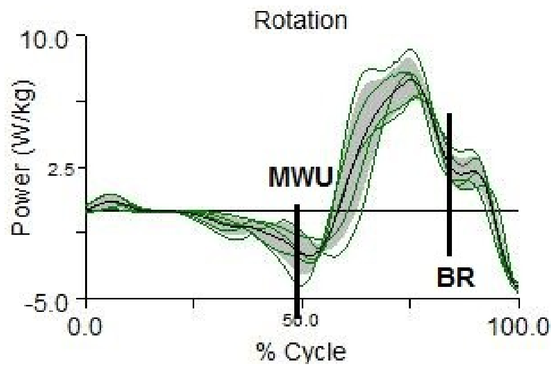


Figure 42. Subject 2 (HS) Overhand Rotation power

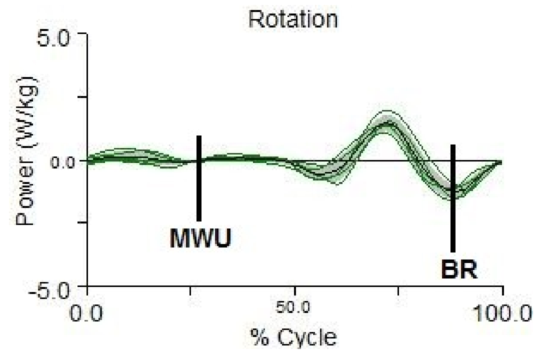


Figure 43. Subject 11 (WS) Overhand Rotation power

During the acceleration phase of the overhand, all subjects demonstrated an angular velocity in the direction of opposite rotation. At BR, the angular velocities for all subjects were still in contralateral rotation. The moments of force, on the other hand were slightly more varied. Except for one subject, all other subjects showed that, during the acceleration phase the moments were in the same direction as the angular velocity indicating that the forces were rotating the trunk. At BR, however, 2 subjects had null moments, 4 had ipsilateral rotation moments and the other 6 had contralateral rotation moments, resembling the BR moments of the hybrid throw. Half of the subjects were still deploying force to rotate their trunks in the direction of the throwing motion while the others were either not using their lumbar spine or had already started to oppose the contralateral rotation. The powers measured during the acceleration phase were all eventually in the positive direction indicating that the lumbar spine was concentrically active in producing movement but at BR, 8 subjects still demonstrated positive powers while 3 were already slowing down the motion and had negative powers. The last subject had zero power at BR. This differs from the hybrid in that all subjects except one had positive powers at BR for the hybrid method. As the overhand throw relies less on rotation and occurs more in the sagittal plane, this may be why we see a variety of techniques at BR.

During follow-through for the overhand throw, all rotational angular velocities continued to be in the direction opposite to the dominant side. 9 subjects demonstrated ipsilateral rotation moments, countering the motion seen with the angular velocities while the other 3 showed forces that contributed to the rotation. The power observed during follow-through moved towards negative for all subjects indicating that the lumbar spine was slowing down the rotation after the effort of the acceleration phase.

Description of sidearm throw

For the last type of throw, the sidearm, the graphs show a bigger variability in timing of the phases, magnitudes and directions of the curves. At MWU, the extension/flexion angular velocity for 10 of the subjects showed that their lumbar spine was moving in flexion while the other 2 subjects were very close to neutral. The corresponding moments were in extension for 10 subjects while the other two had flexor moments at MWU. 8 subjects had negative powers and the remaining 4 had positive powers at MWU albeit most of them were close to neutral. For the sidearm throw at MWU, the lumbar spine is moving in flexion while the forces are aiming to oppose this flexion by eccentrically slowing down this induced flexion.

During the acceleration phase, the shape of the angular velocity curves varies between subjects. The following 4 graphs are from subject 1, 2 and 7 (HS) as well as subject 5(WS).

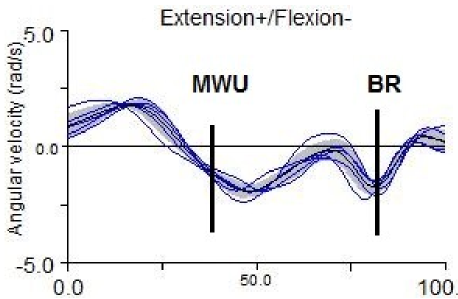


Figure 44. Subject 1(HS) Sidearm Extension/flexion angular velocity

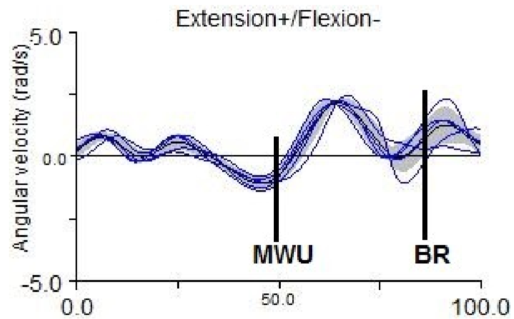


Figure 45. Subject 2(HS) Sidearm Extension/flexion angular velocity

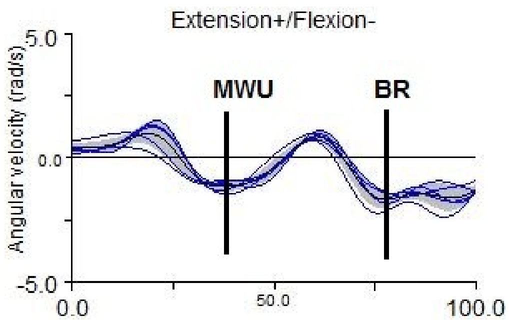


Figure 46. Subject 7(HS) Sidearm Extension/flexion angular velocity

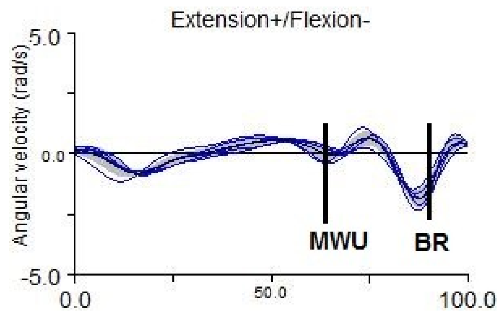


Figure 47. Subject 5(WS) Sidearm Extension/flexion angular velocity

Subject 1 flexes his spine throughout the acceleration phase but subject 2 extends his spine during the same period. Subject 5 and 7 are more similar although subject 7 starts from MWU in flexion where subject 5 is almost at neutral. This variety in motion is perhaps explained by the fact that the sidearm is mostly a rotational motion and that since flexion and extension are secondary, each subject will show individual differences. The sidearm also tends to be used less often by lacrosse players as it is harder to master and obtain a great deal of precision with it (Hanna 1980). The WS demonstrated more consistency with their angular velocities between subjects perhaps because as they are initially moving slower than the others, they are more similar in the technique used. The resulting angular velocity at BR however was in flexion for all subjects except one.

The moments at BR were in extension for all subjects, which means the forces applied to the lumbar spine were to control or reverse the flexion movement occurring at BR. The following graphs are examples of the moments in the sagittal plane.

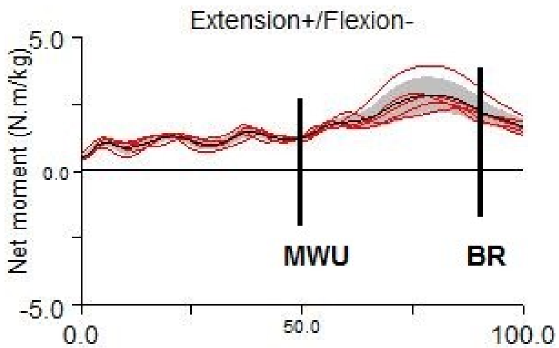


Figure 48. Subject 2 (HS) Sidearm extension/flexion moment

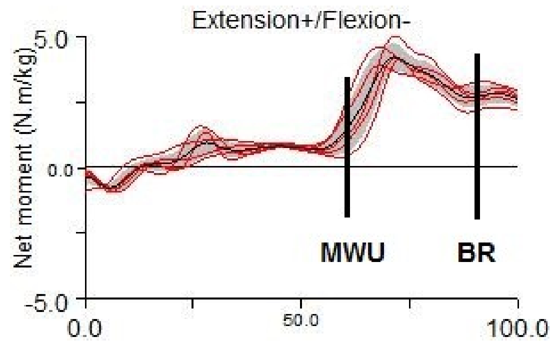


Figure 49. Subject 5 (WS) Sidearm extension/flexion moment

The powers reflect less production of energy during the acceleration phase in extension and flexion than previously seen with the hybrid and overhand. Considering that during the sidearm, the thrower mostly rotates his spine in the transverse plane, the powers generated for flexion and extension are as a result quite small. The measured powers also support the deceleration occurring already at BR. All the subjects except one had negative powers at BR meaning they were already slowing down the motion in the sagittal plane by the time the ball left the stick. The deceleration possibly started early for the sidearm to transfer energy to the next segments in the kinetic chain or it may also be that our estimation of when the ball left the stick was erroneous for this different type of throw. The following graphs are examples of power in extension and flexion.

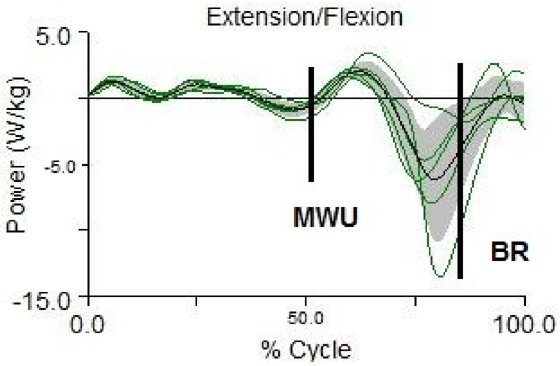


Figure 50. Subject 2 (HS) Sidearm extension/flexion power

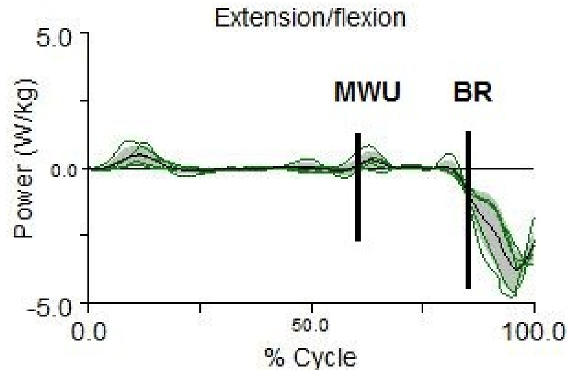


Figure 51. Subject 3 (WS) Sidearm extension/flexion power

For the follow-through phase of the sidearm, 10 subjects moved their lumbar spine into extension. The moments were exclusively in extension indicating that those that were not yet moving into extension were trying to reverse the flexion velocity. The powers were more varied where 6 subjects started at BR in negative power but moved into positive, 5 had negative powers throughout their follow-through and one had positive power. While most subjects were slowing down the motion during this phase a few may have actively returned to neutral and therefore initiated extension to recover from the slight flexion induced during the throw.

As mentioned above, the main movement occurring with the sidearm throw is rotational. The angular velocities in rotation at MWU were different for half of the subjects. 6 subjects were still rotating towards their dominant side while 6 were already rotating towards the opposite side. Half of the subjects therefore initiated lumbar rotation before moving their upper extremities and their sticks. The following graphs are example of the angular velocities in rotation.

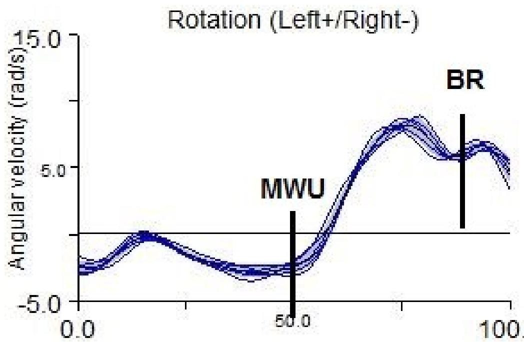


Figure 52. Subject 2 (HS:R) Sidearm Rotation Angular Velocity.

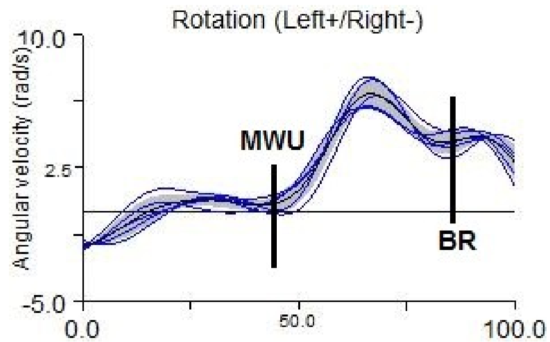


Figure 53. Subject 9 (WS:R) Sidearm Rotation Angular Velocity.

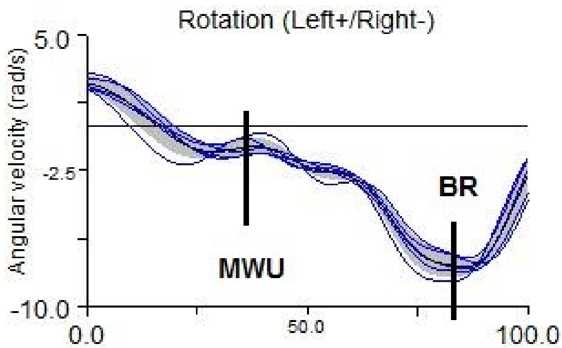


Figure 54. Subject 1 (HS:L) Sidearm Rotation Angular Velocity.

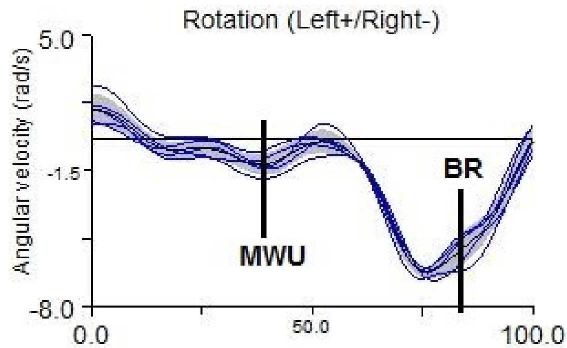


Figure 55. Subject 11 (WS:L) Sidearm Rotation Angular Velocity.

The moments at MWU were all in contralateral rotation except for one subject which means that the forces were either trying to start producing the rotation that is necessary for the acceleration phase or countering the still occurring ipsilateral rotation at MWU. The following graphs are of right and left handed throwers and their rotational moments for the sidearm throw.

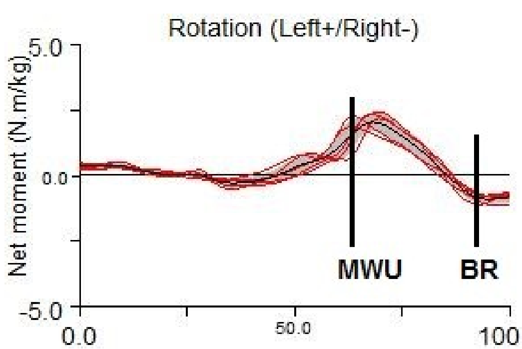


Figure 56. Subject 4 (HS:R) Sidearm Rotation Moment.

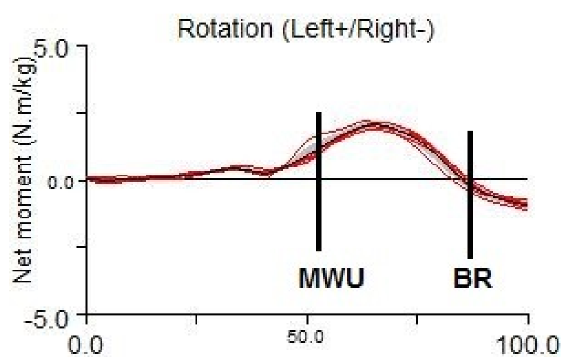


Figure 57. Subject 5 (WS:R) Sidearm Rotation Moment

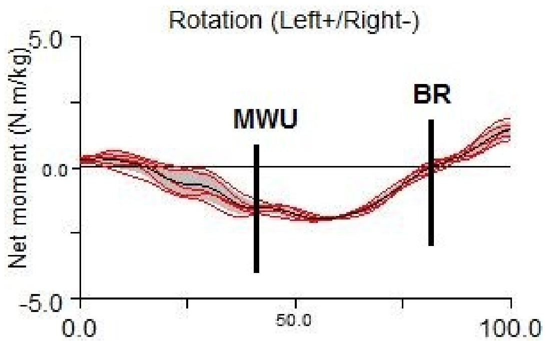


Figure 58. Subject 8 (HS:L) Sidearm Rotation Moment.

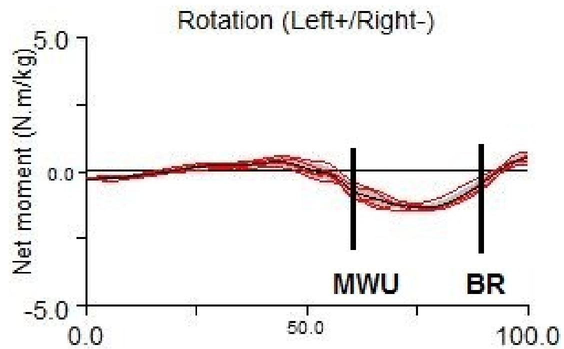


Figure 59. Subject 3 (WS:L) Sidearm Rotation Moment.

Only 4 subjects demonstrated positive powers at MWU while all the others showed negative powers meaning that the work being done was mostly to slow down a motion and not yet to create movement. Here are examples of the rotation power by subject 2 (HS) and subject 12 (WS).

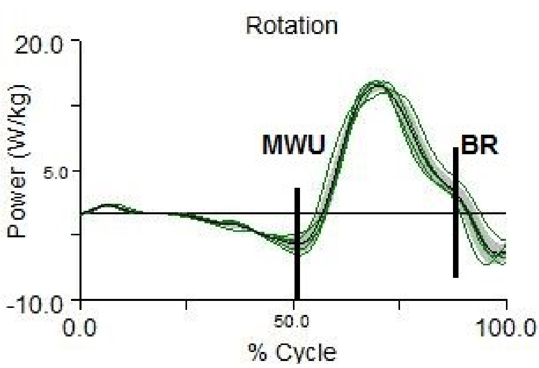


Figure 60. Subject 2 (HS) Sidearm rotation power.

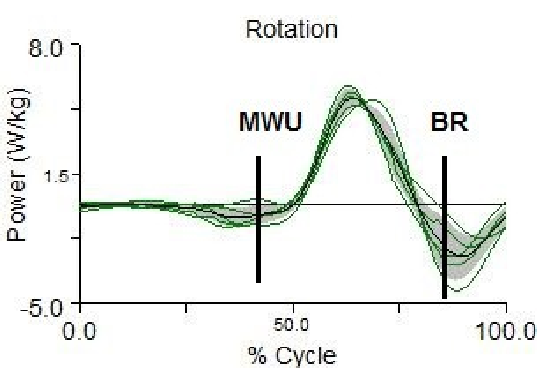


Figure 61. Subject 12 (WS) Sidearm rotation power

During the follow-through phase, the angular velocities were all in opposite rotation still indicating that subjects were rotating away from their dominant side. The moments, however, were all in ipsilateral rotation indicating that the forces applied to the spine were to counter this opposite rotation. By the end of follow-through, all subjects had negative powers, which also permit the slowing down of rotation during this phase.

EMG results

To minimize the scope of this research, the EMGs of only one subject will be discussed. Subject 2 had some of the fastest average stick speed but unfortunately during his data collection, the EMG wires became undone, which went unnoticed until data collection had been completed. Subject 8 was chosen to have his EMGs analyzed as he demonstrated some of the fastest average stick speeds. Please refer to Appendices 37 through to 45 for the EMG results for Subject 8. The units for the ordinates are mV but the scale varies between graphs. The abscissae are percentage of the activity duration.

As no comparison between subjects was done, the normalization with the maximal voluntary contraction (MVC) was omitted. The trial maximums of each muscle exceeded the measured MVCs, which also rendered the normalization difficult. In a study by Pink et al. (1993) with right-handed golfers, subjects demonstrated 75% of the measured MVC in the right erector spinae (ES) while their left had 50% of the MVC during the forward swing motion and acceleration phase, respectively. The abdominal obliques were not separated into internal and external obliques but reached 62% of the MVC for the right and 54% of the MVC for the left during the forward swing and 64% of the MVC for the right and 42% of the MVC for the left during the acceleration phase. The peaks reached by the trunk muscles in this research for subject 8 occurred at some point during the acceleration phase and exceeded the measured MVCs. This may mean the MVC was not measured accurately or that the subject was not able to deliver a maximal contraction or that the lacrosse motion simply exceeds the maximal isometric contractions elicited with the manual muscle testing.

For all 3 types of throws, the follow through phase consisted of the trunk's forward flexion being slowed down, with some eccentric activity in the ES. The EO and IO are active to slow down the rotation and subject 8 showed some activity in his RA likely as a postural muscle, once he resumes an upright position. As the muscle activity for the follow through phase was similar for the 3 types of throws, it will not be discussed further in this section.

During the wind-up phase of the hybrid throw, subject 8 demonstrated greater activity in the right external oblique (EO) as did subjects in a throwing study by Hirashima et al. (2002) who were right-handed but showed greater activation of their left EO during the stride phase of throwing. A very slight difference was seen between this subject's right and left rectus abdominus (RA) as well as his right and left erector spinae (ES). Both of these muscles were also not very active during the wind-up phase. His left internal oblique (IO) was at first more active but towards the end of the phase, his right IO was more active (Figure 62). This muscular activity was consistent with the wind-up motion of turning towards the dominant side, in this case his left side. As expected his right EO and his left IO contributed to the left rotation of his lumbar spine in the first half of the wind-up.

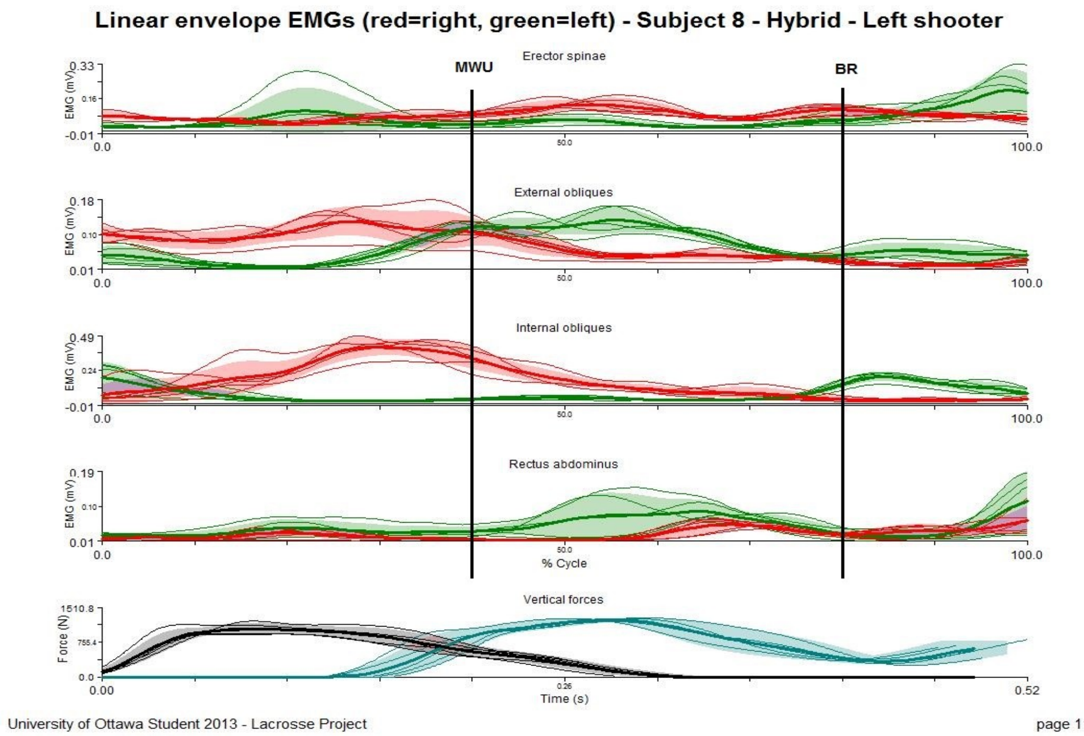


Figure 62. Subject 8, EMGs for Hybrid

Figure 63 shows the angular velocities, moments and powers for his hybrid throw for Subject 8. His angular velocity reflects a left-sided rotation during wind-up. The moment of force being in right rotation at the end of the wind-up phase as well as the power, which was positive, the right IO being more active at the end of this phase indicates that he started actively rotating towards the right. The average activity of the ES, which shows a large standard deviation between trials, and the RA are fairly minimal during the wind-up phase.

At MWU, the ES and RA were still fairly quiet. The right and left EO were activated but more or less equal to one another. The right IO, however, was more active than the left indicating this subject had indeed started rotating to the right.

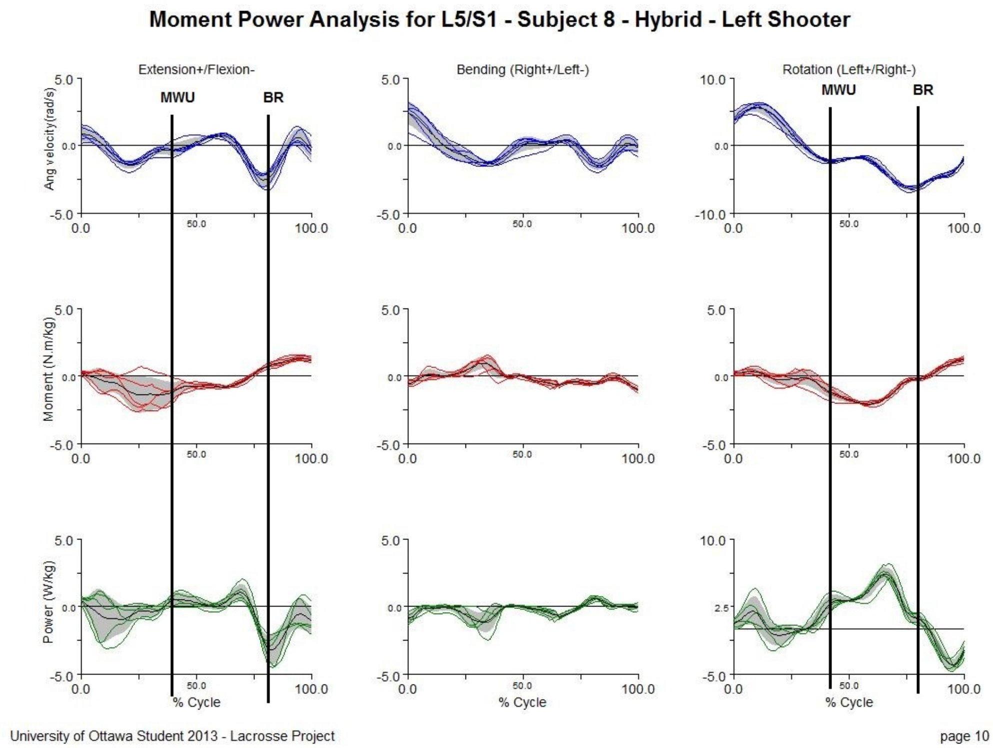


Figure 63. Subject 8, Angular velocities, Moments and Powers for Hybrid

During the acceleration phase, the right ES was slightly more active than the left but overall still fairly quiet. The left EO was more active than the right, which is consistent with the right rotation that is occurring at the lumbar spine as reflected by the angular velocity, the moment and the positive power. The right IO started the phase by being fairly active but quieted down as the left EO became more active. The RA was more active on the left than the right but as the acceleration phase progressed and the lumbar spine flexed, permitting it to participate in this active trunk flexion as reflected by the flexor moment and positive power. By BR, even though the trunk was still moving in flexion, the extensor moment and negative power indicated that the motion was decelerating. At BR we can see that the RA was barely active but that the ES was only slightly activated, likely to start opposing the flexion and start slowing down the motion.

The bilateral EO and right IO also had minimal activity at BR but the left IO was contracting. As the angular velocity at that point was in right rotation, the moment was almost absent and the power was moving towards the negative side, the left IO maybe active in slowing down the forceful right rotation that had just occurred.

For the overhand throw of subject 8, (Figure 64) the left ES was slightly more than the right during the wind-up phase. The trunk was extending at the very beginning of this phase but then moving into flexion (Figure 65). The moment of force indicates extensor but also has a wide standard deviation during that phase. The average power for extension/flexion between trials is mostly positive but also has a wide standard deviation during wind-up. The left ES may be more active to counter the flexion that occurred at the end of wind-up as the power dips just below neutral into negative values. The left RA was slightly more active than the right in the second half of wind-up but the RA action was possibly to prestretch the muscles before the acceleration phase or to control the extension of the lumbar spine. The right EO was more active than the left and, although initially the left IO was more active than the right, the output of the right quickly increased. The angular velocity for the wind-up phase was in left rotation while the moment was in left then right rotation. The rotation power average was at first positive but then changed to negative. As the right EO is a left rotator this supports the initial left rotation velocity, moment and positive power as the trunk was moving into left rotation in the initial part of wind-up. The right IO, however, was a right rotator, which is more active than the left for the later 2/3 of this phase. As the moment switches to right rotation and the power to negative, the right IO may be more active to slow down the left rotation of the trunk or to contract to prepare for the right rotation that will occur during the acceleration phase.

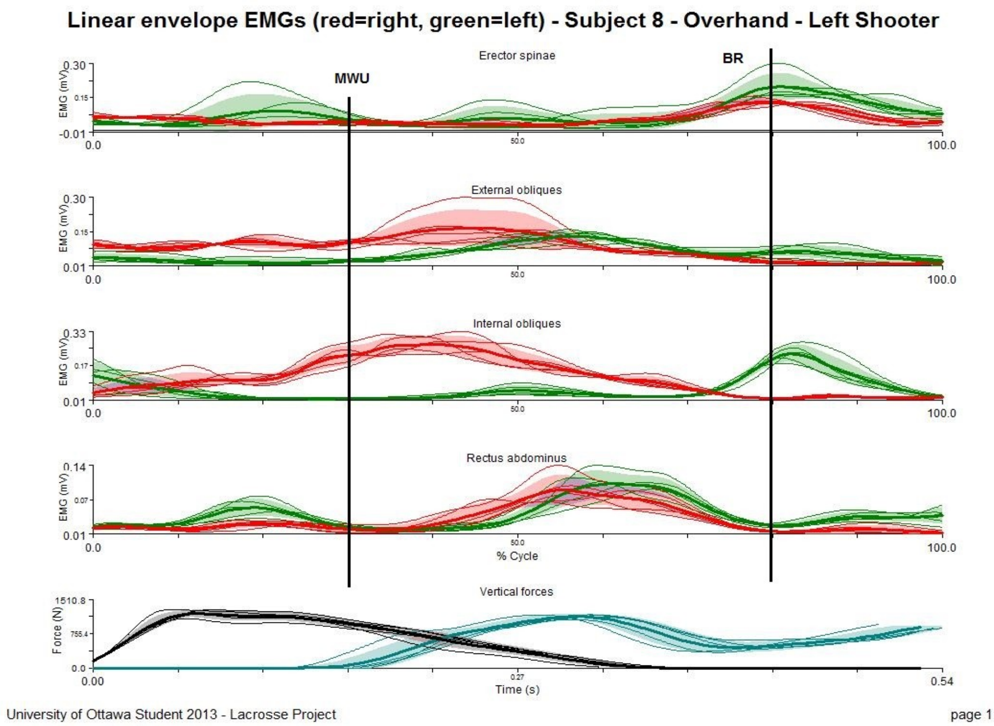


Figure 64. Subject 8, EMGs for Overhand

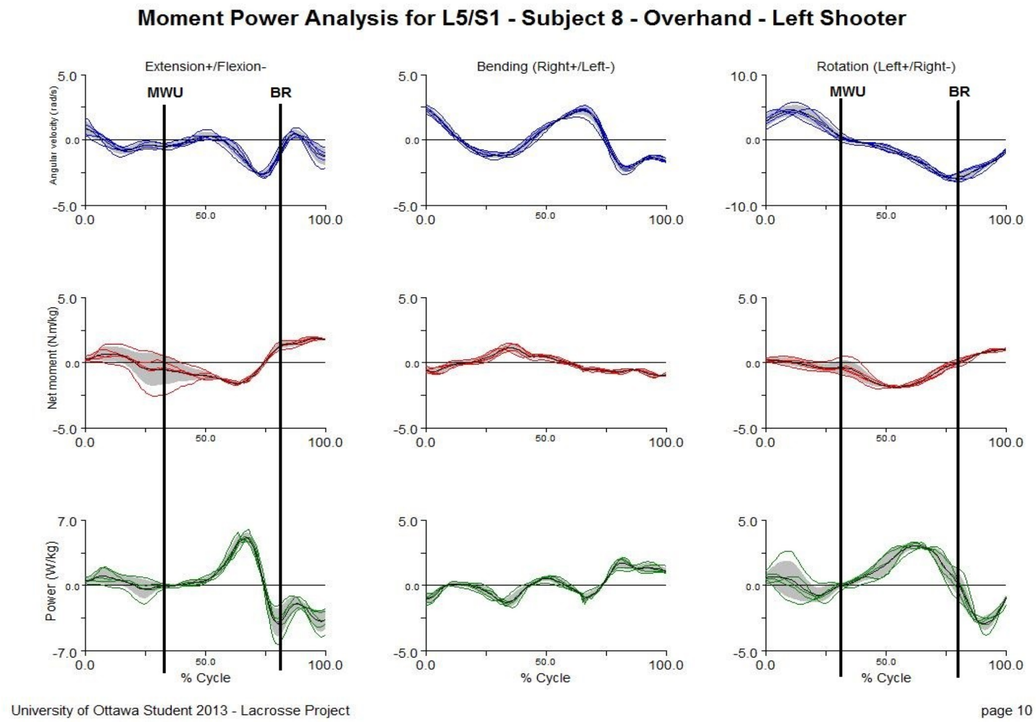


Figure 65. Subject 8, Angular velocities, Moments and Powers for Overhand

At MWU the ES and RA were relatively quiet but, the angular velocity, moment and power were also very close to zero. The right EO and IO were still more active than their left counterpart. The right IO is likely contracting to initiate the rotation and flexion that the acceleration phase entails but may also be contracting to increase intra-abdominal pressure and further stabilize the lumbar spine. The right EO action is left rotation and side flexion. While there is no indication of left rotation in the velocity or moment, the spine is moving into left side flexion at MWU. The moment in side bending however is to the right and the power is negative so the forces acting on the lumbar spine are to counter this left side flexion and slow it down which does not explain the activity of the right EO. It may be active to increase abdominal pressure and, like the IO, contribute to the stability of the lumbar spine.

During the acceleration phase, the ES is relatively quiet until the last 10% of the phase. The RA is activated especially over the second half. As the angular velocity is mostly in flexion and the power are positive, the RA is likely active to contribute to the forceful flexion of the trunk as the stick moves forward and down. A study by Hirashima et al. (2002) also found that the RA had most of its activity just before ball release. The ES activity, likely to slow down the forward flexion, is not reflected by the moment, which returns towards zero and the power which is still positive in the last 10% of this phase. This may also be due to an error in estimating BR. The right EO remains more active for the first half of the acceleration phase, continuing the actions described at MWU, but then both sides become relatively quiet and remain quiet to BR. The right IO remains more active for the majority of this phase, to contribute to the right trunk rotation seen in both the velocity and the moment and in the positive values of the power. Then in the last 5% of the phase the left IO becomes more active perhaps to slow down the motion as the moment returns to zero and the power dips towards neutral as well around BR.

For the sidearm throw, the ES activity during wind-up of subject 8 was slightly greater in the right than the left at first but the left gradually increased to be almost equal by MWU (Figure 66).

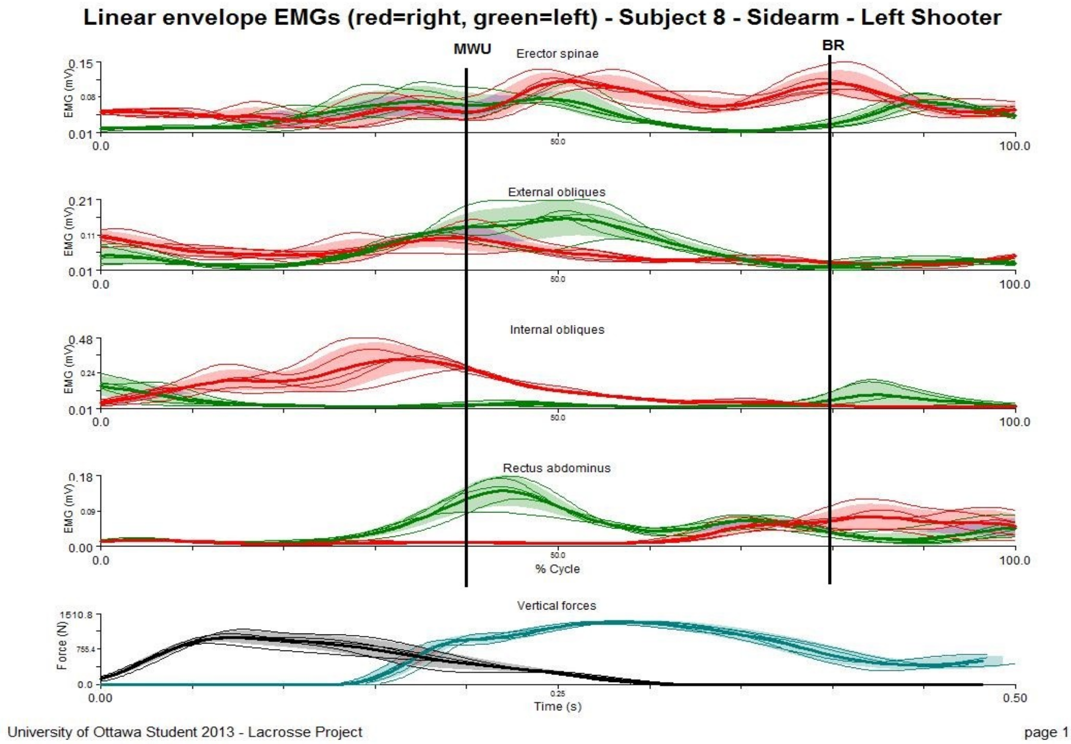


Figure 66. Subject 8, EMGs for Sidearm

The angular velocity during that phase is mostly in flexion (Figure 67) although the moment is relatively neutral until it moves to a flexor moment around MWU which would explain the RA activity closer to MWU. The extension/flexion power also is relatively neutral, slightly positive at first then negative then back to positive. While the maximum mV reached by the ES of subject 8 during wind-up for the hybrid and overhand throw was around 0.15, the average mV during this phase of the sidearm throw is only about half of that value. Since the sidearm wind-up relies a lot more on rotation from the lumbar spine, this may explain why the ES is less active for this type of throw. Its activity may be to oppose or control the flexion of the spine in this phase.

