A COMPARISON OF STANDING AND KNEELING OVERHAND THROWING

by

Shaun Hager

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Exercise Science

Spring 2011

Copyright 2011 Shaun Hager
All Rights Reserved
A COMPARISON OF STANDING AND KNEELING OVERHAND THROWING

By

Shaun Hager

Approved:

__________________________________________________________

James G. Richards, Ph.D.
Professor in charge of thesis on behalf of the Advisory Committee

Approved:

__________________________________________________________

Todd D. Royer, Ph.D.
Chair of the Department of Kinesiology and Applied Physiology

Approved:

__________________________________________________________

Kathleen S. Matt, Ph.D.
Dean of the College of Health Sciences

Approved:

__________________________________________________________

Charles G. Riordan, Ph.D.
Vice Provost for Graduate and Professional Education
ACKNOWLEDGMENTS

James Richards, Ph.D. for this opportunity and his continuous advice, and guidance during the past two years.

My friends and lab-mates that have helped me over the past two years.
# TABLE OF CONTENTS

LIST OF TABLES .................................................................................................................. v
LIST OF FIGURES .................................................................................................................. vi
ABSTRACT ............................................................................................................................. vii

Chapter

1 SPECIFIC AIMS .................................................................................................................... 1

   Specific Aim 1 .................................................................................................................... 2
   Hypothesis 1.1 .................................................................................................................. 3
   Hypothesis 1.2 .................................................................................................................. 3
   Specific Aim 2 .................................................................................................................. 3
   Hypothesis 2.1 .................................................................................................................. 4

2 BACKGROUND AND SIGNIFICANCE ................................................................................. 5

   Upper Extremity Injury .................................................................................................... 5
   Review of Methods .......................................................................................................... 7
   The Use of Ultrasound to Identify Skeletal Landmarks .................................................. 10
   Alternate Throwing Method ............................................................................................ 11
   Summary ....................................................................................................................... 12

3 METHODS .......................................................................................................................... 13

   Participants ...................................................................................................................... 13
   Procedures ....................................................................................................................... 13
   Data Analysis ................................................................................................................ 14

4 RESULTS AND DISCUSSION ............................................................................................ 17

   Results ........................................................................................................................... 17
   Discussion ...................................................................................................................... 18

5 CONCLUSION ..................................................................................................................... 26

REFERENCES ....................................................................................................................... 27

Appendix

   INFORMED CONSENT ................................................................................................. 30
LIST OF TABLES

Table 1  Anatomical Locations of Modified ISG Marker Set ......................... 14
Table 2  Markers Used for Segment Coordinate System Construction ............ 16
Table 3  Primary Variables for Specific Aim 1 .............................................. 22
Table 4  Primary Variable for Specific Aim 2 .............................................. 22
LIST OF FIGURES

Figure 1  Scapular Motion ................................................................. 9
Figure 2  Shoulder Internal/External Rotation Angle (external = negative) .......... 23
Figure 3  Shoulder Abduction/Adduction Angle (adduction = negative) .......... 23
Figure 4  Shoulder Flexion/Extension Angle (extension = negative) ............... 24
Figure 5  Elbow Flexion/Extension Angle (extension = negative) ................. 25
ABSTRACT

Overhand throwing is stressful to the shoulder and elbow joints, so it is no surprise that approximately 60% of shoulder injuries occur in baseball (8). Previous studies have attempted to link overhand throwing mechanics with injuries, however none have accounted for the contribution of the scapula despite its obvious role in shoulder movement. This is primarily due to the inadequacies of traditional motion capture methods to track scapular motion. To overcome these inadequacies we intend to use ultrasound probes, alongside traditional motion capture to measure scapular movement. However, the vast amount of trunk translation associated with the standing overhand throw exceeds the mechanical limits of most ultrasound sensors. Therefore, the purpose of this study is to determine if kneeling throwing is similar to standing throwing, so that kneeling throwing can be used to accommodate for the mechanical limits of ultrasound in order to track scapular motion. Twenty-six college males were analyzed, and each subject threw from both a standing and kneeling position. Five of the seven primary kinematic variables were not statistically different between conditions, and for the two variables that were different, the time at which maximum external rotation occurred and shoulder rotation at ball release, there means remained within one standard deviation of each other. Ball velocity and linear shoulder excursion, or a measure of trunk tilt, were both, as expected, statistically different between conditions. Finally, a comparison of throw initiation methods
showed the time at which stride foot contact occurred was not significantly different than the time at which the trunk reversed its rotation direction about the global z-axis. In conclusion, the kneeling throw appears to be representative of the standing throw, and it is assumed that if the humerus is moving in a similar than so is the scapula. Kneeling throwing may allow the use of ultrasound sensors to track scapular movement in further research.
Chapter 1

