A Comparison of Trunk Rotation Flexibility and Trunk Rotation Kinematics during Throwing between Division I Collegiate Softball Position Players with and without a History of Shoulder or Elbow Pain

Veronica J Aragon

A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Masters of Art in the Department of Exercise & Sport Science in the College of Arts & Sciences.

Chapel Hill
2010

Approved by:

Advisor: Joseph B. Myers, PhD, ATC

Reader: Darin A. Padua, PhD, ATC

Reader: Sakiko Oyama, MS, ATC

Reader: Benjamin M. Goerger, MS, ATC

Reader: Scott Oliaro, MA, ATC

© 2010
Veronica J Aragon
ALL RIGHTS RESERVED

ABSTRACT

Veronica J Aragon: A Comparison of Trunk Rotation Flexibility and Trunk Rotation Kinematics during Throwing between Division I Collegiate Softball Position Players with and without a History of Shoulder or Elbow Pain
(Under the direction of Dr. Joseph B. Myers)

Throwing is a whole body movement that requires the transfer of energy via the trunk from the lower extremity to the upper extremity. Ineffective transfer of energy is thought to cause abnormal stresses on the joints of the throwing arm, that lead to injury. The purpose of this study was to compare trunk kinematics during throwing and trunk flexibility between softball position players with and without a history of shoulder/elbow pain. Trunk rotation kinematics at three time points during throwing and trunk rotation flexibility measured with three clinical tests were compared between groups. Results revealed that limited trunk flexibility measured using the half kneeling rotation test with the bar in back was associated with a history of shoulder/elbow pain. Trunk rotation kinematics was not different between groups. The clinical test may be used by clinicians to identify softball players who may be at increased risk for developing shoulder/elbow pain.

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

CHAPTER 1

INTRODUCTION

Introduction

The sport of softball began in 1880 as a derivation of baseball and was officially named softball in 1930 (Flyger, Button et al. 2006). Over the years softball has continued to grow and the International Softball Federation now recognizes 122 national federations (Flyger, Button et al. 2006). It can be estimated that there are about 16,079 participants at the collegiate level in the United States (Marshall, Hamstra-Wright et al. 2007).

Currently there is little epidemiological data available for softball injuries in position players. The NCAA injury surveillance system reveals that upper extremity injuries in softball players accounts for 33.1 % of injuries during games and 33% of injuries during practice (Marshall, Hamstra-Wright et al.). A recent epidemiologic study in high school athletes reports that girls are more likely to sustain upper extremity injuries as a result of overuse/chronic mechanisms versus boys who are more likely to sustain shoulder injuries from contact with playing surface or noncontact mechanisms. High school epidemiology research also demonstrates that for baseball (24.3%) and softball (50.2%), shoulder injuries are a result from throwing not including pitching. Sprains and strains were found to be the most common shoulder injuries accounting for 52.9% in softball players (Bonza, Fields et al. 2009).

With a high percentage of upper extremity injuries occurring in softball players, it is important to identify potential risk factors so that appropriate intervention programs can be developed. Weakness of the scapular stabilizers and rotator cuff muscles (Ludewig and Cook 2000; Cools, Witvrouw et al. 2003; Barden, Balyk et al. 2005; Hess, Richardson et al. 2005), altered activation patterns of the scapular stabilizers and rotator cuff muscles (Ludewig and Cook 2000; McClure, Bialker et al. 2004; Downar and Sauers 2005; Myers, Pasquale et al. 2005; Laudner, Myers et al. 2006; McClure, Michener et al. 2006; Laudner, Stanek et al. 2007; Oyama, Myers et al. 2008), altered scapular kinematics (Morgan, Burkhart et al. 1998; Burkhart, Morgan et al. 2003; Downar and Sauers 2005; Myers, Laudner et al. 2006; Ruotolo, Price et al. 2006; McClure, Balaicuis et al. 2007; Laudner, Sipes et al. 2008), posterior shoulder tightness (PST) and decreased internal rotation (Aguinaldo, Buttermore et al. 2007; Aguinaldo and Chambers 2009) have previously been investigated and suggested as possible factors contributing to upper extremity injuries. One area that has received little attention and may significantly contribute to shoulder and elbow pain is trunk rotation flexibility and trunk rotation kinematics. Decreased trunk rotation flexibility, limited trunk rotation kinematics and altered timing of trunk rotation during throwing may have an implication in shoulder or elbow pain because of its role of transferring energy to the upper extremity during throwing (Putnam 1991; Putnam 1993; Aguinaldo, Buttermore et al. 2007; Aguinaldo and Chambers 2009).

Kinematics and kinetics of throwing in position players have not been thoroughly examined in baseball or softball and therefore is assumed to be similar to what has been reported for baseball pitching. Although throwing is typically considered an upper extremity movement, successful throwing results from the effective transfer of energy from the lower extremity to the upper extremity which is mediated by the trunk

(Aguinaldo, Buttermore et al. 2007). Ineffective transfer of energy is generally thought to result in "throwing with too much arm (Putnam 1993)." This results in excessive amount of stress placed on the shoulder or elbow that can potentially lead to injury. According to the summation of speed principle, the speed of the distal end of a chain is a direct result of the individual speeds of the proximal segments within that sequence (Putnam 1993). Also important in achieving maximal speed at ball release from the distal segment, is that all segments preceding it must reach maximum angular speeds at the same time (Stodden, Langendorfer et al. 2006). Thus a combination of appropriate timing and summation of energy will result in optimal delivery. Energy transfer at the trunk begins prior to front foot contact as the pelvis rotates forward before the torso, leaving the torso behind and creating a "lag effect," thus providing an eccentric loading of the trunk musculature which results in a storage of elastic energy (Stodden, Langendorfer et al. 2006). Subsequently, energy transfer at the trunk occurs as torso velocities reach twice that of pelvis velocities during throwing (Stodden, Langendorfer et al. 2006). The last sequence in transferring energy to the distal upper extremity segments is the forward linear motion (flexion) of the trunk (Fleisig, Barrentine et al. 1996; Stodden, Fleisig et al. 2001).

Three instances that stand out in the throwing cycle are front foot contact (FFC), instance of maximal shoulder external rotation (MER), and ball release (BR) (Dillman, Fleisig et al. 1993). FFC marks the end of the stride phase during which the upper body and the lower body move in synchrony, and the beginning of the late cocking phase when transfer of energy occurs as the pelvis rotates first followed by rotation of the upper torso (Stodden, Fleisig et al. 2001). Proper execution of this phase allows for efficient transfer of energy (Kibler 1998). MER marks the end of the arm cocking phase. The instance of

MER is referred to as the instance of “full tank of energy” due to the tension on the anterior shoulder musculature, and at this instance allows storage of energy that is used to accelerate the upper limb during the arm acceleration phase (Feltner and Dapena 1986). BR occurs at the end of the arm acceleration phase during which the upper torso motion acts as the major contributor to ball speed (Aguinaldo, Buttermore et al. 2007; Aguinaldo and Chambers 2009). Thus if the pelvis and upper torso do not move effectively, contribution would only come from the arm which would result in a potential increase in stress at the shoulder or elbow (Rose, Phillips et al. 2008). The trunk has been shown to be important in the transfer of energy during throwing; hence it was important to begin to investigate the differences in trunk rotation flexibility and pelvis and upper torso kinematics in individuals with and without a history of shoulder or elbow pain.

The half kneeling rotation test (bar back (HKRT-B) and bar front (HKRT-F)) (Lephart, Smoliga et al. 2007) and seated rotation test (SRT) (Fletcher and Hartwell 2004; Fradkin, Sherman et al. 2004; Thompson and Osness 2004; Lephart, Smoliga et al. 2007) are clinical tests that are used to assess trunk rotation flexibility, which have been used in golfers to identify limitations in trunk range of motion. The half kneeling rotation test may be better to use on throwers because it puts a person into a position in which they must also remain balanced. With the feet in line with each other, it may better represent throwing posture than the traditional seated rotation measurement. Several studies have been conducted to evaluate effectiveness of exercise programs that focus on the trunk flexibility and strength as well as other exercises on golfers (Stodden, Fleisig et al. 2001; Aguinaldo, Buttermore et al. 2007). All these studies found that there was either an increase in trunk range of motion, trunk strength, or golf performance after completion of the program. These studies suggest that if the trunk rotation flexibility is found to be associated with shoulder or elbow injury, then the half kneeling rotation test and the seated rotation test may potentially be used to identify deficiencies, which can be corrected with a training program.

Current literature relates angular kinematics of the pelvis and the upper torso to performance measures, such as pitched baseball velocities, or makes comparisons in male overhead athletes of different age groups or skill levels (Aguinaldo, Buttermore et al. 2007). Aguinaldo et al. (Atwater 1979; Wang 2006) reported that professional pitchers exhibited lesser amounts of peak shoulder internal rotation torque possibly due to professional pitchers' ability to conserve energy longer, resulting in efficient transfer of energy across the glenohumeral joint. This was only one study that was found to make any comparison with torques in the shoulder and trunk rotations. Most other research has emphasized performance and has overlooked the potential implication of trunk rotation kinematics during throwing on shoulder injuries. The trunk plays an important role in transferring energy to the distal segments and therefore was investigated as a potential risk factor to shoulder injury.

With the sport of softball increasing in popularity and prevalence of upper extremity injuries increasing as more people participate, it was important to begin to study the biomechanics of these athletes in order to understand etiology and develop prevention strategies. Since trunk rotation is important in transferring energy to the shoulder and elbow during ball propulsion and absorbing stresses at the joints during limb deceleration, it is becoming an area of greater interest. As of yet, there was no study looking at the relationship between trunk rotation kinematics and upper extremity pain.

Therefore the primary purpose of this study was to compare the amount of trunk rotation and timing of trunk rotation during throwing between collegiate softball players with and without a history of shoulder or elbow pain. The secondary purpose of this study was to compare the trunk flexibility characteristics measured using the half kneeling rotation test (bar in front and bar in back) and seated trunk rotation test between collegiate softball players with and without a history of shoulder or elbow pain. As a measure of performance, ball velocity was also compared between subjects with and without a history of shoulder or elbow pain. The relationship between trunk rotation kinematics during throwing and ball velocity was explored to see if trunk rotation kinematics during throwing can predict performance. Lastly, the relationship between the clinical measures of trunk rotation flexibility and trunk rotation kinematics during throwing was explored to see if clinical measures of trunk flexibility may be used as predictors of trunk rotation kinematics during throwing.

Research Questions

Research Question 1: Is there a difference in upper torso orientation angle means during throwing between subjects with and without history of shoulder or elbow pain?

a. At instant of front foot contact

b. At instant of maximum shoulder external rotation

c. At instant of ball release

Research Question 2: Is there a difference in pelvis orientation angle means during throwing between subjects with and without a history of shoulder or elbow pain in?

a. At instant of front foot contact

b. At instant of maximum shoulder external rotation

c. At instant of ball release

Research Question 3: Is there a difference in upper torso-pelvis separation angle means during throwing between subjects with and without history of shoulder or elbow pain?

a. At instant of front foot contact

b. At instant of maximum shoulder external rotation

c. At instant of ball release

Research Question 4: Is there a difference in initiation of trunk rotation means during throwing between subjects with and without a history of shoulder and elbow pain?