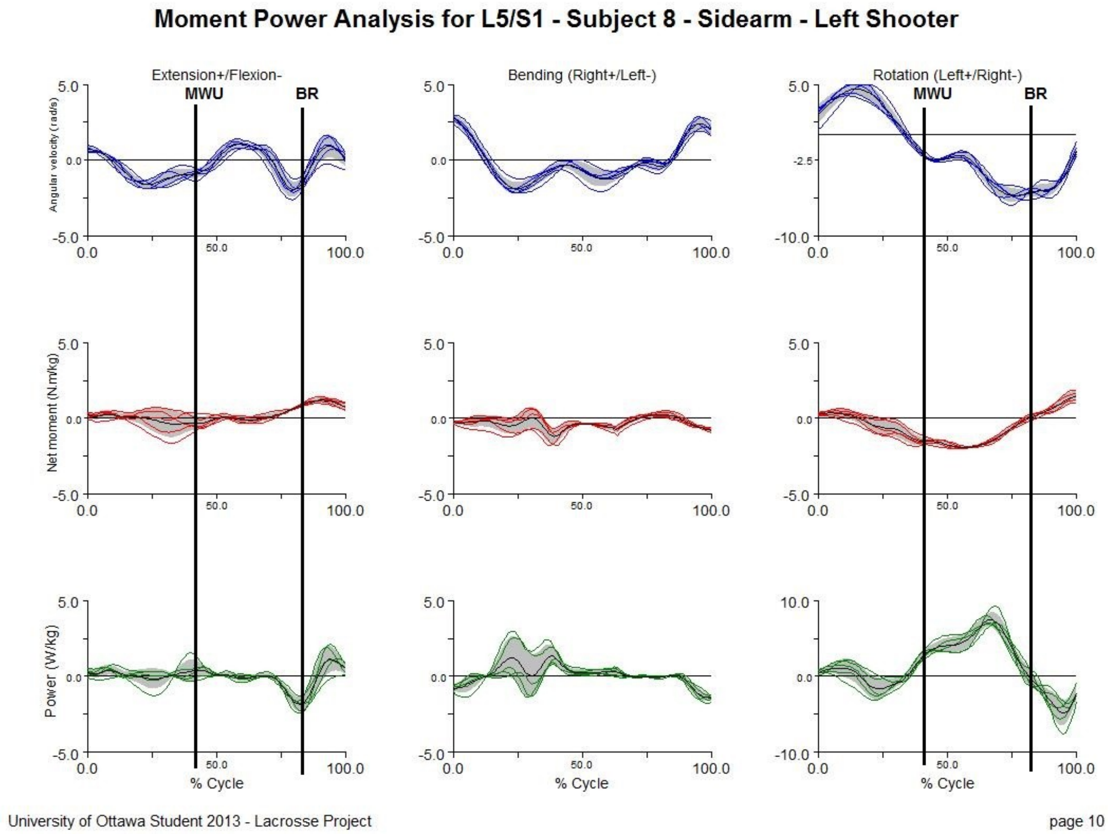


Figure 67. Subject 8, Angular Velocities, Moments and Powers for Sidearm

The EO activity is slightly greater on the right than left so it may be contributing to the left rotation initially in the wind-up phase. At MWU, according to the side bending graphs, the angular velocity is in left side flexion as is the moment and the power is positive. This may explain why the left EO is active as well. The right IO is at its most active while the left is relatively quiet during the wind-up phase. Its action may be to slow down the left rotation of wind-up as is reflected by the right rotation moment and negative power but not by the right rotation angular velocity.

By MWU, the ES is slightly active but the left RA is almost at its most active. The angular velocity at this point is in slight flexion as is the moment and the power is slightly positive indicating that the RA is likely contributing to moving the lumbar spine into slight flexion, initiating the acceleration phase. Why the left RA is active while the right RA stays around zero is difficult to explain as the right and left RA usually activate together (Carr et al, 1994). Other studies, such as the one by Chow et al. (2003) also measured a difference in the activation of the left and right RA in right handed tennis players where the left was more active than the right so it is possible to have different levels of activation between the two sides. In the other graphs, while minor differences were measured between the right and left RA, this one is of greater amplitude. It is not likely due to poor electrode contact as there is activity later in the cycle in the right RA but perhaps due to electrode placement error. The right IO, at MWU, is more active than the left and, as the angular velocity and the moment at that point is in right rotation, as well as the power being positive, it is acting on starting the right rotation of the upcoming acceleration phase.

During the acceleration phase, the ES is active mostly on the right. As the angular velocity starts in flexion but then moves to extension and then back to flexion by BR, the moment is in flexion at first but then neutral and finally in extension by BR. The power is slightly positive at first but then neutral and negative around BR. The left RA contributes to the initial flexion at the beginning of this phase and then the ES is active in eccentrically controlling the flexion occurring around BR. The principal motion of the acceleration phase is the rotation towards the right as supported by the moment. The left EO and the right IO are active in creating this right rotation as evidenced by the positive power although they return to neutral in the second half of the phase as BR occurs which is once again reflected by the power and the moment returning to neutral.

When comparing the 3 types of throws, subject 8 had less activation of his ES for the sidearm throw than for the hybrid or overhand. As mentioned above, the sidearm requiring less flexion likely requires less ES activity to stop the motion. The average activity in the EO was slightly higher for the sidearm than for the hybrid or overhand. As the sidearm relies on rotation more to produce and slow the motion, increased activity in the EO is logical. The activity in the IO is slightly less for the overhand throw which, as it relies less on rotation, would have lower activation than for the hybrid and sidearm. The RA maximal values were similar for the 3 types of throw which could reflect the use of the RA by subject 8 as a lumbar stabilizer.

The EMG was analyzed for a single subject, therefore observations cannot be generalized to the hybrid, overhand and sidearm throw at lacrosse. The EMG findings are used here to support the angular velocities, moments and powers that were measured. A study by Chow et al. (2003) has shown a difference in muscle activation between 3 types of serves in tennis. Further analysis of the data using the measured maximum as a normalizing measure or further study into the muscle activity during the throwing lacrosse motion with a more efficient normalization procedure, may reveal similar differences between the 3 types of throws or more consistency between subjects. Further research may allow discovering which muscle activation pattern is the most efficient and least likely to lead to injury.

Results:

For our first research question, the objective was to establish the consistency between trials for each given variable. In the following tables (3 to 6), the mean angular velocities for flexion, extension, ipsilateral rotation and contralateral rotation are outlined for each subject and each type of throw. The standard deviations for each throw as well as the coefficients of variability are also noted. The graphs found after each table clarify the distribution of the coefficients of variability for each subject with each type of throw. Please note that the axis values for the coefficients of variability (y-axis) are different for each graph.

Table 3. Mean maximal angular velocities for L5-S1 flexion

Subject	Throw	Mean max. angular velocity, flexion (deg/s)	Standard deviation (deg/s)	Coefficient of variability (%)
1	Hybrid	127.4	16.65	13.07
	Overhand	130.1	32.5	25.0
	Sidearm	121.7	11.92	9.79
2	Hybrid	90.6	16.75	18.49
	Overhand	117.2	22.8	19.43
	Sidearm	97.3	13.02	13.39
3	Hybrid	72.5	10.73	14.81
	Overhand	197.3	98.6	50.0
	Sidearm	73.8	15.09	20.4
4	Hybrid	167.3	36.3	21.7
	Overhand	220	28.9	13.17
	Sidearm	178.7	34.7	19.40
5	Hybrid	108.2	40.2	37.1
	Overhand	104.8	23.2	22.1
	Sidearm	108.7	20.3	18.69
6	Hybrid	226.	32.3	14.28
	Overhand	620.	66.3	10.67
	Sidearm	312.	83.1	26.6
7	Hybrid	126.6	23.9	18.92
	Overhand	181.5	14.16	7.81
	Sidearm	107.4	17.72	16.50
8	Hybrid	147.7	32.6	22.1
	Overhand	154.8	10.18	6.58
	Sidearm	147.9	54.0	36.5
9	Hybrid	177.6	33.8	19.05
	Overhand	153.3	25.4	16.55
	Sidearm	110.9	16.31	14.71
10	Hybrid	278.	20.6	7.40
	Overhand	277.	13.14	4.74
	Sidearm	171.0	43.1	25.2
11	Hybrid	68.9	18.80	27.3
	Overhand	73.9	21.2	28.7
	Sidearm	85.7	33.3	38.9
12	Hybrid	104.7	10.16	9.71
	Overhand	102.7	17.59	17.12
	Sidearm	87.7	8.63	9.84

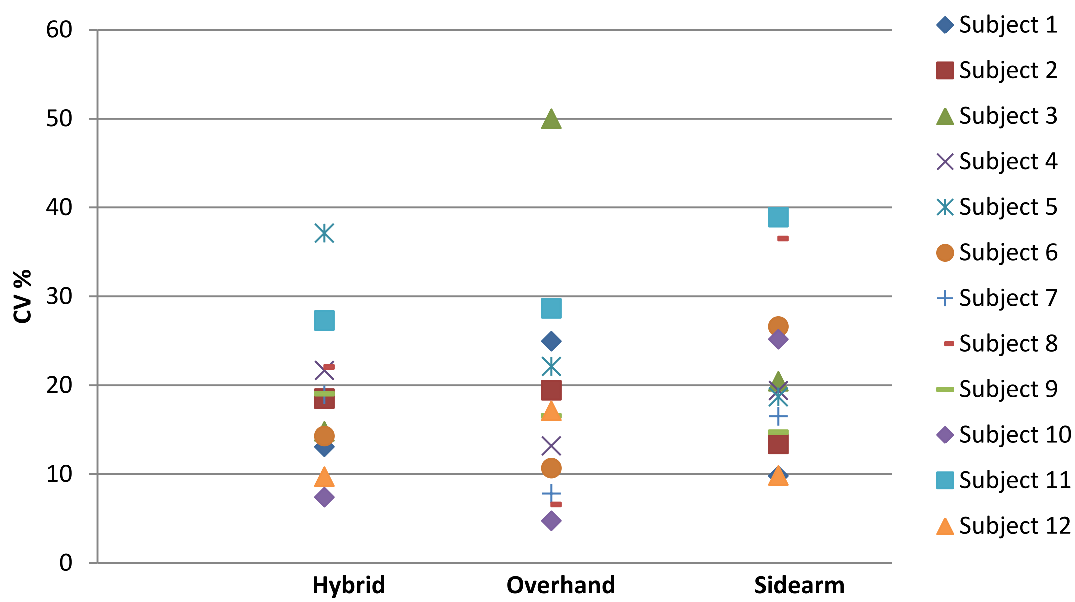


Figure 68. Coefficients of variability for maximum angular velocity of L5-S1 flexion

Table 4. Mean maximal angular velocities for L5-S1 extension

Subject	Throw	Mean max. angular velocity, extension (deg/s)	Standard deviation (deg/s)	Coefficient of variability (%)
1	Hybrid	115.0	7.83	6.81
	Overhand	100.2	17.98	17.95
	Sidearm	110.8	6.75	6.09
2	Hybrid	108.2	19.45	17.97
	Overhand	105.3	14.57	13.84
	Sidearm	130.6	7.84	6.00
3	Hybrid	47.1	6.76	14.34
	Overhand	92.5	56.6	61.2
	Sidearm	68.3	18.22	26.7
4	Hybrid	80.2	37.8	47.1
	Overhand	76.0	7.62	10.03
	Sidearm	119.7	25.3	21.2
5	Hybrid	114.4	71.0	62.1
	Overhand	76.6	29.9	39.0
	Sidearm	44.9	10.54	23.5
6	Hybrid	108.1	13.75	12.72
	Overhand	149.3	19.56	13.11
	Sidearm	121.4	10.13	8.34
7	Hybrid	65.7	14.96	22.8
	Overhand	57.1	5.88	10.31
	Sidearm	77.4	18.03	23.3
8	Hybrid	98.0	49.4	50.4
	Overhand	107.3	22.4	20.9
	Sidearm	115.3	44.6	38.7
9	Hybrid	173.0	24.8	14.34
	Overhand	166.4	33.8	20.3
	Sidearm	126.6	61.5	48.5
10	Hybrid	117.6	53.3	45.4
	Overhand	101.0	267.0	26.7
	Sidearm	152.8	11.87	7.77
11	Hybrid	56.5	15.19	26.9
	Overhand	99.4	113.8	114.4
	Sidearm	103.5	57.9	55.9
12	Hybrid	72.2	31.1	43.1
	Overhand	58.1	12.83	22.1
	Sidearm	73.3	18.01	24.6

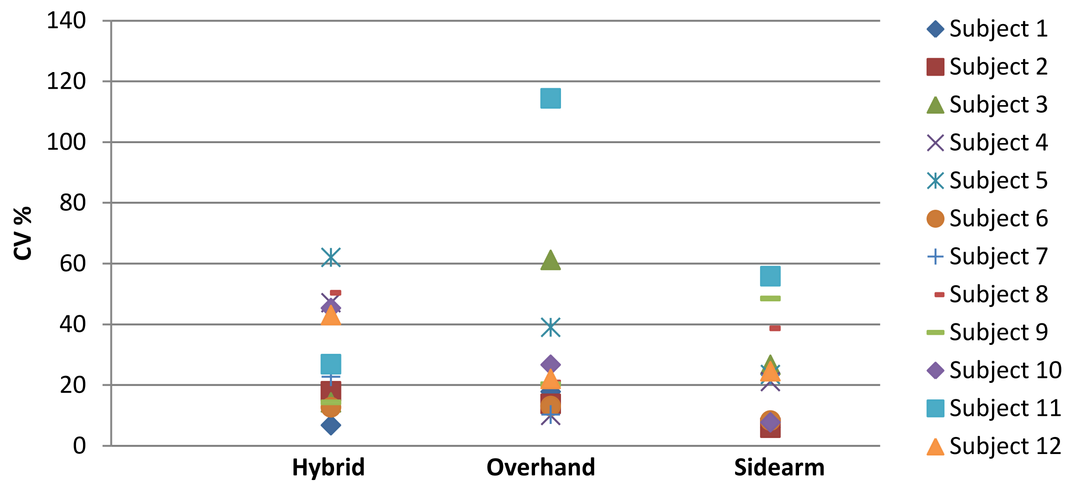


Figure 69. Coefficients of variability maximum angular velocity of L5-S1 extension

Table 5. Mean maximal angular velocities for L5-S1 ipsilateral rotation

Subject (throwing side)	Throw	Mean max. angular velocity, ipsilateral rotation (deg/s)	Standard deviation (deg/s)	Coefficient of variability (%)
1 Left handed	Hybrid	108.7	41.8	38.5
	Overhand	181.0	14.61	8.07
	Sidearm	173.0	22.7	13.13
2 Right handed	Hybrid	178.4	12.56	7.04
	Overhand	182.9	33.4	18.26
	Sidearm	191.7	19.57	10.21
3 Left handed	Hybrid	180.5	23.4	12.94
	Overhand	185.3	159.5	86.1
	Sidearm	158.0	17.31	10.96
4 Right handed	Hybrid	172.8	16.86	9.76
	Overhand	167.7	31.9	18.99
	Sidearm	180.5	43.0	23.8
5 Right handed	Hybrid	59.5	19.32	32.5
	Overhand	60.4	12.32	20.4
	Sidearm	49.0	9.07	18.50
6 Right handed	Hybrid	104.2	30.5	29.3
	Overhand	121.1	19.00	15.70
	Sidearm	106.6	26.1	24.5
7 Left handed	Hybrid	167.0	25.5	15.29
	Overhand	183.6	17.24	9.39
	Sidearm	207.	16.73	8.09

8 Left handed	Hybrid	328.	39.6	12.08
	Overhand	275.	34.1	12.40
	Sidearm	268.	37.3	13.94
9 Right handed	Hybrid	164.3	15.73	9.58
	Overhand	147.9	16.98	11.48
	Sidearm	138.1	20.1	14.53
10 Right handed	Hybrid	165.3	8.36	5.06
	Overhand	183.2	42.7	23.3
	Sidearm	245.	22.8	9.31
11 Left handed	Hybrid	141.8	32.4	22.8
	Overhand	109.7	22.6	20.6
	Sidearm	134.3	14.76	10.99
12 Left handed	Hybrid	105.5	15.57	14.75
	Overhand	109.4	13.16	12.03
	Sidearm	106.1	13.30	12.53

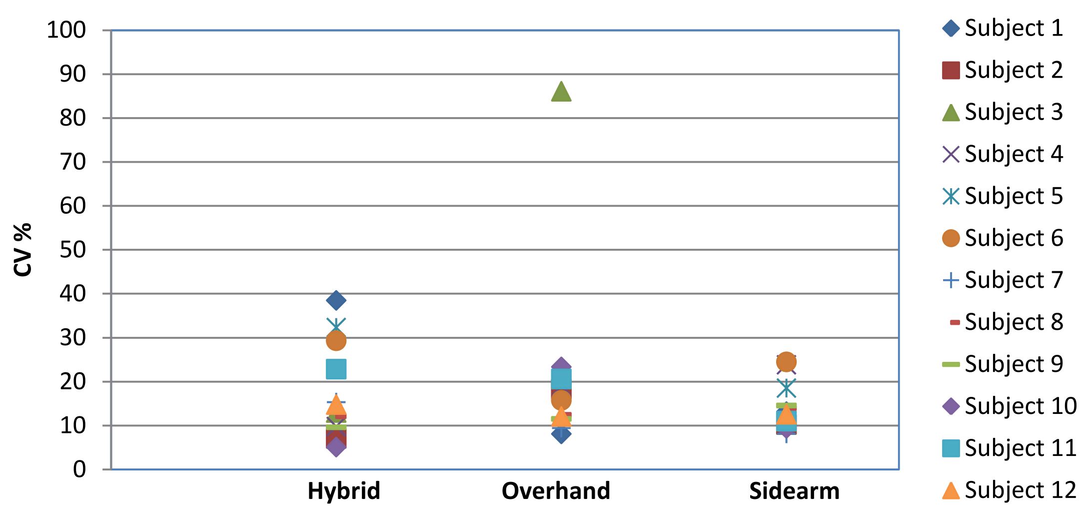


Figure 70. Coefficients of variability for maximum angular velocity of L5-S1 ipsilateral rotation

Table 6. Mean maximal angular velocities for contralateral rotation

Subject (throwing side)	Throw	Mean max. angular velocity, contralateral rotation (deg/s)	Standard deviation (deg/s)	Coefficient of variability (%)
1 Left handed	Hybrid	457.	28.9	6.33
	Overhand	406.	32.8	8.08
	Sidearm	454.	28.7	6.32
2 Right handed	Hybrid	457.	9.98	2.18
	Overhand	459.	30.5	6.64
	Sidearm	484.	22.5	4.66

3 Left handed	Hybrid	407.	33.3	8.19
	Overhand	362.	37.2	10.28
	Sidearm	352.	32.3	9.18
4 Right handed	Hybrid	583.	25.7	4.42
	Overhand	622.	44.0	7.07
	Sidearm	523.	43.7	8.34
5 Right handed	Hybrid	105.5	7.50	7.11
	Overhand	104.8	18.29	17.46
	Sidearm	112.8	10.50	9.30
6 Right handed	Hybrid	409.	29.0	7.07
	Overhand	378.	8.64	2.28
	Sidearm	380.	52.6	13.84
7 Left handed	Hybrid	338.	54.6	16.14
	Overhand	314.	9.01	2.86
	Sidearm	410.	13.76	3.35
8 Left handed	Hybrid	366.	23.0	6.29
	Overhand	345.	23.1	6.68
	Sidearm	367.	20.4	5.57
9 Right handed	Hybrid	379.	54.6	14.40
	Overhand	345.	37.6	10.91
	Sidearm	384.	46.4	12.09
10 Right handed	Hybrid	613.	31.3	5.11
	Overhand	565.	39.5	6.98
	Sidearm	651.	36.2	5.56
11 Left handed	Hybrid	285.	31.0	10.89
	Overhand	212.	18.67	8.79
	Sidearm	369.	15.74	4.26
12 Left handed	Hybrid	408.	50.1	12.26
	Overhand	394.5	41.6	10.55
	Sidearm	391.	68.8	17.61

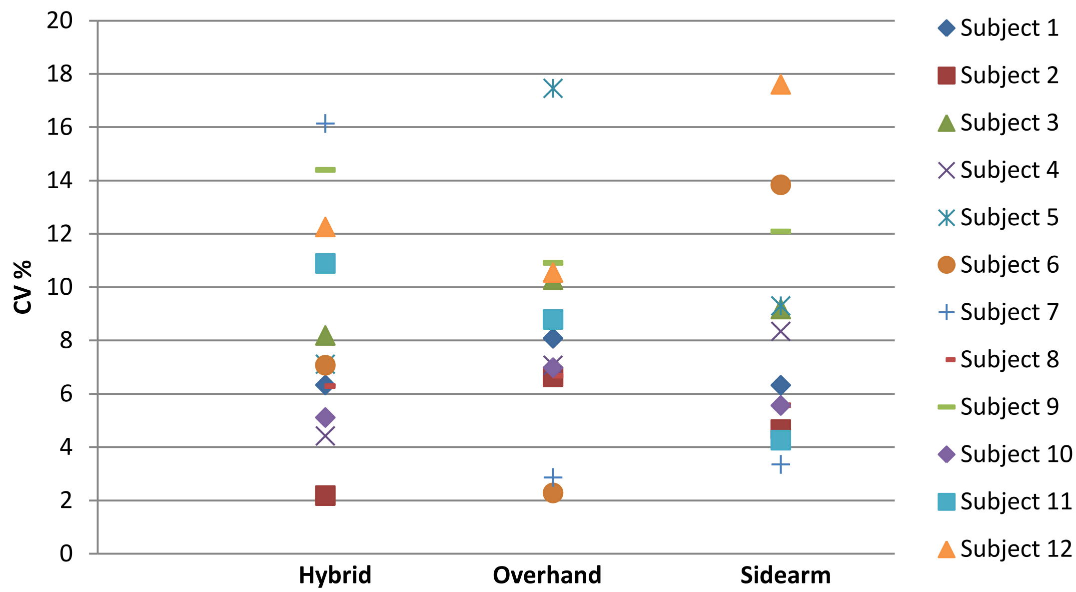


Figure 71. Coefficients of variability for maximum angular velocity of L5-S1 contralateral rotation

Peak positive and negative powers for flexion/extension for each trial and averaged across the 5 chosen trials for each type of throw by the subjects are contained in tables 7 and 8. Included are the mean powers for each type of throw (in W/kg) as well as the standard deviations and coefficients of variability. The graphs following each table (Figures 72 to 75) illustrate each subject's coefficient of variability for each type of throw. Note that the axis values for the coefficients of variability (y-axis) are different for each graph.

Table 7. Mean peak positive powers for L5-S1 flexion/extension

Subject	Throw	Mean maximum positive power, L5-S1 ext/flex (W/kg)	Standard deviation (W/kg)	Coefficient of variability (%)
1	Hybrid	1.3	0.82	62.62
	Overhand	1.59	0.54	34.19
	Sidearm	1.60	0.49	30.69
2	Hybrid	1.51	0.24	16.19
	Overhand	1.23	0.18	14.65
	Sidearm	2.35	0.70	29.64

3	Hybrid	1.17	0.13	11.49
	Overhand	2.75	0.62	22.45
	Sidearm	0.6	0.37	62.09
4	Hybrid	1.67	1.53	91.86
	Overhand	2.82	4.48	158.76
	Sidearm	2.93	2.57	87.6
5	Hybrid	6.58	5.54	84.22
	Overhand	1.53	1.88	122.42
	Sidearm	3.22	1.20	37.32
6	Hybrid	1.86	1.12	60.37
	Overhand	3.22	1.26	39.28
	Sidearm	3.26	0.76	23.39
7	Hybrid	2.05	0.82	39.87
	Overhand	1.46	0.72	49.09
	Sidearm	3.08	1.48	47.96
8	Hybrid	1.96	0.26	13.07
	Overhand	5.34	0.50	9.40
	Sidearm	2.09	0.93	44.74
9	Hybrid	3.75	1.80	47.87
	Overhand	11.18	5.87	52.56
	Sidearm	7.37	4.49	60.88
10	Hybrid	3.59	2.26	63.1
	Overhand	4.24	1.34	31.72
	Sidearm	9.95	2.35	23.65
11	Hybrid	1.69	0.79	46.45
	Overhand	1.89	0.95	50.44
	Sidearm	0.76	0.35	46.57
12	Hybrid	1.52	0.80	52.45
	Overhand	1.56	0.94	60.26
	Sidearm	1.31	0.59	44.97

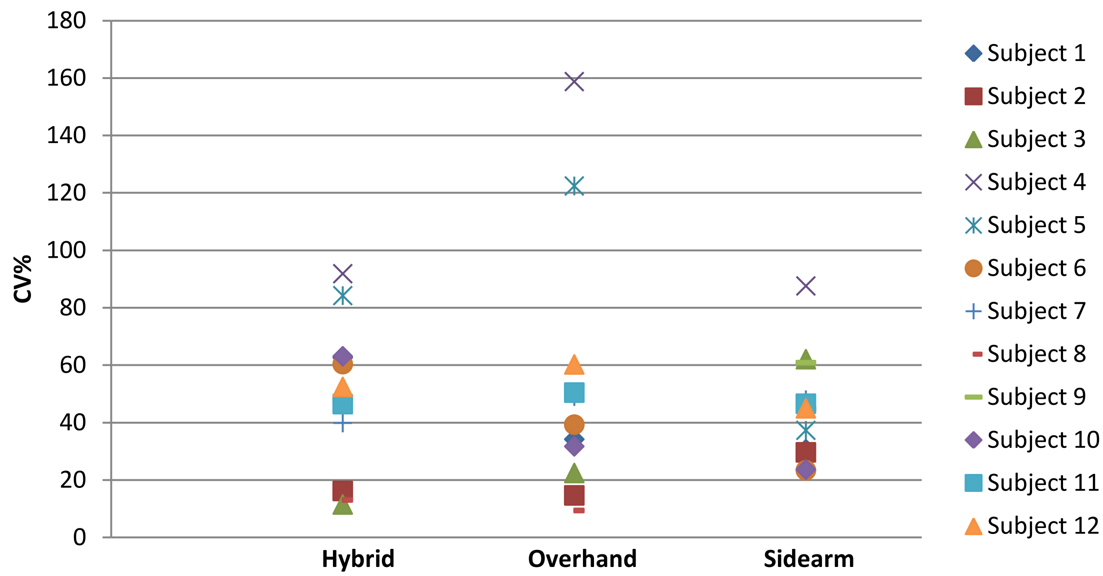


Figure 72. Coefficients of variability peak for positive power of L5-S1 flexion/extension

Table 8. Mean peak negative powers for L5-S1 flexion/extension

Subject	Throw	Mean maximum negative power, L5-S1 ext/flex (W/kg)	Standard deviation (W/kg)	Coefficient of variability (%)
1	Hybrid	4.30	1.10	25.58
	Overhand	6.50	0.92	14.17
	Sidearm	0.85	0.36	42.8
2	Hybrid	11.74	3.31	28.20
	Overhand	8.09	1.75	21.61
	Sidearm	6.84	4.38	63.93
3	Hybrid	7.25	0.86	11.86
	Overhand	7.86	1.30	16.51
	Sidearm	4.03	0.60	14.78
4	Hybrid	7.13	5.71	80.10
	Overhand	13.29	6.11	45.97
	Sidearm	4.43	3.43	77.44
5	Hybrid	7.45	1.81	24.31
	Overhand	5.89	1.46	24.77
	Sidearm	5.01	0.60	11.90
6	Hybrid	9.24	4.39	47.55
	Overhand	27.37	8.86	32.36
	Sidearm	18.98	7.40	39.01
7	Hybrid	4.49	0.46	10.25
	Overhand	4.77	0.72	15.01
	Sidearm	3.43	0.86	25.04

8	Hybrid	3.27	1.11	34.03
	Overhand	4.76	1.11	23.40
	Sidearm	2.39	1.14	47.79
9	Hybrid	9.43	5.50	58.38
	Overhand	6.96	3.12	44.78
	Sidearm	3.92	2.38	60.72
10	Hybrid	6.14	1.20	19.57
	Overhand	6.09	2.54	41.74
	Sidearm	8.61	3.89	45.21
11	Hybrid	3.96	0.69	17.54
	Overhand	4.70	0.76	16.08
	Sidearm	2.01	0.37	18.43
12	Hybrid	1.75	0.57	32.91
	Overhand	3.36	0.78	23.32
	Sidearm	1.11	0.13	12.16

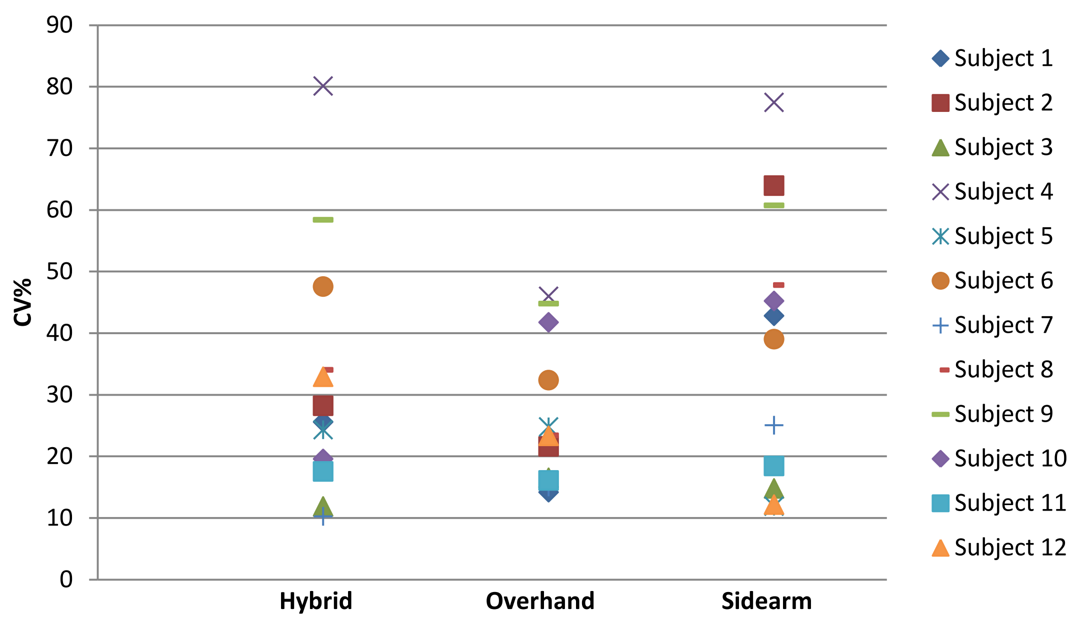


Figure 73. Coefficients of variability peak negative powers for L5-S1 flexion/extension

These peak powers occurred at different phases of the motion. The following table outlines in directions, either flexion or extension, of the moments of force when peak power was reached. The flexion moments are highlighted as the majority of subjects had peak negative and positive powers in extension for all 3 types of throws.

Table 9. Moments at peak positive and negative powers for L5-S1 flexion/extension

Subject	Hybrid		Overhand		Sidearm	
	Peak +ve flex/ext	Peak –ve flex/ext	Peak +ve flex/ext	Peak –ve flex/ext	Peak +ve flex/ext	Peak –ve flex/ext
1	Extension	Extension	Flexion	Extension	Extension	Extension
2	Extension	Extension	Extension	Extension	Extension	Extension
3	Flexion	Extension	Flexion	Extension	Flexion	Extension
4	Extension	Extension	Extension	Extension	Extension	Extension
5	Extension	Extension	Extension	Extension	Extension	Extension
6	Flexion	Extension	Extension	Extension	Extension	Extension
7	Extension	Extension	Extension	Extension	Extension	Extension
8	Extension	Extension	Flexion	Extension	Extension	Extension
9	Extension	Extension	Extension	Extension	Extension	Extension
10	Flexion	Extension	Flexion	Extension	Extension	Extension
11	Flexion	Extension	Flexion	Extension	Flexion	Extension
12	Flexion	Extension	Flexion	Extension	Flexion	Extension

Peak positive and negative powers in rotation for each trial and averaged over the 5 chosen trials for each type of throw by the subjects are reported in tables 10 and 11. Included are the mean power for each type of throw (in W/kg), the standard deviations, and the coefficients of variability. The following graphs (Figures 74 and 75) illustrate each subject's coefficient of variability for each type of throw.

Table 10. Mean peak positive powers for L5-S1 rotation

Subject (throwing side)	Throw	Mean maximum positive power, L5-S1 rotation (W/kg)	Standard deviation (W/kg)	Coefficient of variability (%)
1 Left handed	Hybrid	7.32	1.20	16.43
	Overhand	4.01	0.92	22.97
	Sidearm	6.71	0.85	12.64
2 Right handed	Hybrid	8.78	1.57	17.86
	Overhand	7.61	1.11	14.60
	Sidearm	14.95	0.56	3.76
3 Left handed	Hybrid	3.32	0.24	7.36
	Overhand	2.23	0.62	27.65
	Sidearm	3.60	0.15	4.18
4 Right handed	Hybrid	15.60	0.99	6.36
	Overhand	14.56	2.35	16.15
	Sidearm	15.32	1.39	9.07

5 Right handed	Hybrid	1.07	0.14	13.34
	Overhand	0.65	0.25	38.72
	Sidearm	1.59	0.30	18.93
6 Right handed	Hybrid	7.14	0.94	13.21
	Overhand	2.98	0.72	24.21
	Sidearm	9.16	0.52	5.70
7 Left handed	Hybrid	5.04	0.65	12.82
	Overhand	3.20	0.42	13.26
	Sidearm	7.50	0.74	9.86
8 Left handed	Hybrid	6.22	0.64	10.24
	Overhand	3.10	0.17	5.46
	Sidearm	7.65	1.00	13.08
9 Right handed	Hybrid	4.47	3.53	78.93
	Overhand	2.84	1.03	36.35
	Sidearm	2.85	1.27	44.71
10 Right handed	Hybrid	7.86	1.06	13.55
	Overhand	5.54	1.21	21.83
	Sidearm	23.18	4.79	20.68
11 Left handed	Hybrid	3.22	0.74	23.00
	Overhand	1.47	0.32	22.08
	Sidearm	4.68	0.62	13.25
12 Left handed	Hybrid	3.91	1.42	36.34
	Overhand	4.05	0.72	17.65
	Sidearm	5.39	0.39	7.17

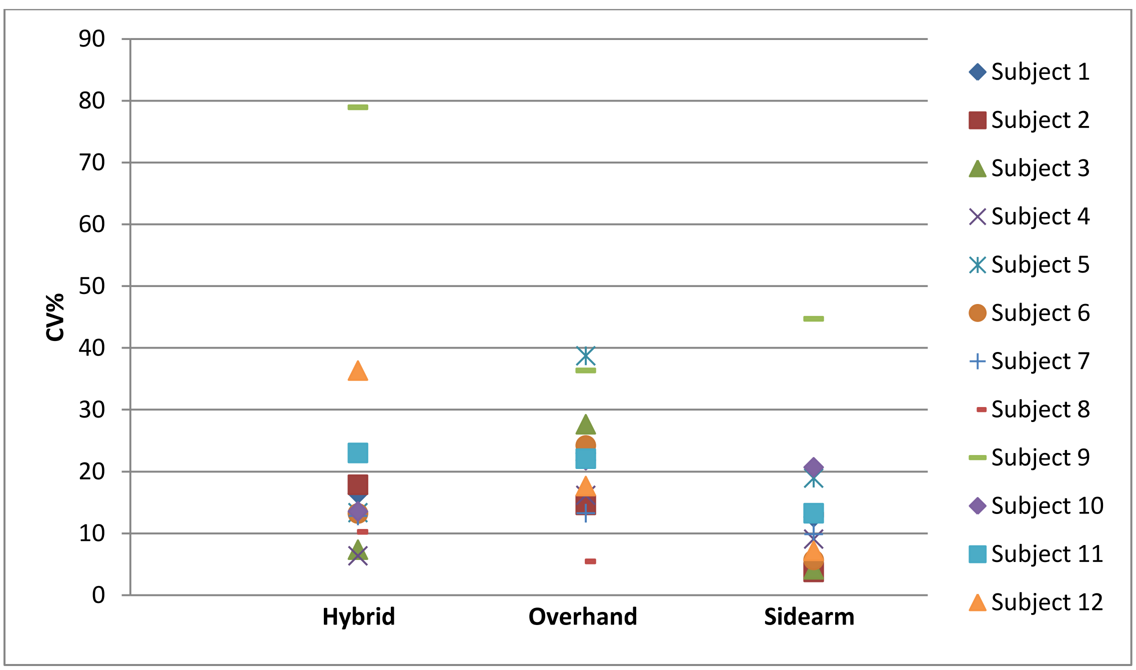


Figure 74. Coefficients of variability for peak positive power of L5-S1 rotation

Table 11. Mean peak negative powers for L5-S1 rotation

Subject (throwing side)	Throw	Mean maximum negative power, L5-S1 rotation (W/kg)	Standard deviation (W/kg)	Coefficient of variability (%)
1 Left handed	Hybrid	3.17	1.36	42.83
	Overhand	1.19	0.44	37.14
	Sidearm	4.84	0.30	6.12
2 Right handed	Hybrid	3.97	0.55	13.87
	Overhand	4.45	0.34	7.71
	Sidearm	4.98	1.08	21.61
3 Left handed	Hybrid	2.69	0.28	10.52
	Overhand	1.75	0.46	26.49
	Sidearm	2.12	1.08	51.025
4 Right handed	Hybrid	3.80	0.44	11.59
	Overhand	3.88	1.24	31.84
	Sidearm	4.46	0.82	18.37
5 Right handed	Hybrid	1.44	0.33	22.69
	Overhand	1.57	0.49	30.86
	Sidearm	1.39	0.42	29.99
6 Right handed	Hybrid	3.32	1.80	54.25
	Overhand	2.87	0.55	19.13
	Sidearm	3.7	0.39	10.54
7 Left handed	Hybrid	4.0	0.37	9.33
	Overhand	2.88	0.72	24.96
	Sidearm	4.89	1.21	24.70
8 Left handed	Hybrid	4.12	0.55	13.35
	Overhand	2.98	0.50	16.80
	Sidearm	5.01	1.65	32.99
9 Right handed	Hybrid	6.47	2.13	32.98
	Overhand	9.58	2.55	26.66
	Sidearm	3.93	0.42	10.59
10 Right handed	Hybrid	1.85	0.21	11.43
	Overhand	2.17	0.94	43.63
	Sidearm	6.71	2.58	38.47
11 Left handed	Hybrid	1.63	0.42	25.81
	Overhand	1.33	0.21	15.77
	Sidearm	3.29	0.38	11.43
12 Left handed	Hybrid	3.40	0.97	28.43
	Overhand	2.87	0.56	19.65
	Sidearm	2.80	1.00	35.84

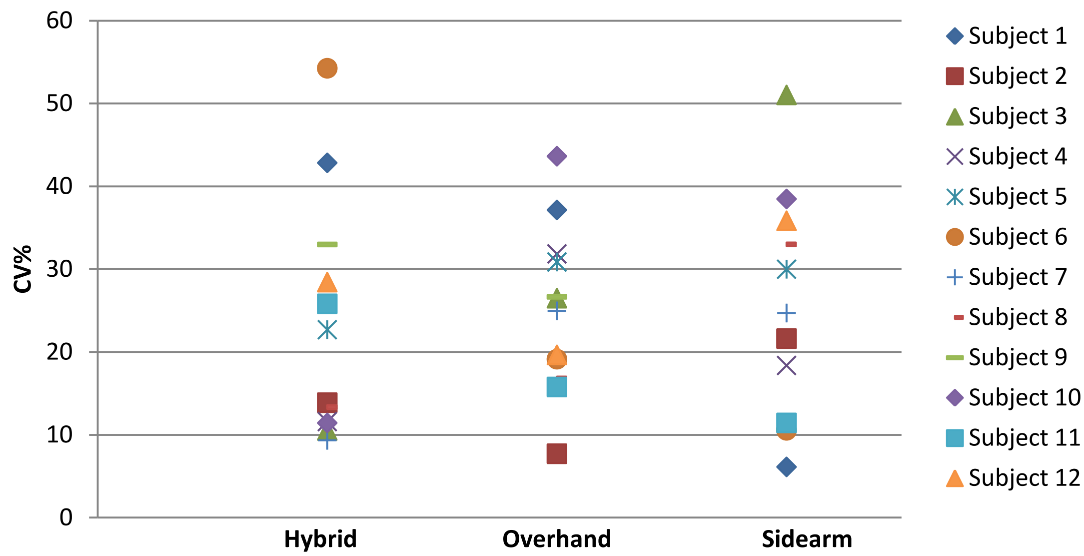


Figure 75. Coefficients of variability for peak negative power of L5-S1 rotation

As outlined above for the maximum positive and negative powers in flexion and extension, the following table (Table 12), describes which moment of rotation (right or left rotation) was occurring at the time that peak powers were reached. The right and left handed subjects have been divided as their moments will be opposite due to their throwing dominance. Right handed throwers will start their motion with their stick on their right hand side and rotate their shoulders towards their left hip during the motion. The left handed throwers will accomplish the opposite. Note that the left handed throwers all had the same moments occurring at peak powers. The right handed throwers that differed from the majority have been highlighted.