SPECIFIC AIMS

The scapula plays an important role in many upper extremity movements including throwing. However, to our knowledge, the scapula has not been specifically observed during high velocity throwing. The lack of a “suitable non-invasive method” (1) for scapular tracking provides the necessity to develop a method for monitoring this movement. This study is designed to provide the preliminary information for future research on developmental overhand throwing mechanics. The intent is to provide a framework for the use of ultrasound sensors to track the three-dimensional movement of the scapula under the skin during the throwing motion. Using ultrasound to describe the position of boney tissue has been shown to be accurate and repeatable in both the lower limb (2) and at the shoulder (1). However, it has not been used during overhand throwing. One limitation to using ultrasound for this purpose is the vast amount of trunk translation associated with standing throwing, which exceeds the standard length (1m) of most ultrasound cables. (3). Shortening the linear shoulder translation associated with throwing from a standing position might facilitate the use of ultrasound for describing scapular function during an overhand throw. Throwing from a kneeling position is one approach to shortening linear shoulder translation that is familiar to most athletes. However,
the effect that throwing from this position has on arm kinematics is unclear, and in order to infer measurements of scapular function obtained from a kneeling position to the standing throw, it must be shown that arm kinematics are similar when throwing from both standing and kneeling positions. The purpose of this study is to determine whether arm kinematics measured during a throw from a kneeling position are different from arm kinematics measured from a standing position.

**Specific Aim 1**

To determine if throwing from a kneeling position is significantly different from a traditional standing over hand baseball throw. A standing throw is often associated with a large stride step. The step with the foot contralateral to the throwing arm can reach lengths greater than one half the height of the thrower in children (4). There is also an extraordinary amount of trunk translation that is associated with a standing throw. Stodden et al. showed that anterior trunk tilt at ball release could reach values up to 58.3° in children. The amount of trunk translation associated with the standing overhand throw is greater than the range of motion of most ultrasound probes. By eliminating a large amount of this trunk movement, future studies may be able to use ultrasound to track the scapula during throwing. We believe that having our subjects throw from a kneeling position, thus eliminating the stride step, will vastly decrease the amount of trunk movement associated with throwing. However, it has not been shown that the arm kinematics
used to throw from a kneeling position match those used when throwing from a standing position.

**Hypothesis 1.1**

There will be no statistical differences between standing and kneeling throwing conditions for arm orientation at specific events or total arm excursion for shoulder I/E rotation, shoulder horizontal F/E, shoulder Ab/Adduction, and elbow F/E.

**Hypothesis 1.2**

There will be statistical differences between throwing conditions for linear shoulder excursion and ball velocity.

**Specific Aim 2**

To determine the accuracy of using the trunk orientation about the z-axis of the global coordinate system to determine the initiation of throwing. Traditionally stride foot contact (SFC) is used to determine the initiation of the throwing motion (5,6,7). However, when a subject is throwing from one knee there is no stride step and therefore no way to identify the beginning of the throw. We believe that the trunk rotation about the vertical axis will reverse direction at approximately the same time that stride foot contact occurs in a standing throw.
Hypothesis 2.1

The time at which the orientation of the trunk coordinate system reverses direction about the global Z-axis will be related to the time of SFC.
Chapter 2

BACKGROUND AND SIGNIFICANCE

Upper Extremity Injury

Throwing is a complex movement that involves the coordination of multiple joints in the upper extremity. Due to these complexities, approximately 60% of shoulder injuries occur in baseball players (8). It has also been reported that an estimated 6% of youth baseball players are injured during play with 26% of these injuries occurring at the shoulder or upper arm (9). There have been numerous studies done on the effects of throwing on the joints of the upper arm including the elbow, and the glenohumeral (GH) joint. However, there is a lack of information on how the scapula moves during an overhand throw. Miyashita et al. reported that the majority of shoulder injuries take place during the cocking and acceleration phase of throwing and often occur at the GH joint. However, to fully explain the stresses that occur at the GH joint the movements of all the shoulder joints including the scapulothoracic joint must be known (10).