Research Question 5: Is there a difference in means of trunk flexibility between subjects with and without shoulder or elbow pain during the:

a. HKRT-B

    1. Throwing shoulder rotating forward?

    2. Throwing shoulder rotating backward?

b. HKRT-F

    1. Throwing shoulder rotating forward?

    2. Throwing shoulder rotating backward?

c. SRT

    1. Throwing shoulder rotating forward?

    2. Throwing shoulder rotating backward?

Research Question 6: Is there a difference in ball velocity between subjects with and without a history shoulder or elbow pain?

Research Question 7: Are there relationships between trunk rotation kinematics during throwing and ball velocity?

Research Question 8: Are there relationships between the clinical measures of trunk rotation flexibility and trunk rotation kinematics during throwing?

Null Hypotheses

Null Hypothesis 1: There will be no difference in upper torso orientation angle during throwing between subjects with and without a history shoulder or elbow pain.

a. At instant of front foot contact
b. At instant of maximum shoulder external rotation
c. At instant of ball release

Null Hypothesis 2: There will be no difference in pelvis orientation angle during throwing between subjects with and without a history of shoulder or elbow pain.

a. At instant of front foot contact
b. At instant of maximum shoulder external rotation
c. At instant of ball release

Null Hypothesis 3: There will be no difference in upper torso-pelvis separation angle during throwing between subjects with and without a history of shoulder or elbow pain.

a. At instant of front foot contact
b. At instant of maximum shoulder external rotation
c. At instant of ball release

Null Hypothesis 4: There will be no difference in initiation of trunk rotation during throwing between subjects with and without shoulder or elbow pain.

Null Hypothesis 5: There will be no difference in means of trunk flexibility between subjects with and without a history of shoulder or elbow pain during the:

a. HKRT-B

    1. Throwing shoulder rotating forward

    2. Throwing shoulder rotating backward

b. HKRT-F

    1. Throwing shoulder rotating forward

    2. Throwing shoulder rotating backward

c. SRT

    1. Throwing shoulder rotating forward

    2. Throwing shoulder rotating backward

Null Hypothesis 6: There will be no difference in ball velocity between subjects with and without a history of shoulder or elbow pain.

Null Hypothesis 7: There will be no relationships between trunk rotation kinematics during throwing and ball velocity.

Null Hypothesis 8: There will be no relationships between the clinical measures of trunk rotation flexibility and trunk rotation kinematics during throwing.

Research Hypotheses

Research Hypothesis 1: Subjects with a history of shoulder or elbow pain will have less upper torso orientation angle than subjects with no pain.

a. At instant of front foot contact

b. At instant of maximum shoulder external rotation

c. At instant of ball release

Research Hypothesis 2: Subjects with a history of shoulder or elbow pain will have less pelvis orientation angle than subjects with no pain.

a. At instant of front foot contact

b. At instant of maximum shoulder external rotation

c. At instant of ball release

Research Hypothesis 3: Subjects with a history of shoulder or elbow pain will have smaller upper torso-pelvis separation angle than subjects with no pain.

a. At instant of front foot contact

b. At instant of maximum shoulder external rotation

c. At instant of ball release

Research Hypothesis 4: Subjects with a history of shoulder or elbow pain will initiate trunk rotation earlier than subjects with no pain.

Research Hypothesis 5: Subjects with a history of shoulder or elbow pain will have less trunk flexibility than subjects with no pain.

a. HKRT-B

   1. Throwing shoulder rotating forward

   2. Throwing shoulder rotating backward

b. HKRT-F

   1. Throwing shoulder rotating forward

   2. Throwing shoulder rotating backward

c. SRT

   1. Throwing shoulder rotating forward

2. Throwing shoulder rotating backward

Research Hypothesis 6: There will be no difference in ball velocity between subjects with and without a history of shoulder or elbow pain.

Research Hypothesis7: There will be relationships between trunk rotation kinematics during throwing and ball velocity.

a. Upper torso and Pelvis orientation angle

    1. At FFC: Smaller (more closed) orientation is related to greater ball velocity

    2. At MER: Greater (more open) orientation is related to greater ball velocity

    3. At BR: Greater (more open) orientation is related to greater ball velocity

b. Upper torso-pelvis separation angle

    1. At FFC: Greater (more coiled) is related to a greater ball velocity

    2. At MER: Closer to zero (more parallel) is related to greater ball velocity

    3. At BR: Smaller (more coiled) is related to greater ball velocity

c. Initiation of trunk rotation will occur later in subjects who throw faster

Research Hypothesis 8: There will be relationships between the clinical measures of trunk rotation flexibility and trunk rotation kinematics during throwing.

a. Greater HKRT-B, HKRT-F, SRT when the throwing shoulder is moving forward is related to:

    1. Greater (more open) maximum upper torso and pelvis orientation

    2. Smaller (more closed) minimum upper torso-pelvis separation

b. Greater HKRT-B, HKRT-F, SRT when the throwing shoulder is moving backward increases is related to:

    1. Smaller (more closed) minimum upper torso and pelvis orientation

2. Greater (more open) maximum upper torso-pelvis separation angle

Operational Definitions

- **Shoulder pain:** For this study shoulder pain is defined as a history of any pain in the shoulder that has limited an athlete on three or more occasions during practice or competition or has required an athlete to receive some form of treatment for more than a week within the last two years based on the results of a questionnaire.
- **Elbow Pain:** For this study elbow pain is defined as a history of any pain in the elbow that has limited an athlete on three or more occasions during practice or competition or has required an athlete to receive some form of treatment for more than a week within the last two years based on the results of a questionnaire.
- **Throwing:** Throwing is defined as the athlete throwing as they normally would in a game situation for a distance of 25.86 meters.

Assumptions

- All subjects will fill out the questionnaire to the best of their ability.
- All subjects will throw as they normally do in a game situation.
- Subjects will have similar softball playing history.

Delimitations

- Subjects will have no current or recent history (3 months) of:
    - Back injury
    - Neurological disorder
    - Cervical spine injury that may cause neurological impairment

    - Thoracic outlet syndrome
    - Shoulder surgery
    - Abdominal musculature injury
- Subjects will be blinded with the specific purpose of the study to ensure that subjects throwing is unaffected by the study.
- Throwing kinematics will be evaluated out in the field so that throwing movements are performed in a natural environment.

Limitations

- Participants are limited to division I softball position players in the state of North Carolina, therefore this population may not be an accurate representation of softball players across the country.
- Throwing kinematics may differ based on player position.

CHAPTER 2

LITERATURE REVIEW

Upper extremity injury is of great concern for medical professionals dealing with overhead athletes. With overhead athletes performing repetitive motions, continuous stress is placed on the shoulder and elbow that can lead to chronic/overuse injuries (Dillman, Fleisig et al. 1993; Werner, Fleisig et al. 1993; Fleisig, Andrews et al. 1995; Barrentine, Fleisig et al. 1998). At an early age, athletes are taught proper biomechanics to attempt to reduce stresses on the upper extremity joints, prevent injury, and optimize performance (Cools, Witvrouw et al. 2005; Hess, Richardson et al. 2005; Laudner, Myers et al. 2006; Myers, Laudner et al. 2006). In overhead sports such as softball and baseball, where throwing is essential, shoulder and elbow injuries can lead to significant time loss. Potential injury risk factors for upper extremity joint injuries in overhead athletes identified to date include, abnormal scapular kinematics, muscular weakness, altered muscle activation, and decreased glenohumeral motion(Atwater 1979; Putnam 1993). Although typically thought of as an upper extremity motion, throwing requires whole body movements in transferring energy from the lower extremity to the upper extremity(Herring and Chapman 1992). For optimal performance, energy must be transferred effectively through the torso at the appropriate time(Flyger, Button et al. 2006). Despite the important role the trunk plays in the throwing motion, the potential role of the trunk in shoulder or elbow injuries in overhead athletes has been understudied. Thus trunk rotation kinematics during throwing has become a recent topic of interest for researchers. The purpose of this literature review was to present epidemiological data for baseball and softball injuries, common shoulder and elbow injuries due to throwing, discuss injury risk factors for the throwing athlete, discuss the biomechanics of throwing, and discusses the importance of the trunk as it relates to throwing.

Softball

The sport of softball was first introduced in the 1880's as an indoor derivation of baseball. The rules and style of game are very similar to baseball and differ only slightly by the style of pitch, size of the ball and size of the field. The style of pitching for fast pitch softball is a wind-mill pitch (Werner, Gill et al. 2001; Hill, Humphries et al. 2004; Werner, Jones et al. 2006). It has been reported that female fast-pitch wind-mill pitchers have similar stresses placed on the shoulder as the overhand pitchers in baseball and therefore are at risk for similar injuries (Flyger, Button et al. 2006). Softball as a sport has grown not only in the United States but also at the international level with the International Softball Federation recognizing 122 national federations (Marshall, Hamstra-Wright et al. 2007). In the United States, at the collegiate level, there is an estimated 16,079 female participants (Marshall, Hamstra-Wright et al. 2007). As the number of participants increases, it is important to start to investigate injury epidemiology in this sport and biomechanical factors that may be associated with the injuries seen in these overhead athletes to promote safe participation in sports.

Softball and Baseball Epidemiology

Currently, there is little epidemiological data available for position players in both softball and baseball. The NCAA injury surveillance system reveals that upper extremity injuries in softball players account for 33.1% of injuries during games and 33% of injuries during practice (Bonza, Fields et al. 2009). A recent epidemiological study in high school athletes reports that girls are more likely to sustain shoulder injuries as a result of overuse/chronic mechanisms versus boys who are more likely to sustain shoulder injuries from contact with playing surface or noncontact mechanisms (Bonza, Fields et al. 2009). The same study also reports that 24.3% of injuries in baseball and 50.2% of injuries in softball are a result of throwing not including pitching (Bonza, Fields et al. 2009). Shoulder injuries during pitching were found to be more common in baseball than in softball (32.6% and 12.5% respectively) (Powell and Barber-Foss 2000). On the other hand, Powell et al (Powell and Barber-Foss 2000) reported slightly different findings when studying sex related injury patterns. Although not differentiating between specific upper extremity joints injured, Powell et al found that in baseball and softball throwing (excluding pitching) resulted in 36% and 28.1% of injuries respectively, while pitching in baseball and softball accounted for 27.1% and 14.5% of injuries respectively (Neer 1972; Atwater 1979). These findings may differ from Bonza et al because Powell et al did not look at injuries to individual joints and instead reported injuries occurring from a specific activity. Nonetheless, both reported that injuries in softball players are more prevalent as a result of throwing and not pitching. A higher percentage of injuries due to throwing and not pitching may be attributed to the fact there are more position players than pitchers on a team. Reviewing the 2009 online team rosters for the softball teams in the Atlantic Coast Conference, only 18% of softball players are pitchers thus over 80% are position players. With a greater number of position players it is more likely that a greater number of injuries will result due to throwing and not pitching. Currently, pitching mechanics is studied, but little is being done for throwing in position players. With more injuries occurring as a result of throwing, it was important to begin to investigate the biomechanics of position players to indentify risk factors for injury.