Table 12. Moment directions at peak positive or negative power for L5-S1 rotation

Subject (throwing side)	Hybrid		Overhand		Sidearm	
	Peak +ve rotation	Peak –ve rotation	Peak +ve rotation	Peak –ve rotation	Peak +ve rotation	Peak –ve rotation
2 (right)	Left	Right	Left	Right	Left	Right
4 (right)	Left	Left	Left	Left	Left	Right
5 (right)	Left	Right	Left	Right	Left	Right
6 (right)	Left	Right	Left	Left	Left	Right
9 (right)	Right	Right	Right	Right	Right	Right
10 (right)	Left	Right	Left	Right	Left	Left

1 (left)	Right	Left	Right	Left	Right	Left
3 (left)	Right	Left	Right	Left	Right	Left
7 (left)	Right	Left	Right	Left	Right	Left
8 (left)	Right	Left	Right	Left	Right	Left
11 (left)	Right	Left	Right	Left	Right	Left
12 (left)	Right	Left	Right	Left	Right	Left

The table below (Table 13) presents the means of the coefficients of variability for all 15 trials for each subject so as to identify which subject tended to have overall consistency as opposed to those who were inconsistent. Each variable is represented in a column where CV (%) is the abbreviation for coefficient of variability in percentage and where "Vel" is the abbreviation angular velocity, "flex" is for flexion, "ext" for extension, "irot" for ipsilateral rotation and "crot" for contralateral rotation. The other four columns continue with the coefficients of variability for positive (+) and negative (–) powers (p) for the flexion/extension (f-e) movements and the rotations (rot). The mean for each variable is found at the bottom of each column.

Table 13. Means of coefficients of variability for each subject and each variable

Subject	V flex.	V ext.	V. irot.	V crot.	+ p f-e	–p f-e	+p rot	–p rot
1	15.94	10.28	19.88	6.91	42.5	27.52	17.35	28.7
2	17.10	12.6	11.84	4.49	20.16	37.91	12.07	14.40
3	28.41	34.09	36.65	9.22	32.01	14.38	13.06	29.35
4	18.08	26.11	17.52	6.61	112.74	67.84	10.53	20.6
5	25.98	41.5	23.79	11.29	81.32	20.33	23.66	27.85
6	17.18	11.39	23.15	7.73	41.01	39.64	14.37	27.97
7	14.41	18.79	10.92	7.45	45.64	16.77	11.98	19.66
8	21.72	36.66	12.81	6.18	22.40	35.07	9.59	21.05
9	16.77	27.73	11.86	12.47	53.77	54.63	53.33	23.41
10	12.44	26.62	12.56	5.88	39.49	35.51	18.69	31.18
11	31.61	65.73	18.12	7.98	47.82	17.35	19.44	17.67
12	12.22	29.91	13.10	13.47	52.56	22.8	20.39	27.97
Mean	19.32	28.45	17.68	8.31	49.29	32.48	18.71	22.82

As there also may be a differences between throws in each of the variables for the coefficient of variability. The following graphs show the average for all subjects but separated into different throws. The graph in Figure 76 contains the angular velocities; Figure 77 has the powers.

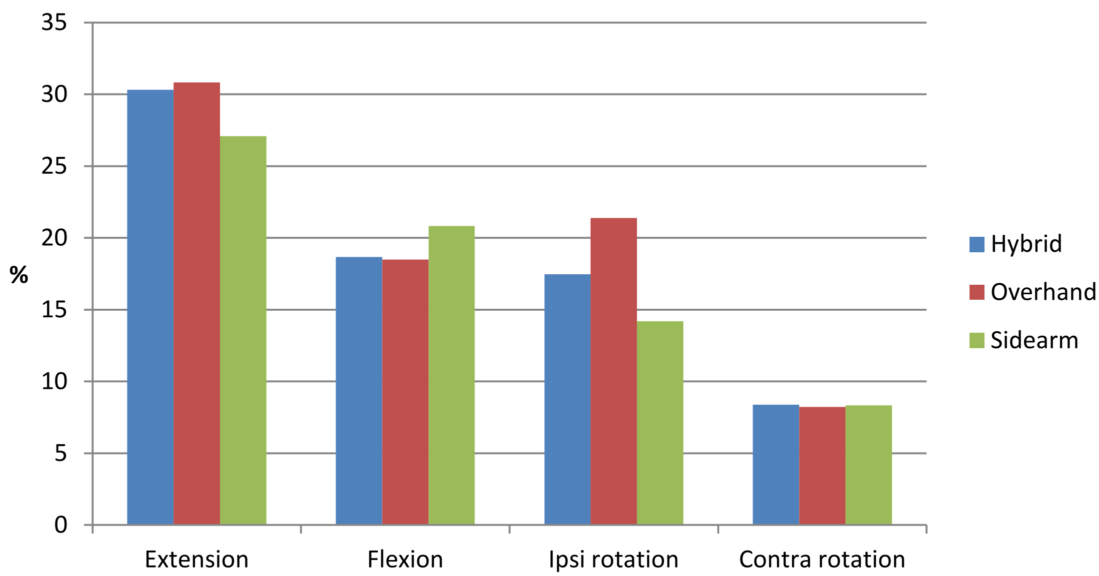


Figure 76. Mean coefficients of variability for each type of throw of L5-S1angular velocity

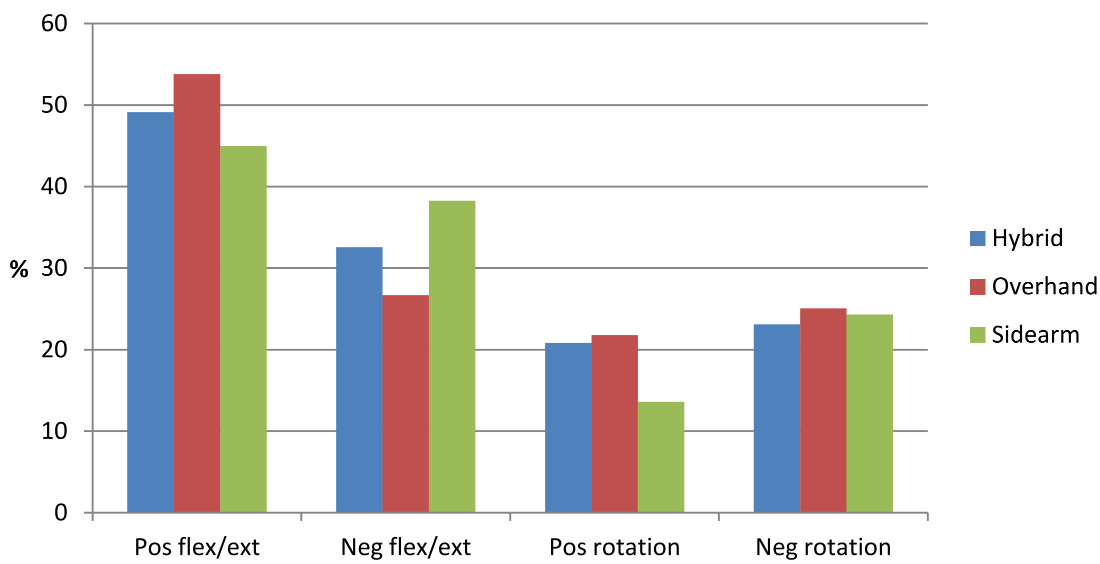


Figure 77. Mean coefficients of variability for each type of throw of L5-S1 power

The second research question was to identify whether there were differences between the 3 types of throws. Figure 78 shows the differences in the mean maximal flexion angular velocities between the hybrid, overhand and sidearm types of throwing. The units for the angular velocity are degrees per second.

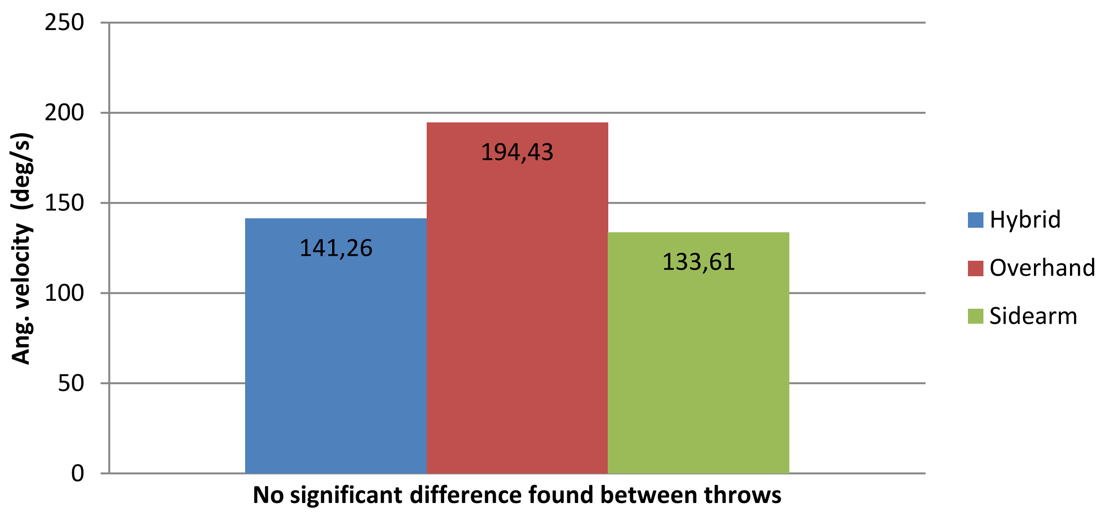


Figure 78. Mean maximal angular velocity for L5-S1 flexion

A one-way repeated-measures ANOVA was conducted to compare the hybrid, overhand and sidearm angular velocities in flexion. There were no significant effect for type of throw (Wilk's lambda=0.577, F(2,11) =3. 67, p=0.064) and therefore no significant differences found between throws. The observed power was 0.537.

The Graph in Figure 79 shows the differences in the mean maximal extension angular velocity between the hybrid, overhand and sidearm type of throwing. Once again, the units for the angular velocity are degrees per second but please note that the scale is less than for the previous graph.

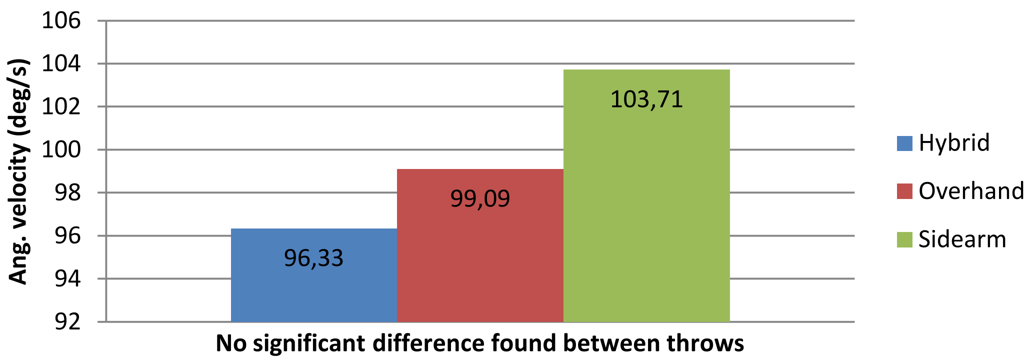


Figure 79. Mean maximal angular velocities for L5-S1 extension

A one-way repeated-measures ANOVA was conducted to compare the hybrid, overhand and sidearm angular velocities in extension. There were no significant effect for type of throw (Wilk's lambda = 0.952, F(2,11) =0.254, p=0.781) and therefore no significant differences were found between throws. The observed power was 0.080.

The following graph in Figure 80 shows the mean values for the ipsilateral rotation angular velocity between the 3 types of throws. The units for the angular velocity are still degrees per second and the scale has been adjusted to the values presented.

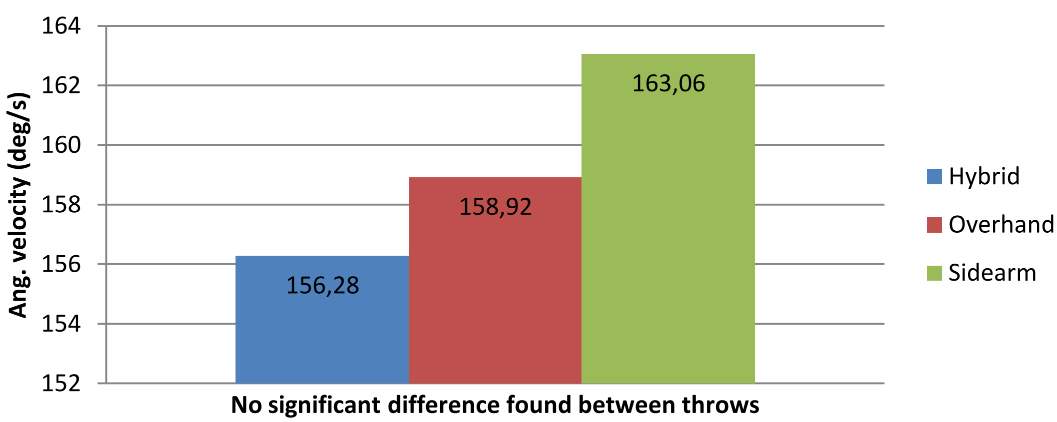


Figure 80. Mean maximal angular velocities for L5-S1 ipsilateral rotation

Once again, a one-way repeated-measures ANOVA was completed to compare the angular velocity in ipsilateral rotation between the 3 types of throwing. There were no significant effect for type of throw (Wilk's lambda=0.961, F(2,11)=0.203, p=0.819) and therefore no significant differences were found between throws. The observed power was 0.074.

The final angular velocity to be reported is the contralateral rotation. The following graph (Figure 81) outlines the differences between the hybrid, overhand and sidearm throws.

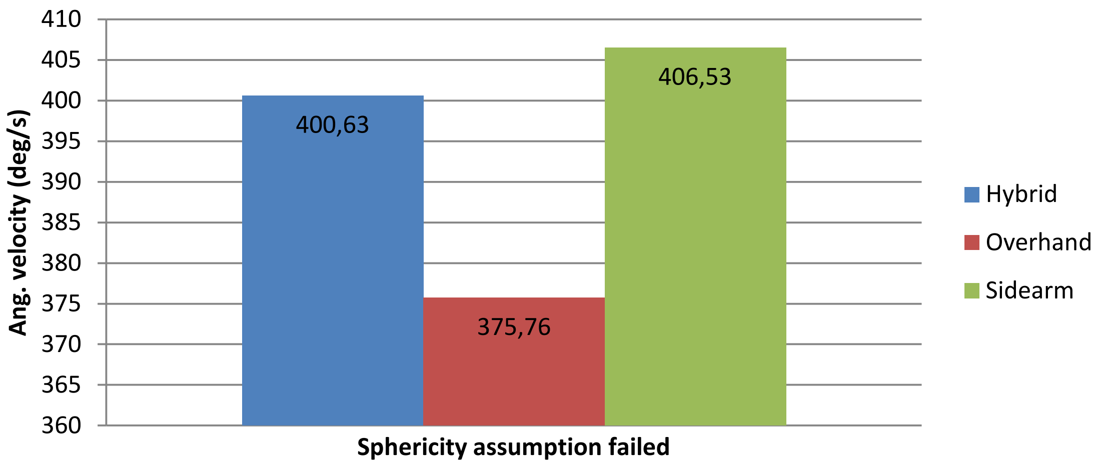


Figure 81. Mean maximal angular velocity for L5-S1 contralateral rotation

A one-way repeated-measures ANOVA was again conducted to compare the angular velocities in contralateral rotation between the three types of throws. The sphericity assumption was not fulfilled and the Greenhouse-Geisser or Huyn-Felt corrections did not offer significant results. However the multivariate tests showed a significant difference between the types (Wilk's lambda=0.537, F(2,11) =4.306, p=0.045). Multivariate partial eta squared was 0.463 indicating that 46.3% of the variance in the angular velocity in contralateral rotation at L5-S1 is accounted for by type of throw. Post-hoc comparisons using Bonferroni correction indicated that the mean angular velocity from the hybrid throw (M=401, SD=38.0) was significantly different than the overhand throw (M= 376, SD=40.0). However, the sidearm throw did not differ from the hybrid or the overhand. These results are not significant since, as mentioned above, the sphericity assumption was not met.

The next variables to be compared were the mean peak powers. The first of the following 4 graphs (Figure 82) presents the values for the mean peak positive power in flexion/extension for each of the 3 types of throws.

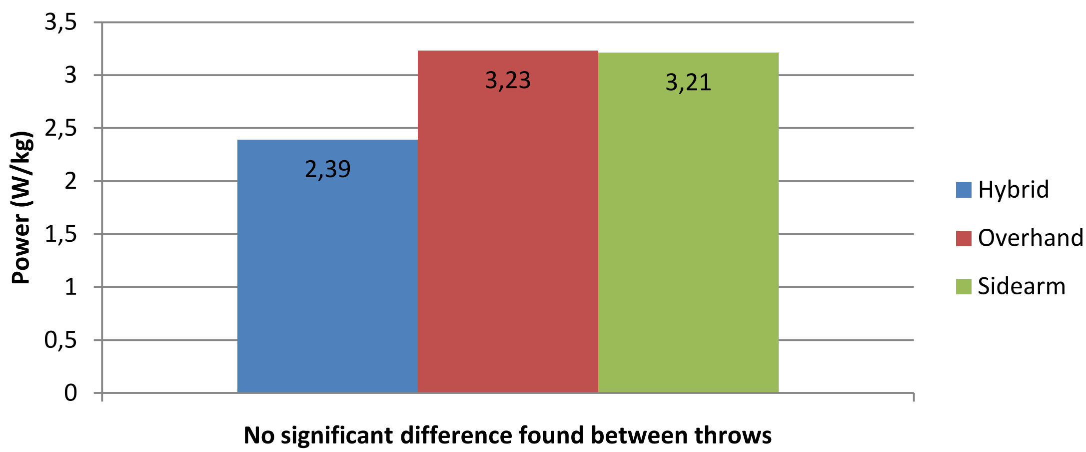


Figure 82. Mean peak positive powers for L5-S1 flexion/extension

A one-way repeated-measures ANOVA was again conducted to compare the positive power means in extension/flexion between the 3 types of throws. There were no significant differences found between the hybrid, overhand and sidearm shooting patterns (Wilk's lambda=0.873, $F(2,11)=0.730$, $p=0.506$). The observed power was 0.141.

The following graph shows the mean negative power in flexion/extension at L5-S1 (Figure 83) for each type of throws.

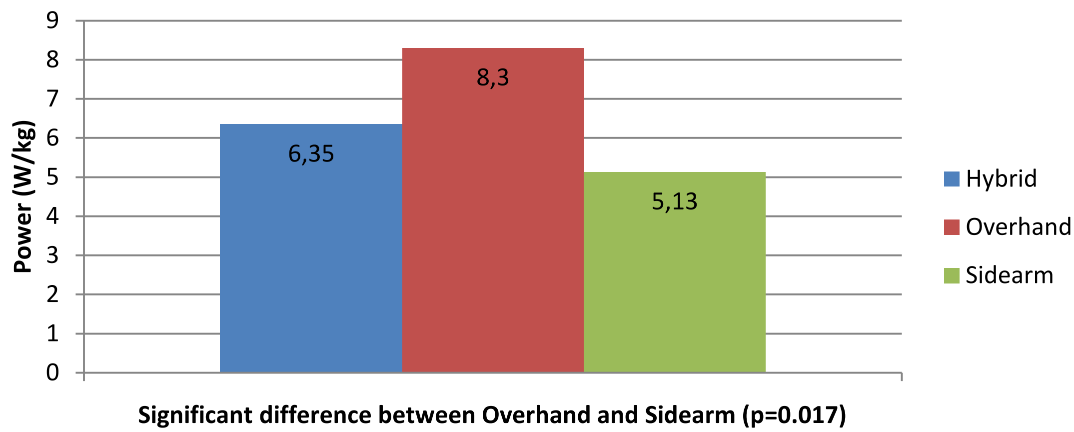


Figure 83. Mean peak negative power for L5-S1 flexion/extension

A one-way repeated-measures ANOVA compared the means to determine whether there were differences between the hybrid, overhand and sidearm for peak negative power at L5-S1. There was a significant difference as Wilk's lambda= 0.422, F(2,11) =6.860 with p=0.013. Partial eta squared was 0.578, meaning that 57.8% of the variance in peak negative power can be attributed to the type of throw. Post-hoc comparisons using Bonferroni correction indicated that the mean power from the overhand throw (M=8.30, SD= 1.881) was significantly different than the sidearm (M=5.13. SD=1.416) but that the hybrid did not significantly differ from the other two types.

The next graph outlines the mean peak positive powers for rotation at L5-S1 (Figure 84) for each type of throw.

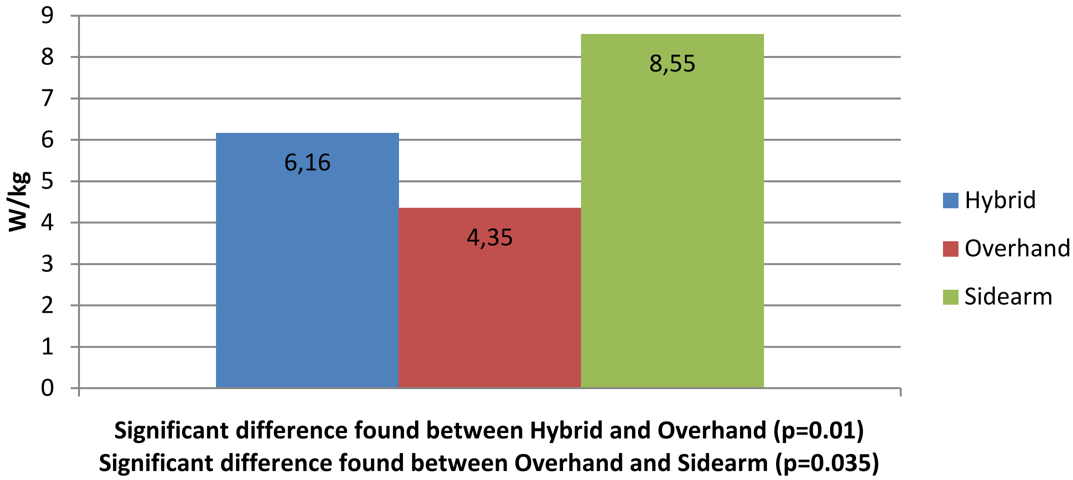


Figure 84. Mean peak positive power for L5-S1 rotation

Once again, a one-way repeated-measures ANOVA was conducted to see if significant differences could be found between throws. There was a significant effect for the type of throw as Wilk's lambda=0.289, F(2,11)=12.323 with p=0.002. Partial eta squared was 0.711, which means that 71.1% of the variance in the peak positive rotation power can be accounted for by type of throw. Post-hoc comparisons, using Bonferroni corrections, indicated that there was a significant difference between the overhand (M=4.35, SD= 1.066) and the hybrid (M=6.16, SD=1.076) as well as between the overhand and sidearm (M=8.55, SD=1.819).

The last variable that each type of throw was compared through is the mean peak negative power in rotation at L5-S1 and the following graph outlines its values (Figure 85).

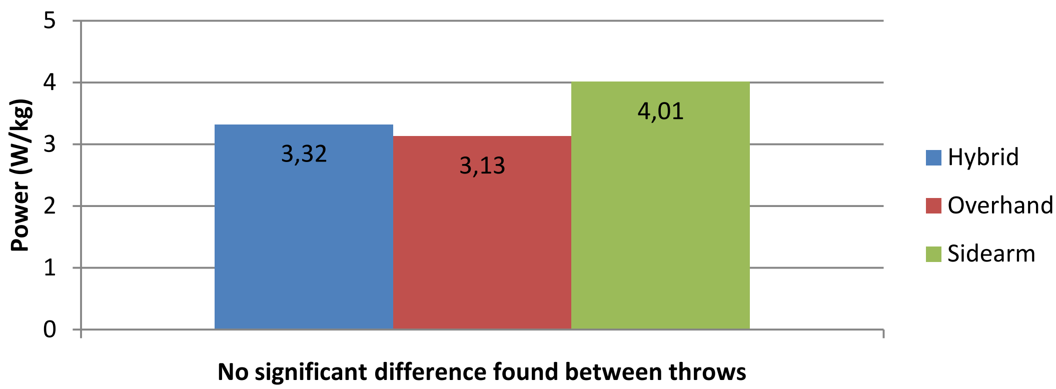


Figure 85. Mean peak negative power for L5-S1 rotation

The last one-way repeated-measures ANOVA showed that there were no significant difference in mean peak negative powers for L5-S1 rotation (Wilk's lambda=0.856, F(2,11)= 0.841, p=0.460). The observed power was 0.156. There were no significant differences between the types of throw.

As several one-way ANOVAs were calculate, the following table outlines their results for each of the variables. The variables where a significant difference was found are outlined in grey.

Table 14. Results from the ANOVAs

Variable	Wilk's lambda	F value	p value	Differences between throws
Angular velocity flexion	0.577	3.67	0.064	none
Angular velocity extension	0.952	0.254	0.781	none
Angular velocity ipsilateral rotation	0.961	0.203	0.819	none
Angular velocity contralateral rotation	0.537	4.31	0.045	**failed sphericity assumption**
Peak positive power flexion/extension	0.873	0.730	0.506	none
Peak negative power flexion/extension	0.422	6.86	0.013	Overhand and Sidearm
Peak positive power rotation	0.289	12.32	0.002	Hybrid and Overhand Overhand and Sidearm
Peak negative power rotation	0.856	0.841	0.460	none

Stick speeds were based on the markers applied to the stick head. Maximal speed of the mid-point of the two distal markers was calculated for each trial and averaged per type of throw. This data is outlined in the table below (Table 15) and the following graph (Figure 86). The units for the stick speed were calculated in meters per second but converted into kilometers per hour as presented in this table. Please note that due to a static trial labeling error, no data were available for the stick speed of Subject 9.

Table 15. Average stick speeds per throwing method

Subject	Mean Hybrid (km/h)	Mean Overhand (km/h)	Mean Sidearm (km/h)
1	95.5	92.4	90.5
2	97.1	97.7	102.1
3	86.8	84.5	92.5
4	91.8	86.3	90.6
5	87.8	88.2	91.1
6	100.3	94.8	100.5
7	93.5	92.5	95.8
8	100.3	97.5	91.9
10	92.0	90.4	97.6
11	80.6	80.4	74.5
12	84.0	82.9	81.5

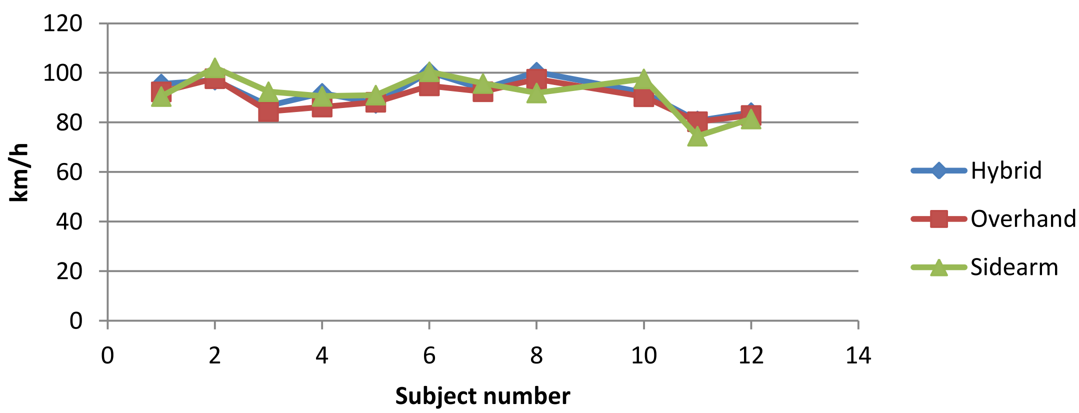


Figure 86. Graph average stick speeds

The fastest individual trial stick speed for the hybrid throw was 103.0 km/h by Subject 1 but the slowest was 87.1 km/h by Subject 11. The fastest overhand was

99.4 km/h by Subject 2 but the slowest was 84.2 km/h by Subject 11. Finally, the fastest sidearm was 103.3 km/h by Subject 2 and once again, the slowest was 77.0 km/h by Subject 11. The following graph (Figure 87) shows the average fastest stick speed in kilometers per hour for each type of throw.

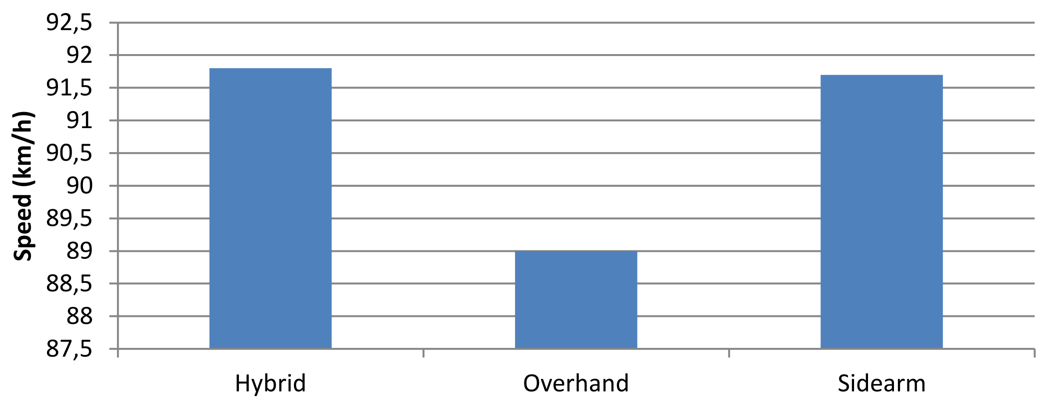


Figure 87. Average fastest stick speeds

While collecting data, the subjects were given no advice as to how to approach the throwing area. The subjects were instructed to finish their throws with one foot on a particular the force plate depending on whether they were right or left throwers. Some opted to use a walking approach to successfully land on the force plates while others felt their best performance could be obtained if they skipped or hopped towards the force plates. Subjects 3, 5, 9, 11 and 12 walked while the others hopped. It was noticed from the stick speeds that the “hoppers” seemed to reach better speeds than the “walkers”. The graph below (Figure 88) outlines the stick speeds for the walkers and the hoppers for each type of throw.

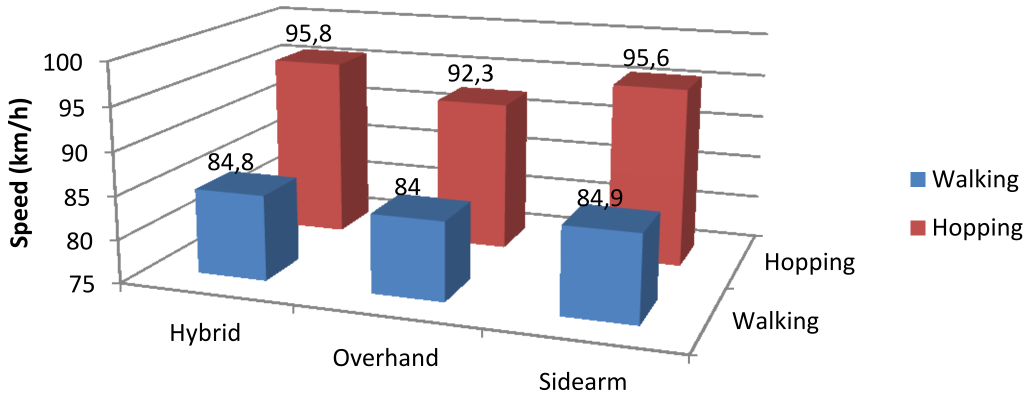


Figure 88. Mean maximum stick speed for hopping vs. walking approach

To see if the different approach had a significant effect on stick speed, a factorial, repeated-measures ANOVA was conducted to determine if there was an effect between the types of throws. There was no effect between the types of throws but the type of approach did have a significant effect on stick speed. (F=17.261, p=0.002, partial eta squared 0.657 and observed power 0.957).

Discussion

Discussion of findings: Research Question #1

The first research question pertained to the subjects' consistency between trials. By observing the graphs in the appendices, one can observe that some subjects had much greater standard deviations and varied from trial to trial or even between phases of a given throwing technique. The maximal values were found for each trial and an average was calculated for each type of throw. From the mean and standard deviation of each type of throw, a coefficient of variation (CV) for each variable was calculated. Unfortunately, the literature review did not reveal any other studies that used the CV as a measure of variation in kinetics or kinematics. The website, www.westgard.com, recommends that for good method performance the CV should be below 5% and that if it exceeds 10% then results are not likely valid. This website, however, uses the CV for measurement error as its purpose is to offer "Tools, Technologies and Training for Healthcare Laboratories". Forbes et al. (2007) found a CV of 4.1% in peak power on a Wingate cycle test after ingestion of an energy drink. Spencer et al. (2013) found a CV of 1.5 to 1.8% on the timed performance of elite cross-country skiers and a 4 to 10% CV due to terrain between performances. These sources are not similar to this research and their CV values cannot be used as benchmarks of what is acceptable. The CV values of each variable will therefore be compared within this study to discuss their differences.

For the maximal flexion angular velocity, the CV varied from 4.74% by subject 10 for the overhand to 50.0% by subject 3 for the overhand as well. The lowest CV for the hybrid throw was 7.40% (subject 10) and the highest was 37.1% (subject 5). As for the sidearm, the lowest value was 9.79% (subject 1) and the highest 38.9% (subject 11).

The highest values for each type of throw were from subjects who walked as an approach while the lowest values were all from subjects who hopped. It may be that the subjects who walked had to alter their technique to accommodate the laboratory setting. By forcing them to land on given force plates, their normal stance may have been altered and therefore affected how their trunk has to flex during throwing creating a wide margin between trials. When looking at individual CVs to determine which type of throw seemed to cause the most variation in the flexion angular velocity, the results were varied and not conclusive. Five subjects had the highest CV with the hybrid, 4 with the overhand and 3 with the sidearm. On the other hand, 5 subjects had their lowest CV with the overhand, 4 with the sidearm and 3 with the hybrid. The fact that each subject exhibits their lowest CV for a different type of throw may have to do with individual preferences or level of comfort. If, for example, a given subject prefers the hybrid in a game setting, this type of throw may be better rehearsed and therefore present a lower CV as the player is more consistent. When averaging the individual CV for each type of throw, the mean for the hybrid throw was 18.66%, for the overhand 18.48% and for the sidearm 20.8%. Although the difference between the types of throws was not large, the overall variation for this variable was fairly wide considering that “the CV of an individual athlete’s performance is typically a few percent” (www.sportsci.org, 2013). In a game situation, the starting position of a throw will likely be different. The player will not always be in a straight line with the goalie as the laboratory setting was and they would likely be dealing with body contact unless they were on a breakaway. As flexion of the trunk is an integral part of the acceleration phase, the subject may perform this motion with a wide variation as a reflection of their training. In other words, they have learned to not quite execute this motion the same way as the starting point will be very different in a practical setting, which is possibly reflected by the high variability in the motion.

For the extension angular velocity, the values in deg/s were lower, which is to be expected as the extension range of motion present is much less than flexion. The CV values varied from 6% for the sidearm of subject 2 to 114.4% for the overhand of subject 11. This wide variety in CV may be due to the fact that extension occurs mostly at wind-up for the overhand and hybrid throw and as reflected by the graphs in the Appendices and discussed previously, each trial was quite different during that phase. The lowest values for the hybrid were 6.81% (subject 1) and for the overhand, 10.03% (subject 4). The highest CV values were 62.1% for the hybrid of subject 5 and 55.9% for the sidearm of subject 11. Similar to the flexion angular velocity, the lowest values were by hopping subjects while the highest values were from walking subjects. The maximal and minimal CV values for each subject were also diversified and not conclusive. Six subjects had their highest value with the hybrid throw, 4 with the overhand and 2 with the sidearm. 5 subjects had their lowest value with the sidearm, 4 with the overhand and 3 with the hybrid. When averaging all individual CVs for the extension angular velocity, the hybrid throw showed 30.3% variability, the overhand was 30.8% and the sidearm 27.1%. While the difference between throws is likely not significant, this variable has higher CVs than the flexion angular velocity. This may be attributable to the starting position being different or the fact that, on any given throw, the subjects chose to go further into lumbar extension to have greater range of motion over which they could develop speed. The extension being a motion that does not contribute to the actual development of speed but more so part of the winding up phase, its maximal angular velocity possibly varies more than flexion as it is a better rehearsed motion included in the acceleration phase.