A reoccurring theme with today's baseball coaches is the call for throwers, especially pitchers, to increase velocity. In order to achieve this improvement, countless hours must be spent practicing proper pitching mechanics. Davis et al. recently reported that increased pitch counts in youth
baseball pitchers have been linked to incidences of increased shoulder and elbow pain (11). It has also been reported that during all throwing motions a distraction force occurs at the shoulder. This force acts on the upper arm and effectively pulls the humerus away from the GH joint. Injuries are thought to result from this force and the rapid dissipation of energy in the upper arm following ball release (7). As the number of pitches increases, so does the number of times this injury mechanism occurs. In order to fully understand this injury mechanism it is imperative that we understand the contribution of all the underlying structures.

The prevalence of injury to the upper extremity during the cocking and acceleration phases of throwing has been attributed to peak angular velocities of the shoulder and extreme shoulder rotation and abduction angles (9). Maximum external shoulder rotation is identified as the point that terminates the cocking phase and initiates the acceleration phase (6). Through the acceleration phase, the shoulder quickly internally rotates in order to produce the maximum amount of velocity on the baseball. It has been accepted that the amount of stress on the shoulder and the elbow is proportional to the amount of shoulder external rotation (10). This may be due to the observation that maximum shoulder external rotation exceeds normal limits during a baseball pitch (12). The predominant musculature for positioning the arm during the cocking phase is the supraspinatus, infraspinatus, teres minor, deltoid, trapezius, and biceps brachii. Accelerating the arm through the next phase is attributed to pectoralis major, serratus anterior, subscapularis, and latissimus dorsi (13). Many of these muscles attach at both the scapula and the humerus, while a few
(trapezius, serratus anterior, and subscapularis) don't articulate with the humerus at all. Yet there has been no observation of the movement of the scapula during high speed throwing. Due to the musculoskeletal articulation between the humerus and the scapula at the GH joint, it is intuitive to think that any motion causing increased stress to the upper arm would in turn cause increased stress to the scapula.

There has been a wealth of research conducted on the complex movements of the upper extremity during throwing (4-11). The research has primarily focused on stresses at the elbow and at the GH joint and the associated kinematics. Davis et al. (11) reported humeral internal rotation torques and elbow varus loads. These parameters were chosen because the motions associated with poor mechanics were said to be easily identifiable by coaches or parents. It was reported that correct position of the hand on top of the ball during pitching would help to minimize loads at both the elbow and the shoulder. Fleisig et al. (5) observed the same variables in varying levels of pitching development, and they reported the risks for injury at these joints to be the same. They also reported no significant difference in the spatial and temporal parameters between varying levels of development. This provides youth baseball coaches with evidence for teaching proper throwing mechanics to athletes at a young age.

**Review of Methods**

The use of motion capture data is often coupled with high-speed video to help determine when specific events in the throwing motion occur.
Researchers often describe events based on stride foot contact, maximal external rotation, ball release, and the head moving in front of the hips (6,7,11). This works to provide a temporal structure to assess kinematics and kinetics of the elbow and shoulder during high speed throwing.

The research that has been done on the throwing motion has been repeatable and reliable. It is often done with motion analysis cameras operating at a minimum of 200 Hz due to the high velocity of the arm moving through the acceleration phase. Markers can be placed on upper extremity anatomical landmarks at previously validated locations (ISG marker set). Placement of these markers enables the reconstruction of coordinate systems and the rotation orders for the shoulder and elbow joints as reported by Wu et al (14). However, due to the movement of the scapula underneath the skin, markers on anatomical landmarks of the scapula fail to follow scapular motion during throwing. The scapula goes through a complex set of movements, some of which are described in figure 1 (15).
In some cases, the location of the scapula has been observed in low-velocity throwing (15) with the use of electromagnetic surface sensors. Three sensors attach to the sternum, acromion, and humerus; and they allow the scapula to be measured in 3-dimensional space. This is important as it represents an attempt to accurately track the scapula, although it comes with obvious limitations. For the results to be accurate, the system must be used in a room where there is no electromagnetic field. Therefore it must be isolated from other buildings and electronic equipment. Similar to ultrasound, this equipment cannot be used during high-velocity standing throwing due to the mechanical constraints.
of its wires. In their pilot research Meyer et al. (15) tried to use the electromagnetic sensors during high speed throwing, but the movement artifact from the cables provided inaccurate results. Finally, because multiple surface sensors are attached at one point on the skin, skin motion artifact poses another significant limitation. Small errors in scapular position have been reported for electromagnetic surface motion during dynamic arm motions (15). Due to the increase in movement range and speed during throwing, it is safe to assume that the amount of skin movement would only increase from simple dynamic arm movements.