Common Shoulder and Elbow Injuries in Throwers

Injuries are common to every sport, but overhead athletes are at particularly greater risk for shoulder and elbow injuries than other athletes due to their physical characteristics and biomechanical demands placed on the shoulder during throwing. Specifically, subacromial impingement, internal impingement, superior labrum anterior to posterior (SLAP) lesions, bicipital tendinosis and rotator cuff pathologies, are common shoulder injuries in overhead athletes, and therefore will be described next.

Subacromial Impingement: Subacromial impingement is a very common injury seen in throwers and is a compression of the structures (long head of biceps tendon, or supraspinatus tendon) underneath the coracoacromial arch (anterior edge of the acromion, coracoid process and coracoacromial ligament). Decrease in the space available for structures that lie within the subacromial space cause impingement and thus results in pain during abduction and internal rotation (Ludewig and Cook 2000). In young overhead athletes, this narrowing of the subacromial space can be attributed to abnormal scapular movement and inadequate glenohumeral dynamic joint stability (Ludewig, Cook et al. 1996; Lukasiewicz, McClure et al. 1999; Ludewig and Cook 2000). In order for the humerus to effectively clear the subacromial space and get into an abducted position for throwing, the scapula must upwardly rotate, externally rotate, and posteriorly tilt (McQuade, Dawson et al. 1998; Tsai, McClure et al. 2003; Ebaugh, McClure et al. 2006; Ebaugh, McClure et al. 2006). Due to the repetitive nature of throwing, fatigue of the muscles that move the scapula in these directions may occur, which results in decreased scapular movement (Dillman, Fleisig et al. 1993). The decrease in scapular movement can cause the structures underneath the subacromial space to be impinged during throwing because the arm is abducted to 90 degrees throughout most throwing phases(Graichen, Hinterwimmer et al. 2005). Inadequate dynamic joint stability allows excessive humeral movement at the glenohumeral joint, thus further narrowing of the subacromial space and increasing the potential for impingement to occur (Walch, Boileau et al. 1992).

Internal Impingement: Another type of impingement was described by Walch et al as the intra-articular impingement that occurs in all shoulders in an abducted and externally rotated position. When the shoulder is in 90 degrees of abduction and 90 degrees of external rotation (90-90 position) the posterior-superior rotator cuff may be impinged between the posterior labrum/glenoid rim and the greater tuberosity (Meister 2000). Throwers with internal impingement will typically describe pain in the arm cocking and deceleration phase, which typically results in an inability to fully rotate the shoulder due to pain(Meister 2000). Increased glenohumeral external rotation range of motion and repetitive positioning of the shoulder in the 90-90 position during the cocking phase of throwing predisposes overhead athletes to this condition(Meister 2000). Repetitive impingement may also eventually lead to fraying and tearing of the posterior rotator cuff muscles (Andrews, Carson et al. 1985; Burkhart, Morgan et al. 2003).

SLAP Lesions: Glenoid labrum tears, specifically superior labrum anterior to posterior (SLAP), lesions are common in throwers. The SLAP lesion occurs on the superior labrum where the tendon of the long head of the biceps brachii muscle inserts on the labrum (Wang 2006). Overhead athletes are prone to sustaining this injury because of the repetitive traction on the labrum caused by the eccentric contraction of the biceps during throwing (Andrews, Carson et al. 1985; McLeod and Andrews 1986). Introduced by Andrews et al is the concept of the "grinding factor" as a cause for labral tears. During the arm acceleration and arm deceleration phases the translation of the humeral head combined with the high joint compression force results in a grinding of the humeral head on the labrum (Burkhart, Morgan et al. 2003). Another potential cause in throwers is the peel back mechanism, which occurs during late cocking when the arm is abducted and externally rotated. In the cocked position the pull of the biceps tendon on the superior portion of the labrum shifts to a more posterior position, causing a twist at the base of the biceps. The posterior shift and the twisting of the biceps "peels back" the superior labrum posteriorly (Wang 2006).. The athletes with SLAP lesion will typically complain of pain with clicking during abduction and external rotation. The athlete will also notice a decrease in ball velocity (Atwater 1979).

Bicipital Tendinosis: Bicipital tendinosis is one of the most common causes of anterior shoulder pain in throwers (Sakurai, Ozaki et al. 1998). Inflammation occurs in the biceps tendon as it passes through the bicipital groove of the humerus. The long head of the biceps brachii has been implicated in stabilizing the humeral head through eccentric contraction during throwing (Meister 2000). The long head of the biceps serves two main functions 1) to internally rotate the humerus from extreme ranges of external rotation and 2) to resist distraction and compress the humeral head against the glenoid cavity (Wang 2006). Repetitive use of this muscle during throwing can cause tensile overload and extreme point tenderness over the bicipital groove and pain during throwing (Jobe, Tibone et al. 1983; DiGiovine 1992).

Rotator Cuff Injuries: Rotator cuff injuries may cause pain in the anterior, posterior, or superior aspect of the shoulder depending on which rotator cuff muscle is affected. High EMG activation level of the rotator cuff muscles have been documented during throwing (Jobe, Tibone et al. 1983). The infraspinatus and the teres minor have peak activity during the late cocking and follow through phases of throwing (Stodden, Fleisig et al. 2001). The muscles functions to produce a downward force to counteract the superior sheer fo(Jobe, Tibone et al. 1983)rce produced by the deltoid during the late cocking phase, produce joint compression force to counteract the high joint distraction force throughout the throwing movement, and eccentrically control humeral internal rotation during the follow through phase. The subscapularis has peak activity during the arm cocking phase and the follow through phase (Atwater 1979; Feltner and Dapena 1986; Dillman, Fleisig et al. 1993; Fleisig, Barrentine et al. 1996; Escamilla, Fleisig et al. 1998; Wang 2006). It is important to understand the activation levels of the muscles during throwing, since muscles may be at greater risk for injury during the phase in which EMG activity is the highest. Throwing is a repetitive motion that continually puts a throwers arm in positions that can lead to injury (Atwater 1979; Wang 2006). High demand placed on the shoulder and impingement of the rotator cuff tendons lead to tissue overload, degeneration and eventually tearing of the rotator cuff (King, Brelsford et al.

1969; Barnes and Tullos 1978; Jobe and Ciccotti 1994; Miller and Savoie 1994; Davidson, Pink et al. 1995; Hamilton, Glousman et al. 1996; Chen, Rokito et al. 2001).

Common throwing related elbow injuries in overhead athletes include medial epicondylitis and injury to the ulnar collateral ligament. Medial epicondylitis is the inflammation of the flexor-pronator muscle group as a result of overload from extrinsic valgus stresses and intrinsic muscular contractions (Jobe and Ciccotti 1994; Davidson, Pink et al. 1995; Hamilton, Glousman et al. 1996). The muscles involved from the flexor-pronator group are the humeral head of the pronator teres, flexor carpi radialis, and sometimes the flexor carpi ulnaris (Jobe, Tibone et al. 1983). EMG studies have found that the pronator teres possesses its highest activity during the acceleration phase of throwing (Chen, Rokito et al. 2001). Medial epicondylitis typically begins as microtears that later progress to fibrosis and granulation of the tissue at the elbow (Morrey and An 1983; Morrey and An 1985; Morrey 1986; Hotchkiss and Weiland 1987; Regan, Korinek et al. 1991; Fleisig, Andrews et al. 1995). The ulnar collateral ligament is the primary stabilizer of valgus stress during throwing (Miller and Savoie 1994). Injury typically occurs due to repeated throwing activity in which a combination of high magnitude of elbow valgus torque and rapid elbow extension (valgus-extension overload) places high magnitude of tensile stress on the ligament (Fleisig, Andrews et al. 1995; Chen, Rokito et al. 2001). Therefore, valgus stress during the cocking and acceleration phase may cause microtears of the ulnar collateral ligament (Jobe, Stark et al. 1986). Improper throwing mechanics, poor flexibility and inadequate conditioning may increase the valgus stress placed on the ulnar collateral ligament causing attenuation and possible rupture of the ligament (Meister 2000).

Potential Injury Risk Factors in Overhead Athletes

Overtime, the throwing shoulder adapts to the repetitive motion, which allows the athlete to perform the movement efficiently and potentially reduce the risk of injury(Meister 2000). Abnormal adaptations or failure to adapt may put an overhead athlete at increased risk for injury (Ludewig and Cook 2000; Meister 2000; Reddy, Mohr et al. 2000; Burkhart, Morgan et al. 2003; Hess, Richardson et al. 2005; Laudner, Myers et al. 2006; Ruotolo, Price et al. 2006; Dun, Fleisig et al. 2007; Laudner, Stanek et al. 2007; McClure, Balaicuis et al. 2007; Laudner, Sipes et al. 2008). To date, extensive research has identified glenohumeral joint range of motion alteration, abnormal scapular kinematics, muscle weakness, and alteration of the timing of muscle activation as potential risk factors for injury in the overhead athlete (Burkhart, Morgan et al. 2003; Downar and Sauers 2005; Myers, Laudner et al. 2006).

Research suggests that the dominant shoulder of overhead athletes display posterior shoulder tightness and glenohumeral internal rotation deficit (GIRD) (Burkhart, Morgan et al. 2003). GIRD is defined as a loss of internal rotation when compared to the non throwing arm (McClure, Balaicuis et al. 2007; Laudner, Sipes et al. 2008). Posterior shoulder tightness has been implicated as one cause of GIRD and research has demonstrated that stretching programs are effective in decreasing posterior shoulder tightness, increasing internal rotation and therefore potentially reducing the risk of injury (Kronberg, Brostrom et al. 1990; Crockett, Gross et al. 2002; Osbahr, Cannon et al. 2002; Reagan, Meister et al. 2002). Osseous change as a result of torsion moments at the humerus during throwing may also influence the amount of range of motion characteristics (Crockett, Gross et al. 2002; Osbahr, Cannon et al. 2002; Reagan, Meister et al. 2002). The dominant limb has been shown to show increase in humeral torsion (Crockett, Gross et al. 2002), thus increasing the amount of external rotation and in turn decreasing internal rotation (Downar and Sauers 2005).

Despite significant GIRD, it was demonstrated that the total arc of motion was not significantly different between throwing arm and the non throwing arm in baseball players without shoulder injuries (Morgan, Burkhart et al. 1998; Ruotolo, Price et al. 2006). On the other hand, another study found that there was an average loss of 9.6^o in total arc of motion on the throwing arm when compared to their non throwing arm in baseball players with shoulder pain (Ludewig and Cook 2000). These studies suggest that significant loss in total arc range of motion in the throwing arm, rather than presence of GIRD alone may increase risks for shoulder injury.