The maximum ipsilateral angular velocity rotation values were obtained from the wind-up phase while the subjects' shoulders rotated towards their dominant side. The lowest CV was 5.06% from the hybrid throw of subject 10 and the highest value was 86.1% from the overhand of subject 3. The highest CV for the hybrid throw was 38.5% (subject 1) and the highest sidearm was 24.5% (subject 6). The lowest overhand was 8.07% (subject 1) and for the sidearm, 8.09% (subject 7). Except for the overhand, the highest CVs were by hoppers as were all of the lowest values. This differs from the extension and flexion velocity, which elicited greater CVs from the walkers than the hoppers. The hoppers may need to modify their rotation speed from trial to trial because since their approach is faster, it forces them to wind-up faster. It is logical to think that the faster the motion, the harder it is to reproduce it from trial to trial. In terms of which type of throw seemed to have more variation, 6 subjects had their highest ipsilateral rotation CV with the hybrid throw, 3 with the overhand and 3 with the sidearm. The lowest CVs were for the hybrid for 5 subjects, overhand for 3 subjects and sidearm for 4 subjects. Since the hybrid requires a mix between the sagittal and the transverse plane of movement, the speed of rotation varied more from trial to trial for some subjects while others seemed to reproduce a similar speed of motion in their lumbar spine from trial to trial. These differences are likely due to individual preferences and aptitudes. The average CVs for the ipsilateral rotation velocity were similar to those of flexion but lower than extension, which is another trunk motion mostly used for the wind-up. The lower variability of the rotation may indicate that it was better rehearsed or that it cannot vary too much for efficient throwing. In other words, the amount and the speed of ipsilateral rotation are more stable than the extension for successfully throwing. For the hybrid throw, the mean CV was 17.46%, for the overhand 21.4% and for the sidearm, 14.20%. The sidearm was the throwing technique requiring the most rotation but it also had the least amount of variation in the rotation occurring during wind-up. The sidearm is harder to use on the run (Hanna 1980) so it has possibly been repeated in practice and in game settings in a more stationary position, imitating the lab setting and therefore producing a less variable velocity.

For the maximal contralateral rotation, which occurs during the acceleration phase while the shoulders rotate away from the dominant side, the CV values were much lower than for the other variables. The lowest overall CV was 2.18% for the hybrid of subject 2 while the highest value was 17.61% for the sidearm of subject 12. The highest overhand CV was 17.46% (subject 5) and for the hybrid, 16.14% (subject 7) while the lowest overhand was 2.28% (subject 6) and sidearm was 3.35% (subject 7). The range between the lowest and highest value was also much lower for this variable indicating that the subjects were more consistent on contralateral rotation speed than any other variables. This may indicate that this component of the movement is important to the efficiency of throwing and therefore cannot vary greatly to be successful. Since it mostly occurs during the acceleration phase, it is an integral part of the kinetic chain to produce stick and ultimately ball speed and is less perturbed by outside parameters than the other velocities. The highest CVs by each individual were for the hybrid throw for 3 subjects, the overhand for 6 subjects and the sidearm for the remaining 3. The lowest CVs for 5 subjects were with the hybrid throw, 4 for the overhand and 3 for the sidearm. This does not reflect a clear majority of which type of throw seemed to cause the least or the most amount of variation. The average CVs were comparable between types of throw: 8.37% for hybrid, 8.22% for the overhand and 8.34% for the sidearm. These means are very similar even if the required rotation for each throw is different. The contralateral rotation velocity was therefore fairly stable across trials and types of throws even meeting acceptable values for measurement error by Statistics Canada: "Estimates with a coefficient of variation less than 16.6% are considered reliable for general use. Estimates with coefficients of variation between 16.6% and 33.3% should be accompanied by a warning to caution users about the high levels of error. Estimates with coefficients of variation higher than 33.3% are deemed to be unreliable." (www.statcan.gc.ca, 2013). Statistics Canada uses the CV as a measure of error and not consistency, which leaves our CVs still much higher than the few percent reported for sports performances (www.sportsci.org).

When looking at individual CVs and which type of throw was the highest or lowest for each subject, several subjects had similar results with the same plane angular velocity. Table 16 shows which type of throw had the highest and lowest CV for each variable and each subject. Eight subjects had their lowest CV in flexion and extension angular velocities for the same throw while only 4 had their highest with the same type of throw. Six subjects had their lowest CV for rotational angular velocities with the same type of throw and 6 had their highest CV with the same type of throw. This may indicate that in a given plane such as flexion and extension, subjects are able to reproduce similar velocities for a given throw. This may indicate a well-rehearsed motion; however, it may also indicate a lack of adaptation in the motion. In rotation, 6 subjects had the lowest CV with the same type of throw and 6 had their highest CV with the same type of throw. Certain subjects such as subject 4 had the same type of throws for both planes on the highest and lowest CV while others, such as subject 1, had the same throws in the sagittal plane or subject 2, 10 and 11 in rotations. This may indicate that they have a less and a most practiced throw.

Table 16. Highest and lowest CV by type of throw for angular velocity

S	Extension low CV	Flexion low CV	Extension high CV	Flexion high CV	Ipsi. rot'n low CV	Contra. rot'n low CV	Ipsi. rot'n high CV	Contra. rot'n high CV
1	Sidearm	Sidearm	Overhand	Overhand	Overhand	Sidearm	Hybrid	Overhand
2	Sidearm	Sidearm	Hybrid	Overhand	Hybrid	Hybrid	Overhand	Overhand
3	Hybrid	Hybrid	Overhand	Overhand	Sidearm	Hybrid	Overhand	Overhand
4	Overhand	Overhand	Hybrid	Hybrid	Hybrid	Hybrid	Sidearm	Sidearm
5	Sidearm	Sidearm	Hybrid	Hybrid	Sidearm	Hybrid	Hybrid	Overhand
6	Sidearm	Overhand	Overhand	Sidearm	Overhand	Overhand	Hybrid	Sidearm
7	Overhand	Overhand	Sidearm	Hybrid	Sidearm	Overhand	Hybrid	Hybrid
8	Overhand	Overhand	Hybrid	Sidearm	Hybrid	Sidearm	Sidearm	Overhand
9	Hybrid	Sidearm	Sidearm	Hybrid	Hybrid	Overhand	Sidearm	Hybrid
10	Sidearm	Overhand	Hybrid	Sidearm	Hybrid	Hybrid	Overhand	Overhand
11	Hybrid	Hybrid	Overhand	Sidearm	Sidearm	Sidearm	Hybrid	Hybrid
12	Overhand	Hybrid	Hybrid	Overhand	Overhand	Overhand	Hybrid	Sidearm

A greater variability might not indicate a poorly mastered throw. It may be that as the final velocity of a given throw, perhaps the one with the most variation, is quite high, it is extremely hard to throw with a maximal effort every time. Referring back to table 15, to the averages of stick speed, this is true for some subjects. For example, subject 4 has the lowest CV in flexion and extension for his overhand throw and the highest for the hybrid throw. These also happen to be the throws with his lowest and highest stick velocity. On the other hand, some subjects did the exact opposite such as subject 5 who had the lowest CVs in flexion and extension on his sidearm throw which had the fastest stick speed but had the highest CVs on the hybrid throw which averaged the lowest stick velocity. No pattern can be detected between stick speeds and the type of throw which causes the most or least variation in angular velocities.

A larger variation may also be a reflection on their physical condition. Well-conditioned athletes may not always recruit the same pattern to produce the same output. If several of their joints along the kinetic chain have strong, well balanced musculature producing the throwing motion, on different trials they may rely less or more on their lumbar spine to produce the motion. An athlete with a weakness in their hip for example, may rely more on their lumbar spine to produce the maximal stick speed and therefore may have smaller CVs as they consistently use the same pattern to throw.

To compare the subjects' consistencies, all the angular velocity CVs were averaged and the subjects were ranked from lowest to highest in table 17.

Table 17. Average coefficient of variation for angular velocities per subject

Subject	Average CV (%)	Rank
1	13.25	3
2	11.51	1
3	27.1	11
4	17.08	6
5	19.70	10
6	14.49	5
7	12.89	2
8	19.34	9
9	17.21	8
10	14.38	4
11	30.9	12
12	17.18	7

The most consistent subject was subject 2 (CV = 11.51%) while the least was subject 11 (CV = 30.9). Subject 2 had one of the fastest stick speeds while subject 11 was the slowest. Consistency in repeating the motion may be an indication of efficacy or a reflection of the level of experience. Subject 2 is a professional lacrosse player while subject 11 plays at a local senior level. They both have been playing for approximately the same amount of years but subject 2 has benefited from a higher level of coaching in the past few years and may have greatly improved his technique.

The 6 highest CVs are held by the walking subjects and subject 8. Subject 8 also had some of the fastest stick speeds. He played at a local level and may have shown greater variability than the other hoppers as a reflection of the speed. When producing faster stick velocities, it may be harder to consistently produce the fastest speed and therefore result in a wider range of velocities for each variable. Subject 2 having more training and recent experience as well as earning a living playing lacrosse, allows him more time to finely tune the motion and possibly have less variability. The walking approach may cause more variations from trial to trial and may have been used by some subjects only to land on the force plates in the laboratory setting. In a game it may not be their chosen approach, which renders it less rehearsed and therefore less consistent.

The experience of the subjects also varied. At the time of testing, subject 3 and 12 (WS) and subject 1 (HS) played at a recreational local level. Subject 5 and 9 (WS) played on a local field lacrosse team where player 9 is a specialist of face-offs or draws and therefore has less practice at shooting at maximal speed since he almost never shoots but rather passes the ball to teammates and then gets off the surface of play. Subject 4 (HS) also played on a local field lacrosse team where he is a defensive player with a longer stick. In field lacrosse, each team is allowed a maximum of 4 “long poles” on the field at a time. Subject 4 has mostly played with a longer stick in the past few years, which may explain his higher CVs as it was required for him to shoot with a shorter stick for data collection, introducing equipment bias for this specific subject (Hopkins 2000). Subject 7 and 8 (HS) played on local box lacrosse teams. Subject 6 and 10 (HS) as well as subject 11 (WS) play box and field lacrosse on local teams. As mentioned above, the most experienced player is subject 2 who plays lacrosse throughout the year: professionally in the winter time and then in a senior box lacrosse league in the summer as well as a local field lacrosse team. It is not surprising that he produced some of the fastest stick speeds as well as the lowest CVs.

CVs were also calculated for the peak powers. As the values for power, in W/kg were lower than for the angular velocity, lower CVs could have been expected. Hopkins (2000) mentions that, “Typically error gets bigger as the value of the measure gets bigger.” This was not true for the positive power in extension and flexion. The CVs were the highest overall for the powers. The lowest CV was 9.40% for the overhand of subject 8, while the highest was 158.8% for the overhand of subject 4. Subject 4 also had the highest hybrid CV at 91.9% and the highest sidearm at 87.6%. The lowest hybrid was 11.49% by subject 3 and the lowest sidearm was 23.4% by subject 6. Subject 4 had the highest overall amount of variation for the positive flexion/extension power and as mentioned above, it may be due to the change in his stick length. The lowest CV for each subject was divided amongst the type of throws. 4 had their lowest value with the hybrid, 2 with the overhand and 6 with the sidearm. Once again the sidearm being on the low side may be due to its low reliance on flexion and extension. Three subjects had their highest CVs with the hybrid throw, 5 with the overhand and 4 with the sidearm. No clear majority can be established between the types of throws.

When the peak positive power is matched to the moment of force occurring at the same time, the results were also quite varied. For the hybrid throw, 7 subjects had their peak positive power with an extensor moment while 5 had a flexor moment. For the overhand, 6 subjects had flexor moments at peak power and 6 had extensor moments. For the sidearm, the gap widened as 3 had flexor moments and 9 had extensor moments. In other words, for the extensor moment subjects, their lumbar extensors produced greater concentric work, likely during wind-up or at the end of follow-through, than did their flexors or abdominals during the acceleration phase. This may indicate weak abdominals or a heavy reliance on hip flexors to create the flexion necessary for the acceleration phase. For the sidearm throw, as it requires less work in flexion/extension than in rotation, a greater portion of subjects had greater positive power in extension than in flexion. The acceleration phase of the sidearm does not rely as heavily on the abdominals or the flexors to produce force. These variations may be due to individual differences in performance caused by different levels of training, physical condition or muscular imbalances in not only the lumbar spine but also surrounding joints. When all the subjects' CVs for a given throw were averaged, the hybrid had 49.1% variation, the overhand 53.8% and the sidearm 45.0%. The difference between the types of throws wasn't likely significant; however, the sidearm was the lowest and since it contains the least amount of flexion and extension during its active phase, it may explain why the variation for the positive power of that motion was less.

The maximal negative extension/flexion power CVs were somewhat lower than for the positive power indicating that there was more consistency in how much power was used or created to slow down the motion. All of the corresponding moments of force at the time of peak power were in extension. Every single subject demonstrated the highest level of negative power in trying to slow down a flexion movement at or after

BR. The lowest overall CV was 10.25% for the hybrid throw of subject 7 but the highest overall was 80.1% for the hybrid throw of subject 4. Subject 4 also had the highest CV for the overhand at 46.0% and for the sidearm at 77.4%. The lowest CV for the overhand was by subject 1 at 14.17% and for the sidearm at 11.90 by subject 5. Subject 4 had the highest percentage of variation for all 3 types of throws both for the positive and negative power in the sagittal plane. This may be due to the change in equipment by shortening his stick and possibly causing him to have to modify how he threw. If a slightly different strategy was used for every trial as he adapts to the new stick length, he may have used very different levels of power every time and therefore had a high CV for each throw.

When the CVs were averaged per type of throw, the hybrid had an overall mean of 32.5%, the overhand 26.6% and the sidearm, 38.3%. The overhand had the least amount of variation so subjects were more consistent in using negative power with the throwing type requiring the most work in decelerating flexion during the late acceleration and follow-through phase. Three subjects had their highest CVs with the hybrid throw, 2 with the overhand but 7 with the sidearm. Three subjects had their lowest CVs with the hybrid throw, 7 with the overhand and 2 with the sidearm. As opposed to the positive power in this plane, more subjects had a greater variation in negative power with the sidearm. This may be because flexion and extension are minimal components of the sidearm; the control the subjects develop in slowing down this motion was less in this type of throw than the others. It may also reflect that the sidearm is a throwing technique that is difficult to master and not used as often as the hybrid or the overhand even if it is efficient and harder to check than the other two techniques (Hanna 1980; Scott 1976). On the other hand, the overhand had the lowest CV for the most subjects which may reflect that a slight majority of the subjects have well practiced strategies to slow down the main component of the acceleration phase of the overhand.

As for the peak positive rotation power, the overall CV values were lower indicating a greater consistency with the production of rotation than for the extension/flexion movement. The lowest CV was 3.76% from the sidearm of subject 2 and the highest was 78.9 from the hybrid of subject 9. The highest overhand was 38.7% (subject 5) and the highest sidearm was 44.7% (subject 9). The lowest hybrid was 6.36% (subject 4) and the lowest overhand was 5.46% (subject 8).

The overall average CV for the hybrid was 20.8%, for the overhand 21.7% and for the sidearm a lower value, 13.6%. As the sidearm required a concentric rotation effort to accelerate the ball, it may be why there is less room for variation in the peak positive power in that direction as opposed to the other two types of throws which are more of a combination between motions in the sagittal and transverse plane. Perhaps the combination movement causes a difference between trials as the contribution from each plane varies. The moment of force for each peak positive power in rotation was a contralateral moment except for one subject who had an ipsilateral moment on all 3 types of throws (subject 9). For example, a right-handed thrower by rotating his shoulders towards the left during the acceleration phase would indeed have a contralateral moment at the time of peak power, occurring right before or at BR. Subject 9, being less experienced at throwing at maximal speeds may not have developed the most efficient way to use rotation and had his peak positive power during the wind-up phase. His lumbar spine likely doesn’t contribute much to the active or concentric action of rotation to produce the maximal speed of the stick. He perhaps relies more on his upper extremities, which not only renders his throwing method less efficient, but also might increase the possibility of repetitive strain injury to his upper body.

Which type of throw seemed to elicit the higher CV values for the positive rotation peak power? Two subjects had their highest CVs with the hybrid, 9 with the overhand and 1 with the sidearm. Three subjects had their lowest CVs with the hybrid, 2 with the overhand and 7 with the sidearm. A slight majority was observed in consistency of positive power with the sidearm perhaps as the rotation is the main motion for this throw but also the most powerful. Nine subjects had their highest average positive powers in the sidearm. While one might argue that it is difficult to maintain maximal levels of power throughout trials, there is still a greater amount of reproducibility in the output of work for the one type of throw that recruits the most rotation. On the other hand, the throw that required the least amount of rotation, the overhand, had the highest number of subjects who had their highest CVs. Like the sidearm, which had the greatest numbers of high CVs for the negative extension/flexion power, the overhand may vary in how much rotation power is created as it varies in use from trial to trial.

For the peak negative rotation power, the CVs were slightly higher than for the positive power but still lower than for the extension/flexion powers. In the sagittal plane, the subjects demonstrated a greater level of consistency in slowing down the motion than in creating the motion. With rotation, the eccentric control at the end of the acceleration phase and during the follow-through showed a slightly higher CV than the production of rotation power. The lowest overall CV was 6.12% for the sidearm of subject 1 while the highest CV was 54.3% for the hybrid of subject 6. The highest overhand was 43.6% (subject 10) while the highest sidearm was 51.0% (subject 3). The lowest hybrid was

9.33% (subject 7) and the lowest overhand was 7.71 % (subject 2). Subject 1, 6, 10, 7 and 2 were all using the hopping approach while subject 3 was the only walker. The type of approach doesn't likely affect the variation in negative rotation power as the peak likely occurs as the acceleration phase ends at BR or shortly thereafter during follow-through. At that point, the walkers and the hoppers may have different values of power but within subjects, the variations in levels of negative power may fluctuate due to individual differences such as motor control, strength, training and experience. Hopkins (2000) quotes "An individual's maximum power output changes between trials because of changes in mental or physical state". It is therefore quite hard to maintain a maximal effort for all trials which may cause a fluctuation in how that motion is slowed down afterwards.

The mean CV for the hybrid throw was 23.1%, for the overhand 25.1% and for the sidearm, 24.3%. The minimal difference between the 3 types of throws shows that overall the subjects are almost equally consistent in slowing down the motion of rotation. 4 subjects had their highest CV with the hybrid, 5 with the overhand and 3 with the sidearm. 6 subjects had their lowest CV with the hybrid, 2 with the overhand and 4 with the sidearm. While the number of subjects is fairly well divided among type of throw for the highest CV, the hybrid has an even half of the subject who recorded their lowest CV with it. The hybrid is well mastered by most players and has the most accuracy (Scott 1976) which may be why half of the subjects obtained their lowest CV with it.

The moment of force present at the time of peak negative power was an ipsilateral rotation for all subjects except one on the hybrid and sidearm and 2 on the overhand. This is quite consistent with the effort of slowing down the contralateral rotation occurring during the acceleration phase therefore making the ipsilateral rotators contract eccentrically resulting in a negative power but ipsilateral rotation moment.

In Table 18 is a summary of which type of throw caused the highest and lowest CV for each subject in the positive and negative powers. We can see that 6 subjects (highlighted in blue) had more consistency creating and slowing down motion in the sagittal plane for a given type of throw and 6 subjects had the same type of throw create the lowest variation for positive and negative rotation power. This type of throw may be better rehearsed or more common to them or perhaps their body is better adapted to the creation and attenuation of the forces required as a result of specific or general training in a given plane.

Table 18. Highest and lowest CV by type of throw for power

S	+ve power flex/ext low CV	–ve power flex/ext low CV	+ve power flex/ext high CV	–ve power flex/ext high CV	+ve power rotation low CV	–ve power rotation low CV	+ve power rotation high CV	–ve power rotation high CV
1	Sidearm	Overhand	Hybrid	Sidearm	Sidearm	Sidearm	Overhand	Hybrid
2	Overhand	Overhand	Sidearm	Sidearm	Sidearm	Overhand	Overhand	Sidearm
3	Hybrid	Hybrid	Sidearm	Overhand	Sidearm	Hybrid	Overhand	Sidearm
4	Sidearm	Overhand	Overhand	Hybrid	Hybrid	Hybrid	Overhand	Overhand
5	Sidearm	Sidearm	Overhand	Overhand	Hybrid	Hybrid	Overhand	Overhand
6	Sidearm	Overhand	Hybrid	Hybrid	Sidearm	Sidearm	Overhand	Hybrid
7	Hybrid	Hybrid	Overhand	Sidearm	Sidearm	Hybrid	Overhand	Overhand
8	Overhand	Overhand	Sidearm	Sidearm	Overhand	Hybrid	Sidearm	Overhand
9	Hybrid	Overhand	Sidearm	Sidearm	Overhand	Sidearm	Hybrid	Hybrid
10	Sidearm	Hybrid	Hybrid	Sidearm	Hybrid	Hybrid	Overhand	Overhand
11	Hybrid	Overhand	Overhand	Sidearm	Sidearm	Sidearm	Overhand	Hybrid
12	Sidearm	Sidearm	Overhand	Hybrid	Sidearm	Overhand	Hybrid	Sidearm

Five subjects on the other hand (highlighted in yellow), had the greatest amount of variation creating and stopping motion in the extension/flexion motion for the same type of throw while 4 had both their highest CVs for rotation powers with the overhand and one with the hybrid. This may show a specific weakness of individual subjects in mastering a certain type of throw or may indicate a certain weakness or muscle imbalance in their lumbar spine which requires them to vary their motor control.

The overall average of all CVs for power for each subject was calculated (Table 19) as well as ranking subjects from the lowest CV to the highest.

Table 19. Average coefficients of variation for powers per subject

Subject	Average CV (%)	Rank
1	29.0	6
2	21.1	1
3	22.2	3
4	52.9	12
5	39.6	10
6	30.8	7
7	23.5	4
8	22.0	2
9	46.3	11
10	31.2	9
11	25.6	5
12	30.9	8

The CV values for the powers are much greater than for the angular velocities that is the reverse of what Hopkins (2000) has said that typical error gets bigger as the value of the measure gets bigger. The values for angular velocities in deg/s were much greater than the ones in W/kg for the powers. However, in this case, we can appreciate that a maximal power output will be difficult to maintain for all trials causing fluctuations in values. Along the same line, if there are variations in the positive powers in a certain plane, then the power required to attenuate that motion, will also fluctuate. The two subjects with the least amount of variation in powers were also two of the subjects who produced the fastest stick speeds. This may be that they are very consistent in producing power and then slowing the motion with their lumbar spine, which may be an indication of efficiency. On the other hand, subject 6 who was also a fast thrower was 7th in rank for values of CVs. His variation in power may be a reflection that power will fluctuate from trial to trial as a maximal performance cannot be maintained between trials (Hopkins 2000). Subject 4 had the highest average CV, which may be attributable to his stick change, although we cannot exclude the possibility that he would have been the most variable subject even without the equipment bias. As opposed to the angular velocities where the subjects using a hopping approach seemed more consistent than the walkers, the powers blur the line between the two approaches. As mentioned before, this may be due to the fact that the majority of the peak powers were registered during the acceleration phase while most of the negative powers occurred around BR or during follow-through, at which point the faster or slower approach doesn't influence the variation in the values. This research didn't identify this source of bias until the analysis of the data so it cannot be affirmed that the different approaches caused fluctuations in our variables except for stick speed which showed a significant difference between the two approaches.

To summarize the results for the first research question, the literature review did not identify a benchmark study indicating what a significant or adequate CV value would be to rate consistency. Findings could only be compared between variables and subjects. For the angular velocities, the highest CV values were in extension and the lowest with contralateral rotation. For the powers, the highest CV values were with positive extension/flexion power and the lowest with positive rotation. Differences within subjects may be due to experience, level of comfort with a given throw, physical condition, motor control patterns, weakness or muscle imbalances in their lumbar spine or in surrounding joints as well as changes in mental status and capacity to perform at their perceived maximum in a laboratory setting. The sample did not control these many issues as subjects had different levels of experience, their lumbar spine were not assessed for weakness or imbalances and subjects were not asked to rate their performance or identify which type of throw they favour. For subject 4 and perhaps others as well, the change in equipment may have caused greater variations in performance.

With any of the 3 types of throws, the speed of motion as well as the power produced in the two planes studied (sagittal and transverse) also seemed to vary. A given type of throw requiring less motion in a given plane could be where the greatest variations were calculated. On the other hand, a throw requiring the most action in a given plane could also contain the greatest variability. Less variation when the plane of movement was less present in a given throw was also observed. For example, some subjects varied how much flexion they produced between hybrid trials or how much rotation power came from their lumbar spine between overhand trials. These differences were hypothetically due to fatigue, training or the fact that it was required for them to slightly change their patterns for the laboratory setting but one cannot confirm why the differences happened as they were not controlled for.

No clear majority on which type of throw caused the most variation was observed which may be dependent on each subject’s individual differences and preferences. If which type of throw each subject was most comfortable or efficient with had been controlled for, we may have been able to further comment on this aspect instead of offering possibilities of causes for our results.

Discussion of findings: Research Question #2

The second research question was to see if there was a difference in the variables between types of throws. For the four angular velocities, none showed a significant difference between throws. Contralateral rotation did have a p-value of 0.045 but failed the sphericity assumption. With the Greenhouse-Geisser or Huynh-Feldt corrections the p-value was 0.115 and 0.112, respectively, so contralateral rotation angular velocity did not show a significant difference between throws.

A study by Akutagawa and Kojima (2005) found a difference between one-handed and two-handed backhand stroke in tennis for the angular velocity of the pelvis although the direction was not specified. The one-handed style produced velocities of 280.7°/s and the two-handed, 538.6°/s. This indicates that differences between techniques exist in other sports as well, although in a motion that only remotely resembles the one we measured.

Hirashima et al. (2007) identified that the rotation of the trunk had a significant main effect on fingertip speed in throwing. Werner et al. (2008) also found that the higher the trunk rotation speed, the higher the ball velocity was in baseball. When comparing these results to other studies, the overall average for contralateral rotation was 394.3°/s with the maximum average being 406.5°/s for the sidearm. Ferdinands et al. (2009) found an angular velocity of 74.5°/s of pelvic rotation during the power phase of cricket bowlers. As they did not define pelvic rotation, this may not be comparing to the same motion. Burnett et al. (1996) found lumbar counter rotations of 462.7°/s and 416.3°/s in different types of bowlers at cricket. Nho et al. (2010) found that the maximal pelvis rotation velocity in overhand pitching was between 400°/s and 700°/s. Chu et al. (2010)

found that in golfers during the acceleration phase of the swing, the pelvic rotation velocity was 388.1°/s. Marras et al. (1995) found that trunk twisting velocity was a predisposing factor to injury. They identified that a rotational velocity greater than 45.12°/s could lead to injury and that velocities in rotation of 49.72°/s placed a worker at high risk for injury. Several studies (Crewe et al. 2013, Bartlett 2003, Burnett et al. 1998) have tried to identify which bowling technique may be more damaging to the lumbar spines of bowlers as several pathologies and injuries are found in that group of athletes. As the subjects showed fairly high rotation velocities, higher than what has been identified as harmful in the working spectrum, it would be interesting to further study the presence of lower back pathology in lacrosse players. Donatelli et al. (2012) did report, however, that generating rapid spinal movements is much safer when the spine is not flexing. The faster rotational movement seems to occur during the sidearm with likely the least amount of flexion. However, the overhand, which includes some rotation and flexion, also has velocities exceeding what is recommended by the Marras study.

The difference in angular velocity for flexion between throws was somewhat significant if a p-value of 0.10 is accepted instead of 0.05. The partial eta squared for flexion angular velocity was 0.423 and the observed power was 0.537. If a p-value of 0.10 was accepted, then a significant difference was observed between the overhand and the sidearm. As the overhand relies mostly on flexion to create the necessary output, the angular velocity in flexion can be expected to be higher than for the sidearm, which relies more on rotation. Stodden et al. (2005) found that an increase in trunk tilt at ball release in baseball had a significant effect on ball velocity. This was also supported by Werner et al. (2008). While these studies didn’t report angular velocity but rather a specific range of motion at a specific point in the throwing sequence, it would be interesting to further study the total range of motion caused by the lacrosse throw for comparison. The difference observed in flexion velocity between the overhand and sidearm might also be a total flexion difference between the two throws.

The overall average for flexion velocity was 156.4°/s with the highest value being 194.4°/s for the overhand. In other studies, the mean flexion during the power phase was 310°/s (Ferdinands et al. 2009) for cricket bowlers although Burnett et al. (1996) found a maximal flexion velocity of the lumbar spine of 1412°/s for mixed technique bowlers as opposed to 1012°/s for side-on or front-on bowlers. Bartlett et al. (1996) showed that experienced bowlers demonstrated lumbar flexion velocities of 529°/s while college players had 355°/s. For overhand throwing, a study by Hong et al. (2001) found that the absolute flexion velocity for the trunk was 630°/s. A study looking at trunk speed in handball players (Van den Tillaar, 2007) reported trunk flexion velocities of 279°/s. While all of those velocities exceeded the average in this study, one study pertaining to golf (Horan et al. 2010) measured the thoracic and pelvic tilts during the swing at golf. Their measured pelvic tilt velocity was 177°/s, which was slightly lower than ours. Note again that Marras et al. (1995) identified that 49.5°/s was a flexion angular velocity that predisposes to injury. They ranked that a flexion/extension velocity of 59.1°/s as placing a worker at high risk for lumbar injuries.

The remaining two angular velocities, extension and ipsilateral rotation, did not show a significant difference between throws. The observed power for extension was 0.08 and for ipsilateral rotation 0.074. Had the sample been larger, the observed power may have increased and a true difference or lack thereof may have been confirmed between throws for these two variables. The absence of a significant difference may, however, be due to the fact that both motions are present mostly during wind-up. This phase of the throw may be more similar between throws in the speed at which subjects executed the motions. Dun et al. (2008) had looked at kinetic and kinematic differences in the lumbar spine of baseball pitchers throwing from the wind-up or the stretch position and did not identify a difference between the two techniques. Fleisig et al. (2006) looked at differences between different types of throws in baseball and did not identify differences in the trunk kinetics or kinematics although they did detect differences in the shoulder and elbow. Since the power was extremely low, one cannot conclude that the lack of difference reflected by these data were valid.

The peak positive power in flexion/extension also did not reveal a significant difference between throws. Once again, the power for this variable was very low at 0.141. The peak negative power in rotation was also not significant, with an observed power of only 0.156. Both of these observed powers are too low to affirm that there was no significant difference in these variables between throws. The data and sample size don't show enough power to support this lack of difference.

The peak negative power in flexion/extension did show a significant difference between types of throw, more precisely between the overhand and sidearm. The overhand requiring a larger contribution from flexion during the acceleration phase than the sidearm also requires a larger power to stop the motion creating a significant difference with the sidearm. One study by Crewe et al. (2013) discussed the difference between cricket fast bowlers with and without a quadratus lumborum asymmetry. They chose to focus on lateral flexion and therefore did not offer the powers measured in the sagittal plane. Their negative power in side bending for their symmetrical group was 33.8 W/(kg.m). When converting values for peak negative power in the sagittal plane to compare to theirs in the frontal plane, the overall average was 3.64 W/(kg.m). The eccentric work their subjects had to achieve in cricket bowling in side bending is far superior to the slowing of flexion in this study. The two motions, thus, differ greatly from one another.

The peak positive rotation power also showed a significant difference between types of throws where the overhand had a significant difference with the hybrid and with the sidearm. The overhand requiring less of its power from rotation during the acceleration phase had the lowest average positive power in rotation and when compared with the hybrid and sidearm, was significantly different. The hybrid requiring some rotation had an average power (6.16 W/kg) higher than the overhand (4.35 W/kg) but the sidearm (8.55 W/kg) had the highest average in positive rotation power as most of its acceleration phase power was produced through rotation.

It could not be identified what level of power may be damaging to the spine or even what other sports had measured as sagittal or transverse plane powers. A properly trained and conditioned lumbar spine would possibly be able to produce and attenuate the motions of throwing at lacrosse without risk of injury. McGill (2006) discussed that if dynamic stabilization was not present, then repetitive aggressive rotational movements can be destructive to spinal segments causing instability and pain. Putnam (1993) has found that core stability was necessary to allow the optimal transfer of force from the lower extremity through the trunk to the upper extremity. Nho et al. (2010) elaborated that the legs and trunk served as main force generators of the kinetic chain. Gordon and

Dapena (2006) found that in tennis, the main contributors to racquet speed were, amongst many others, the rotation of the lower trunk. All of these studies point to the fact that a well conditioned, experienced and pain free lumbar spine is capable of contributing to a rotational throwing motion such as the one studied although the same motion is also capable of causing damage to a poorly conditioned lumbar spine due to the repetitiveness of high velocities that are potentially damaging. Further studies into each type of throw, controlling for weaknesses and imbalances of the lumbar spine as well as surrounding joints need to be done to properly answer these questions.

Following our findings however, one could recommend to a lacrosse athlete that has injured his extensor muscles to refrain from using the overhand throw as it has higher powers to eccentrically stop the flexion motion and therefore could exacerbate the problem occurring in their extensor muscles. In a similar fashion, if a lacrosse player developed a facet joint issue in his lumbar spine, he should refrain from using the sidearm throwing motion since it showed greater positive rotational powers.

Discussion of findings: Stick speeds

The measured stick speeds were likely a little slower than what the subjects could have produced in a game or practice setting. The study by Crisco et al. (2009) found that ball speed for the men in their study was on average 3.5 m/s faster than the stick speed. By adding the 12.6 km/h found in the Crisco study the fastest throw would still be 115.9 km/h in this study. Subject 2, who produced that stick speed, has had the opportunity to have his ball speed measured in game settings by a radar gun. He reported throwing speeds exceeding 100 mph which represent speeds greater than 160.9 km/h, a difference of 45 km/h with what was registered in the lab. As measures of ball speed for game settings were not available for all subjects, one cannot generalize that there is a difference with their speed as well. It can be hypothesized that the forced stance on the force plates as well as the fear of hitting the measuring equipment may have decreased their performance.

The subjects in Crisco et al. (2009) had an average stick speed of 103.7 km/h. while the average stick speed for this study was 91.1 km/h. Their subjects did not have to land on force plates and the testing was done in a gymnasium. The target was the size of a regulation lacrosse net. The environment for their testing was a closer simulation of game situations, which may have allowed for better performances by the subjects in terms of stick speeds.

If the stick speed is adjusted to include the margin of error found in the Crisco study, the mean ball speed would be 103.7 km/h. Several studies have reported release ball speed for cricket bowlers. Ferdinands et al. (2009) had an average speed of 31.9 m/s (114.8 km/h) while Crewe et al. (2013) had an average speed of 30.7 m/s (110.5 km/h) while Bartlett (2003) found that fast bowlers could release the ball at 140 km/h all of which are higher than this measured average speed. In baseball, Robb et al. (2010) reported an average ball velocity of 38.8 m/s (139.7 km/h) for professional pitchers, Dun et al. (2008) found an average ball velocity of 38.5 m/s (138.6 km/h) while Fleisig et al. (1996) as well as Werner et al. (2008) found that baseball pitchers could throw at 126 km/h all of which are also higher than the adjusted measure of 103.7 km/h. In other throwing sports, however, the studies didn’t reveal speeds as high as the measured lacrosse stick velocity. Fleisig et al. (1996) found that football quarterbacks could throw at 75.6km/h. Oliver and Plummer (2011) reported an average velocity of 24.1 m/s

(86.8 km/h) for windmill softball pitching. Van den Tillaar (2007) reported an average ball velocity of 77.6 km/h in experienced handball players. Sasakawa and Sakurai (2008) reported disc release speeds of 78.1 km/h in skilled ultimate players. The current study's aim was not to accurately measure maximal stick speeds. To truly rank lacrosse ball speeds and compare them to other sports other research would need to be conducted in a setting which better imitates a game setting. Then a true comparison could be made.

The differences in stick speeds between the two types of approaches (walking vs. hopping) were somewhat reflected in other studies pertaining to other sports. Oliver and Hillary (2011) found that the greater the stride length taken by windmill softball pitchers, the greater ball velocity was reached. Bartlett (2003) in a literature review about cricket, reports that a faster approach from the bowlers lead to greater ball speeds. The hoppers were moving faster during wind-up than the walkers, which could explain why they obtained greater stick speeds. Portus et al. (2004) found that cricket bowlers with higher breaking forces also had higher ball speeds. If the hopping approach had increased speed going into the throw, they likely also had higher braking speeds once their feet were planted, which may support why they had greater stick speeds. A study by Wight et al. (2004) looking at early and late pelvic rotation in baseball pitchers, found no significant difference between the ball velocities of the two groups. As the approach of the subjects the current study was not controlled and the number of subjects was not the same in each group, the differences in ball speed between walkers and hoppers cannot be considered a finding but should direct future studies to control the approach speed.

Conclusion

This study aimed at describing the lacrosse throwing motion in terms of the kinetics and kinematics of the lumbar spine with the view of identifying potential harm to the players. Using a 3D motion capture system, EMG and force plate data, 12 subjects were measured while throwing with the hybrid, overhand and sidearm techniques. The subjects used a variety of strategies to achieve the goal of throwing the ball with each technique. As subjects were of varied experience and levels expertise in lacrosse, a more homogenous sample may have produced less variability of the motions and more consistent patterns for each type of throw. The EMG patterns of the subject analyzed mostly supported the kinetic and kinematic findings in terms of muscle activation patterns.

The within-subject variability was higher during the wind-up and follow-through phases of the throws than the acceleration phase. This may be a result of individual differences in training, preferences, capacity and motor control. It also may indicate that during the wind-up and follow-through phases, players are sometimes exposed to body contact in a game setting while the acceleration phase will not occur if an opponent is hitting them. As a result, they may show more variation during those phases as they are usually responding to outside stimuli. The adaptation to the laboratory setting also contributed to subjects changing their usual pattern because of having to land on the force plates while still attempting to throw the ball with a maximum effort.

No significant differences emerged between the three types of throws in terms of angular velocities at the lumbar spine. A difference was observed in the peak positive rotation and peak negative flexion/extension powers between throws but not in the peak negative rotation or peak positive flexion/extension power. From this research one cannot identify which variable contributes to the efficiency of throwing, which throwing technique is more efficient or on the other hand, more demanding on the lumbar spine. It does open the door to repeating similar research to truly test if differences exist which then could be used to base adequate training for lacrosse players.

Stick speeds were also calculated and a difference was seen between a walking and a hopping approach to throwing. Compared to other sports such as cricket and baseball, the speeds were lower, but higher than reported speeds for football and handball. This may be due, in part to the lab setting preventing the subjects from truly performing at their maximum.

As this study was ground breaking in the world of lacrosse biomechanics, it opens several other questions and areas to be studied. It should, at best, be considered a pilot study to help eliminate factors influencing variability from future research and perhaps contribute to determining which area of this wonderful sport should be studied next.

Recommendations:

- As the power of this study was fairly low, a larger sample size would provide more observed power and therefore more weight to the differences or lack thereof between variables.
- This sample was a convenience sample of local lacrosse players. A more homogenous sample in terms of experience and level of play might have reduced between subject variability. Permitting custom equipment selection for each subject (e.g., length of the stick) would also be helpful in providing top performances from each subject.