Karduna et al. tested two methods of measurement using magnetic tracking devices to detect scapular motion (16). One method consisted of fixing a sensor directly to the acromion, and the other used a sensor on an adjustable hinge that fit over the scapular spine. Both methods were validated against the gold standard of bone pins drilled into the scapula. These methods proved to be accurate for measuring static orientation of the scapula, however, they only produced reliable results up to 120 degrees of humeral elevation. Magnetic tracking is also subject to superficial soft tissue movement, especially during rapid arm movements.

The Use of Ultrasound to Identify Skeletal Landmarks

Ultrasound is an effective tool for observing the position and orientation of skeletal landmarks beneath the skin. It has been used for over twenty years to observe femoral torsion (2). Hudson et al. reported that
ultrasound was reliable and repeatable when observing femoral torsion. The authors also stated that their data supports the clinical use of the methods. Furthermore, ultrasound has been used to observe dynamic movements at the shoulder joint (1). By using 3 ultrasound based markers and a pointer Illyés et al. were able to accurately locate the position of anatomical points throughout the range of motion in the segment local coordinate systems. However, ultrasound has never been used during a movement as complex as overhand throwing. This may be due to the mechanical restrictions of ultrasound cables, which have a standard length of 1m (3).

**Alternate Throwing Method**

Throwing from a kneeling position is a common way for coaches to train youth baseball players. Having the players throw from one knee provides the ability to focus on the specific arm mechanics with relation to the trunk (17). The trunk can be defined or modeled as a non-rigid segment that allows flexion-extension, bending, and twisting while the shoulder can be defined as a “complex structure consisting of multiple joints and bones” (12). High speed over-hand pitching is associated with greater than 58° of anterior trunk tilt for level 3 youth throwers (4). As the level of throwing increases from youth, to high school and college, and then to the professional level the amount of trunk tilt, torso rotational velocities, and the size of the stride step are all increased in order to increase ball velocity (4). This only compounds the affect of trunk translation on the inability to use ultrasound sensors during a standing throw.
Summary

Providing the framework for a later study using ultrasound to monitor throwing mechanics is an important step. There is a gap in the knowledge of throwing with respect to the scapula that can be bridged by developing a non-invasive method to accurately describe its 3-dimensional motion. By having subjects throw from one knee, we intend to show that further research can be conducted from this position to model a standing overhand throw.
Chapter 3

METHODS

Participants

All participants were college males between the ages of 18 and 24 and varied in skill level from recreational throwers to college baseball players. Exclusion criteria included previous shoulder or elbow injury or surgery, and allergies to band-aid adhesive. Data were collected from a sample of 31 subjects. However, the data could not be analyzed for five subjects due to tracking issues resulting in a sample of 26 subjects.

Procedures

Upon arrival at the Human Performance Lab, each subject signed an informed consent form after reading the form and having all questions answered to their satisfaction. They were then fitted with the modified ISG (International Shoulder Group) Upper Extremity marker set consisting of 6 mm reflective markers attached to the following anatomical landmarks of their torso and upper extremities:
Table 1  Anatomical Locations of Modified ISG Marker Set

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C7</td>
<td>Suprasternal Notch</td>
</tr>
<tr>
<td>T8</td>
<td>Xiphoid Process</td>
</tr>
<tr>
<td>Acromion Process (throwing arm)</td>
<td>2nd Distal Metacarpal Head</td>
</tr>
<tr>
<td>Medial Epicondyle of Humerus</td>
<td>Ulnar Styloid Process</td>
</tr>
<tr>
<td>Lateral Epicondyle of Humerus</td>
<td>Radial Styloid Process</td>
</tr>
<tr>
<td>Left Hip</td>
<td>Forearm Offset (medial forearm)</td>
</tr>
<tr>
<td>Right Hip</td>
<td>Acromion Process (non-throwing arm)</td>
</tr>
<tr>
<td>Sacrum</td>
<td>Shoulder Offset (scapula)</td>
</tr>
</tbody>
</table>

The subjects first threw 3-5 low-velocity overhand warm-up throws to make sure they were comfortable with the markers. This was followed by as many warm-up throws as each subject desired. Following the warm-up period, 5 high velocity throws from a standing position were recorded as well as five high velocity throws with the subject kneeling on one knee. The order of these throws was randomized between subjects. All throws were made to a large net located approximately 20 ft (6.10 m) from the subject. The net was marked with a 12 by 24 in (30.5 by 61.0 cm) square target. The accuracy of the throws was not recorded.