Alteration of the scapular kinematics has also been identified as potential risk factor for shoulder injuries. In a study looking at subjects with impingement, it was reported that these subjects have decreased upward rotation at 60^o and 90^o of glenohumeral abduction when compared to a control group (McClure, Michener et al. 2006). On the other hand, a study by McClure et al (Ludewig and Cook 2000) contradicts the results demonstrated by Ludewig and Cook (McClure, Michener et al. 2006), stating that the patient with impingement have an increase in upward rotation. McClure et al (Laudner, Myers et al. 2006) believes that this is a compensation for the weakness and decrease in humeral range of motion in subjects with impingement. Another study looking at throwers with pathological impingement, reported that symptomatic subjects have decreased clavicular elevation and increased posterior tilting (McClure, Bialker et al. 2004). With research reporting abnormal scapular kinematics as a potential risk factor for injury, it has been recommended that individuals participate in strengthening programs to maintain proper positioning of the scapula during overhead motions (Oyama, Myers et al. 2008). Alterations in scapular kinematics have been identified in the overhead athlete's dominant arm when compared to non throwing athletes or to the non-dominant arm at rest (Myers, Laudner et al. 2005) and during elevation (Downar and Sauers 2005; Myers, Laudner et al. 2005). It has been reported that a throwers' dominant arm displays greater amounts of upward rotation when compared to the non-dominant arm (Laudner, Stanek et al. 2007). This increase in upward rotation allows the humeral head to clear the subacromial space effectively and therefore reduce the risk for impingement. Overtime, if the throwing arm does not adapt and the throwing arm displays a decrease in upward rotation, the athlete may be at an increased risk for developing shoulder impingement symptoms. Studies have also noted differences in scapular kinematics between pitchers and position players in baseball. It was reported that pitchers have decreased upward rotation which may put pitchers at a greater risk for injury (Reddy, Mohr et al. 2000; Cools, Witvrouw et al. 2005).

Weakness of the muscles surrounding the shoulder has also been identified as a potential risk factor of shoulder injuries in overhead athletes. Scapular protractors (especially the serratus anterior), the deltoid and rotator cuff muscles of persons with impingement are found to be weaker when compared to normal counterparts (Tyler, Cuoco et al. 2009). It was reported that fatigue of the scapular retractors resulted in a decrease in external rotation strength which can potentially increase the chance of injury (Cools, Witvrouw et al. 2004). Cools et al (Hess, Richardson et al. 2005) found a decrease in force output of the protractors and retractors in overhead athletes with impingement when compared to their non-injured arm.

Altered muscle activation pattern has also been identified in individuals with shoulder injuries. It was reported that individuals with impingement demonstrated a delayed onset of muscle activation of the rotator cuff muscles (Cools, Witvrouw et al. 2003). A study of overhead athletes with impingement symptoms, reported that these subjects had an abnormal recruitment pattern of the trapeizus muscle (Ludewig and Cook 2000). In contrast, Ludewig et al (Ludewig and Cook 2000) reports that there is an increase in upper and lower trapezius muscle activity in patients with fatigue. This increased only occurred when the load was at its greatest (4.6 kg) and during two (61^o-90^o and 91^o-120^o) of the three phases of elevation. The author stated that increase in activity may occur as a compensation for weaknesses in other muscles. During all other phases, the upper and lower trapezius showed a decrease in EMG activity. Ludewig et al (Barden, Balyk et al. 2005) also reported decreases in serratus anterior activity during all phases and load condition. Abnormal amplitude and duration of firing was reported for the rotator cuff muscles and the pectoralis major in subjects with multidirectional instability (Atwater 1979; Putnam 1993). In some cases, it may not be known if the abnormal muscle activity is the cause of the injury or if the injury is the cause of the alteration, but whichever is the case it important to correct these alterations.

As discussed above, current research mainly investigates characteristics of the shoulder girdle as risk factors of the upper extremity injuries but overlooks the potential contribution of trunk flexibility and trunk rotation kinematics during throwing to shoulder and elbow injuries. Throwing is a whole body movement that requires proper biomechanics at multiple joints (Aguinaldo, Buttermore et al. 2007). Energy is transferred from the lower extremity to the upper extremity via the trunk. If the trunk does not transfer energy effectively, throwers tend to generate greater torque at the shoulder to compensate for the lost energy, increasing the risk of overuse injuries (Fleisig, Barrentine et al. 1996). Because of its potential to cause injury at the shoulder and elbow, it is important to consider and begin to investigate the trunk as a potential risk factor for shoulder and elbow injuries in overhead athletes.

Biomechanics of Throwing

Kinematics and kinetics of throwing in position players has not been thoroughly examined in baseball or softball and therefore is assumed to be similar to what has been reported for baseball pitching. Throwing biomechanics can be divided into six phases including the wind-up, stride, arm cocking, arm acceleration, arm deceleration and follow through (Jobe, Tibone et al. 1983). The primary role of each phase, shoulder, elbow, and trunk rotation kinematics and kinetics, and activation pattern of the key musculatures during each phase will be discussed next.

The wind-up phase allows for the thrower to get in a ready position. Lifting of the lead leg results in shifting of the body weight away from the target, which allows generation of the linear momentum in the latter phases of throwing. During this phase the shoulder is in minimal internal rotation, slight abduction with low joint forces and torque production and minimal muscular activity (Fleisig, Barrentine et al. 1996).

During the stride phase, the thrower generates linear momentum by shifting the lead side leg toward the target. Elastic energy, which can be used later in throwing, is stored in soft tissues of the trunk and the arms as the body stretches when the stance foot remains planted and both arms assume an abducted position (Moore and Dalley 2006). The deltoid and rotator cuff muscles are responsible for stabilizing the arm in 90^o of abduction as they form a force couple in which their opposite line of pull creates a compression force that holds the humeral head in the glenoid cavity while minimizing the humeral translation in a supero-inferior direction (Jobe, Tibone et al. 1983). Peak EMG is experienced by the anterior, middle, and posterior deltoid during this phase in order to abduct the arm to 90 degrees position (Jobe, Tibone et al. 1983). The teres minor, infraspinatus, and supraspinatus also become active near the end of this phase to produce a downward pull to minimize the superior translation of the humeral head. The supraspinatus has the highest activation level of all rotator cuff muscles at this phase as it also functions to assist in shoulder abduction, particularly during the first 30 degrees of motion (Putnam 1993).

Forward trunk tilt, which generates linear momentum by shifting the body weight forward, begins during the stride phase. The linear momentum generated by forward weight shifting can be conserved and transferred to generate momentum in distal segments(Hirashima, Kadota et al. 2002). Trunk rotation is initiated with pelvis rotation near the time of front foot contact. The opposite internal oblique of the throwing arm becomes active just prior to foot strike, preventing the upper torso from rotating with the pelvis and thus conserving energy until it is needed (Stodden, Langendorfer et al. 2006). As the pelvis rotates and leaving the upper torso behind, a “lag effect” is created, thus providing an eccentric loading of the trunk musculature which results in storage of elastic energy (Fleisig, Barrentine et al. 1996). Shortly after the initiation of pelvis rotation, the upper torso begins to rotate at twice the velocity of the pelvis (Fleisig, Barrentine et al.

1996; Stodden, Fleisig et al. 2001; Stodden, Langendorfer et al. 2006). At maximal external rotation of the shoulder, upper torso orientation surpasses pelvis orientation. The greater upper torso orientation and the larger velocity indicate that there is a transfer of momentum and energy from the pelvis to the upper torso (Fleisig, Andrews et al. 1995).

The arm cocking phase is the time from front foot contact to maximal shoulder external rotation (Brown, Niehues et al. 1988; Burkhart, Morgan et al. 2003; Downar and Sauers 2005; Myers, Laudner et al. 2006). The elbow moves into more extended position and the shoulder is maintained in 90^{o} of abduction and becomes increasingly externally rotated while the rest of the body is “un-cocked”, followed by initiation of trunk forward rotation. It is reported that throwers arms can possess up to 10^{o} to 15^{o} more external rotation in the throwing arm (Brown, Niehues et al. 1988). This allows for a greater range for the arm to rotate forward and generate velocity (Jobe, Tibone et al. 1983; DiGiovine 1992; Fleisig, Andrews et al. 1995). In this phase, shoulder musculature is very active in order to resist increasing distraction and translational forces that are generated. Eccentric contraction of the internal rotators (pectoralis major, latissimus dorsi, anterior deltoid, teres major, and subscapularis) is necessary to decelerate external rotation by producing a shoulder internal rotation torque, which peaks just prior to maximum shoulder external rotation (Jobe, Tibone et al. 1983; Cain, Mutschler et al. 1987). To resist anterior humeral head translation due to external rotation, the infraspinatus and teres minor produce a posterior force (Fleisig, Andrews et al. 1995). Just prior to maximum shoulder external rotation, there is a peak in anterior shear force and horizontal adduction torque, produced by anterior shoulder musculature (pectoralis major, anterior deltoid, subscapularis) allowing the arm to continue to move forward and to resist posterior translation of the humerus (Dillman, Fleisig et al. 1993). All these forces allow for the humeral head to stay stabilized within the glenoid fossa and allow for the continuation of the throwing motion. During the arm cocking phase, if the pelvis is too closed (posterior aspect of the pelvis visible to the throwing target), then the pelvis may not be able to rotate efficiently and will result in limited energy contribution from the lower extremity. If the pelvis is too open (anterior aspect of the pelvis visible to the throwing target), then energy may be transferred to the trunk prematurely (Hirashima, Kadota et al. 2002). Thus timing of rotation is important in order for the appropriate amount of energy to be transferred to the distal segments. The last sequence of transferring energy from the upper torso to the arm is the forward linear motion (flexion) of the trunk. Peak EMG activity for the rectus abdominis was found to occur just before ball release, thus assisting with linear trunk motion (Stodden, Langendorfer et al. 2006). Linear trunk motion promotes the “lag effect” in the sagittal plane as passive eccentric loading of the rectus abdominis and internal/external obliques results from trunk hyperextension (Feltner and Dapena 1986). This results in lagging of the upper extremity relative to the trunk, which allows storage of energy in the anteriorly positioned soft tissues that are put on stretch, but also results in production of peak valgus torque at the elbow and peak external rotation torque at the shoulder(Fleisig, Andrews et al. 1995).

Arm acceleration is the explosive phase from maximum shoulder external rotation to ball release (Bradley and Tibone 1991; DiGiovine 1992). The elbow extends rapidly during this phase with peak extension velocity exceeding 2000°/sec. The elbow also experiences joint distraction force approximating one’s body mass at the time of ball release. This is the phase where shoulder internal rotators contract concentrically to produce high internal rotation velocity (DiGiovine 1992). The rotator cuff muscles and scapular stabilizers are very active in this phase implying the need for humeral head and scapular stabilization at this time (Fleisig, Barrentine et al. 1996). The internal rotation velocity increases as the shoulder internally rotates, and reaches its maximum speed near the time of ball release (Fleisig, Barrentine et al. 1996). At this time the trunk flexes forward, which is enhanced by the straightening of the lead knee. The straightening of the knee provides a stable base for the trunk to rotate (Fleisig, Andrews et al. 1995).