- Assessing subjects for the presence of faulty muscle control in the lumbar spine but also in the surrounding joints by a physiotherapist with the use of manual muscle testing and muscle length tests would exclude the subjects presenting with muscle imbalances. Injury or pain in the lumbar spine or lower extremities was the exclusion criteria but muscle imbalance may exist without pain and contribute to poor strategies in throwing. Future study may also research these different patterns between dysfunction-free and imbalanced subjects.
- For future research in the field, controlling for the type of approach (walking vs. hopping) and analyzing these two groups separately, may also render the results more cohesive.
- By having repetitive data collection sessions or practice sessions subjects would be more comfortable with the laboratory setting and landing on force plates. Furthermore, collecting the data during a practice may allow for a more natural performance by the subjects.
- It would have been beneficial in this study, to have subjects rate their level of comfort with each type of throw. By identifying subjects who, for example, seldom use the sidearm in games or who rate the hybrid as their favorite method of throwing, we may have been able to relate to their best or poorest performance on a given type of throw.
- Adding video data to the infrared camera pictures, may have allowed for better estimation of ball release and other phases of throwing.

References

Abrams, Geoffrey D.; Sheets, Allison L.; Andriacchi, Thomas.; Safram, Marc R. (2011) Review of tennis serve motion analysis and the biomechanics of three serve types with implications for injury. *Sports Biomechanics* 10(4): 378-390

Adrian, Marlene J. and Cooper, John M. (1995) *Biomechanics of Human Movement.* Dubuque, IA, Wm. C. Brown Communications Inc. 572 p.

Akutagawa, Susumu and Kojima, Takeji (2005) Trunk motion torques through the hip joints during the one and two handed backhand tennis strokes. *Journal of Sports Science* 23(8) 781-793

Allard, P. and Blanchi J-P. (1996) *Analyse du mouvement humain par la biomécanique.* Ville Mont-Royal, Québec, Décarie Éditeur, 281p.

Attebrant, Monica.; Mathiassen, Svend Erik and Winkel, Jorgen. (1995) Normalizing upper trapezius EMG amplitude: Comparison of ramp and constant force procedures. *Journal of Electromyography and Kinesiology* 5(4):245-250

Bartlett, R.M.; Stockill, N.P.; Elliott, B.C.; Burnett, A.F. (1996) The biomechanics of fast bowling in men's cricket: A review. *Journal of Sports Science* 14: 403-424

Bartlett, Roger M. (2003) The science and medicine of cricket: an overview and update. *Journal of Sports Science* 21:733-752

Bartlett, Roger (2007) *Introduction to Sports Biomechanics 2nd Edition.* New York, Taylor and Francis Group, 292p.

Burden, Adrian and Bartlett, Roger (1999) Normalisation of EMG Amplitude: an evaluation and comparison of old and new methods. *Medical Engineering and Physics* 21:247-257

Burnett, A.F.; Barrett, C.J.; Marshall, R.N.; Elliott, B.C.; Day, R.E. (1996) Three dimensional measurements of lumbar spine kinematics for fast bowlers in cricket. *Clinical Biomechanics* 13: 574-583

Callaghan, Jack.; Patla, Aftab and McGill, Stuart.(1999) Low back three-dimensional joint forces, kinematics, and kinetics during walking. *Clinical Biomechanics* 14:203-216

Carr, L.J.; Harrison, Linda M. and Stephens, J.A., (1994) Evidence for bilateral innervation of certain homologous motoneurone pools in man. *Journal of Physiology* 475 (2): 217-227

Chow, JW.; Shim, J-H and Lim, Y-T. (2003) Lower trunk muscle activity during the tennis serve. *Journal of Science and Medicine in Sport* 6(4):512-518

Chu, Yungchien.; Sell, Timothy C.; Lephart, Scott M. (2010) The relationship between biomechanical variables and driving performances during the golf swing. *Journal of Sports Science* 28(11): 1251-1259

Clarys, Jan Pieter. (2000) Electromyography in sports and occupational settings:an update of its limits and possibilities. *Ergonomics* 43(10):1750-1762

Cole, M.H. and Grimshaw, P.N.(2008) Electromyography of the trunk and abdominal muscles in golfers with and without low back pain. *Journal of Science and Medicine in Sport* 11:174-181

Crewe, Helen.; Campbell, Amity.; Elliott, Bruce.; Alderson, Jacqueline. (2013) Lumbo-Pelvic Biomechanics and Quadratus Lumborum Asymmedty in Cricket Fast Bowlers. *Medicine and Science in Sports and Exercise* 45(4): 778-783

De Zee, Mark.; Hansen, Lone.; Wong, Christian.; Rasmussen, John and Simonsen, Erik B. (2007) A generic detailed rigid-body lumbar spine model. *Journal of Biomechanics* 40:1219-1227

Dick, Randall.; Romani, William A.; Agel, Julie.; Case, Jim G. and Marshall, Stephen W. (2007) Descriptive epidemiology of collegiate men's lacrosse injuries: national collegiate athletic association injury surveillance system, 1988-1989 through 2003-2004. *Journal of Athletic Training* 42(2):255-261

Donatelli, Robert.; Dimond, Donn.; Holland, Matt. (2012) Sport specific biomechanics of spinal injuries in the athlete (throwing athletes, rotational sports and contact-collision sports). *Clinical Sports Medicine* 31(3):381-396

Dun, Shouchen.; Kingsley, David.; Fleisig, Glenn S.; Loftice, Jeremy and Andrews, James (2008) biomechanical comparison of the fastball from wind-up and the fastball from stretch in professional baseball pitchers. *American Journal of Sports Medicine* 36(1):137-141

Ferdinands, René E.D.; Kersting, Uwe.; Marshal, R.N. (2009) Three-dimensional lumbar segment kinetics of fast bowling in cricket. *Journal of Biomechanics* 42: 1616-1621

Fernandez-Pena, Eneko.; Lucertini, Francesco and Ditroilo, Massimiliano. (2009) A maximal isokinetic pedalling exercise for emg normalization in cycling. *Journal of Electromyography and Kinesiology* 19:e162-e170

Fleisig, Glenn S.; Escamilla, Rafael F.; Andrews, James R.; Matsuo, Tomoyuki; Satterwhite, Yvonne and Barrentine, Steve W. (1996) Kinematic and kinetic comparison between baseball pitching and football passing. *Journal of Applied Biomechanics* 12:207-224

Fleisig, Glenn S.; Kingsley, David S.; Loftice, Jeremy W.; Dinnen, Kenneth P.; Ranganathan, Rajiv.; Dun, Souchen.; Escamilla, Rafael F. and Andrews, James R. (2006) Kinetic comparison among the fastball, curveball, change-up and slider in collegiate baseball pitchers. *American Journal of Sports Medicine* 34(3), 423-430

Forbes, Scott C.; Candow, Darren G.; Little, Jonathan P.; Magnus, Charlene.; Chilibeck, Philip D. (2007) Effect of red bull energy drink on repeated wingate cycle performance and bench press muscle endurance. *International Journal of Sports Nutrition and Exercise Metabolism* 17: 433-444

Gonzalez, D. and Dietrich, G. (2003) Three-dimensional kinematic analysis of javelin throw: from real situation to biomechanical model. *Science and Sports* 18:216-218

Gordon, Brian J. and Dapena, Jesus. (2006) Contributions of joint rotations to racquet speed in the tennis serve. *Journal of Sports Sciences* 24(1): 31-49

Greene, Hunter S.; Cholewicki, Jacek.; Galloway, Marc T.; Nguyen, Carolyn V. and Radebold, Andrea. (2001) A history of low back injury is a risk factor for recurrent back injuries in varsity athletes. *American Journal of Sports Medicine* 29(6):795-800

Grimshaw, Paul.; Lees, Adrian.; Fowler, Neil and Burden, Adrian. (2007) *Sport and Exercise Biomechanics.* New York: Taylor and Francis Group 392p.

Hanna, Mike (1980) *Lacrosse for Men and Women-Skills and Strategies for the Athlete and Coach.* New York, Hawthorn/Dutton, 212p.

Hinton, Richard Y.; Lincoln, Andrew E.; Almquist, Jon L.; Douoguih, Wiemi A. and Sharma, Krishn M. (2005) Epidemiology of lacrosse injuries in high school-aged girls and boys. *American Journal of Sports Medicine* 33(9):1305-1314

Hirashima, Masaya.; Kadota, Hiroshi.; Sakurai, Shizuka.; Kudo, Katzutoshi and Ohtsuki, Tatsuyuki (2002) Sequential muscle activity and its functional role in the upper extremity and trunk during overarm throwing . *Journal of Sports Sciences* 20:301-310

Hirashima, Masaya.; Kudo, Kazutoshi.; Watarai, Koji and Ohtsuki, Tatsuyuki. (2007) Control of 3D limb dynamics in unconstrained overarm throws of different speeds performed by skilled baseball players. *Journal of Neurophysiology* 97:680-691

Hirashima, Masaya and Ohtsuki, Tatsuyuki.(2008) Exploring the Mechanism of Skilled Overarm Throwing. *Exercise and Sports Science Reviews* 36(4):205-211

Hodges Paul W. (1999) Is there a role for transversus abdominis in lumbo-pelvic stability. *Manual Therapy* 4(2):74-86

Hodges, Paul W.; Cresswell, Andrew G.; Daggfeldt, Karl and Thorstensson, Alf. (2001) *In vivo* measurement of the effect of intra-abdominal pressure on the human spine. *Journal of Biomechanics* 34:347-353

Hong, Di-An.; Cheung, Tak K and Roberts, Elizabeth M. (2001) A three-dimensional, six-segment chain analysis of forceful overarm throwing. *Journal of Electromyography and Kinesiology* 11:95-112

Hopkins, Will G. (2000) Measures of reliability in sports medicine and science. *Sports Medicine* 30(1): 1-15

Horan, Sean A.; Evans, Kerrie.; Morris, Norman R.; Kavanagh, Justin J. (2010) Thorax and pelvis kinematics during the downswing of male and female skilled golfers. *Journal of Biomechanics* 43:1456-1462

Huang, Q.-M.; Hodges, P.W. and Thorstensson, A. (2001) Postural control of the trunk in response to lateral support surface translations during trunk movement and loading. *Experimental Brain Research* 141:552-559

Hwang, Seonhong.; Kim, Youngeun and Kim, Youngho. (2009) Lower extremity joint kinetics and lumbar curvature during squat and stoop lifting. *BMC Musculoskeletal Disorders* 10:15-24

Kawasaki, S.; Imai S.; Inaoka H.; Masuda T.; Ishida A.; Okawa, A. and Shinomiya, K. (2005) The lower lumbar spine moment and the axial rotational motion of a body during a one-handed and double-handed backhand stroke in tennis. *International Journal of Sports Medicine* 26:617-621

Khoo, B.C.C.; Goh, J.C.H. and Bose, K. (1995) A biomechanical model to determine lumbosacral loads during single stance phase in normal gait. *Medical Engineering and Physics* 17(January):27-35

Kibler, Ben and Sciascia, Aaron. (2004) Kinetic chain contribution to elbow function and dysfunction in sports. *Clinics in Sports Medicine* 23:545-552

Larivière, Christian and Arsenault, A. Bertrand. (2008) On the use of emg-ratios to assess the coordination of back muscles. *Clinical Biomechanics* 23:1209-1219

Macintosh, Janet and Bogduk, Nikolai (1986) The biomechanics of the lumbar multifidus. *Clinical Biomechanics* 1:205-213

Macintosh, Janet E.; Bogduk, Nikolai and Gracovetsky, Serge. (1987) The biomechanics of the thoracolumbar fascia. *Clinical Biomechanics* 2:78-83

Marras, WS.; Lavender, S.A.; Leurgans, S.E. (1993) The role of dynamic 3dimensional trunk motion in occupationally related low back disorders: The effects of workplace factors, trunk position and trunk motion characteristics on the risk of injury. *Spine* 18:617-628

Marras, William S.; Lavender, Steven A.; Leurgans, Sue E.; Fathallah, Fadi A.; Ferguson, Sue A.; Allread, W. Gary.; Rajulu, Sudhakar L. (1995) Biomechanical risk factors for occupationally related lower back disorders. *Ergonomics* 38(2): 377-410

Marshall, P. and Murphy, B. (2003) The validity and reliability of surface emg to assess the neuromuscular response of the abdominal muscles to rapid limb movement. *Journal of Electromyography and Kinesiology* 13:477-489

McCulloch, Patrick C. and Bach, Bernard R. (2007) Injuries in men's lacrosse. *Orthopedics* 30(1):29-34

McGill, Stuart. (2006) *Ultimate Back Fitness and Performance 3th Edition.* Waterloo, ON, Wabumo Publishers. 319p.

Mero, Antti.; Komi, Paavo V.; Korjus, Tapio.; Navarro, Enrique and Gregor, Robert J. (1994) Body segment contributions to javelin throwing during final thrust phases. *Journal of Applied Biomechanics* 10:166-177

Netto, Kevin J. and Burnett, Angus F. (2006) Reliability of normalisation methods for emg analysis of neck muscles. *Work* 26:123-130

Nicolova, Gergana Stefanova and Toshev, Yuli Emilov. (2007) Estimation of male and femal body segment paramenters of the Bulgarian population using a 16-segmental mathematical model. *Journal of Biomechanics* 40:3700-3707

Noraxon USA Inc. SEMG- Muscle Chart. www.noraxon.com, consulted on June 24, 2010

Oliver, Gretchen D. and Plummer, Hillary. (2011) Ground reaction forces, kinematics and muscle activations during the windmill softball pitch. *Journal of Sports Science* 29(10):1071-1077

Pink, Marilyn.; Perry, Jacquelin.; Jobe, Frank W. (1993) Electromyographic analysis of the trunk in golfers. *The American Journal of Sport Medicine* 21(3):385-388

Portus, Marc R.; Mason, Bruce R.; Elliot, Bruce C.; Pfitzner, Max C. and Done, Richard P. (2004) Technique factors related to ball release speed and trunk injuries in high performance cricket fast bowlers. *Sports Biomechanics* 3(2):263-284

Putnam, C. (1993) Sequential motion of body segments in striking and throwing skills: descriptions and explanations. *Journal of Biomechanics* 26:S125-135

Ranson, Craig A.; Burnett, Angus F.; King, Mark.; Patel, Nitin and O'Sullivan, Peter B. (2008) The relationship between bowling action classification and three-dimensional lower trunk motion in fast bowlers in cricket. *Journal of Sports Sciences* 26(3):267-276

Rash, Gregory S. and Shapiro, Robert. (1995) A three-dimensional dynamic analysis of the quarterback's throwing motion in American football. *Journal of Applied Biomechanics* 11:443-459

Ren, Lei.; Jones, Richard K. and Howard, David. (2008) Whole body inverse dynamics over a complete gait cycle based only on measured kinematics. *Journal of Biomechanics* 41:2750-2759

Renkawitz, Tobias.; Boluki, Daniel and Grifka, Joachim. (2006) The association of low back pain, neuromuscular imbalance, and trunk extension strength in athletes. *The Spine Journal* 6:673-683

Robb, Andrew J.; Fleisig, Glenn.; Wilk, Kevin.; Macrina, Leonard.; Bolt, Becky. (2010) Passive range of motion of the hips and their relationships with pitching biomechanics and ball velocity in professional baseball pitchers. *The American Journal of Sports Medicine* 38(12): 2487-2493

Robertson, D. Gordon. E.; Caldwell, Graham E.; Hamill, Joseph.; Kamen, Gary and Whittlesey, Saunders N. (2004) *Research Methods in Biomechanics.* Champaign, IL:Human Kinetics, 308p.

Sasakawa, Kei and Sakurai, Shinji. (2008) Biomechanical analysis of the sidearm throwing motion for distance of a flying disc: A comparison of skilled and unskilled ultimate players. *Sports Biomechanics* 7(3):311-321

Scott, Bob. (1976) *Lacrosse: Technique and Tradition.* Baltimore, John Hopkins University Press, 219p.

Seay, Joseph F.; Hasselquist, Leif.; Bensel, Carolyn K.; (2011) Carrying a riffle with both hands affects upper body transverse plane kinematics and pelvis trunk coordination. *Ergonomics* 54(2):187-196

SENIAM project- Sensor location (trunk and lower back) www.seniam.org , consulted on June 24, 2010.

Seroyer, Shane T.; Nho, Shane J.; Bach, Bernard R.; Bush, Joseph, Charles A.; Nicholson, Gregory P.; Romeo, Anthony A. (2010) The kinetic chain in overhand pitching: its potential role for performance enhancement and injury prevention. *Sports Health* 2(2):135-146

Shirley, D.; Hodges, P.W.; Eriksson, A.E.M. and Gandevia, S.C. (2003) Spinal stiffness changes throughout the respiratory cycle. *Journal of Applied Physiology* 95:1467-1475

Spencer, M., Losnegard, T., Hallen, J. and Hopkins, WG., (2013) Variability and predictability of performance times of elite cross-country skiers. *International Journal of Sports Physiology Performance* Epub, June 25 2013

Sports Science. "A New View of Statistics" http://www.sportsci.org/resource/stats/precision.html consulted July 18th, 2013

Statistics Canada. "5.0 Data Accuracy and Quality." www.statcan.gc.ca/pub/13f0026m/2007001/ch5-eng.htm consulted July 22, 2013

Stodden, David F.; Fleisig, Glenn S.; McLean, Scott P and Andrews, James R. (2005) Relationship of biomechanical factors to baseball pitching velocity within pitcher variation. *Journal of Applied Biomechanics* 21:44-56

Stodden, David F.; Campbell, Brian M. and Moyer, Todd M. (2008) Comparison of trunk kinematics in trunk training exercises and throwing. *Journal of Strength and Conditioning Research* 22(1):112-118

Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM), Recommendations for Sensor Location in Trunk and (Lower) Back Muscles. http://www.seniam.org, consulted 24 June 2010.

Van den Tillaar, Roland and Ettema, Gertjan. (2007) A three-dimensional analysis of overarm throwing in experienced handball players. *Journal of Applied Biomechanics* 23:12-19

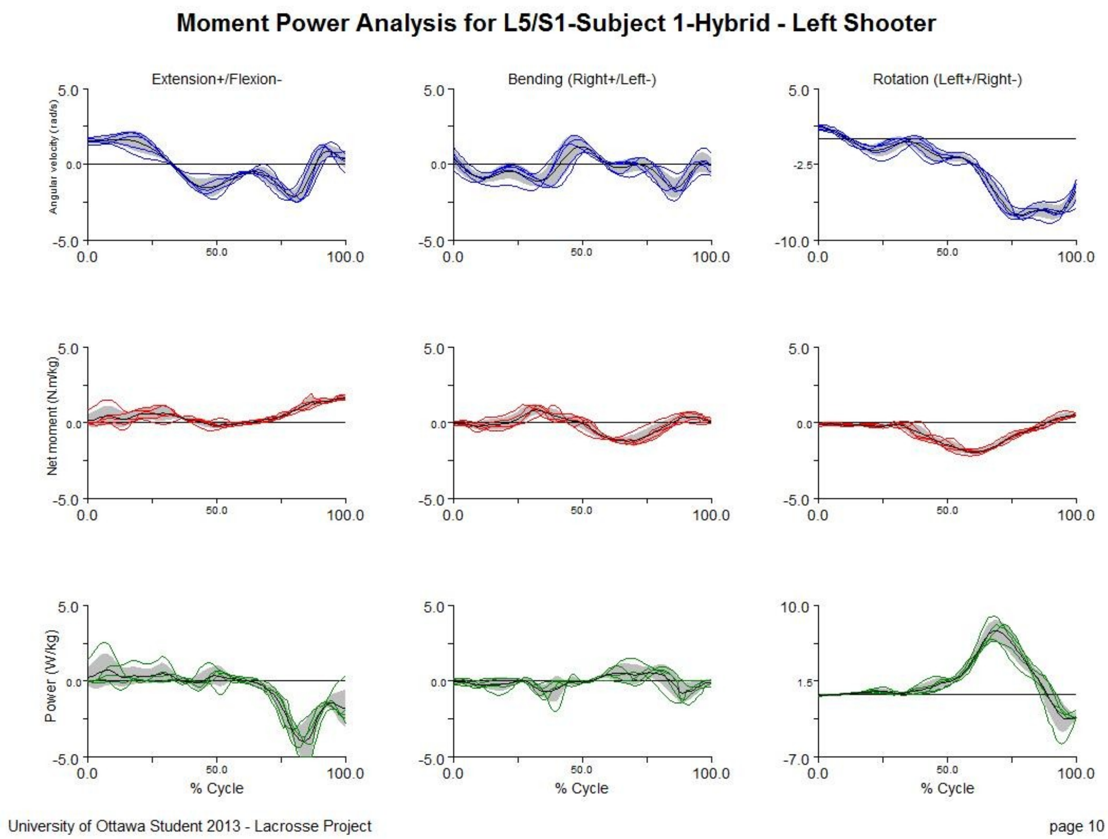
Werner, Sherry L.; Suri, Misty.; Guido, John A.; Meister, Keith and Jones, Deryk (2008) Relationships between ball velocity and throwing mechanics in collegiate baseball pitchers. *Journal of Shoulder and Elbow Surgery* 17(6):905-908

Wight, Jeff.; Richards, James and Hall, Susan. (2004) Influence of pelvis rotation styles on baseball pitching mechanics. *Sports Biomechanics* 3(1):67-84

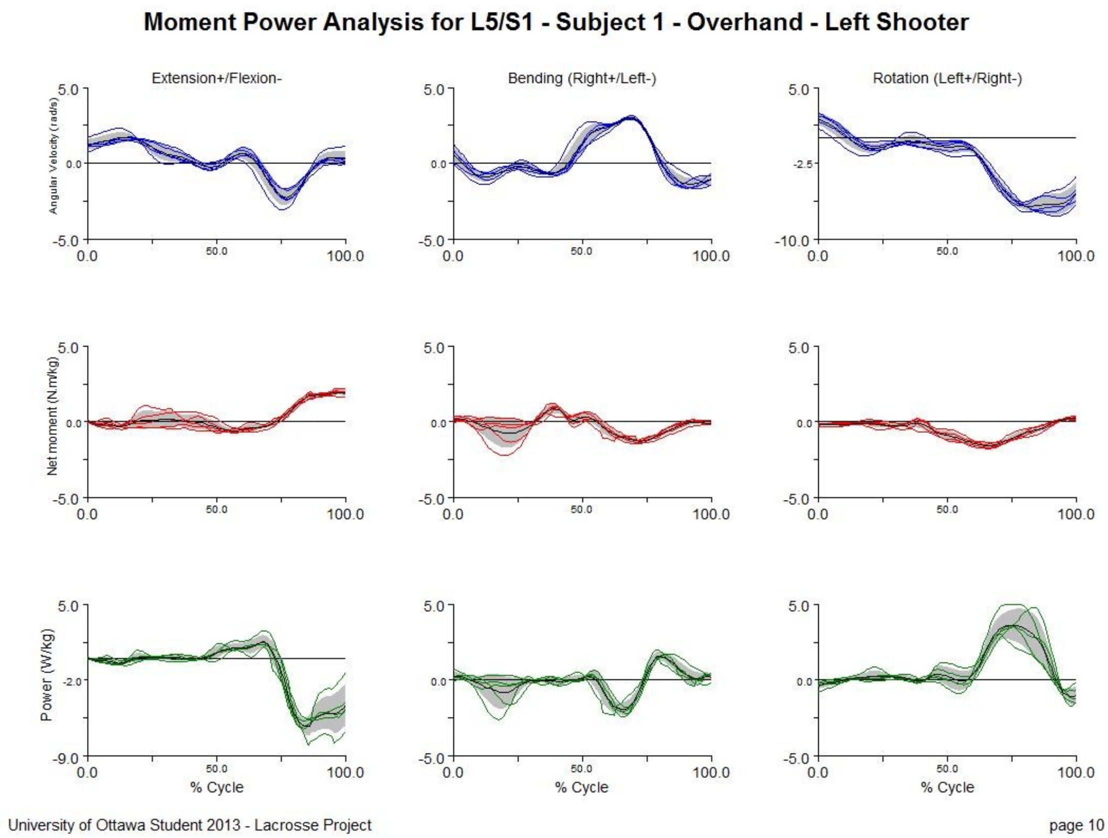
Yang, Jaynie F. and Winter, David A. (1983) Electromyography reliability in maximal and submaximal isometric contractions. *Archives of Physical and Medical Rehabilitation* 64:417-420

Appendices

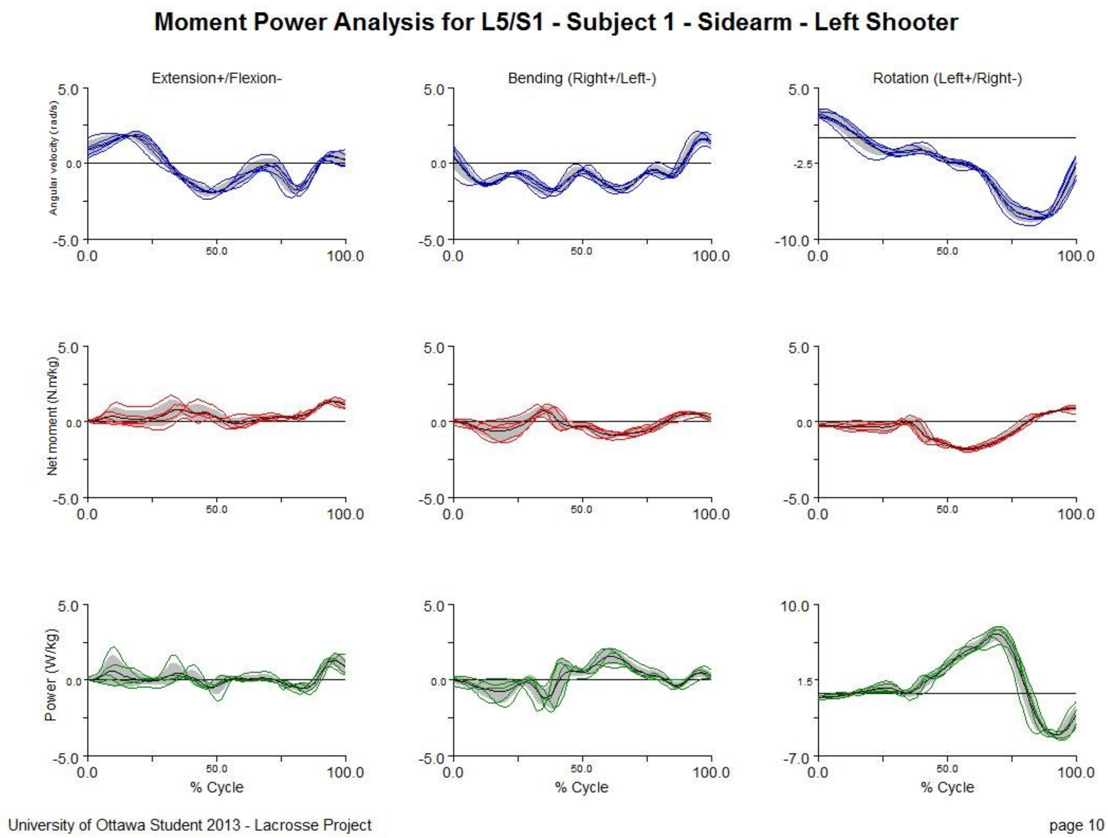
Appendix 1



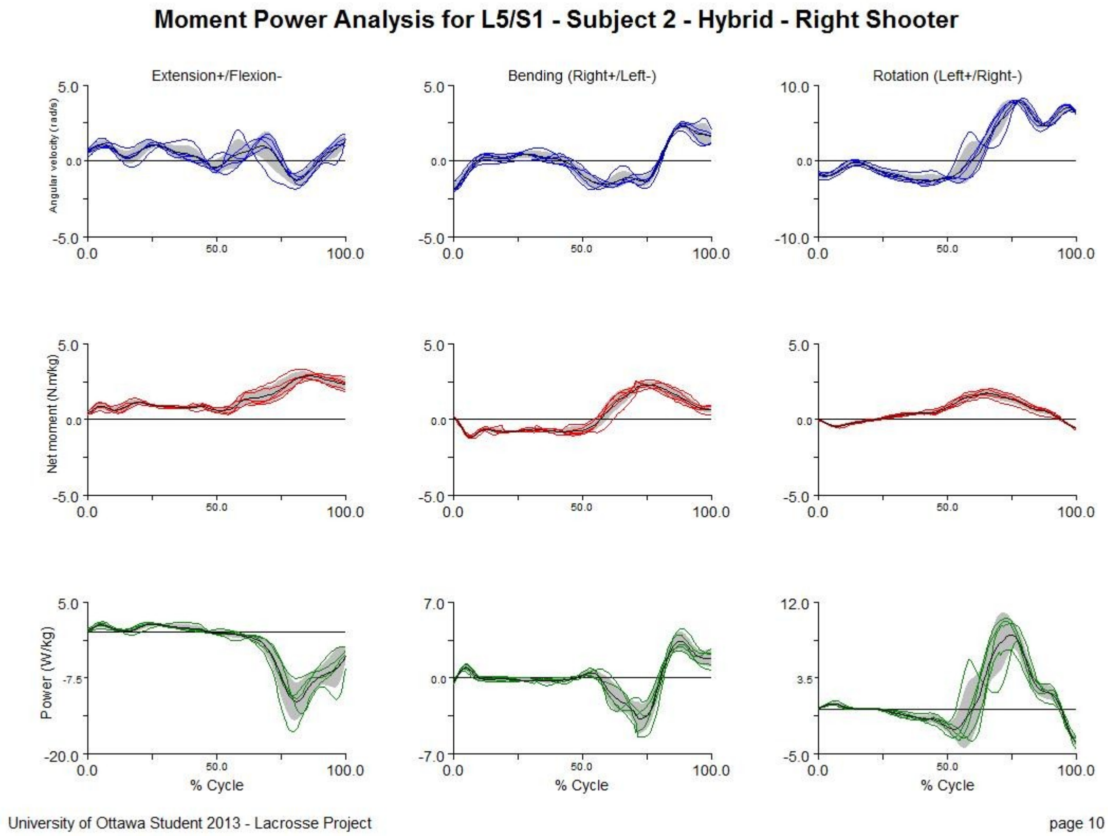
Appendix 2


Moment Power Analysis for L5/S1 - Subject 1 - Overhand - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular Velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

Appendix 3

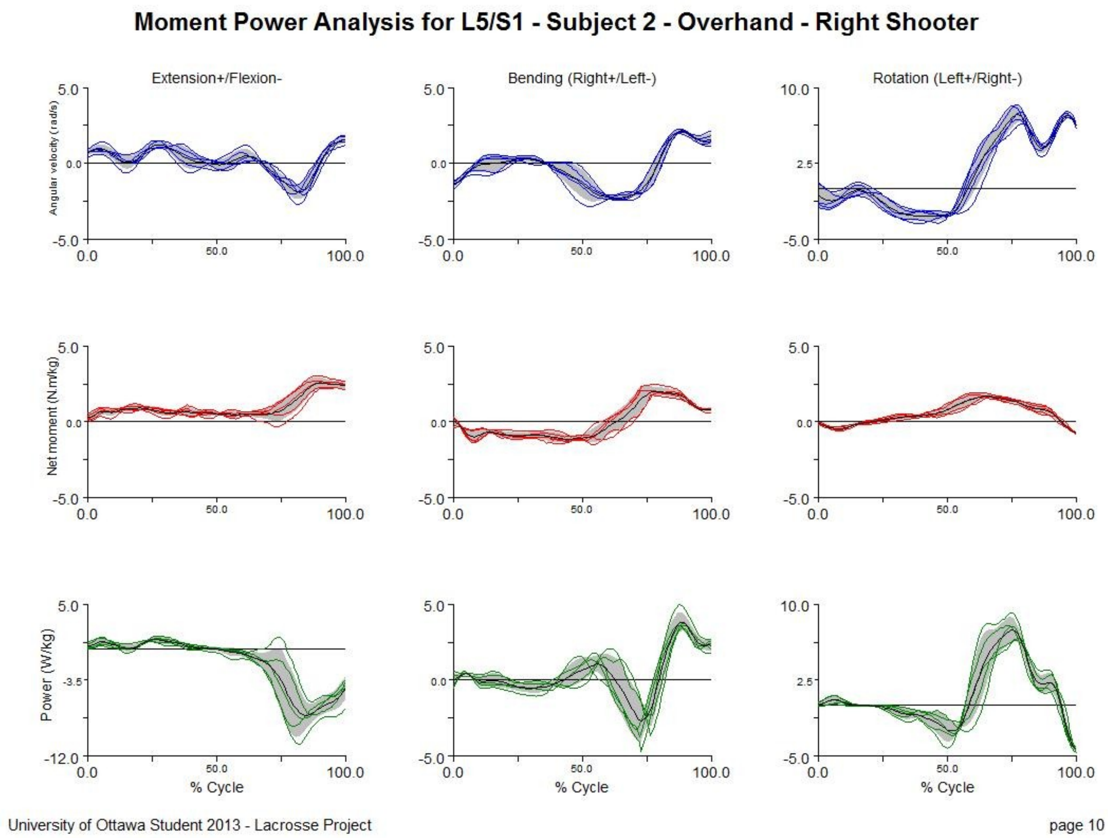

Moment Power Analysis for L5/S1 - Subject 1 - Sidearm - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
% Cycle
% Cycle
5.0
0.0
-5.0
-2.5
-10.0
10.0
1.5
-7.0
50.0
100.0
University of Ottawa Student 2013 - Lacrosse Project
page 10

Appendix 4

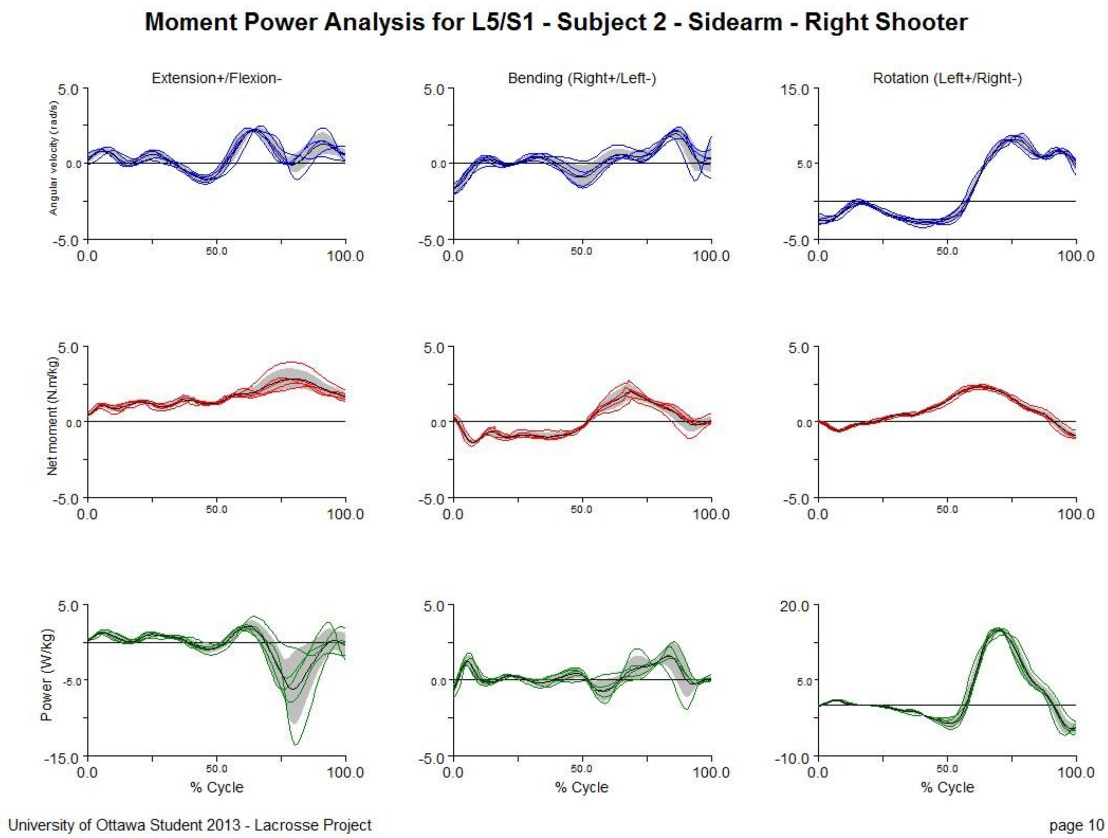


Moment Power Analysis for L5/S1 - Subject 2 - Hybrid - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

Appendix 5

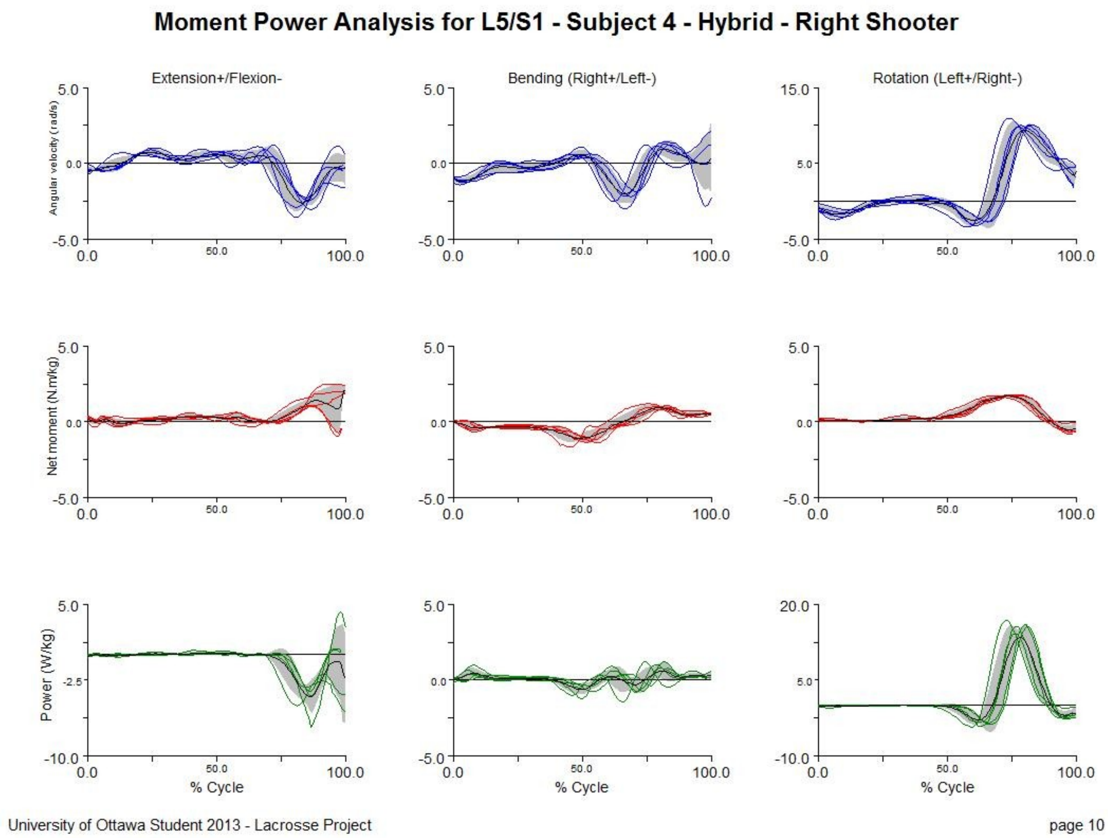

Moment Power Analysis for L5/S1 - Subject 2 - Overhand - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
% Cycle
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