**Data Analysis**

Marker position data was collected using 8 Eagle Motion Analysis Cameras (Motion Analysis Corp., Santa Rosa, CA) operating at 240 Hz, and post processed in LabVIEW (National Instruments, Austin, TX). The kinematic variables calculated from the markers include shoulder abduction and adduction.
angle, shoulder internal and external rotation angle, shoulder flexion and extension angle, linear shoulder excursion, and elbow flexion and extension angle. Linear shoulder excursion was measured as the distance the acromion marker on the throwing shoulder traveled in the direction of the throw. All values were all calculated from throw initiation to 100 ms past ball release, 100 ms was used to account for total shoulder rotation and total linear trunk excursion through the follow through. Ball velocity was recorded with a SpeedTrac X radar run (Outer Limit Sports, Prescott, WI), and ball release was determined by a visual analysis of the throws in Cortex. Two pieces of reflective tape were attached to the ball and ball release was identified as the frame in which these markers began moving away from the subjects’ hand. Variables were then compared between the two throwing conditions using univariate 1-way ANOVAs with repeated measures as well as Pearson product moment correlation coefficients.

Placement of the markers was done in accordance with the ISG for the reconstruction of joint coordinate systems as described by Wu et al (14). For the following segment coordinate systems (Table 2) the axes were defined as:

- X-axis = (distal point – proximal point),
- Y-axis = (intermediate point- proximal point) crossed onto (X-axis),

Joint angles were then calculated using a YZY Euler rotation.
Table 2  Markers Used for Segment Coordinate System Construction

<table>
<thead>
<tr>
<th>Segment</th>
<th>Proximal Point</th>
<th>Distal Point</th>
<th>Intermediate Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk</td>
<td>Cervical center</td>
<td>Thoracic center</td>
<td>T8</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Cervical center</td>
<td>Acromion process</td>
<td>Thoracic center</td>
</tr>
<tr>
<td>Upper Arm</td>
<td>Shoulder joint center</td>
<td>Elbow joint center</td>
<td>Lateral elbow</td>
</tr>
<tr>
<td>Lower Arm</td>
<td>Elbow joint center</td>
<td>Wrist joint center</td>
<td>Lateral elbow</td>
</tr>
</tbody>
</table>

Although throwing from one knee may effectively minimize trunk translation, it prohibits the use of stride foot contact as the point of throw initiation (5-7). To account for this, the orientation of the trunk about the z-axis of the global coordinate system was used. The first derivative of the trunk’s orientation was used to determine when the movement of the trunk about the vertical axis reverses direction. This time point was labeled throw initiation, as the change in trunk rotation direction was expected to coincide with the beginning of the cocking phase of the throw.
Chapter 4

RESULTS AND DISCUSSION

Results

Data for all primary variables are displayed in Table 3. For arm orientation at time specific events and total arm excursion, no statistical differences were hypothesized. Shoulder MER, shoulder I/E rotation ROM, shoulder Ab/Adduction angle at release, shoulder flexion angle at release, and elbow flexion angle at release all showed no statistical differences (p>.1) between throwing conditions. However, the time at which MER occurred, and shoulder I/E rotation angle at release were significantly different (p<.1) between throwing conditions. Graphs for these values are displayed in Figures 1-4. The graphs display the standing mean ± 2 standard deviations, and the kneeling mean dilated to 100 points from throw initiation to 100 ms post ball release. A Pearson product moment correlation analysis was used to assess the relationship between the conditions. All variables showed significant correlations between conditions (r>0.6, p<0.01).

For the values of linear shoulder excursion and ball velocity (Table 3) statistical differences were expected. Both variables were, in fact, significantly
different (p<.01) between throwing conditions. Pearson product correlations were also significant (p<.01) between conditions for both variables.

Data are displayed in Table 4 for the comparison of initiation methods, and it was expected that these methods would be related. A paired t-test was run to detect differences between using SFC or the trunk rotation about the global z-axis to determine throw initiation. The timing of the initiation method was determined by finding the time from initiation to MER (SFC, .2087 s ± .05, trunk rotation, .2088 s ± .02). The mean times for the methods showed no statistical difference (p=.98).