Arm deceleration phase is the time from ball release to maximum shoulder internal rotation (Fleisig, Andrews et al. 1995). The trunk continues to flex forward as the arm continues to internal rotate (Fleisig, Andrews et al. 1995; Fleisig, Barrentine et al. 1996). Large compressive force is produced at the shoulder to counteract the high joint distraction force (Jobe, Tibone et al. 1983; Cain, Mutschler et al. 1987; Bradley and Tibone 1991; DiGiovine 1992; Fleisig, Andrews et al. 1995). Posterior forces are produced by the infraspinatus, supraspinatus, teres major and minor, latissimus dorsi and posterior deltoid to resist anterior humeral translation while eccentric contraction of the infraspinatus, supraspinatus, teres major and minor, and posterior deltoid produce horizontal abduction torque to decelerates horizontal adduction (Jobe, Tibone et al. 1983; Cain, Mutschler et al. 1987; Bradley and Tibone 1991; DiGiovine 1992; Fleisig, Andrews et al. 1995) . Additionally, teres major, latissimus dorsi and posterior deltoid produce an inferior force and adduction torque to resist superior humeral translation and shoulder abduction (Jobe, Tibone et al. 1983; Cain, Mutschler et al. 1987; Bradley and Tibone 1991; DiGiovine 1992; Fleisig, Andrews et al. 1995). The teres minor has been reported to have the highest activity of all the rotator cuff muscles during this phase (Fleisig, Barrentine et al. 1996).

The throwing cycle is completed with the follow-through phase when the arm completes its movement and the athlete returns to a balanced position. Shoulder forces and torques are smaller during this phase and the posterior shoulder muscles continue to eccentrically contract to decelerate and horizontally adduct the arm across the body (Putnam 1993; Stodden, Fleisig et al. 2001).

Importance of Upper Torso and Pelvis Kinematics during Throwing

It is believed that with proper amount of rotation and the correct temporal patterns of rotation will result in better performance (Burkhart, Morgan et al. 2003).

The kinetic chain is important during throwing as it allows for all segments of the body to generate the forces needed to propel a ball. In normal kinetic chain motion the trunk and the legs act as force generators (Putnam 1993). According to the summation of speed principle, the speed of the distal end of a chain is a result of the individual speeds of the proximal segments within the sequence (Putnam 1993). Also important in achieving maximal ball release speed, the distal segments must reach maximum angular speeds at the same time as the proximal segments (Herring and Chapman 1992). A simulation study found that throwing produces the greatest range and velocity when a proximal to distance temporal sequence is followed. It was found that even the smallest alterations in timing resulted in decreases in range and velocity, thus showing the importance of proper timing of proximal to distal sequence (Putnam 1993; Fleisig, Andrews et al. 1995; Fleisig, Barrentine et al. 1996; Stodden, Fleisig et al. 2001; Hirashima, Kadota et al. 2002; Stodden, Langendorfer et al. 2006). During throwing, trunk movement contributes to speed of the distal segments via forward trunk tilt during the stride phase, and trunk rotation during the cocking phase, and linear movement of the trunk during the acceleration phase (Fleisig, Barrentine et al. 1999; Stodden, Fleisig et al. 2001; Aguinaldo, Buttermore et al. 2007).

Current literature relates angular momentums of the pelvis and the trunk to pitched baseball velocities or makes age comparisons in males (Aguinaldo, Buttermore et al. 2007). One such study found that all age groups displayed equal amounts of rotation but that professional pitchers initiated trunk rotation toward the target much later than youth pitchers. This study also reported that professional pitchers exhibited lesser amounts of peak shoulder internal rotation torque than younger pitchers possibly due to professional pitchers' ability to conserve energy longer, thus resulting in efficient energy transfer (Fleisig, Barrentine et al. 1999). Similarly, Fleisig et al. (Aguinaldo, Buttermore et al. 2007) reported pitching kinematic, kinetic, and temporal data in baseball pitchers of different skill levels. The authors reported that professional pitchers displayed the slowest pelvis rotation and the fastest upper torso rotation. On the other hand, contradicting the study by Aguinaldo et al., (Fleisig, Barrentine et al. 1999) Fleisig et al reported that professional pitchers displayed significantly higher shoulder internal rotation torque thus suggesting that a professional pitcher may be at higher risk for injury (Fleisig, Barrentine et al. 1999). Fleisig et al.(Aguinaldo, Buttermore et al. 2007) suggested that the increase in internal rotation torque is attributed to the increased force production by professional players' stronger musculature. Differences in these two studies may be because Aguinaldo et al. (Fleisig, Barrentine et al. 1999) normalized peak internal rotation torque to product of height and weight and Fleisig et al (Stodden, Fleisig et al. 2001) did not. Pitched velocity has been reported to be greater in individuals who have greater average upper torso velocity and average pelvis velocity (Stodden, Fleisig et al. 2001). Pitched velocity has also been reported to increase with greater pelvis orientation angle and upper torso orientation angle during shoulder maximal external rotation. (Putnam 1993; Burkhart, Morgan et al. 2003; Stodden, Langendorfer et al. 2006). Thus greater trunk rotation range of motion may results in a greater pitch velocity and may also have some implication on a history of shoulder or elbow pain.

While trunk rotation kinematics during throwing has been investigated in the context of performance, little investigation has been done in regards to trunk rotation and shoulder or elbow pain. Also the association between trunk rotation during throwing and trunk rotation flexibility is unknown. Since the trunk plays such a large role in transferring energy from the lower extremity to the upper extremity, it is believed that abnormal trunk rotation kinematics can lead to inefficient transfer of energy and thus result in abnormal stresses at the shoulder and elbow joints that would result in injury (Norkin and White 1995; Clarkson 2005).

Measurement of Trunk Flexibility

After describing the importance of the trunk during throwing, it is important to discuss trunk flexibility and how that may contribute to decreased rotation and how to identify it clinically. Trunk rotation can be measured in one of two ways in a clinical setting, either with a goniometer or a tape measure (Norkin and White 1995). The standard method involves the subject seating with their hands across their chest with the clinician using the hips as the land mark for the stationary arm and the acromion as the land mark for the movable arm (Rose, Phillips et al. 2008). Although still using a goniometer, Rose et al. (Rose, Phillips et al. 2008) has established slightly different ways of measuring trunk rotation with the half kneeling rotation test and the seated rotation test. There are two versions of the half kneeling rotation test, one with the subject holding a bar in the back and the second holding the bar in the front. The half kneeling rotation test with the bar in the back locks the scapula which results in only thoracic spine movement. The half kneeling rotation test with the bar in the front, allows for movement of the thoracic and lumbar spine. The seated rotation test performed by Rose et al. (Norkin and White 1995) differs from Norkin and White (Rose, Phillips et al. 2008) only by placement of the goniometer. These tests have been used in golfers to indentify deficiencies that may inhibit performance (Fletcher and Hartwell 2004; Fradkin, Sherman et al. 2004; Thompson and Osness 2004; Lephart, Smoliga et al. 2007). The half kneeling rotation test may be a better test to use on athletes, because it puts them in a position that may be more similar to a throwing posture than the seated rotation test. Several studies have been conducted in the golf population to determine if intervention programs can be used to improve trunk flexibility, trunk strength and golf performance (Thompson and Osness 2004). Thompson and Osness (Thompson and Osness 2004) looked at an 8 week intervention in and elderly golf population and demonstrated that there were improvements in both trunk flexibility and strength with intervention. Thompson and Osness (Norkin and White 1995) used the Norkin and White (Thompson and Osness 2004) approach in measuring trunk rotation, and found that there was about a 20^{o} in rotation after the intervention program. Similar to Thompson and Osness (Lephart, Smoliga et al. 2007), Lephart et al (Norkin and White 1995) used the methods described by and Norkin and White (Lephart, Smoliga et al. 2007) to measure trunk rotation, when looking at an 8 week intervention program in middle aged golfers. Lephart et al (Fletcher and Hartwell 2004) found that there was an increase in trunk rotation after participating in the intervention program. Fletcher et al. (Fradkin, Sherman et al. 2004) and Fradkin et al. (Thompson and Osness 2004; Lephart, Smoliga et al. 2007) did not specifically look at trunk flexibility, but found that when subjects performed an exercises program that incorporated trunk exercises over an extended period of time, demonstrated improvements of golf performance, such as club speed and driving distance. If trunk rotation is demonstrated to be a potential risk factor to shoulder injury there must be some way of identifying those who have limited rotation. The half kneeling rotation test and the seated rotation test are possible tests that can be used in determining those who have limited flexibility. Once individuals are identified as having limited flexibility, intervention programs can be used to correct the limitation (Stodden, Fleisig et al. 2001).

Summary

Throwing is a complex movement that requires contributions from all segments of the body. The trunk is responsible for transferring energy from the lower extremity to the upper extremity. The trunk produces this energy from rotation in the transverse plane and extension/flexion in the sagittal plane (Stodden, Langendorfer et al. 2006; Aguinaldo, Buttermore et al. 2007). Upper torso rotation has been shown to have an effect on pitch velocity, and differences in magnitude and temporal characteristics of trunk rotation have been found among different age groups (Leigh and Yu 2007). However, minimal research has been conducted evaluating the relationship between the trunk and shoulder or elbow injuries. Since the shoulder and elbow are one of the most commonly injured body parts in softball players, it is an area that needs further research. Timing and amount of rotation are important contributors to the throwing motion and therefore more research should begin to focus in this area.

CHAPTER 3

METHODOLOGY

Subjects

Eighty healthy female division I softball position players were recruited for this study. Five intercollegiate softball teams from schools in central North Carolina were contacted for participation in this study. Subjects were included in the study if 1) they were able to throw as they normally would in a game situation, 2) they play a position other than pitcher for at least fifty percent of their total playing time, and 3) did not have pain at the time of testing. Fifteen players reported that they play pitcher for more than fifty percent of their total playing and were thus excluded from the study. Therefore, data from a total of sixty-five position players were used in the data analysis. Pitchers were excluded in order to avoid the influence of shoulder and elbow injuries that may be potentially due to the underhand pitch.

Instrumentations:

Four Video Home System (VHS) video camcorders (Panasonic, Kadoma, Japan: Model; PV-GS35) were used to collect throwing data at a rate of 60 frames per second and a shutter speed of 1/1000 seconds (Escamilla, Fleisig et al. 1998). The four cameras (figure 1) were centered around the throwing circle. The cameras were placed 45 degrees at the front right (figure 1, camera 1), back right (figure 1, camera 2), back left (figure 1, camera 3), and front left (figure 1, camera 4) centered around the throwing circle. The two cameras on the right side were used to film right handed subjects, and the two cameras on the left side were used to film left handed subjects. A ten by ten inch box was taped to the ground centered around the origin.

A 2 x 1.5 x 1 m three dimensional calibration frame(Peak Performance Technologies, Inc., Englewood Colorado) was placed in the center of the throwing circle, which was set in an open area in the outfield, and videotaped prior to data collection (Neer). Additionally, one object was placed at the origin and another object about meter away was used to represent the direction of the x-axis during calibration to establish a global reference frame during data reduction.

Procedures

Prior to subject arrival, the cameras were set up and the calibration frame was videotaped as described in the instrumentation section.