Appendix 6

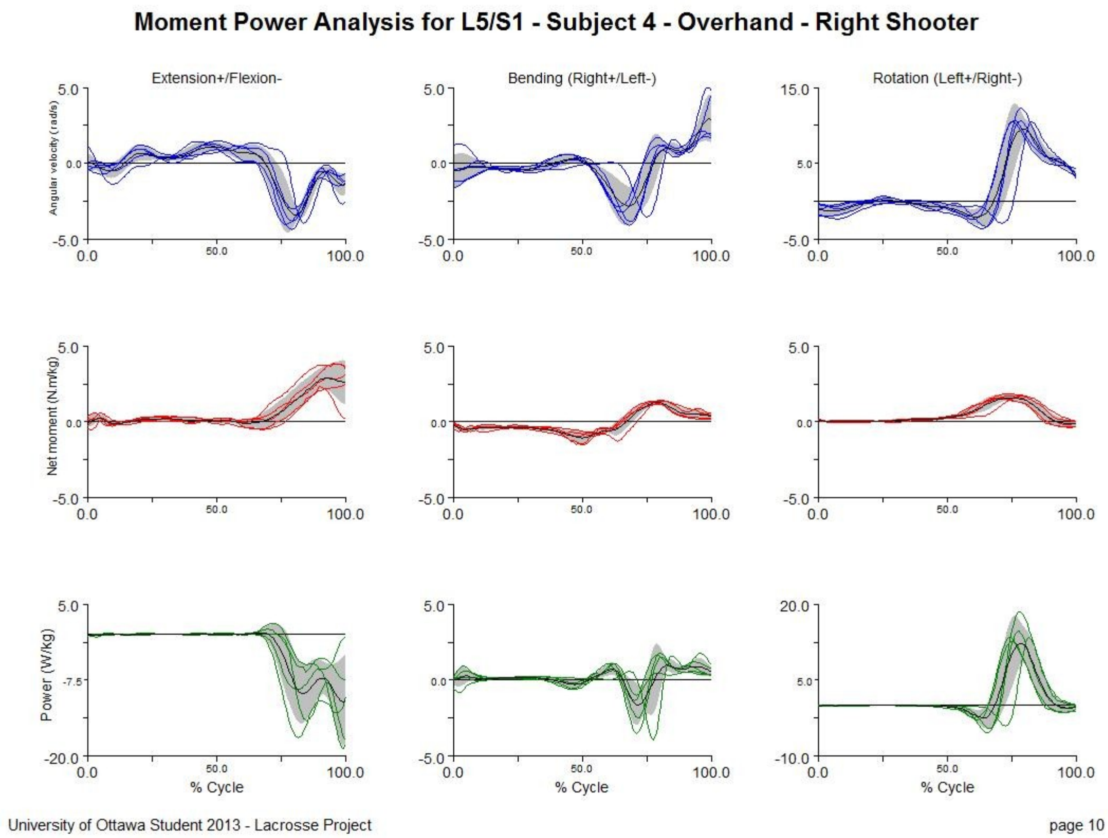


Moment Power Analysis for L5/S1 - Subject 2 - Sidearm - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

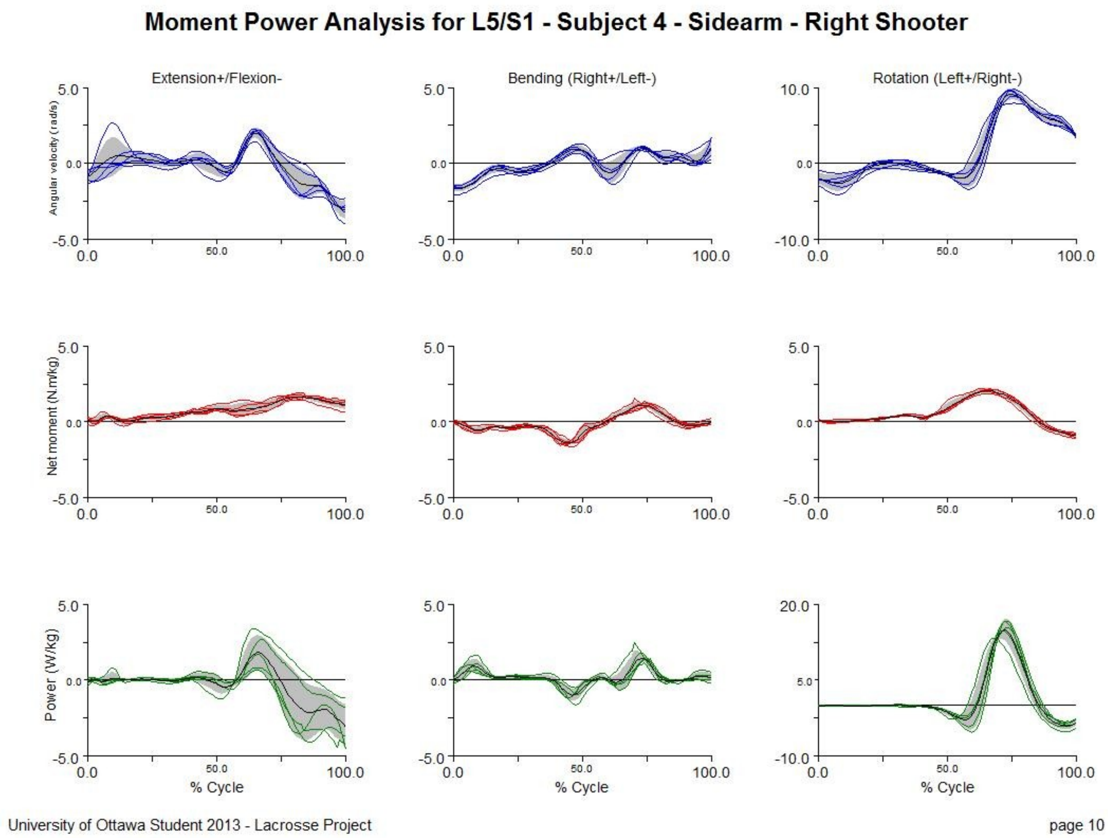
Appendix 7


Moment Power Analysis for L5/S1 - Subject 4 - Hybrid - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

Appendix 8

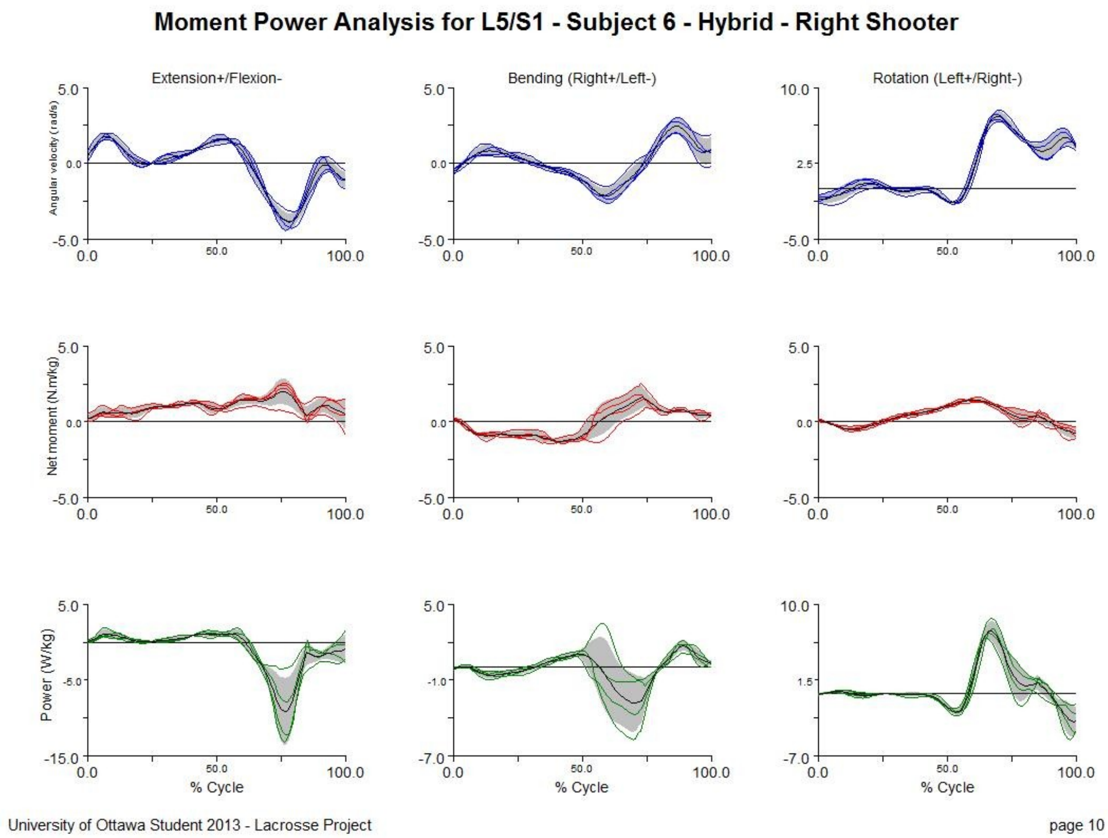

Moment Power Analysis for L5/S1 - Subject 4 - Overhand - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
% Cycle
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

Appendix 9

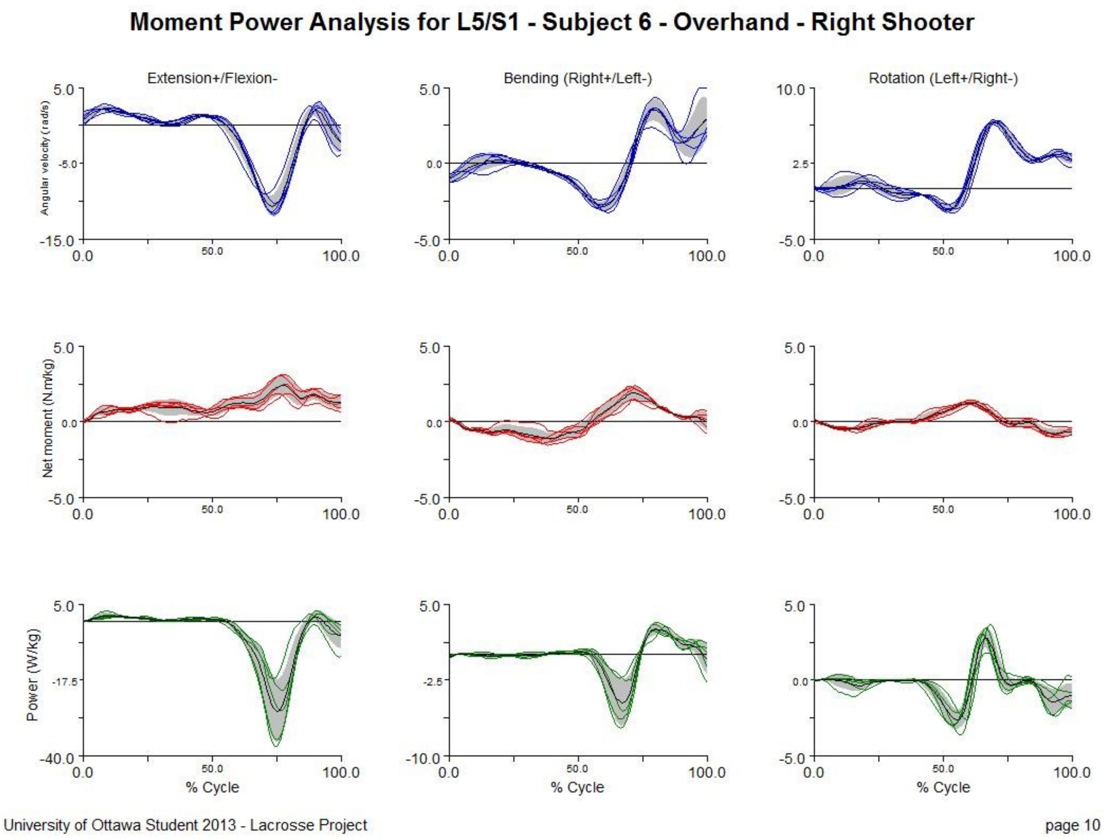


Moment Power Analysis for L5/S1 - Subject 4 - Sidearm - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
% Cycle
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

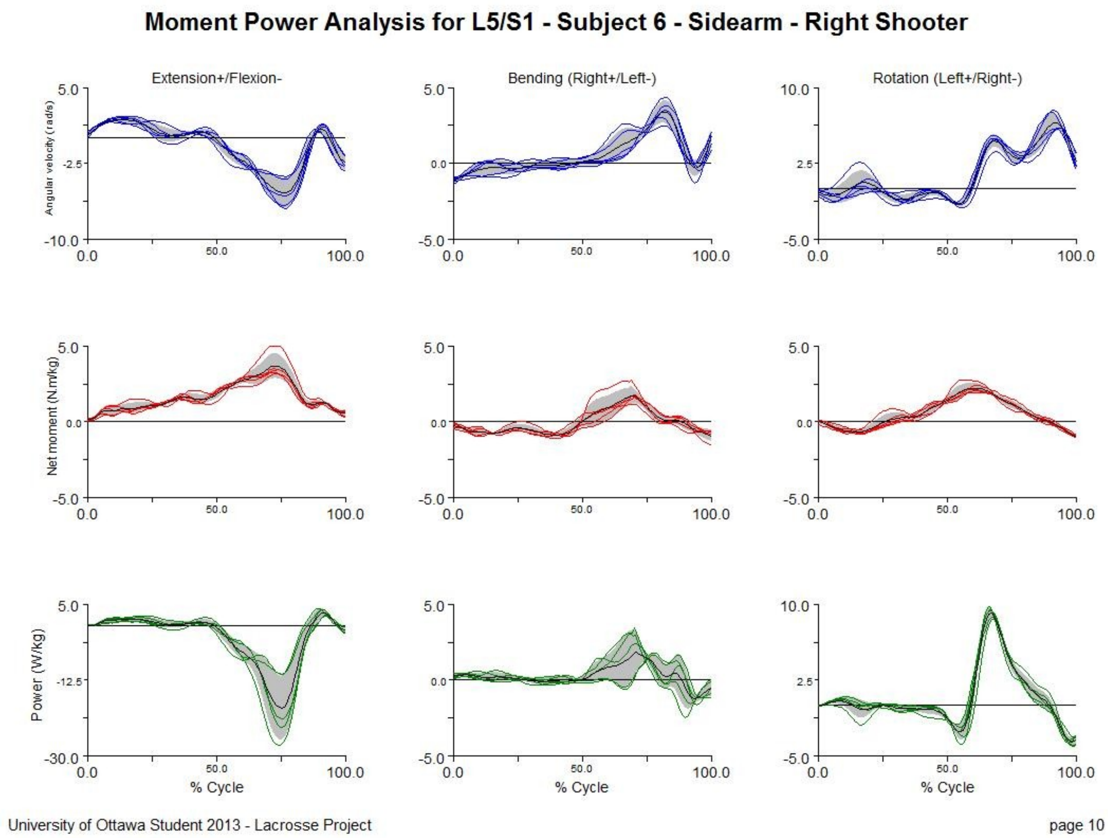
Appendix 10


Moment Power Analysis for L5/S1 - Subject 6 - Hybrid - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

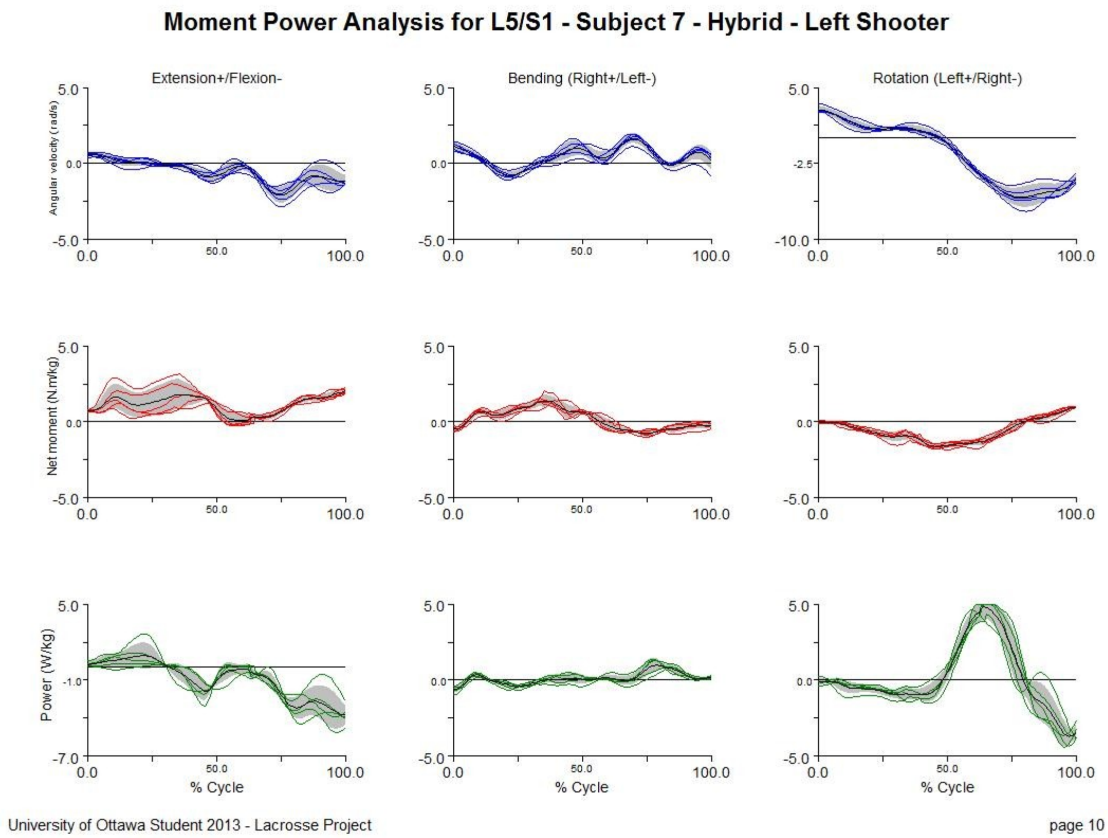
Appendix 11


Moment Power Analysis for L5/S1 - Subject 6 - Overhand - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

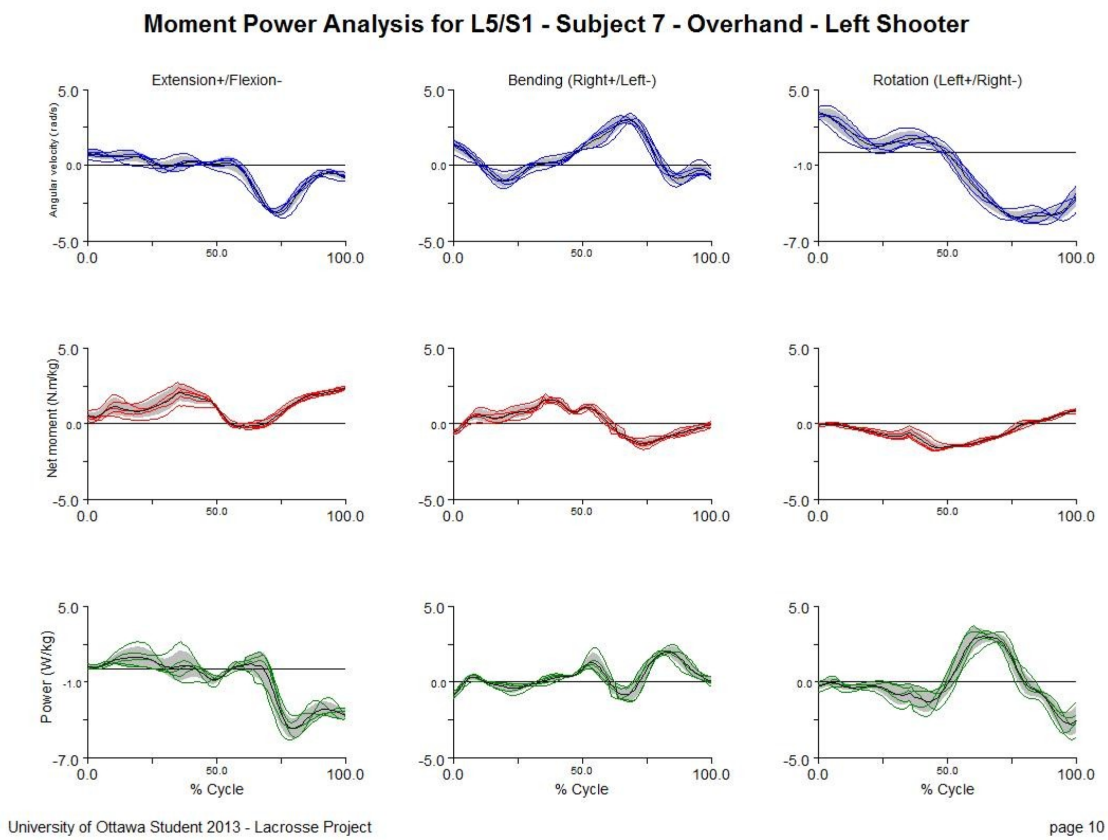
Appendix 12


Moment Power Analysis for L5/S1 - Subject 6 - Sidearm - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

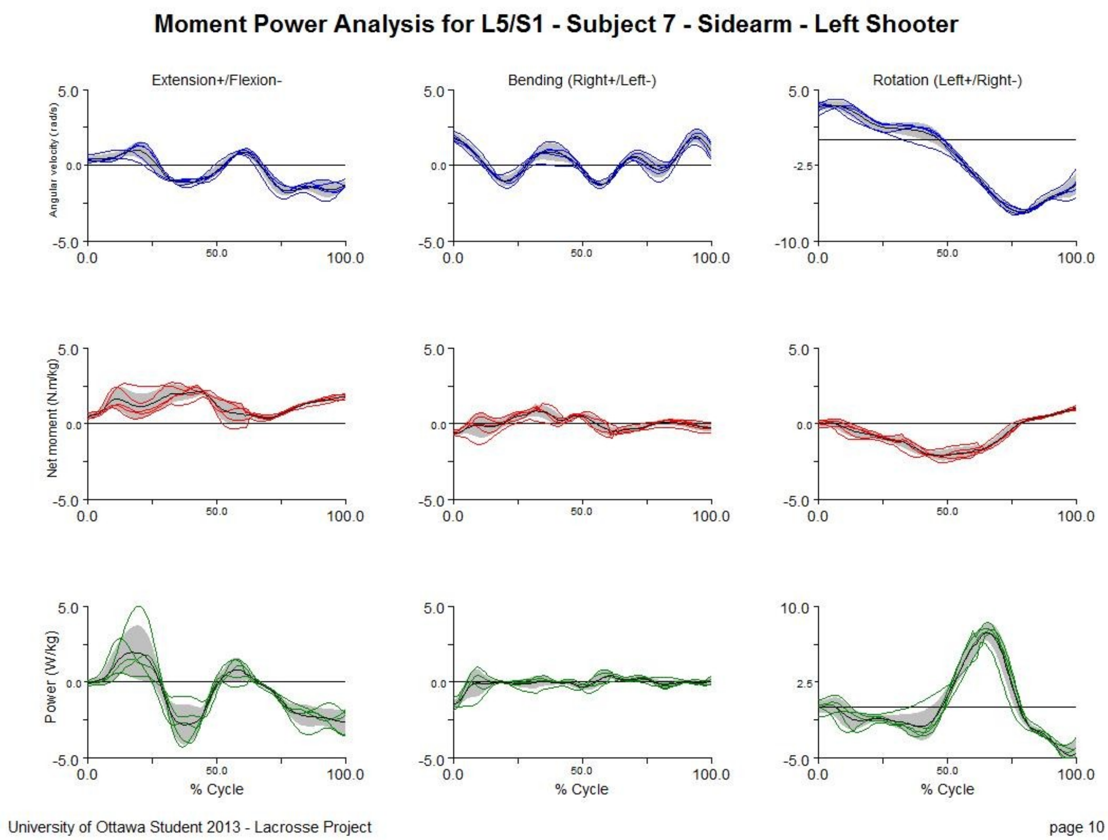
Appendix 13


Moment Power Analysis for L5/S1 - Subject 7 - Hybrid - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

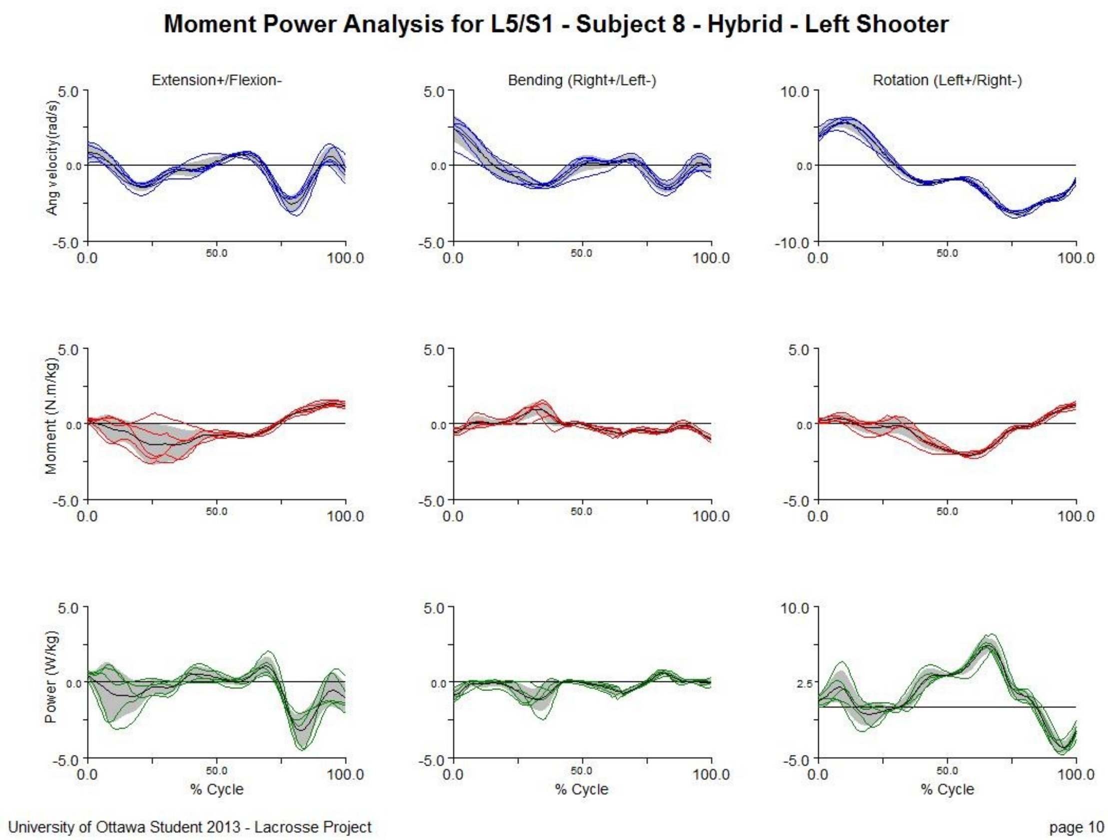
Appendix 14


Moment Power Analysis for L5/S1 - Subject 7 - Overhand - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

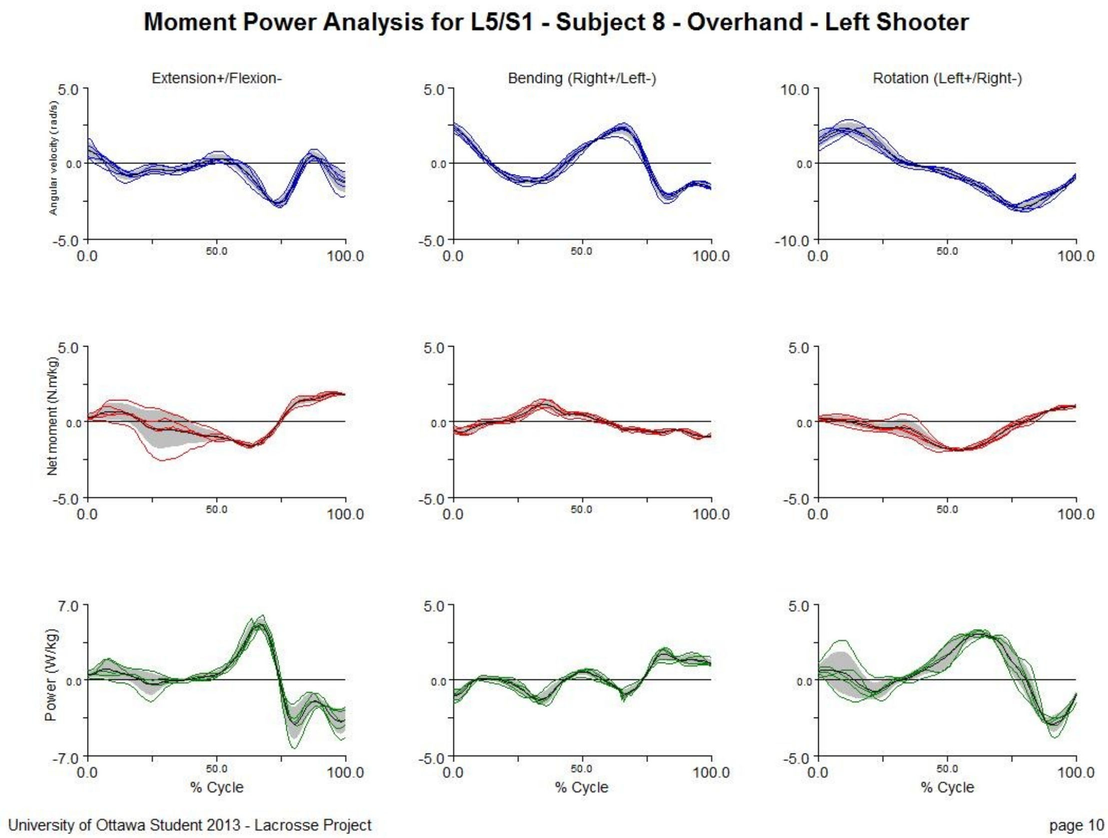
Appendix 15


Moment Power Analysis for L5/S1 - Subject 7 - Sidearm - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
% Cycle
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

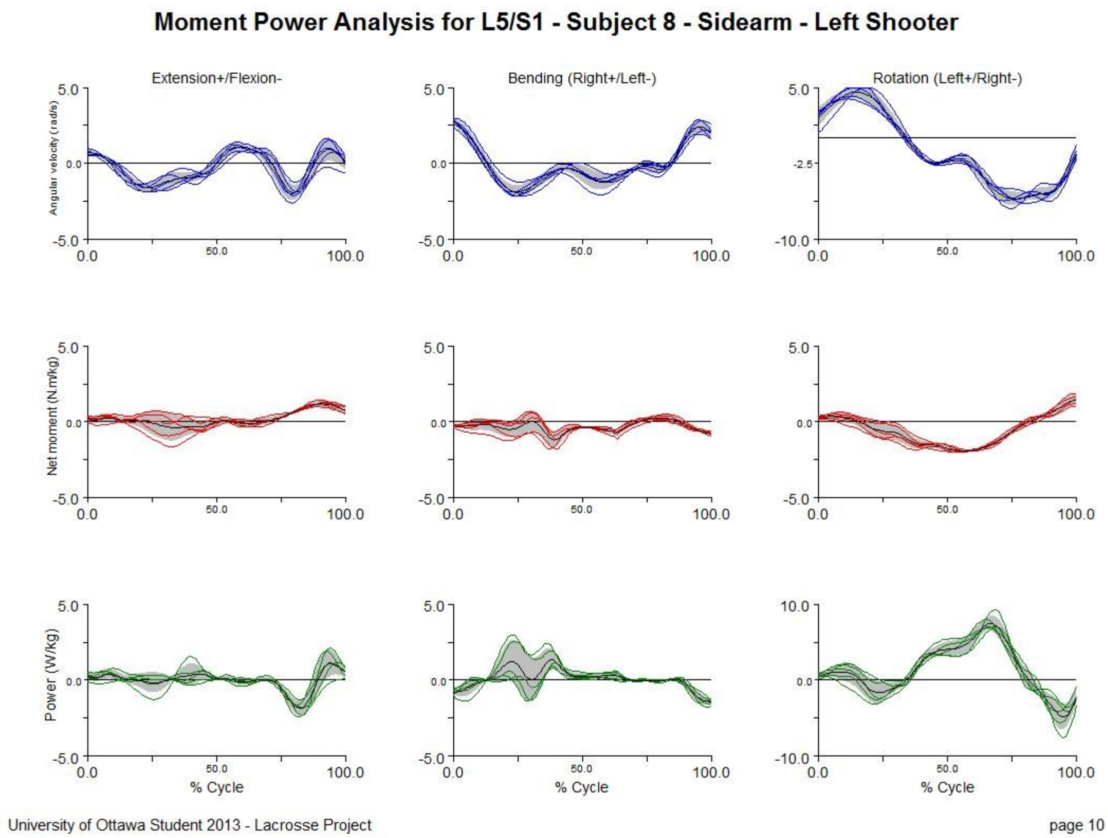
Appendix 16


Moment Power Analysis for L5/S1 - Subject 8 - Hybrid - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Ang velocity(rad/s)
Moment (N.m/kg)
Power (W/kg)
% Cycle
% Cycle
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

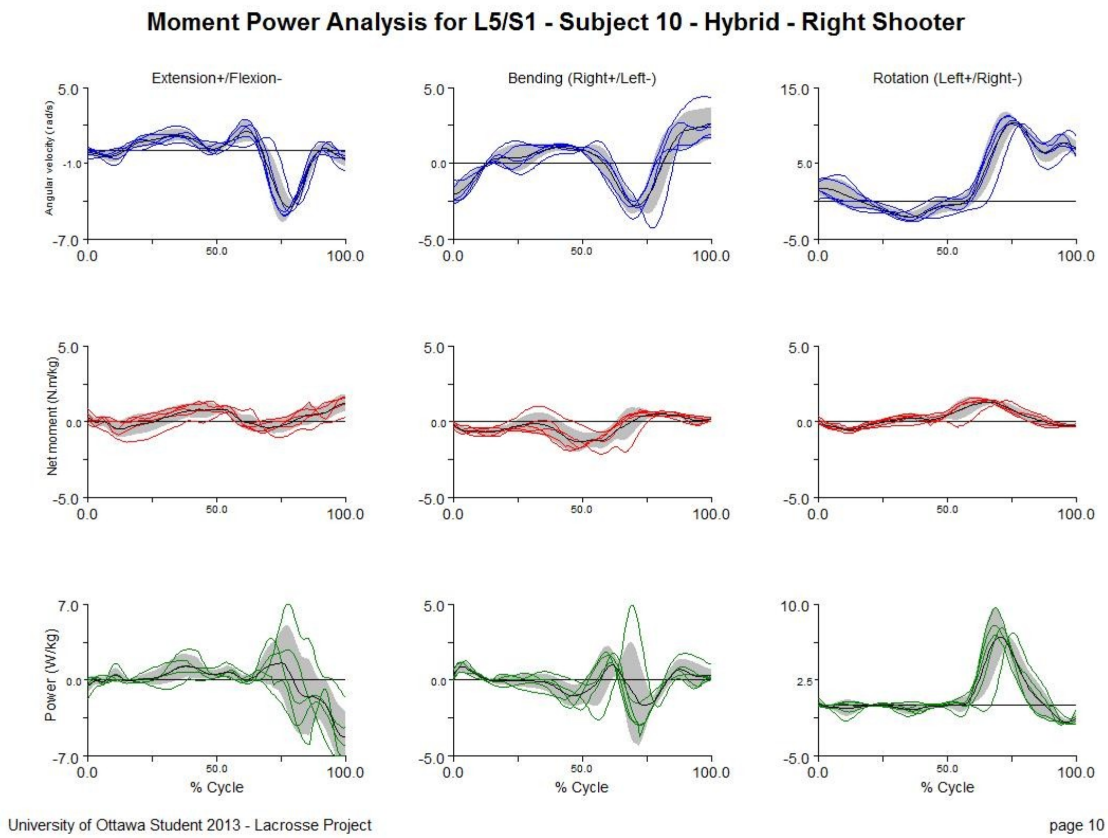
Appendix 17


Moment Power Analysis for L5/S1 - Subject 8 - Overhand - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

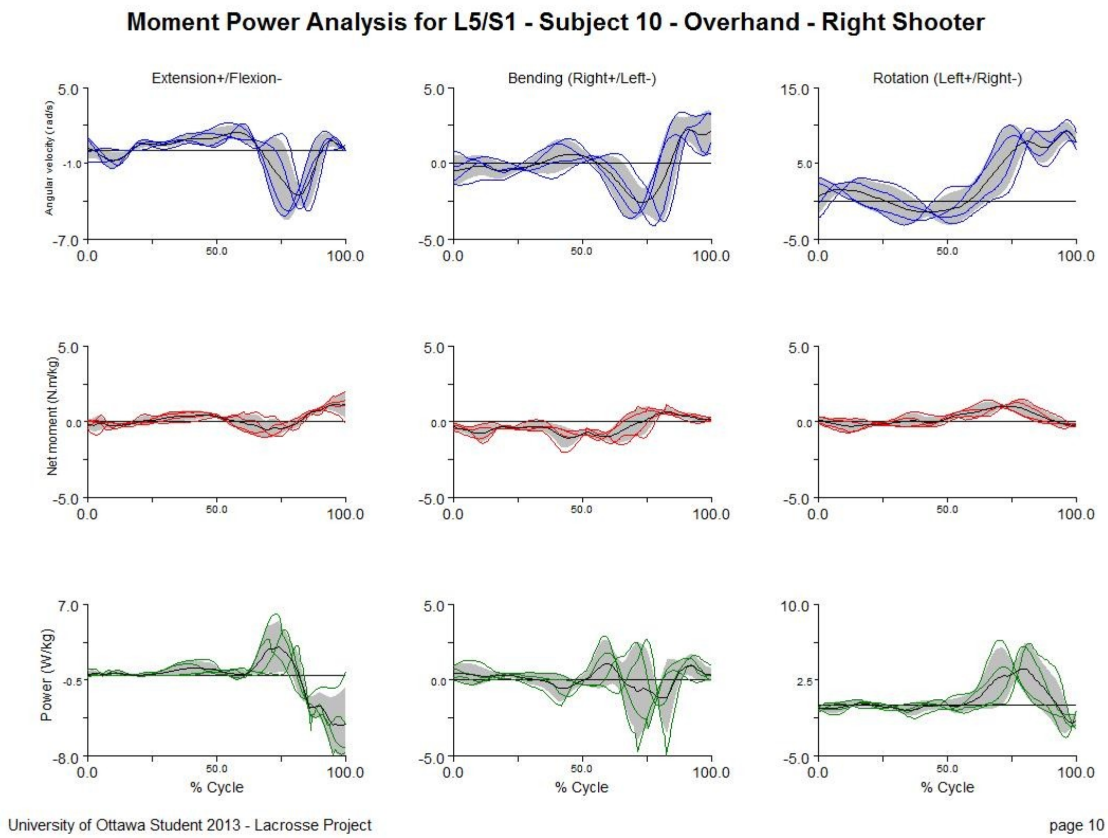
Appendix 18


Moment Power Analysis for L5/S1 - Subject 8 - Sidearm - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