**Discussion**

For arm kinematics (Figures 2-5) and time-specific values (Table 3), the kneeling throw was representative of the standing throw. For the seven variables measured, only two were statistically different between throwing conditions: MER % of throw and shoulder I/E rotation at release (p<.05). For both of these variables, the means remained within one standard deviation of each other. Therefore, even though there were kinematic variables with significant changes, the mean values were less than one standard deviation apart.

The times at which MER occurred during the standing and kneeling throws were 60.6% and 58.1% of the total throw times respectively, which is a difference of approximately 9ms. While these values are statistically different, a difference of only 9ms suggests that this specific event is occurring at similar
times. It has been reported that MER typically occurs at approximately 80% of the throw (5,10). However, one of these studies looked at pitching, not standard throwing, and both studies measured this event as a percentage of the time between initiation and ball release, not 100 ms post ball release. In this study, the throw was measured until 100 ms post ball release, which was necessary for measuring total shoulder rotation and linear trunk excursion. Adding 100 ms to the time of the throw for this calculation drastically changes the percentage of throw at which MER occurs and likely accounts for the differences reported. It is also important to note that pitching may be a faster overall motion than standard throwing which would also cause discrepancies in comparing these studies.

MER is viewed as the most important landmark during throwing because of its direct relationship to stresses at the shoulder, and because it is the rapid internal rotation of the shoulder joint that imparts velocity on the ball (6,10). Shoulder MER and shoulder rotation ROM were not statistically different between throwing conditions. The average MER for standing subjects was 134°; in the reviewed literature the mean MER has been shown to range from 157°-173° in pitchers (5,6,7) and 144° in standard throwing (10). It is expected that in pitching there would be more shoulder external rotation, as the primary goal is often to throw the ball with the largest possible velocity. The values of this study matched much closer to those reported for standard throwing.

The use of the kneeling throw as a replacement for the standing throw is only applicable if the throwing motion is similar between the two conditions. Values of humeral motion appear to be similar between throwing conditions,
however, for the long-term goal of this study we must assume that if the humerus is performing the same motion, then so is the scapula. This assumption will allow the information gained from the potential use of ultrasound to map the scapula during kneeling throwing to be translated to standing throwing. This information will describe the role of the scapula in overhand throwing, and provide additional insight into the mechanisms of shoulder injuries in youth throwers.

Linear shoulder excursion is essentially a measure of trunk translation during the throw, and was measured as the distance that the acromion marker on the throwing shoulder traveled in the direction of the throw. As expected, there were statistical differences between throwing conditions, with the amount of trunk translation in the standing throw greater than double that in the kneeling throw. The vast discrepancy was expected and can be attributed to the use of the stride step in standing throwing. Clearly, this amount of trunk translation would prohibit the use of ultrasound sensors to measure the scapula. The standard ultrasound cable length is approximately 1m (3), while in the standing throw there was nearly 3 times that amount of trunk translation. Therefore, it is confirmed that the kneeling throw is more suitable for measuring scapular kinematics by attaching ultrasound sensors to the back.

Ball velocity was compared between throwing conditions, and was found to be statistically different. This was also expected as the stride step in throwing, resulting in excess trunk tilt, is used to increase ball velocity (4). However, it should be noted that approximately 85% of the standing velocity (59.2 mph ± 7.8) was retained in the kneeling throw (51.2 mph ± 6.6), and the
kneeling mean ball velocity fell slightly more than one standard deviation away from the standing mean. Replication of the standing velocity did not come from differences in MER, and therefore had to be the result of other kinematic factors stemming from the elimination of the stride step. Although it was not measured it is proposed that to compensate for the loss of the stride step, additional trunk rotation may have been used to generate ball velocity. Trunk rotation may provide a much smaller obstacle than trunk translation when trying to use ultrasound sensors for scapular tracking.

During standing throwing SFC is often used to determine throw initiation (5-7). However, the use of kneeling throwing eliminates the stride step, which in turn creates a void for identifying throw initiation. The time at which the trunk coordinate system reverses direction about the global z-axis was not statistically different from SFC. This value was obtained by measuring the angle between the trunk and the global z-axis. Throw initiation was then labeled as the time at which this angle changed direction, or the rotational trunk velocity crossed zero. This method was used to determine throw initiation in both conditions, and was compared to SFC in the standing trials only.