Subjects reported to the stadium of the school that was tested. Prior to participation, subjects signed an informed consent form that was approved by the University of North Carolina-Chapel Hill Biomedical Institutional Review Board. Participants were screened for inclusion and exclusion criteria using section I of the questionnaire (Appendix A). Subjects were excluded if the reported that they pitched for more than 50% of their total playing time. Subjects were also excluded if they (1) reported currently having shoulder, elbow, neck or back pain that would prevent them from throwing in a game situation, (2) experienced numbness or tingling in their throwing arm within the past three days or have been diagnosed with a neurological disorder, (3) reported having surgery on their throwing arm within the past six months, and/or (4) if they were diagnosed by a physician or athletic trainer as having a strain of any trunk muscles within the past week. If participants met the criteria, they proceeded to complete the rest of the questionnaire to provide demographic information (section II) and past medical history (section III). The past medical history was used to determine if the subject was placed in a shoulder/elbow pain or no shoulder/elbow pain group (Appendix A). Subjects were classified into the shoulder/elbow pain group or the no shoulder/elbow pain group based on the past medical history questionnaire. Subjects were placed in the shoulder/elbow pain group if they reported at least one of the following (1) have sustained an injury in which they were unable to throw for three or more days, (2) sustained an injury in which they were only allowed to participate in a limited number of throws for more than a week, and/or (3) sustained an injury in which they were asked to receive treatment for more than a week. Subjects only needed to be pain free at the time of testing. Subjects were not questioned about current rehabilitation programs. All subjects were asked to wear a tank top to aid in visualization of bony landmarks. Sixteen subjects from one of the five schools were tested in practice uniforms due to cold weather.

Subjects underwent three screening tests for trunk flexibility 1) Half kneeling rotation test bar in the back (HKRT-B), 2) half kneeling rotation test bar in front (HKRT-F) and 3) Seated trunk rotation test (SRT). These screening tests assessed the participant's trunk flexibility(Aguinaldo, Buttermore et al. 2007). In our laboratory, moderate to high reliability was obtained through pilot data. The intraclass correlation coefficient and standard error of measurement (SEM) for HKRT-B to the right and left were $ICC_{(2,k)}$ = .672 / SEM = 5.8 deg and $ICC_{(2,k)}$ = .868 / SEM = 3.7 deg, respectively.

The ICC and SEM values for HKRT-F to the right and left were $ICC_{(2,k)}$ = .811 / SEM = 5.0 deg and $ICC_{(2,k)}$ = .856 / SEM = 4.0 deg, respectively. The ICC and SEM values for SRT to the right and left were $ICC_{(2,k)}$ = .798 / SEM = 4.1 deg and $ICC_{(2,k)}$ = .727 / SEM = 5.0 deg, respectively.

1) **HKRT-B (Figure 2):** The subject was asked to get into a half kneeling position with the left knee down on the ground and the right foot directly in front of the left knee. A softball bat was placed behind the back and the subject locked her arms around the bat with her hands on top of her stomach. This position locks the scapula and the lumbar spine so that only the thoracic spine is being tested. A goniometer was used to measure the amount of rotation to the right. The examiner stood to the side of the knee that was up, facing towards the participant. The examiner positioned the stationary arm of the goniometer parallel to the subject's upper back and perpendicular to the examiner's thorax. The subject was asked to rotate as far to right as possible with no discomfort. As the subject rotated, the moveable arm was aligned parallel to the upper back. The test was repeated with the subject switching the position of the legs in order to measure rotation to the left. The subject only rotates to the side of the leg that is up. Start and end position of the goniometer is shown in figure 3.

2) **HKRT-F:** The test was performed in the same manner as the half kneeling rotation test with the bar in the back, except that the bat was placed across the shoulders instead of behind the back. This test measures thoracic and lumbar rotation flexibility. The test was repeated with the subject switching the position of the legs in order to measure rotation to the left.

3) **SRT (Figure 4):** The subject was asked to sit in a chair with their feet together and touching the ground, with the body in an erect upright posture and arms across their chest. The subject was asked to rotate to the right as far as possible with no discomfort. A goniometer was used to measure the amount of rotation with the same alignment as the half kneeling rotation test. The test was repeated with subject rotating to the left as far as possible.

Once a subject completed the questionnaire and the trunk screening tests, she was given ample time to warm up as she normally would, including stretching, non throwing drills and warm up throws. As soon as the subject felt adequately warmed up to make a throw, pre-wrap and tape were placed just above the elbow and at the wrist to aid in the identification of elbow and wrist joint centers during digitization. Once the tape was placed on the subject they were allowed 1-3 practice throws.

Subjects threw a straight line a distance of 25.86 m in the outfield. This distance was chosen because it is the distance from home plate to second base, which is a common distance that position players throw during practices and games. Subjects were instructed to throw as hard and accurate as if in a game situation. They were also instructed to make their front foot land inside the 10 inch by 10 inch box. The ball was thrown to the subject. The subject then caught the ball and threw back to researcher who was 25.86 m away down a straight line. The subject completed five throws with as much time in between each throw for rest as the subject required.

Subjects rated each of their throws on a scale of 1-5 with 1 being the worst throw and 5 being the best throw based on subjective criteria of accuracy of throw and how good the throw felt (Abdel-Aziz and Karara 1971). The speed of each throw was recorded using Jugs (*JK-RG-Gun-R1010)* radar gun. A combination of the highest rated throws and the greatest velocity were chosen for digitization.

Data Reduction

The Direct Linear Transformation (DLT) procedure was used to calculate three dimensional (3-D) coordinates of the bony landmarks (Stodden, Fleisig et al.). The markers on the calibration frame and two additional markers from two camera views were manually digitized using Peak Motus software (Peak Performance Technology, Inc., Englewood, CO) to obtain the Direct Linear Transformation (DLT) parameters, and to define the global coordinate system. The global reference frame was defined such that the X was pointing toward the direction of throwing, Z was the vertical component pointing upward, and Y was the cross-product of Z and X pointing toward the left when facing the direction of throwing (Yu and Andrews 1998). For each throw, six bony landmarks were digitized in each frame for each camera view, starting at five frames before front foot contact to five frames after the instant of ball release. The two camera views were synchronized using a frequency modulated analog audio signal simultaneously transmitted to the cameras. When the 2-D coordinates were synchronized, the DLT procedure was used to obtain the 3-D coordinates. The 3-D coordinates were filtered using a 4^{th} order Butterworth filter with an estimated optimal cutoff frequency of 7.14 (Stodden, Fleisig et al.), and then were used to calculate upper torso orientation, pelvis orientation, and upper torso-pelvis separation angle. Additionally shoulder external rotation angle was calculated to determine the instance of maximal humeral external rotation during throwing.

Three throws were digitized for each subject and then was averaged. Image quality had an influence on digitization, due to some images being clearer than others. Image quality was influenced by the amount of lighting present during the day of testing. Three throws were to be analyzed for each subject but due to tape malfunction, only one or two throws were useable for some subjects. Tape malfunction occurred when the tape would skip frames and thus result in inaccurate synchronization. Only two trials were analyzed for nine subjects and one trial was analyzed for two subjects. The remaining 54 subjects had three trials analyzed.

Moderate to high intra-rater reliability was found during pilot testing for the kinematic variables. Upper torso orientation at FFC, MER, and BR revealed values of $ICC_{(2,k)} = .947$, SEM = 2.52, $ICC_{(2,k)} = .749$, SEM = 6.80, $ICC_{(2,k)} = .732$, SEM = 5.77. Pelvis orientation at FFC, MER, and BR revealed values of $ICC_{(2,k)} = .72$, SEM = 2.70, $ICC_{(2,k)} = .59$, SEM = 9.11, $ICC_{(2,k)} = .757$, SEM = 4.83. Upper torso-pelvis separation angle at FFC, MER, and BR revealed values of $ICC_{(2,k)} = .897$, SEM = 3.05, $ICC_{(2,k)} = .642$, SEM = 9.05, $ICC_{(2,k)} = .472$, SEM = 8.06. Initiation of trunk rotation revealed values of $ICC_{(2,k)} = .318$, SEM = 12.96.

Pelvis orientation (figure 5) was defined as the angle between the line connecting the two ASIS and the global X-axis in the XY plane in a global reference frame. Pelvis orientation was positive when the anterior aspect of the pelvis was visible to the throwing target. Positive orientation was considered the open position of the pelvis. Pelvis orientation is negative when the posterior aspect of the pelvis was visible to the throwing target. Negative orientation was considered the closed position of the pelvis (Stodden, Fleisig et al.).

Upper torso orientation (figure 6) was the angle between the line connecting the bilateral acromion processes and the global X-axis in the XY plane in a global reference frame. Upper torso orientation was positive when the anterior aspect of the upper torso was visible to the throwing target. Positive orientation was considered the open position of the upper torso. Upper torso orientation was negative when the posterior aspect of the upper torso was visible to the throwing target. Negative orientation was the considered the closed position of the upper torso (Myers, Lephart et al. 2008).

Upper torso-pelvis separation angle was the acute angle between the line connecting the acromion and the line connecting the ASIS (Feltner and Dapena 1986). Upper torso-pelvis separation angle was neutral (0 degrees) when upper torso orientation and pelvis orientation were parallel to one another. Upper torso-pelvis separation angle was negative when the upper torso orientation lags behind the pelvis orientation and positive when the upper torso orientation surpasses the pelvis orientation.

Shoulder external rotation angle was calculated as an angle between the forearm vector extending from the elbow to the wrist and the negative Z-axis of the thorax reference frame projected on the XZ plane of the thorax (Feltner and Dapena 1986). The thorax Y-axis was defined as the vector extending from the right shoulder to the left shoulder. The thorax X-axis was defined as the thorax Y-axis crossing the intermediate vector extending from the point bisecting the bilateral ASIS and the point bisecting the bilateral acromion processes. Finally, the thorax Z-axis was calculated as the thorax X-axis crossing the thorax Y-axis. Forearm vector in the global reference frame was transformed and expressed in the thorax reference frame for calculation of the shoulder external rotation angle (Graichen, Hinterwimmer et al.). The instance of the maximal shoulder external rotation was then identified for the calculation of dependent variables.

Three trunk kinematic variables (upper torso orientation, pelvis orientation, and upper torso-pelvis separation angle) were analyzed at three instances, 1) instant of front foot contact, 2) instant of maximum shoulder external rotation (Stodden, Fleisig et al. 2001) , and 3) instant of ball release (Werner, Fleisig et al. 1993; Fleisig, Escamilla et al. 1996; Escamilla, Fleisig et al. 1998). The instances of front foot contact and ball release were identified visually and maximum shoulder external rotation was determined based on the shoulder kinematic data.

In order to identify the timing of upper torso rotation initiation, the three trunk kinematic variables were normalized to the throwing cycle such that 0% is front foot contact and 100% is ball release (Aguinaldo, Buttermore et al. 2007; Aguinaldo and Chambers 2009). Onset time of trunk rotation was defined as the time in which the magnitude, relative to the pelvis, begins to decrease from its maximum value (Stodden, Langendorfer et al. 2006). Calculation of all dependent variables from the 3-D coordinate data was performed using a custom-written program using MatLab software (The MathWorks Inc, Natick MA).

Each trunk rotation flexibility test was taken three times and the mean average was compared between subjects with and without a history of shoulder or elbow pain. Rotation was normalized to throwing arm by defining the direction in which the throwing shoulder was rotating (forward or backward). Rotation when the throwing shoulder is rotating forward was rotation to the left for a right handed thrower and rotation to the right for a left handed thrower. Rotation when the throwing shoulder is rotating backward was rotation to the right for a right handed thrower and rotation to the left for a left handed thrower.