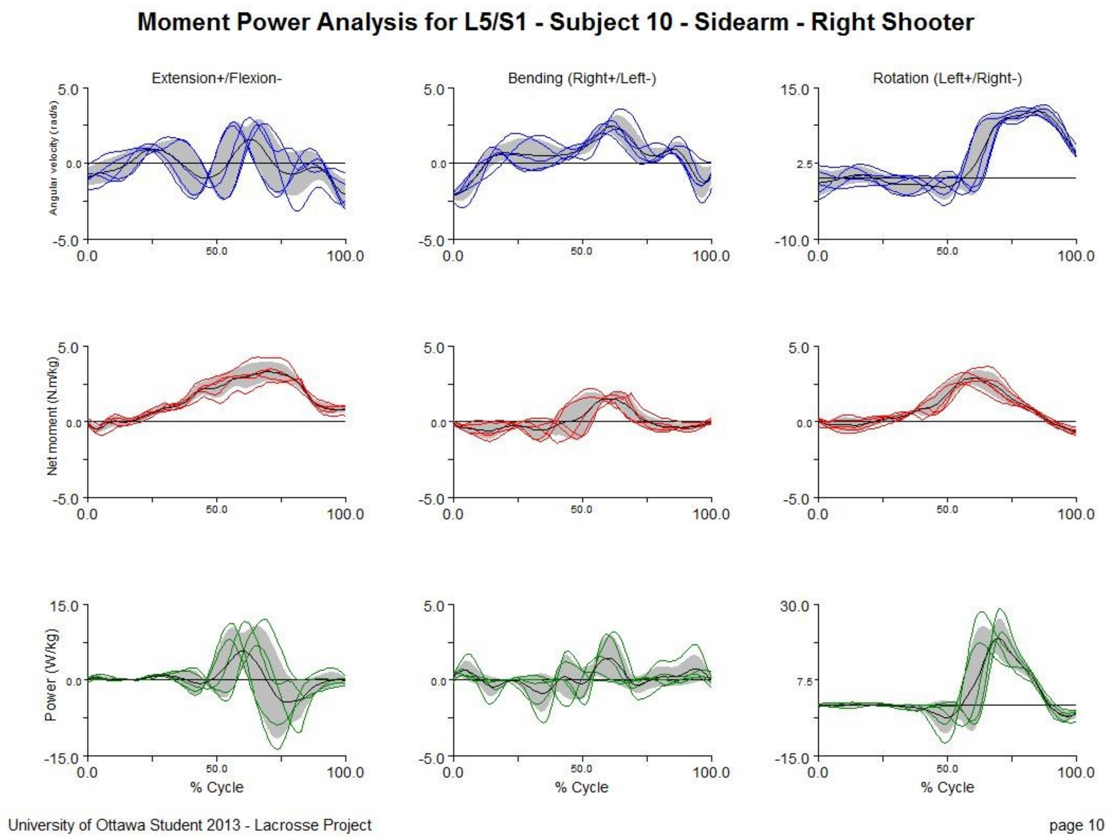
Appendix 19


Moment Power Analysis for L5/S1 - Subject 10 - Hybrid - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
% Cycle
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

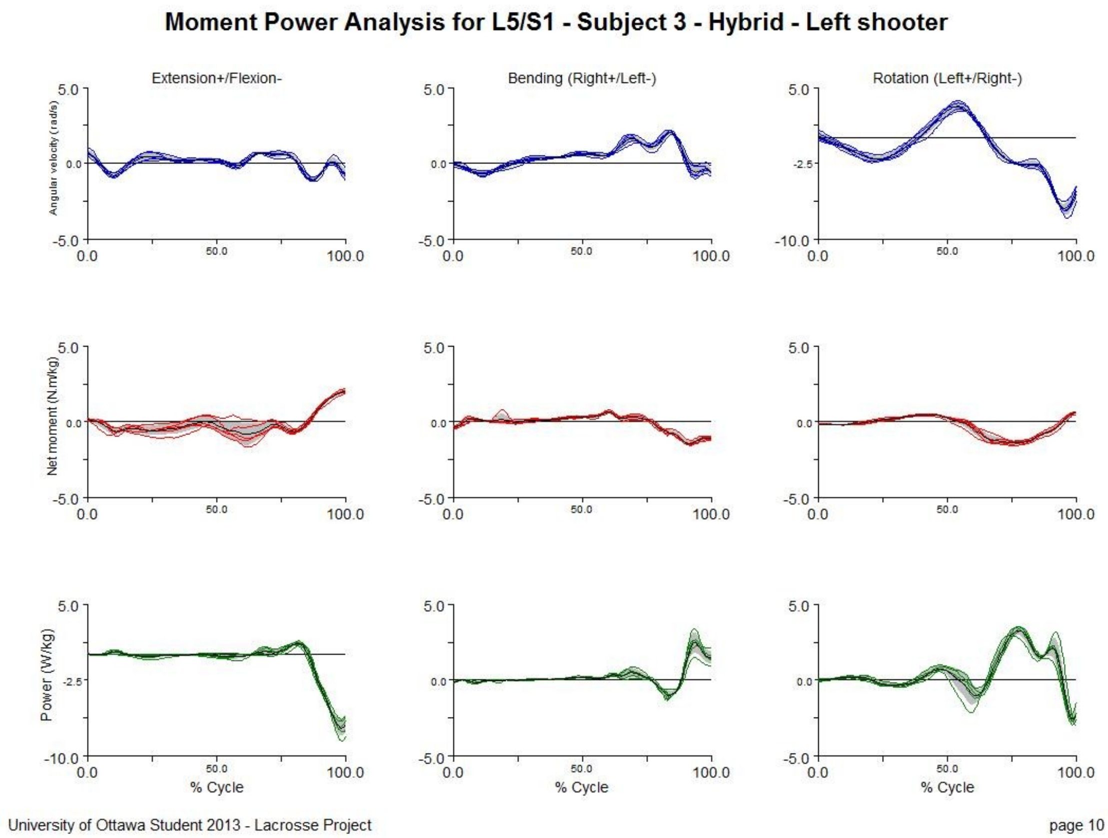
Appendix 20


Moment Power Analysis for L5/S1 - Subject 10 - Overhand - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

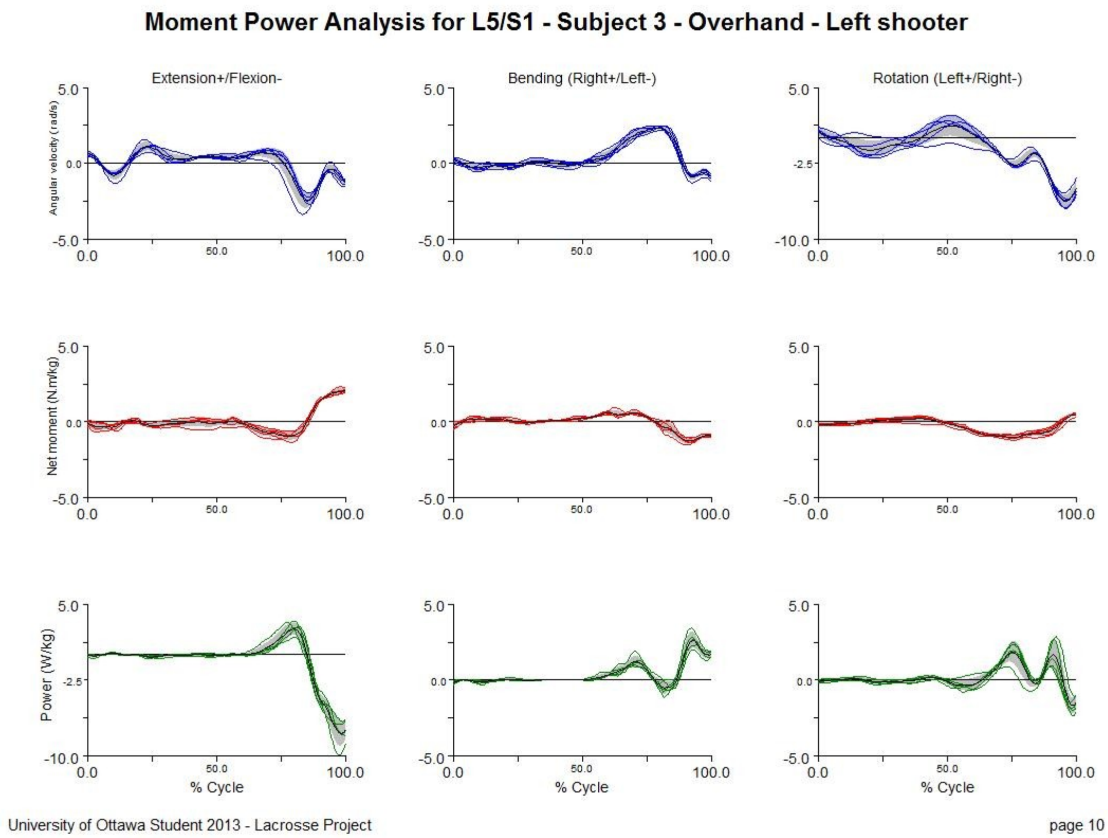
Appendix 21


Moment Power Analysis for L5/S1 - Subject 10 - Sidearm - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

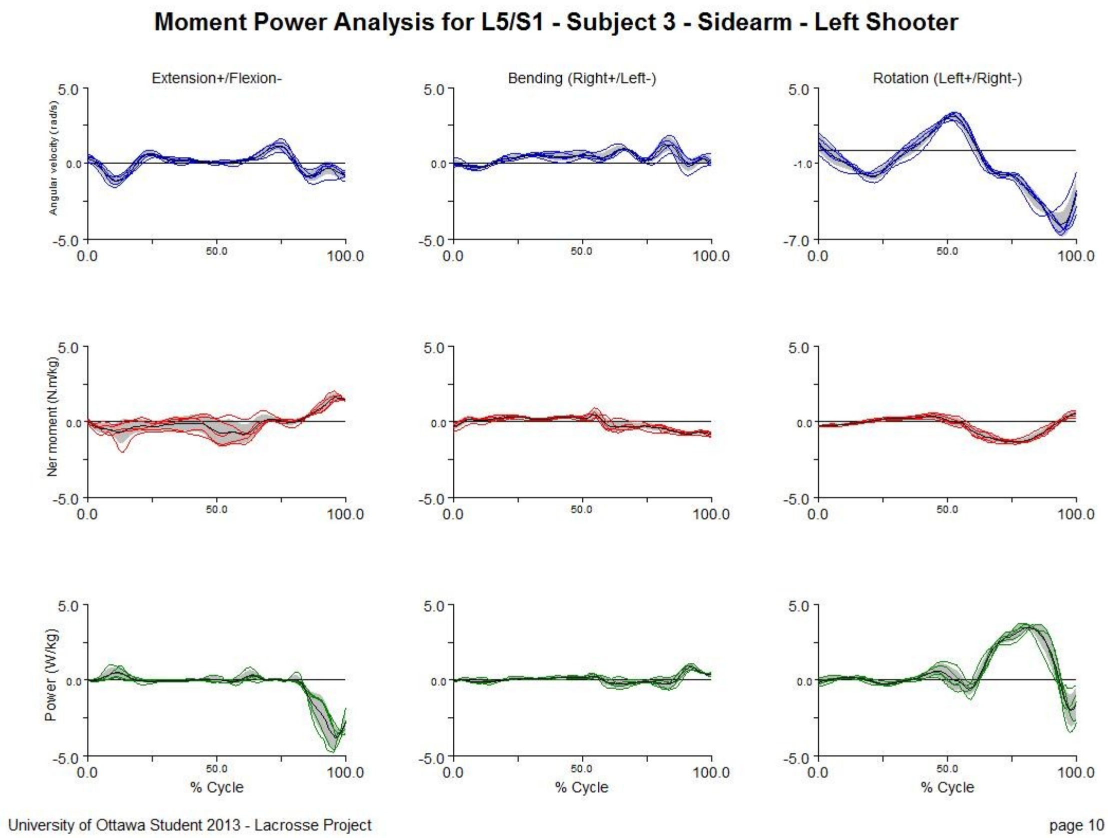
Appendix 22


Moment Power Analysis for L5/S1 - Subject 3 - Hybrid - Left shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

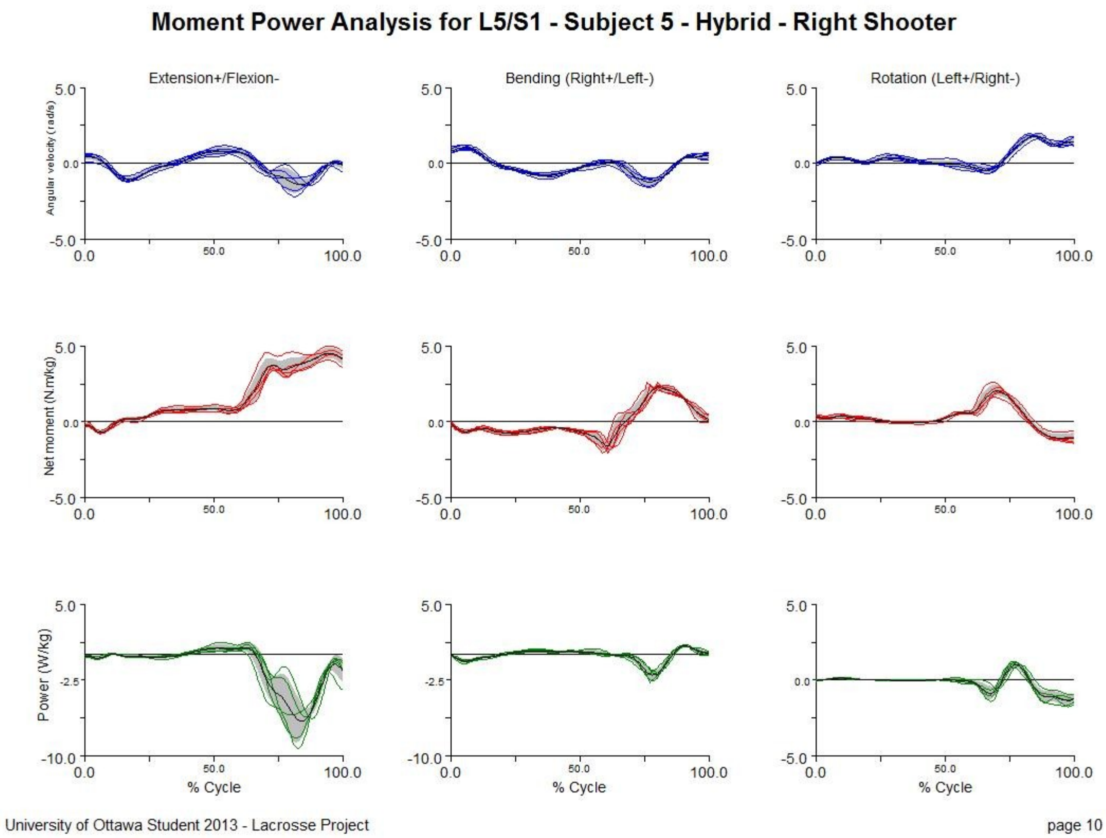
Appendix 23


Moment Power Analysis for L5/S1 - Subject 3 - Overhand - Left shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

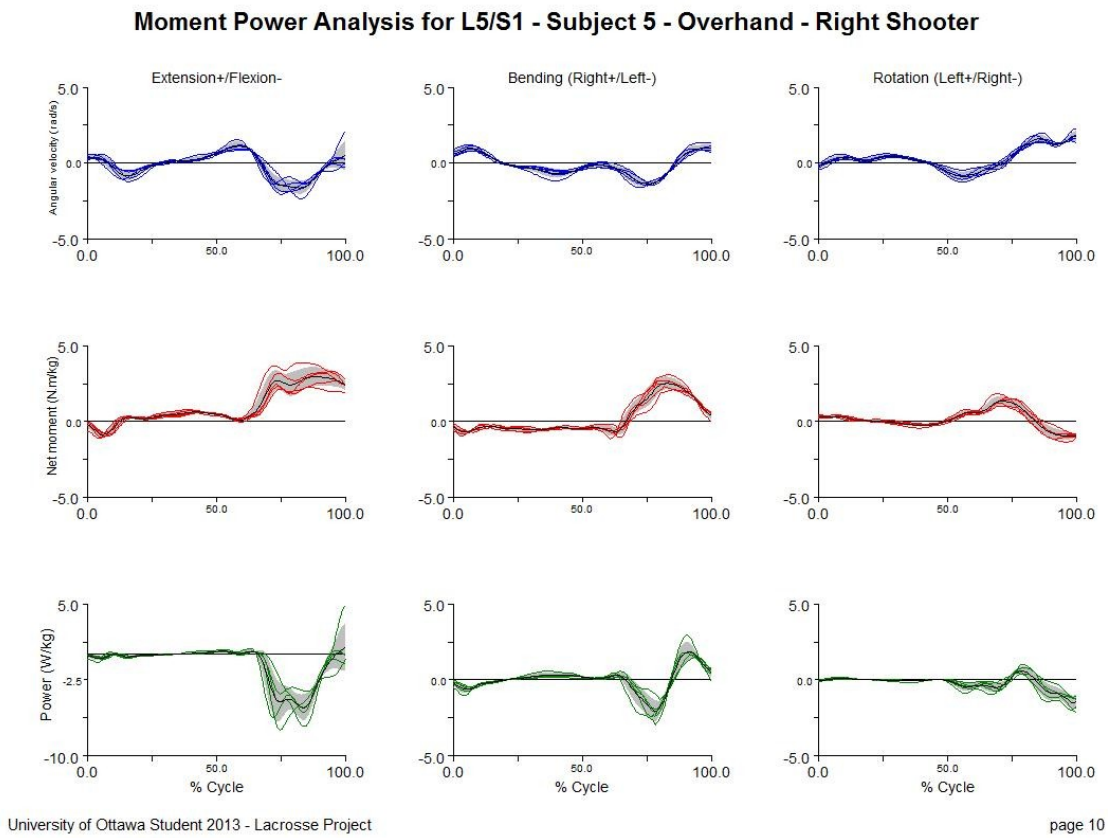
Appendix 24


Moment Power Analysis for L5/S1 - Subject 3 - Sidearm - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Ner moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

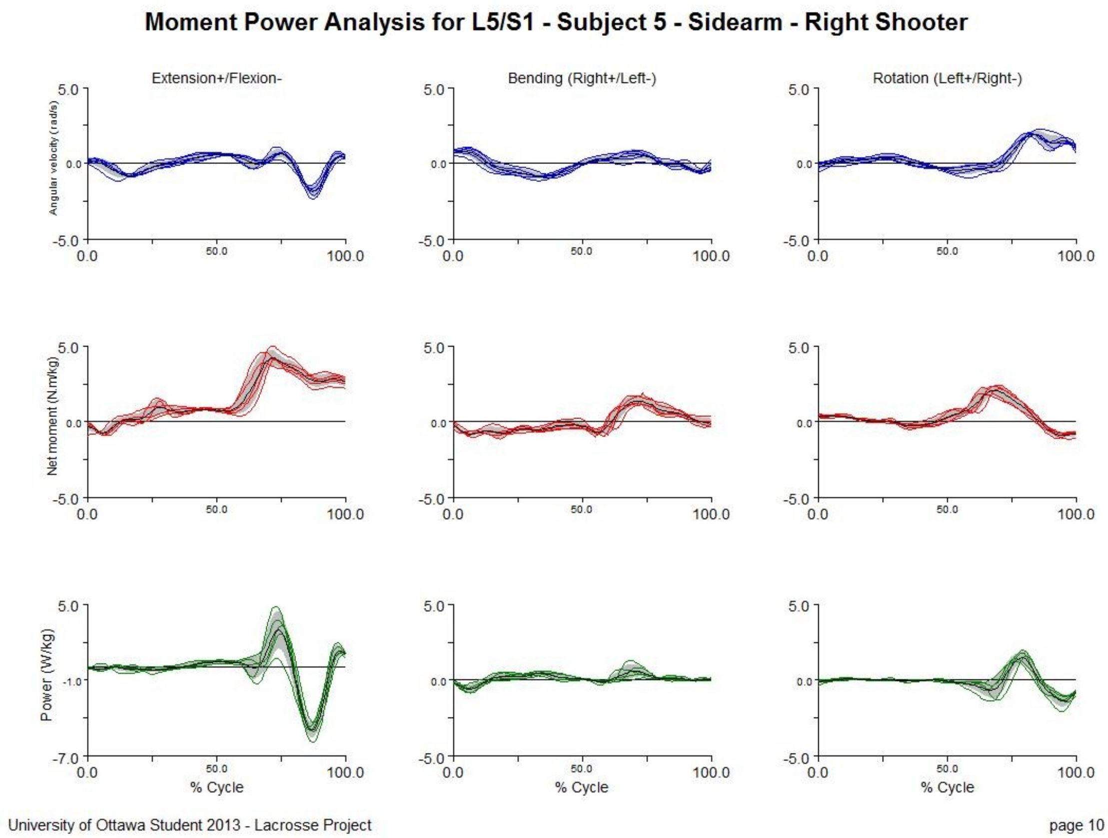
Appendix 25


Moment Power Analysis for L5/S1 - Subject 5 - Hybrid - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

Appendix 26

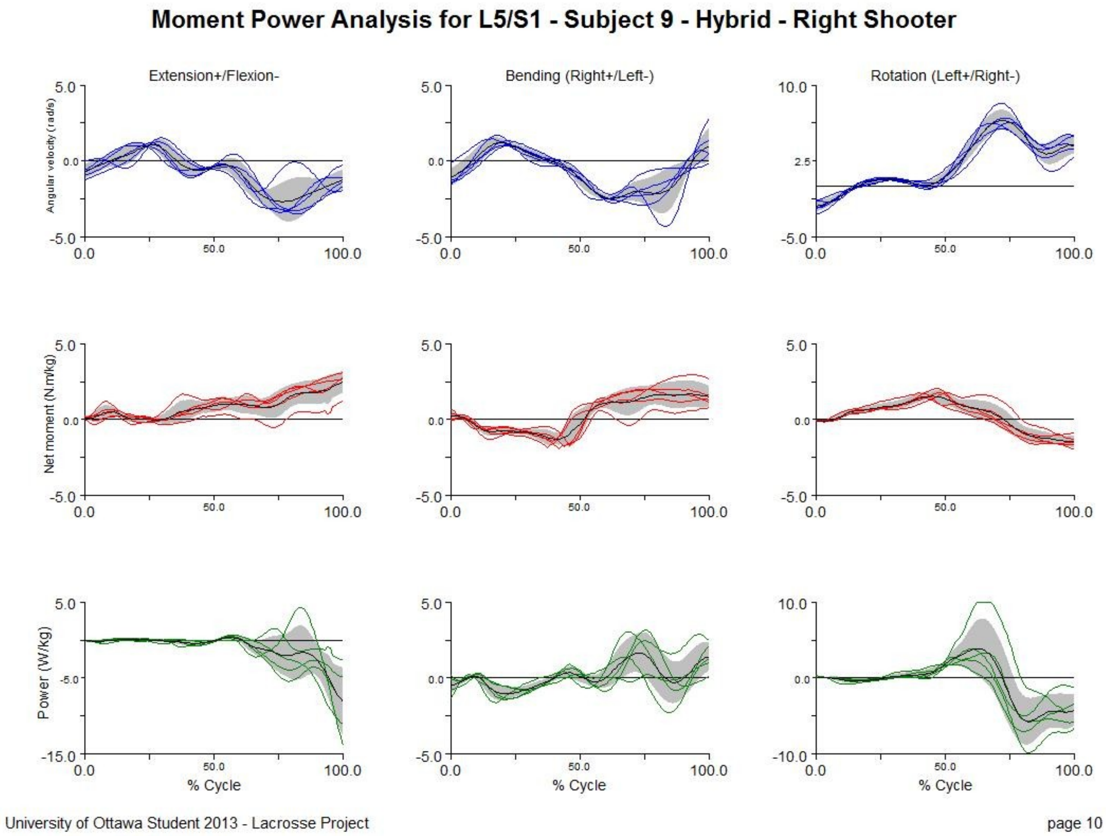

Moment Power Analysis for L5/S1 - Subject 5 - Overhand - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

Appendix 27



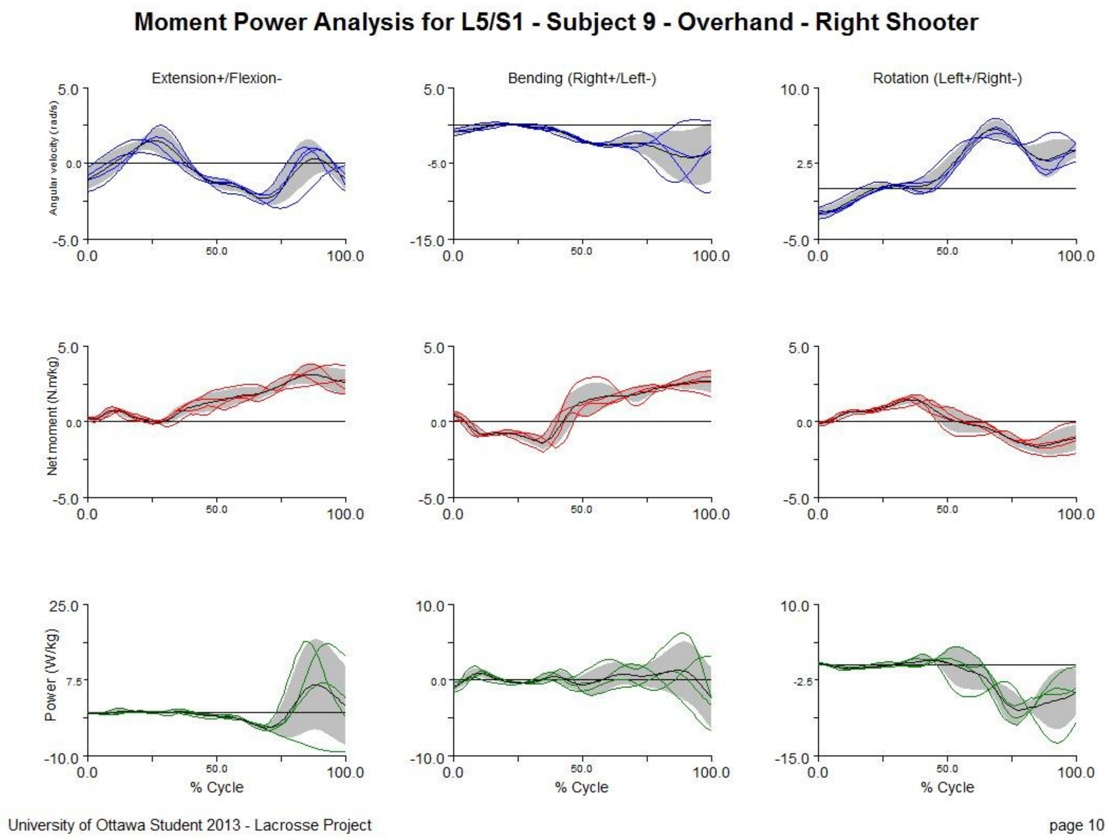
Moment Power Analysis for L5/S1 - Subject 5 - Sidearm - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

Appendix 28

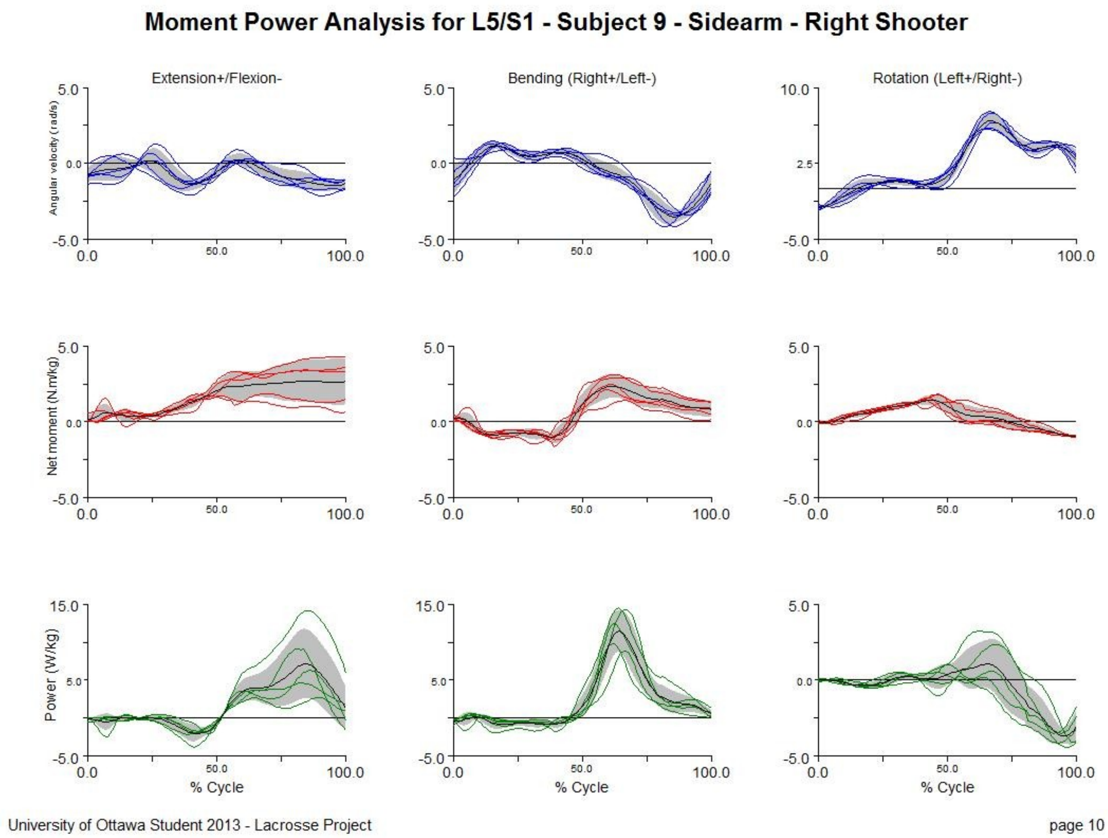


Moment Power Analysis for L5/S1 - Subject 9 - Hybrid - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

Appendix 29

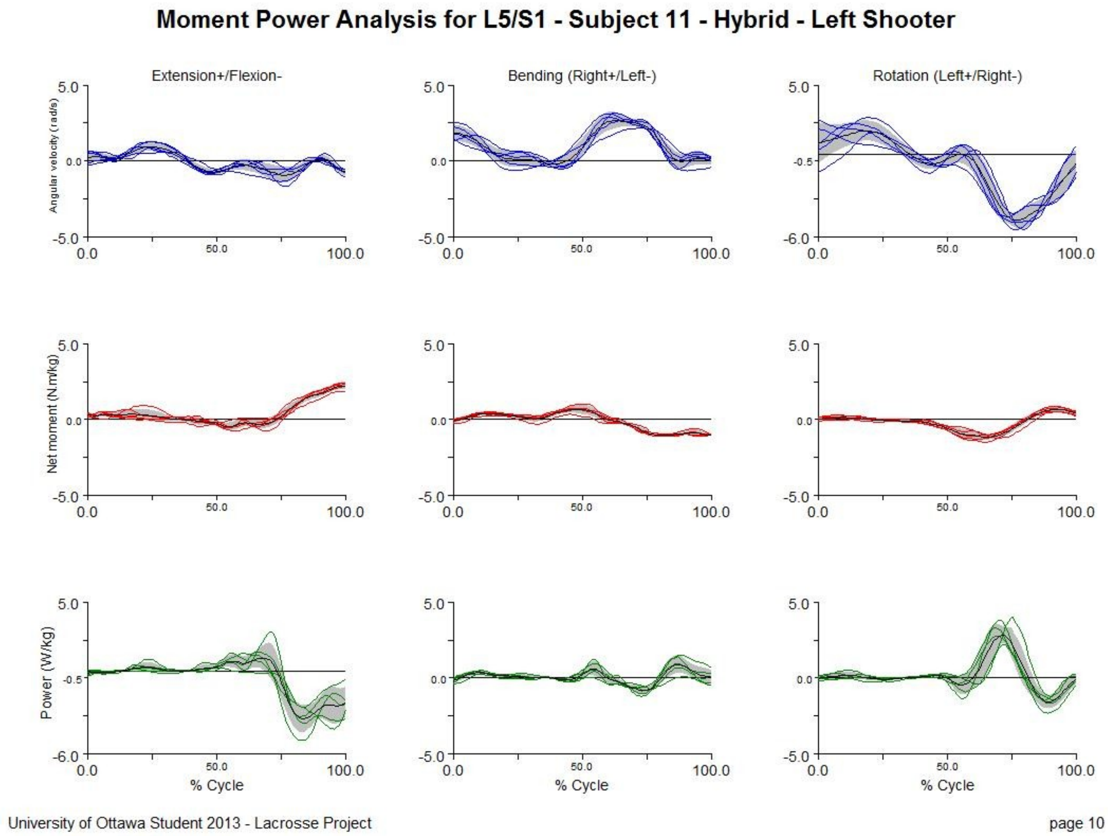

Moment Power Analysis for L5/S1 - Subject 9 - Overhand - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
% Cycle
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

Appendix 30

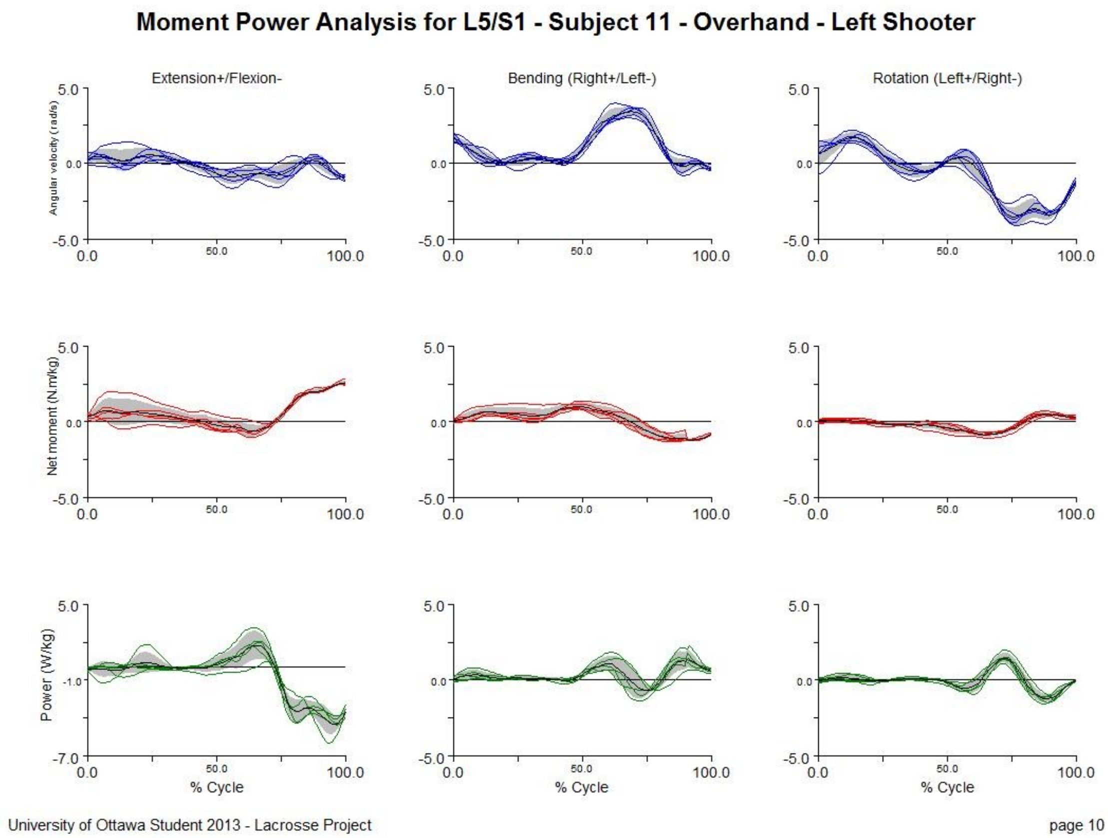


Moment Power Analysis for L5/S1 - Subject 9 - Sidearm - Right Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

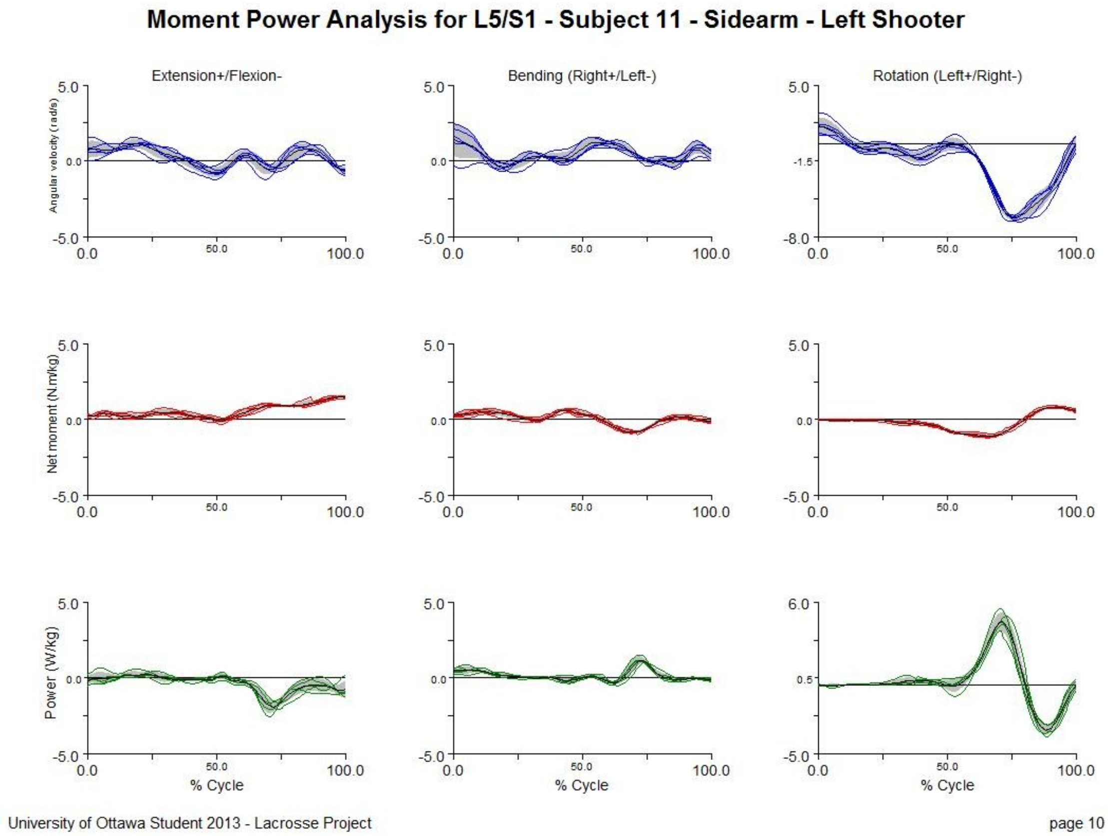
Appendix 31


Moment Power Analysis for L5/S1 - Subject 11 - Hybrid - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