The average time from SFC to MER in standing throwers was .2087 ms ± .05, and the average time from the trunk rotation method to MER was .2088 ms ± .02. The data suggests not only that these events are occurring at nearly the same time, but that the trunk rotation method may also be less variable. Using the trunk rotation method appears to be an adequate solution for determining throw initiation in not only kneeling throwing, but standing throwing as well. It
may be especially useful when the researcher does not have access to force plates, or high-speed video.

Table 3  Primary Variables for Specific Aim 1

<table>
<thead>
<tr>
<th>Throwing Position</th>
<th>Standing Average</th>
<th>Standing Std Dev</th>
<th>Kneeling Average</th>
<th>Kneeling Std Dev</th>
<th>ANOVA P-value</th>
<th>Pearson R</th>
<th>Pearson P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder MER (°)</td>
<td>-134.0</td>
<td>13.6</td>
<td>-130.7</td>
<td>13.06</td>
<td>0.38</td>
<td>.97</td>
<td>.00</td>
</tr>
<tr>
<td>MER (% of Throw)</td>
<td>60.6</td>
<td>3.5</td>
<td>58.1</td>
<td>3.3</td>
<td>0.01*</td>
<td>.60</td>
<td>.00</td>
</tr>
<tr>
<td>Shoulder I/E Rotation ROM (°)</td>
<td>168.5</td>
<td>16.8</td>
<td>164.6</td>
<td>15.6</td>
<td>0.38</td>
<td>.89</td>
<td>.00</td>
</tr>
<tr>
<td>Shoulder I/E Rotation at Release (°)</td>
<td>-92.4</td>
<td>10.8</td>
<td>-86.3</td>
<td>10.1</td>
<td>0.04*</td>
<td>.76</td>
<td>.00</td>
</tr>
<tr>
<td>Shoulder Ab/Adduction at Release (°)</td>
<td>91.0</td>
<td>9.8</td>
<td>90.1</td>
<td>8.8</td>
<td>0.71</td>
<td>.91</td>
<td>.00</td>
</tr>
<tr>
<td>Shoulder Flexion at Release (°)</td>
<td>11.8</td>
<td>11.4</td>
<td>16.4</td>
<td>11.5</td>
<td>0.15</td>
<td>.85</td>
<td>.00</td>
</tr>
<tr>
<td>Elbow Flexion at Release (°)</td>
<td>29.6</td>
<td>11.4</td>
<td>29.5</td>
<td>11.9</td>
<td>0.96</td>
<td>.92</td>
<td>.00</td>
</tr>
<tr>
<td>Linear Shoulder Excursion (cm)</td>
<td>298.8</td>
<td>55.3</td>
<td>148.8</td>
<td>51.7</td>
<td>0.00*</td>
<td>.76</td>
<td>.00</td>
</tr>
<tr>
<td>Ball Velocity (mph)</td>
<td>59.2</td>
<td>7.8</td>
<td>51.2</td>
<td>6.6</td>
<td>0.00*</td>
<td>.45</td>
<td>.00</td>
</tr>
</tbody>
</table>

Table 4  Primary Variable for Specific Aim 2

<table>
<thead>
<tr>
<th>Method</th>
<th>Average Time from Initiation Method to MER (s)</th>
<th>Std Dev</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFC Method</td>
<td>0.2087</td>
<td>0.05</td>
<td>0.98</td>
</tr>
<tr>
<td>Euler Method</td>
<td>0.2088</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2  Shoulder Internal/External Rotation Angle (external = negative)

Figure 3  Shoulder Abduction/Adduction Angle (adduction = negative)

23
Figure 4    Shoulder Flexion/Extension Angle (extension = negative)
Figure 5  Elbow Flexion/Extension Angle (extension = negative)
Chapter 5
CONCLUSION

To understand the mechanism of injury at the shoulder joint during throwing it is imperative to understand the movement of all the associated structures, and current motion capture methods are limited in their ability to monitor scapular kinematics. The results of this study show that kneeling throwing is not different from standing throwing. Therefore, humeral motion in kneeling throwing is representative of humeral motion in standing throwing; and it has been assumed that if the humerus is moving in a similar way, so is the scapula. As a result, kneeling throwing, to accommodate for the mechanical restrictions of ultrasound, can be used to observe scapular kinematics in youth throwers.
REFERENCES


3) Theory and Application of Precision Ultrasonic Thickness Gaging Retrieved 05/15/11 from www.ndt.net/article/wt1097/panam/panam.htm#53


doi:10.1177/0363546509340226

doi:10.1249/MSS.0b013e3181d64103


Appendix

INFORMED CONSENT
WHAT IS THE TITLE OF THE STUDY?
Kinematic Differences of the Upper Extremity When Throwing from Standing and Kneeling Positions.