Data Analysis

Three separate one-between (group), one-within (instance) factor analysis of variance (ANOVA) were run to compare the means of upper torso orientation angle, pelvis orientation angle, upper torso-pelvis separation angle at FFC, MER, BR between subjects with and without shoulder/elbow pain. Additionally, independent samples *t*-tests were run to compare the means of initiation of trunk rotation, trunk flexibility test (HKRT-B, HKRT-F, and SRT when the throwing shoulder is rotating backward and when the throwing shoulder is rotating forward) and ball velocity between subjects with and without shoulder/elbow pain. In case significant mean differences were identified, median dichotomy was used to categorize the subjects into limited vs. not limited flexibility or movement groups. Chi-square analysis was used to further analyze the association between the variable and the shoulder/elbow pain and to calculate the odds ratio. In order to explore the relationships between ball velocity and trunk rotation kinematics during throwing, Pearson correlation coefficients were calculated between the trunk kinematic variables and the ball velocity. Additionally, Pearson correlation coefficients were also calculated to explore the relationship between trunk rotation flexibility measured using HKRT-B, HKRT-F, and SRT, and the trunk rotation kinematics during throwing, specifically the maximum and minimum upper torso orientation, pelvis orientation, and upper torso-pelvis separation angles.

All statistical analyses were run using Statistical Package for Social Science (SPSS) 16 (SPSS Inc, Chicago IL). The level of significance was set at an alpha level of .05.

Analysis Plan by Research Question

RQ	Description	Data source	Statistical method
1	Is there a difference between upper torso orientation angle during throwing and history of shoulder or elbow pain in collegiate softball players?	IV: Shoulder/elbow pain DV: Upper torso orientation	1-within (instances) 1-between (group) factor ANOVA* *Chi square used if ANOVA significant
2	Is there a difference between pelvis orientation angle during throwing and history of shoulder or elbow pain in collegiate softball players?	IV: Shoulder/elbow pain DV: pelvis orientation	1-within (instances) 1-between (group) factor ANOVA* *Chi square used if ANOVA significant
3	Is there a difference between upper torso-pelvis separation angle during throwing and history of shoulder or elbow pain in collegiate softball players?	IV: Shoulder/elbow Pain DV: upper torso-pelvis separation angle	1-within (instances) 1-between (group) factor ANOVA* *Chi square used if ANOVA significant
4	Is there a difference between a history of shoulder or elbow pain and initiation of trunk rotation during throwing in collegiate softball players?	IV: Shoulder/elbow pain DV: timing of rotation	Independent samples *t*-test* *Chi square used if *t*-test significant
5	Is there a difference in means of trunk flexibility when measured with clinical test between subjects with and without a history of shoulder or elbow pain?	IV: shoulder/elbow pain DV: HKRT-B, HKRT-F, SRT	Independent samples *t*-test* *Chi square used if *t*-test significant
6	Is there a difference in ball velocity between subjects with and without shoulder or elbow pain?	IV: Shoulder/Elbow pain DV: ball velocity	Independent samples *t*-test* *Chi square used if *t*-test significant
7	Is there a relationship between trunk rotation kinematics during throwing and ball velocity?	IV: Trunk rotation kinematics DV: Ball Velocity	Pearson Correlation
8	Is there a relationship between trunk rotation flexibility measured using HKRT-B, HKRT-F, and SRT, and the trunk rotation kinematics during throwing?	IV: Trunk Flexibility DV: Trunk rotation kinematics	Pearson Correlation

Figure 1 Camera Positions

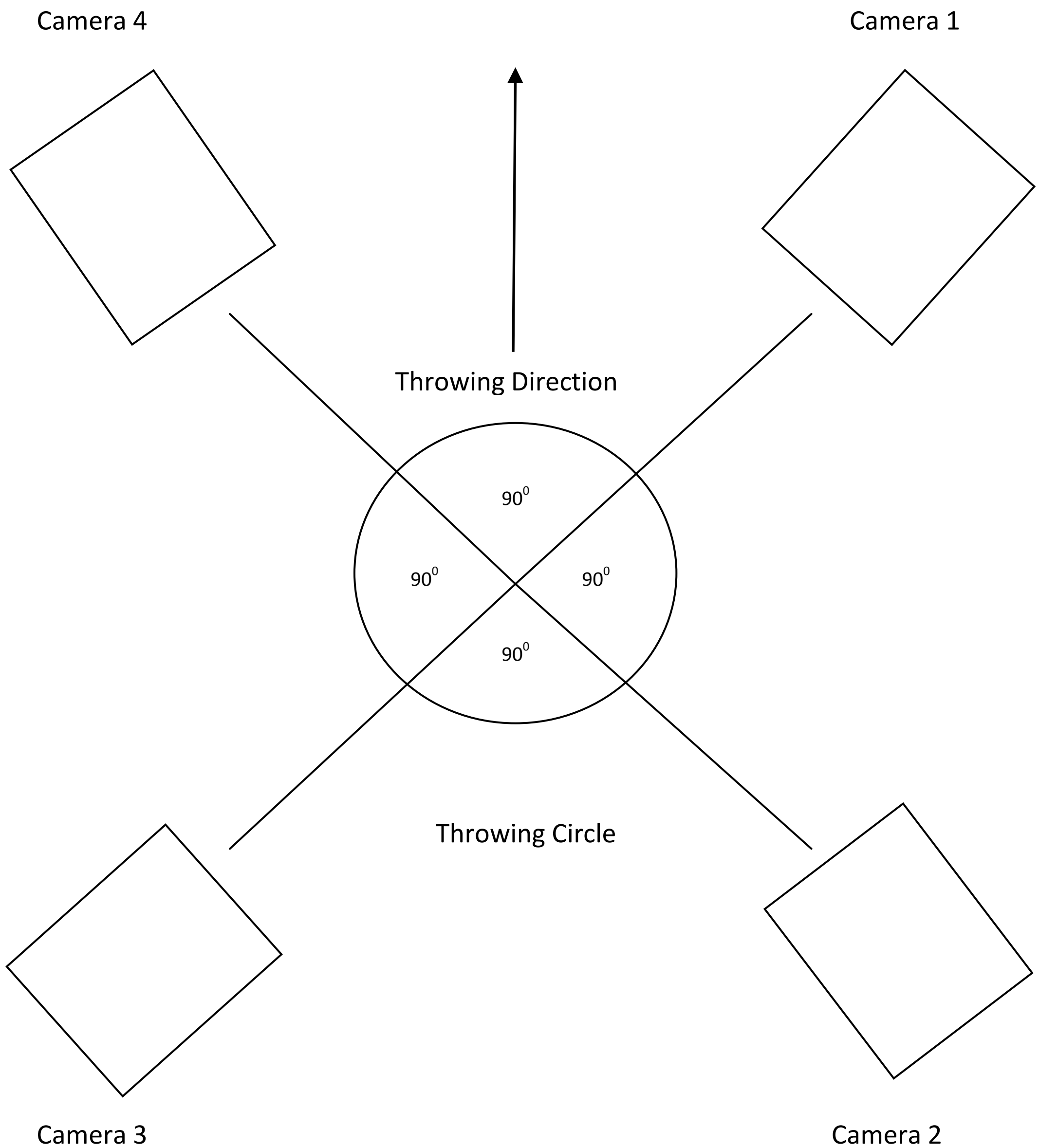
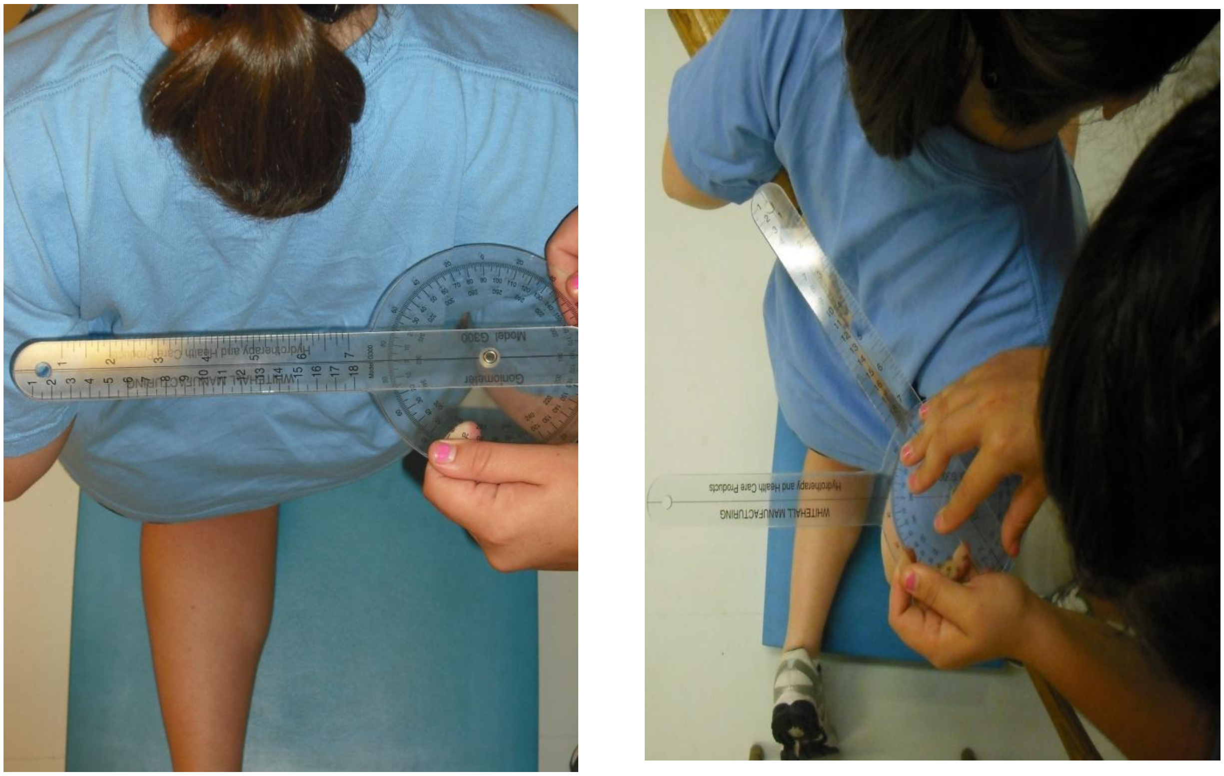


Figure 2 Half Kneeling Rotation Test Bar Back

Start Position

End Position

Figure 3: Start and end positions of the goniometer during trunk flexibility tests



Start Position **End Position**

Figure 4: Seated Rotation Test

Figure 5: Pelvis Orientation: the angle between the line connecting the two ASIS markers and the global X-axis in the XY plane in a global reference frame (Stodden, Langendorfer et al. 2006).