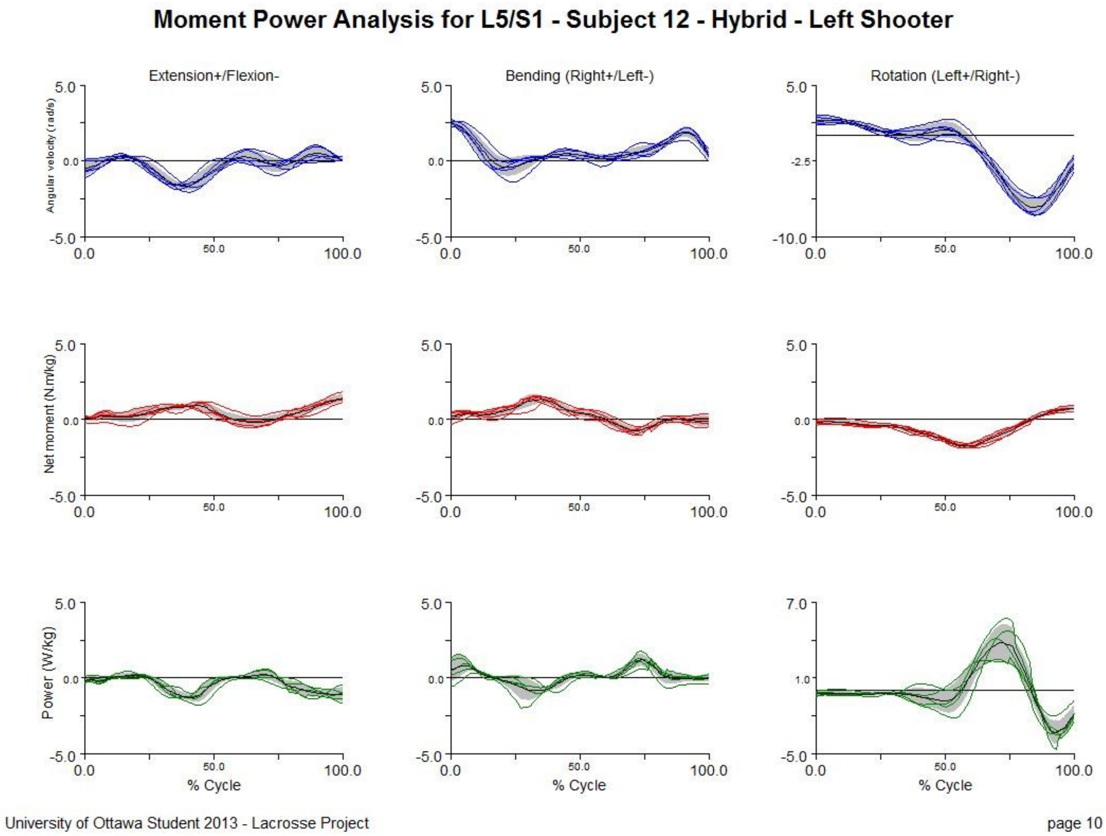
Appendix 32


Moment Power Analysis for L5/S1 - Subject 11 - Overhand - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
5.0
0.0
-5.0
-1.0
-7.0
50.0
100.0
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

Appendix 33

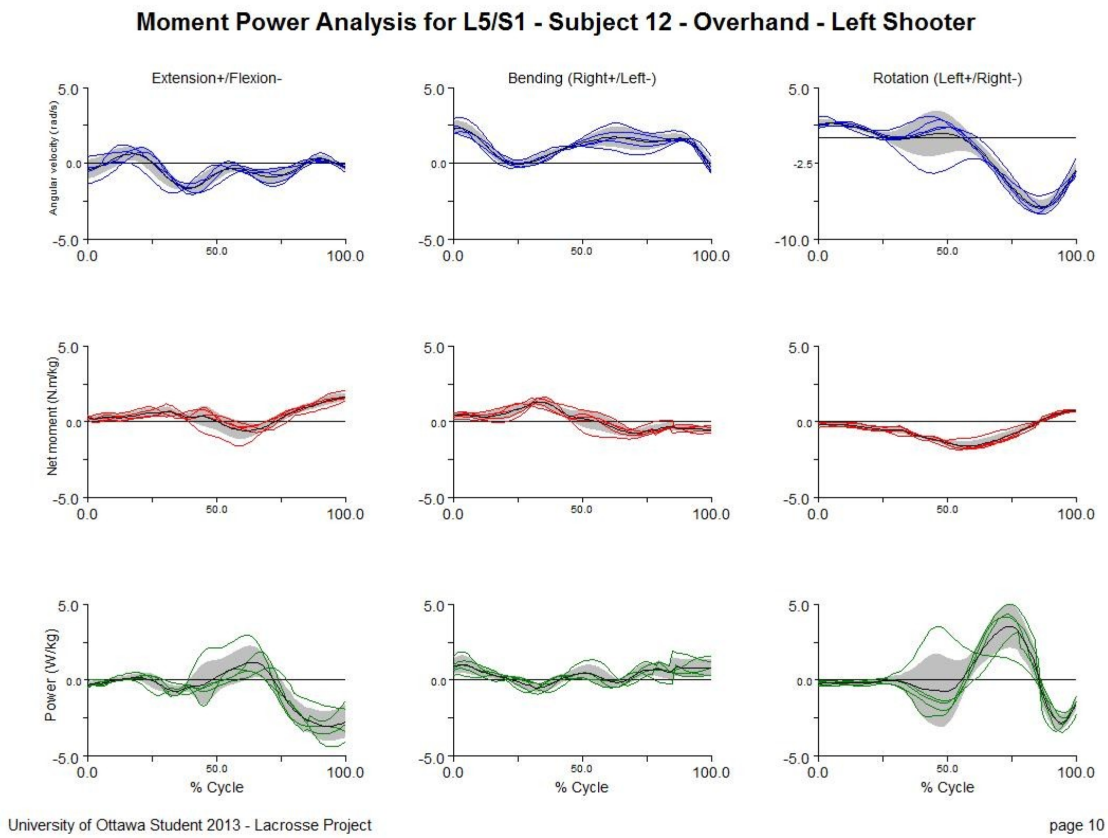

Moment Power Analysis for L5/S1 - Subject 11 - Sidearm - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

Appendix 34

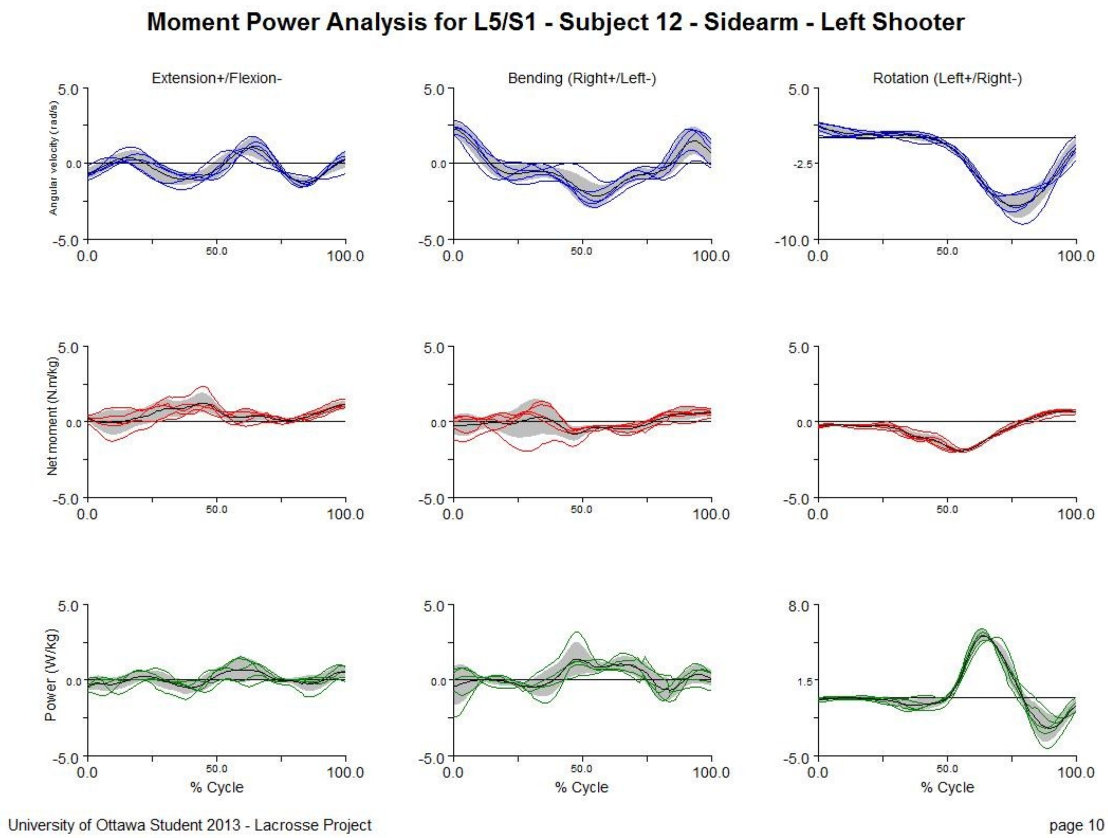


Moment Power Analysis for L5/S1 - Subject 12 - Hybrid - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

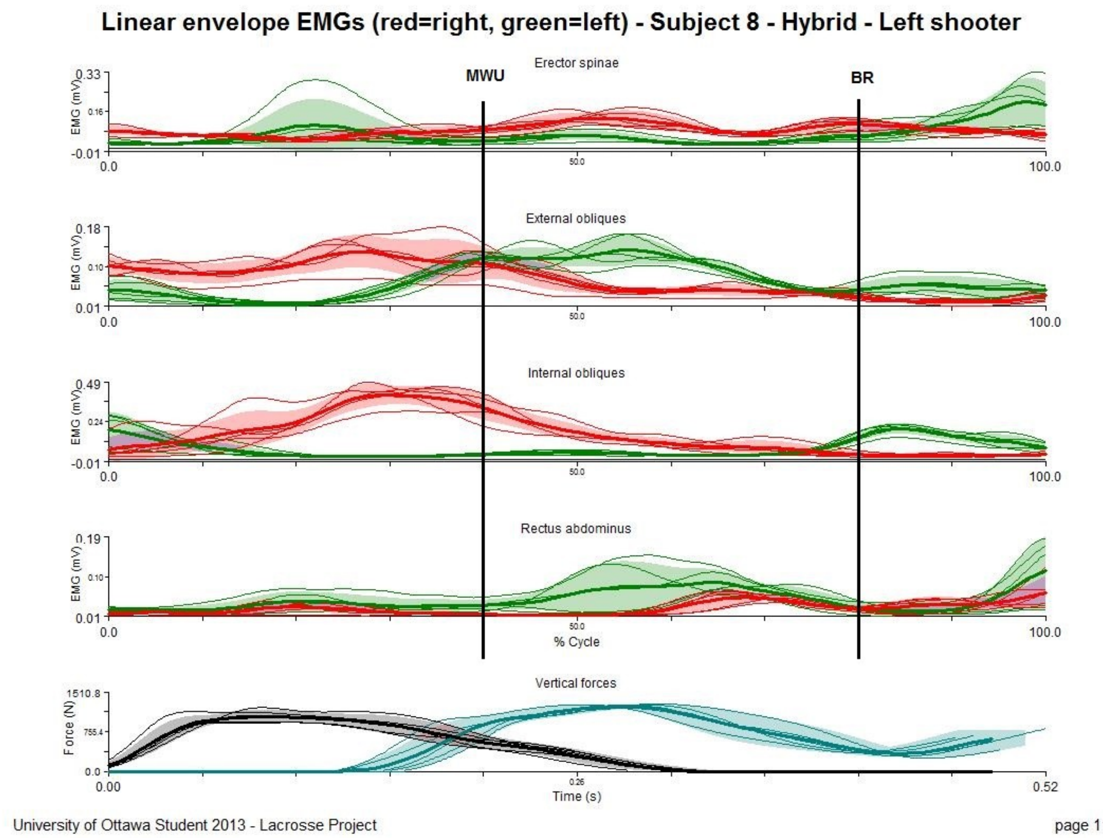
Appendix 35


Moment Power Analysis for L5/S1 - Subject 12 - Overhand - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

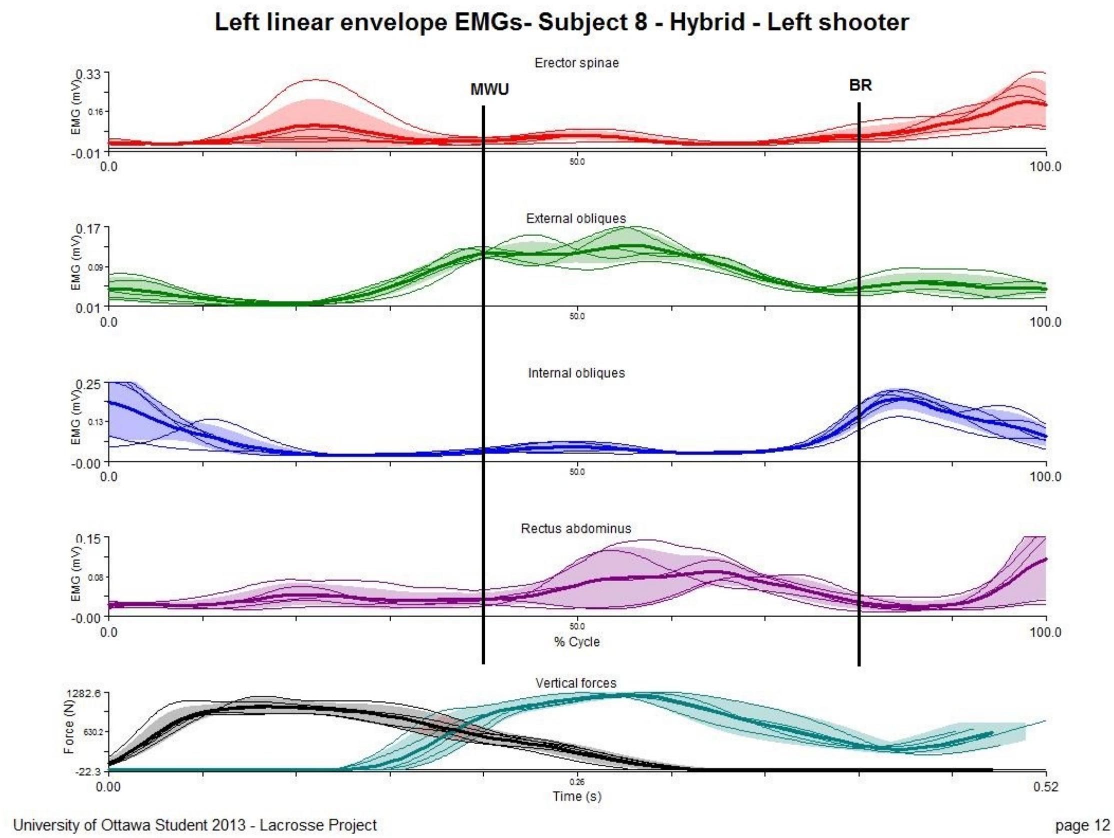
Appendix 36


Moment Power Analysis for L5/S1 - Subject 12 - Sidearm - Left Shooter
Extension+/Flexion-
Bending (Right+/Left-)
Rotation (Left+/Right-)
Angular velocity (rad/s)
Net moment (N.m/kg)
Power (W/kg)
% Cycle
University of Ottawa Student 2013 - Lacrosse Project
page 10

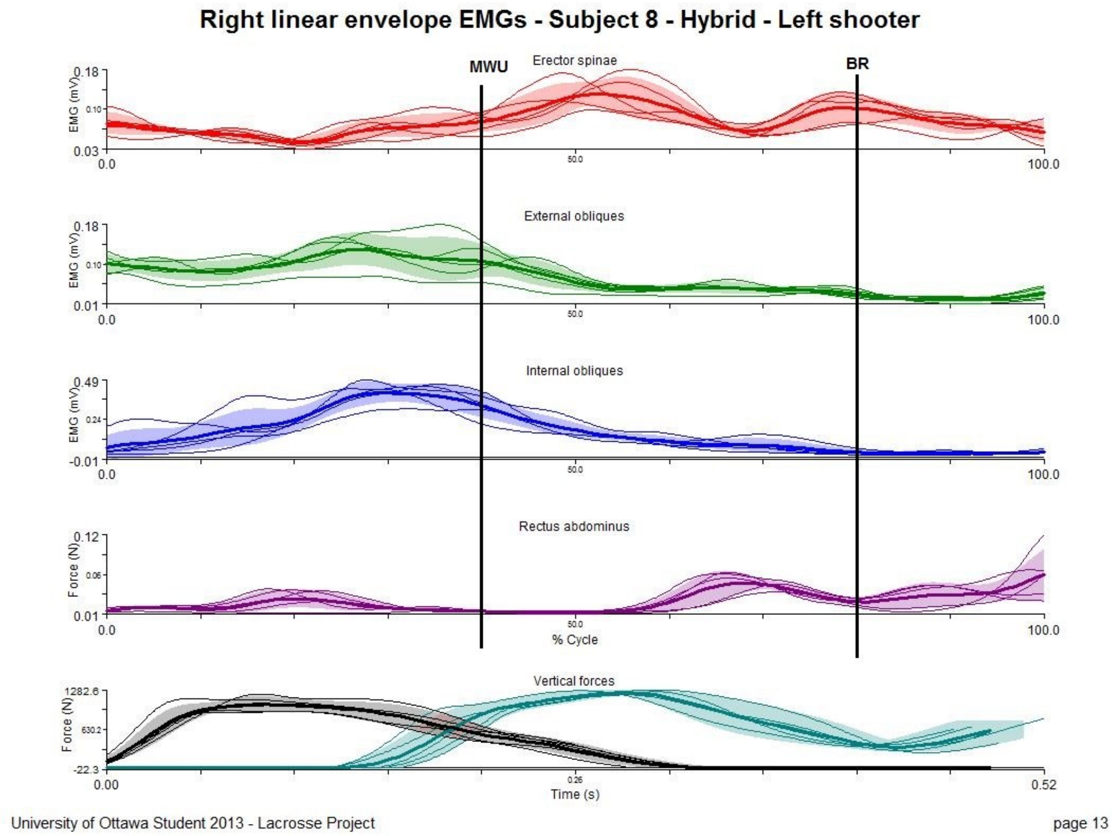
Appendix 37


Linear envelope EMGs (red=right, green=left) - Subject 8 - Hybrid - Left shooter
MWU
BR
Erector spinae
External obliques
Internal obliques
Rectus abdominus
EMG (mV)
% Cycle
Vertical forces
Force (N)
Time (s)
University of Ottawa Student 2013 - Lacrosse Project
page 11

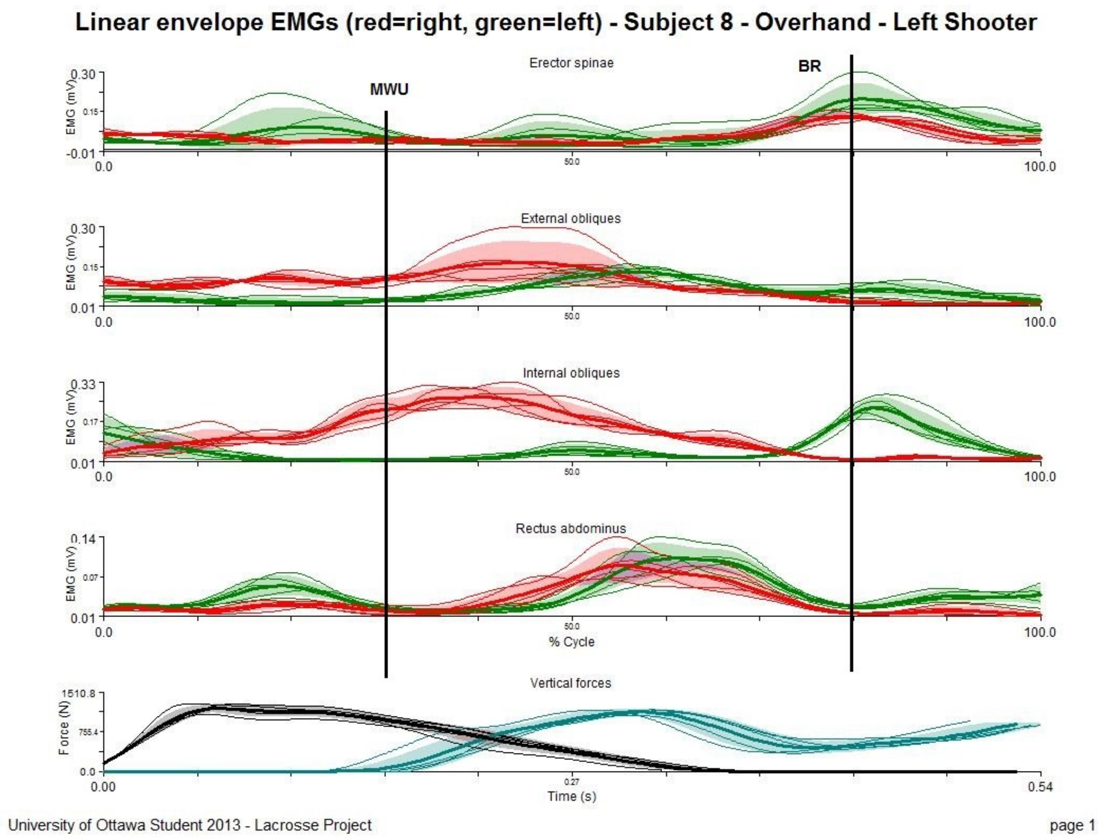
Appendix 38


Left linear envelope EMGs- Subject 8 - Hybrid - Left shooter
Erector spinae
MWU
BR
EMG (mV)
0.33
0.16
-0.01
0.0
50.0
100.0
External obliques
0.17
0.09
0.01
Internal obliques
0.25
0.13
-0.00
Rectus abdominus
0.15
0.08
% Cycle
Vertical forces
Force (N)
1282.6
630.2
-22.3
0.00
0.26
0.52
Time (s)
University of Ottawa Student 2013 - Lacrosse Project
page 12

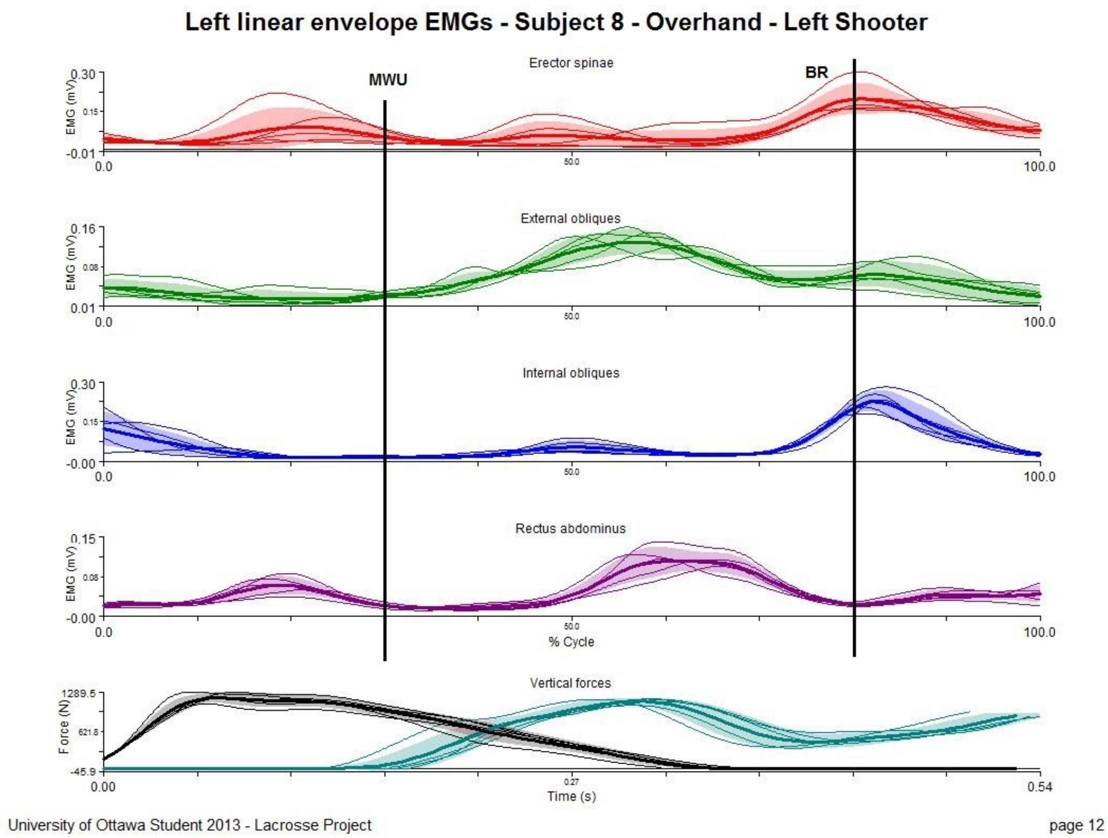
Appendix 39


Right linear envelope EMGs - Subject 8 - Hybrid - Left shooter
MWU
BR
Erector spinae
External obliques
Internal obliques
Rectus abdominus
Vertical forces
EMG (mV)
Force (N)
% Cycle
Time (s)
University of Ottawa Student 2013 - Lacrosse Project
page 13

Appendix 40

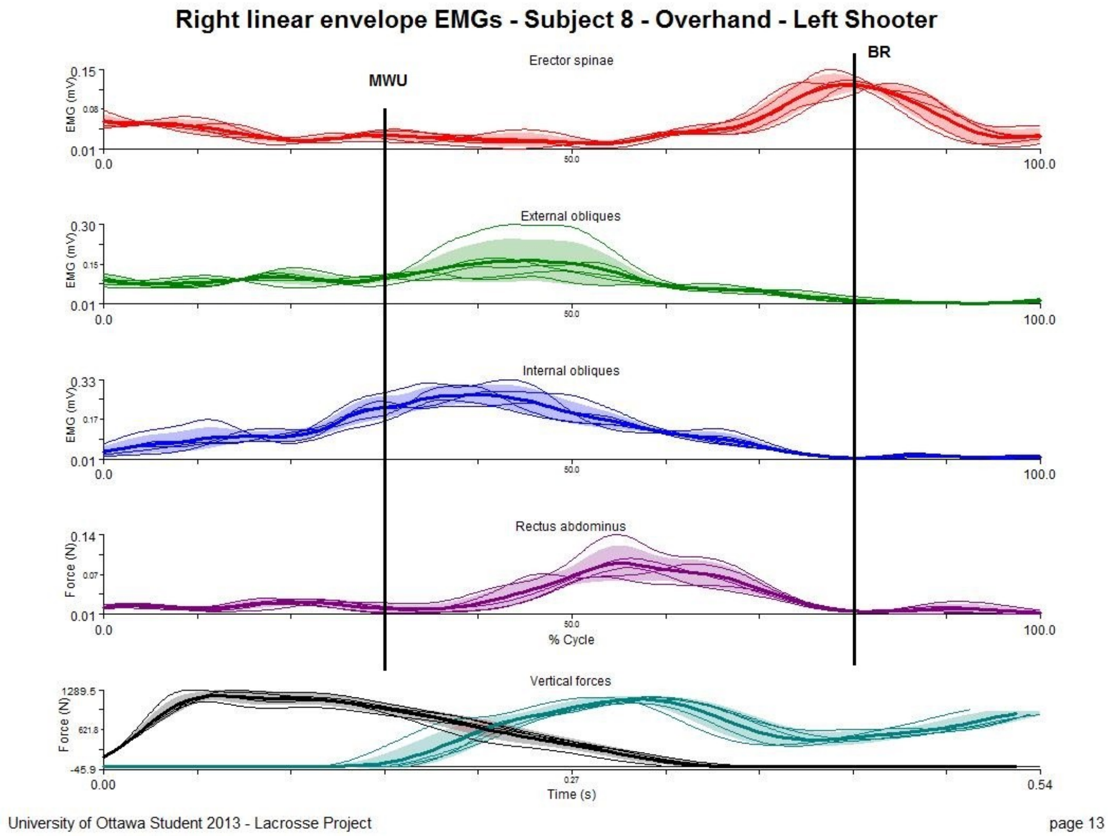

Linear envelope EMGs (red=right, green=left) - Subject 8 - Overhand - Left Shooter
Erector spinae
MWU
BR
External obliques
Internal obliques
Rectus abdominus
EMG (mV)
% Cycle
Vertical forces
Force (N)
Time (s)
University of Ottawa Student 2013 - Lacrosse Project
page 11

Appendix 41



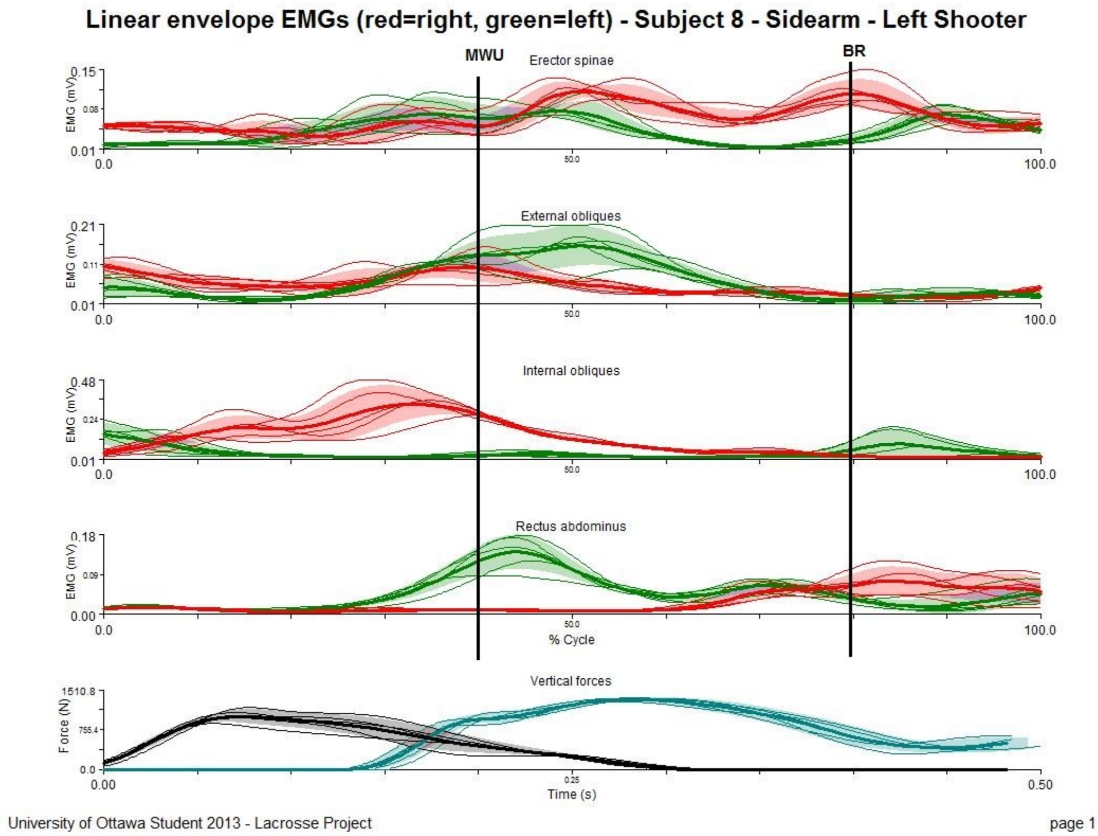
Left linear envelope EMGs - Subject 8 - Overhand - Left Shooter
Erector spinae
MWU
BR
EMG (mV)
0.30
0.15
-0.01
0.0
50.0
100.0
External obliques
0.16
0.08
0.01
Internal obliques
-0.00
Rectus abdominus
% Cycle
Vertical forces
Force (N)
1289.5
621.8
-45.9
0.00
0.27
0.54
Time (s)
University of Ottawa Student 2013 - Lacrosse Project
page 12

Appendix 42

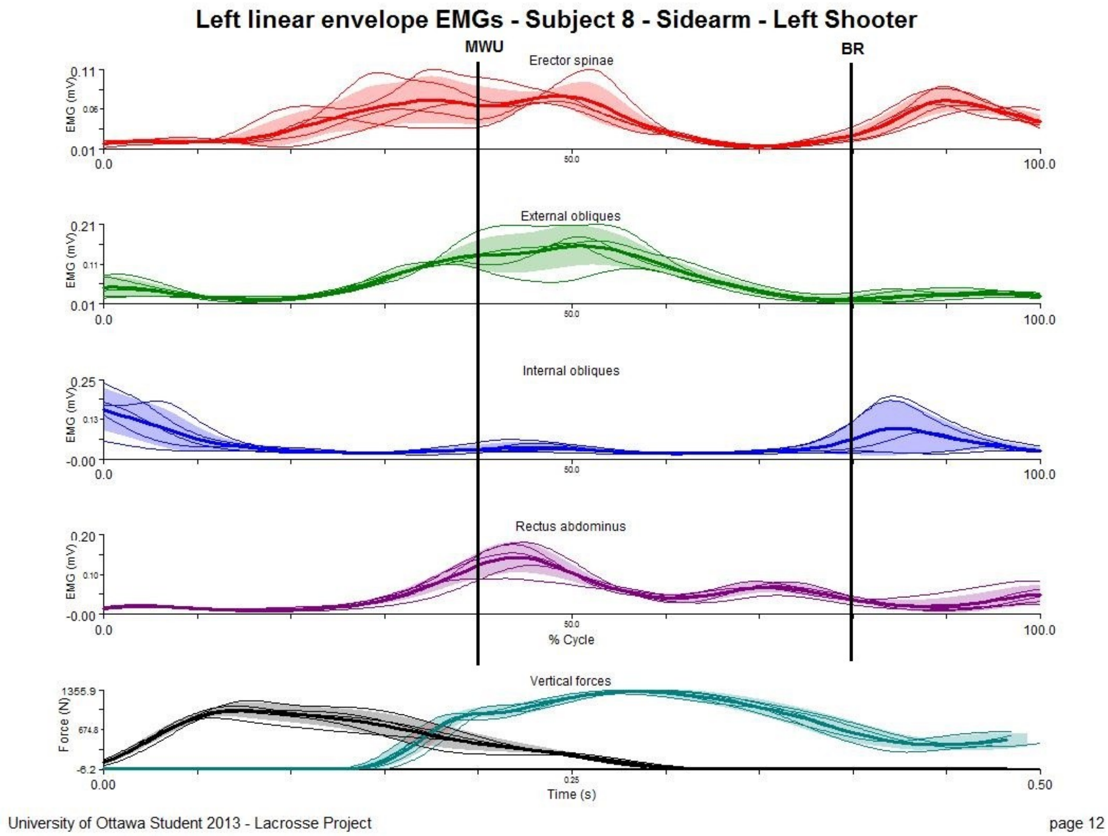


Right linear envelope EMGs - Subject 8 - Overhand - Left Shooter
MWU
BR
Erector spinae
EMG (mV)
0.15
0.08
0.01
0.0
50.0
100.0
External obliques
0.30
0.15
Internal obliques
0.33
0.17
Rectus abdominus
Force (N)
0.14
0.07
% Cycle
Vertical forces
1289.5
621.8
-45.9
0.00
0.27
0.54
Time (s)
University of Ottawa Student 2013 - Lacrosse Project
page 13

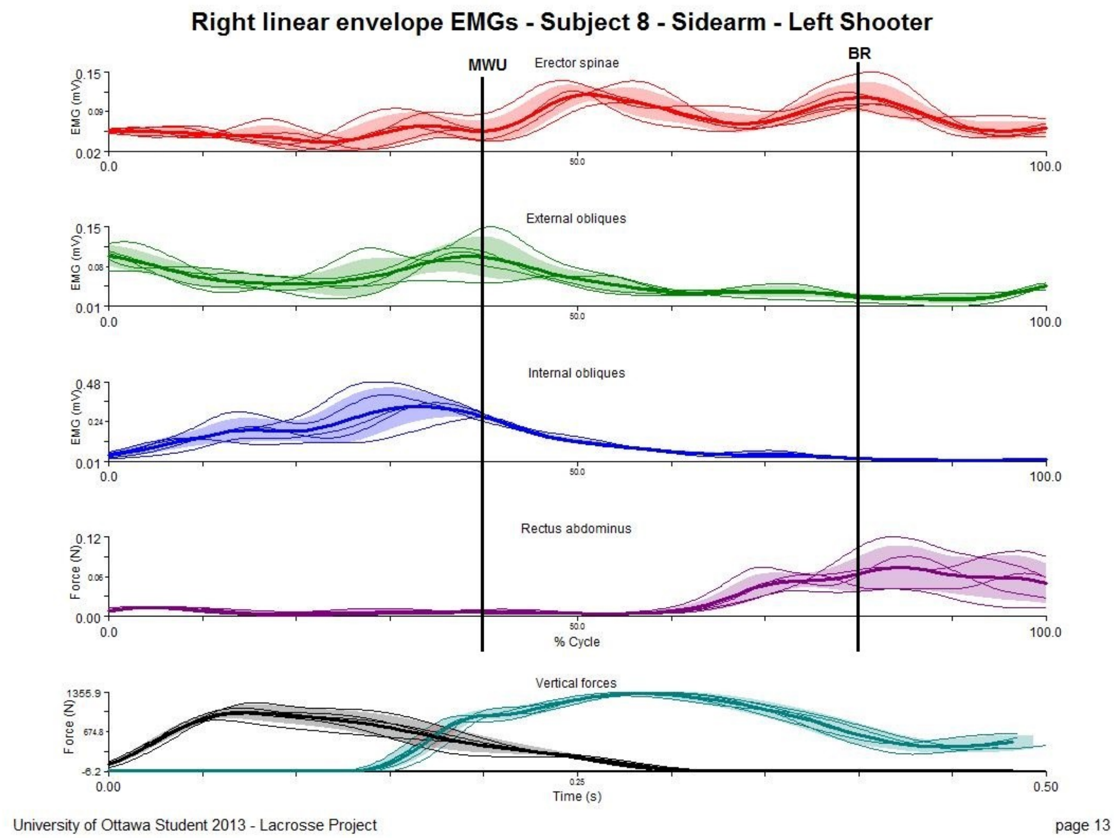
Appendix 43


Linear envelope EMGs (red=right, green=left) - Subject 8 - Sidearm - Left Shooter
MWU
BR
Erector spinae
External obliques
Internal obliques
Rectus abdominus
EMG (mV)
% Cycle
Vertical forces
Force (N)
Time (s)
University of Ottawa Student 2013 - Lacrosse Project
page 11

Appendix 44


Left linear envelope EMGs - Subject 8 - Sidearm - Left Shooter
MWU
BR
Erector spinae
External obliques
Internal obliques
Rectus abdominus
EMG (mV)
% Cycle
Vertical forces
Force (N)
Time (s)
University of Ottawa Student 2013 - Lacrosse Project
page 12

Appendix 45


Right linear envelope EMGs - Subject 8 - Sidearm - Left Shooter
MWU
BR
Erector spinae
External obliques
Internal obliques
Rectus abdominus
Vertical forces
EMG (mV)
Force (N)
% Cycle
Time (s)
University of Ottawa Student 2013 - Lacrosse Project
page 13