1. PURPOSE/DESCRIPTION OF THE STUDY

This study is designed to provide preliminary information for a larger study on developmental throwing mechanics. The intent is to establish the groundwork for using ultrasound sensors to track the motion of the scapula during the throwing motion. To our knowledge, the motion of the scapula has never been measured during the throwing motion, even though it is known to play a role in throwing mechanics.

Ultrasonic measurement of the scapula during movement activities is a difficult task that is complicated by the extraordinary amount of trunk motion during an overhand throw. Specifically, the amount of trunk motion that occurs during an overhand throw is greater than the range of motion provided by most ultrasound probes. One way to decrease the total amount of trunk motion is to throw from one knee (as opposed to a standing position). However, the shoulder and arm mechanics associated with throwing from this position have not been reported in the literature. For the data obtained from ultrasound to be useful, it’s imperative that the shoulder and arm motion measured during a kneeling throw approximates (or is scalable to) that of the standing position.

The purpose of this research study is to determine the differences in arm kinematics between throwing from standing and kneeling positions. No ultrasound measures will be obtained in this preliminary study.

Procedures

Approximately 20 college males will participate in this study (ages 18-24), and participation will last between 1-2 hours. The study will take place in
the Human Performance Laboratory located on the east side of the Fred Rust Arena.

If you choose to participate, you will be asked to throw a baseball into a net (located approximately 20 ft away) under two conditions: throwing from a standing position, and throwing from a kneeling position. Upon arrival at the Human Performance Lab you will be asked a set of questions regarding your medical and surgical history, including any known allergies to band-aids. You will then have reflective markers placed on specific landmarks on your trunk and throwing arm. Next, you will be given 3-5 low-velocity warm up throws to become comfortable with the markers, followed by however many throws you need to adequately warm up. Finally, you will throw 3-5 throws from a standing position, and each of these throws should exceed 60 mph. These will be followed by 3-5 throws from a kneeling position, and each of these should have a minimum velocity of 40 mph. You will be required to kneel on the knee that is on the same side as your throwing arm.

2. CONDITIONS OF SUBJECT PARTICIPATION
   All data will be collected in the Human Performance Laboratory. Motion capture data will be identified using codes, which will be known only to the researchers. Other than age, height, and weight, no personal information will be collected.

   Your participation in this study is completely voluntary. You may also withdraw from the study at any time without consequence. In the event of physical injury as a direct result of these research procedures, you will receive first aid. If you require additional medical treatment, you will be responsible for the cost.

   The investigator may terminate your participation if your data cannot be processed for technical reasons. You will also be notified if there are any significant findings that may affect your willingness to continue participation.

3. RISKS AND BENEFITS

32
The risks associated with this study are minimal. However, any research comes with some risk of injury or discomfort. To minimize this risk, you will not be allowed to participate if you have had a previous shoulder or elbow injury or surgery.

As with any throwing activity, you may experience muscle soreness the next day, especially if you have not thrown for some time. The soreness should go away over the next 2-3 days following the activity.

You will not receive any direct benefit from this study.

4. FINANCIAL CONSIDERATIONS

There will be no financial compensation or costs for participation.

5. CONTACTS

For questions and concerns regarding research procedures:

Dr. James Richards  302-831-7029  jimr@udel.edu
Shaun Hager  631-875-6084  shager@udel.edu

For questions and concerns regarding the rights of individuals who participate in research: Chair, Institutional Review Board, University of Delaware, 302-831-2137

6. SUBJECT ASSURANCES

I have read the above consent form thoroughly and understand that I am a volunteer and can withdraw from participation at any time without any loss of benefits to which a subject is otherwise entitled. The procedures, risks, and benefits have been explained, and I accept all risks involved in this study. I have also received a copy of this form for my records.

7. CONSENT SIGNATURES

My signature indicates that:
• I have read this form and all questions were answered.
• I give my consent to participate in this research study.

Participant’s Name (printed): _________________________________

Participant’s Signature: ____________________________ Date: _______

Investigator’s Signature: ____________________________ Date: _______