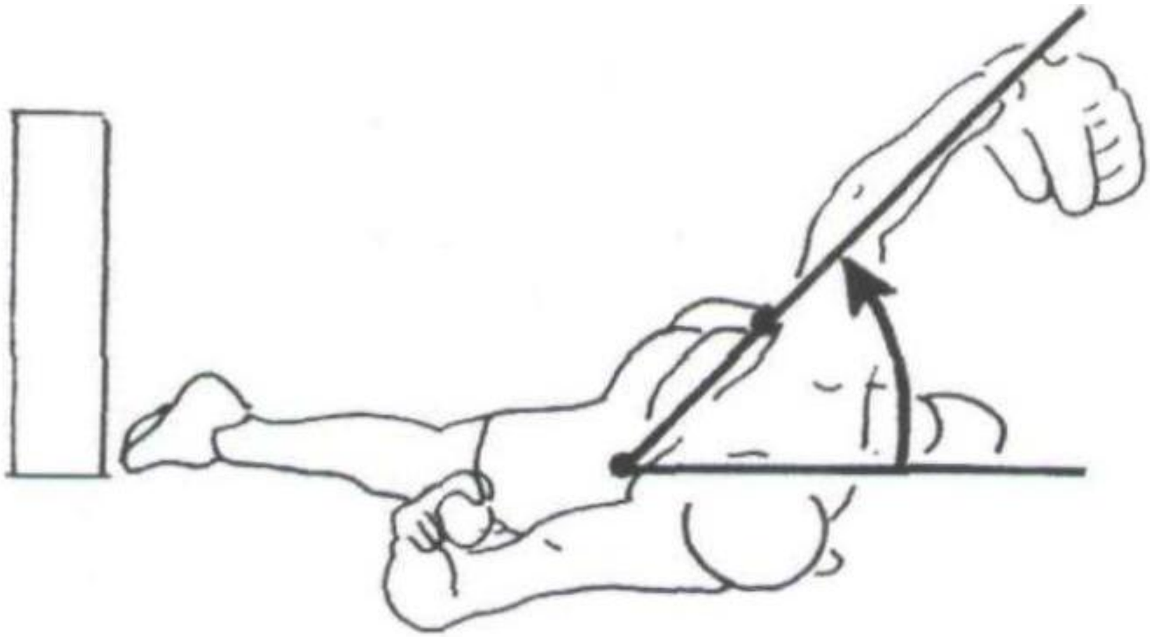
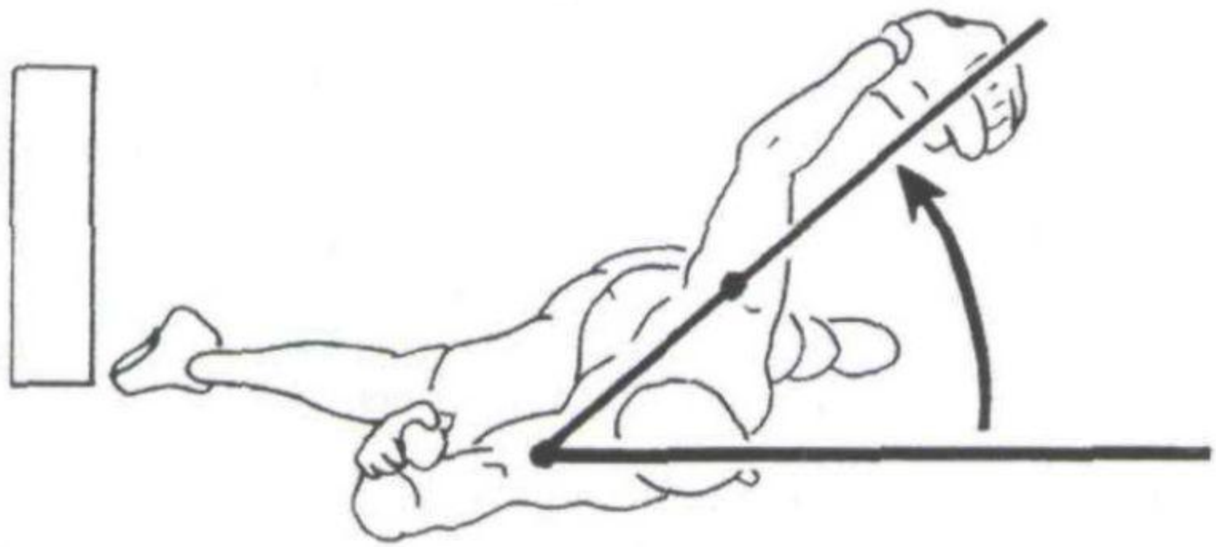


Figure 6: Upper Torso Orientation: the angle between the line connecting the bilateral acromion processes and the global X-axis in the XY plane in a global reference frame (Putnam 1991; Putnam 1993; Aguinaldo, Buttermore et al. 2007; Aguinaldo and Chambers 2009).



CHAPTER 4

RESULTS

A total of eighty division I softball players from five schools in Central North Carolina were tested for this study. Fifteen subjects reported pitching more than 50% of their total playing time, thus were excluded from data analysis. Data from a total of sixty-five subjects were included in the statistical analysis. Of the 65 study subjects, 19 reported a history of shoulder or elbow pain and 46 reported no history of shoulder or elbow pain. A total of twenty eight injuries were reported by 19 subjects. Two subjects reported four injuries, one subject reported three injuries, one subject reported two injuries, and the remaining 15 subjects reported one injury. Types of injuries reported by the athletes are reported in Table 2, and the number of individuals with shoulder or elbow pain is listed by position and by throwing/hitting sides in Table 3 and 4, respectively.

Means and standard deviations of the biomechanical variables at the instances of front foot contact (FFC), maximal shoulder external rotation (MER), and ball release (BR) are presented in Table 5. No significant group by instance interaction was found for upper torso orientation ($F_{(1,126)}$=1.786, p=.172), pelvis orientation ($F_{(1,126)}$=.145, p=.865), or separation angle ($F_{(1,126)}$=2.160, p=.120). Additionally, the timing of initiation of trunk rotation was not different between the subjects with and without a history of shoulder or elbow pain ($t_{(63)}$ = 1.127, p = .264).

Means and standard deviations for clinical measures of trunk rotation flexibility are presented in Table 6. Subjects with a history of shoulder or elbow pain had significantly less trunk rotation when the throwing shoulder is moving forward than subjects with no pain when tested with the half kneeling rotation test with bar in the back (HKRT-B) ($t_{(63)}$ = -2.24, p = .029).

The chi-square analysis demonstrated that having less trunk rotation flexibility when the throwing shoulder is moving forward is significantly associated with a history of shoulder or elbow pain ($\chi 2_{(1)}$ =5.640, p =.018) when measured using the HKRT-B (Table 7). Subjects with trunk rotation flexibility less than the group median (45.0 deg) were 3.98 times more likely to have shoulder or elbow pain. However, trunk rotation flexibility when the throwing shoulder is moving forward was not different between subjects with and without pain when trunk rotation flexibility was tested with half kneeing rotation test with bar in front (HKRT-F) ($t_{(63)}$ = -1.49, p = .141) or with seated rotation test (SRT) ($t_{(63)}$ = .21, p = .833).

There were no between-group differences in trunk rotation flexibility when the throwing shoulder is rotating backward when tested with the HKRT-B ($t_{(63)}$ = -1.92,p = .060), HKRTBF ($t_{(63)}$ = -.73, p = .470), or SRT ($t_{(63)}$ = -.33, p = .743).

Means and standard deviations of ball velocity are presented in table 8. There was no between-group differences in ball velocity ($t_{(63)}$ = -1.119, p = .268).

Pearson correlations were run to explore the relationship between trunk rotation kinematics variables during throwing and ball velocity. Pearson correlation coefficients among the variables are reported in table 9. A moderate inverse relationship was found between both upper torso (r = -.478, p = .001) and pelvis orientations (r = -.522, p = .001) at FFC and ball velocity. The more closed the upper torso and pelvis orientations were at front foot contact, the faster the ball velocity. A weak inverse relationship was found between separation angle at BR ($r = -.288$, $p = .020$) and ball velocity. The more “coiled” the upper torso is relative to the pelvis, the faster the ball velocity. No other correlations were statistically significant.

Pearson correlations were run to explore the relationship between clinical measures of trunk rotation flexibility and trunk rotation kinematic variables during throwing. Pearson correlation coefficients among the variables are reported in table 10 and 11. A weak positive relationship was found between the HKRT-B when the throwing shoulder is rotating forward and minimum separation angle ($r = .251$, $p = .044$). The minimum separation angle is attained when the upper torso is maximally “coiled” relative to pelvis towards the non-throwing shoulder. No other correlations were statistically significant ($p>.05$).

Table 1: Demographic Information (n=65)

	Pain (n=19) Means ± SD*	No Pain (n=46) Means ± SD*
Age (years)	19.42 ± 1.21	19.50 ± 1.15
Height (cm)	162.84 ± 4.78	167.07 ± 8.09
Weight (kg)	71.13 ± 8.84	69.35 ± 9.43
Years of Experience (years)	12.63 ± 2.19	12.02 ± 2.78
Year in School	Frequency	Frequency
Freshmen	4	17
Sophomore	7	7
Junior	7	11
Senior	1	11

*SD = standard deviation

Table 2: Injuries Reported by Athletes

Injury	Frequency
Superior labral anterior to posterior (SLAP)	5
Long head of biceps tendinitis	5
Shoulder impingement	6
Rotator cuff tendinitis	7
Medial epicondylitis	3
Biceps tendinitis at insertion	2
	n=28*

*28 injuries were reported by 19 subjects, two reported four injuries, one reported three injuries, one reported two injuries, 15 subjects reported one injury.

Table 3: Reports of Pain by Positions

Position	Pain (n=19)	No Pain (n=46)	Total (n=65)
Catcher	7 (63.6%)	4 (36.4%)	11
First Base	2 (22.2%)	7 (77.8%)	9
Second Base	2 (28.6%)	5 (71.4%)	7
Third Base	3 (37.5%)	5 (62.5%)	8
Shortstop	2 (33.3%)	4 (66.7%)	6
Left Field	1 (11.%)	8 (88.9%)	9
Center Field	1 (10.0%)	9 (90.0%)	10
Right Field	1 (20.0%)	4 (80.0%)	5

Table 4: Reports of Pain by Throwing and Batting Direction

	Pain (n=19)	No Pain (n=46)	Total (n=65)
Throwing Direction			
Right	17 (28.3%)	43 (71.6%)	60
Left	2 (40.0%)	3 (60.0%)	5
Batting Direction			
Right	14 (29.2%)	34 (70.8%)	48
Left	5 (29.4%)	12 (70.6%)	17

Table 5: Comparison of Biomechanical Variables between Subjects with and without a History of Shoulder or Elbow pain

	Pain (n = 19) Mean ± SD		No Pain (n = 46) Mean ± SD		F	p
Upper Torso Orientation					1.286	.172
Front Foot Contact (°)	-11.6	9.0	-8.3	13.3		
Max. Shoulder External Rotation (°)	80.4	11.6	76.9	13.0		
Ball Release (°)	105.4	4.9	105.9	7.2		
Pelvis Orientation					0.145	.865
Front Foot Contact (°)	11.2	8.8	12.5	12.9		
Max. Shoulder External Rotation (°)	72.3	13.4	72.8	9.3		
Ball Release (°)	85.9	7.1	85.7	8.3		
Separation Angle					2.16	.120
Front Foot Contact (°)	23.1	10.1	20.7	7.9		
Max. Shoulder External Rotation (°)	-7.5	9.8	-3.4	10.7		
Ball Release (°)	-19.5	7.2	-20.0	10.1		
Initiation of Rotation (%)	43.8	10.3	41.0	8.73	*1.13**	.264

* t-statistics

Figure 7: Upper Torso Orientation at Front Foot Contact, Maximum Shoulder External Rotation, and Ball Release

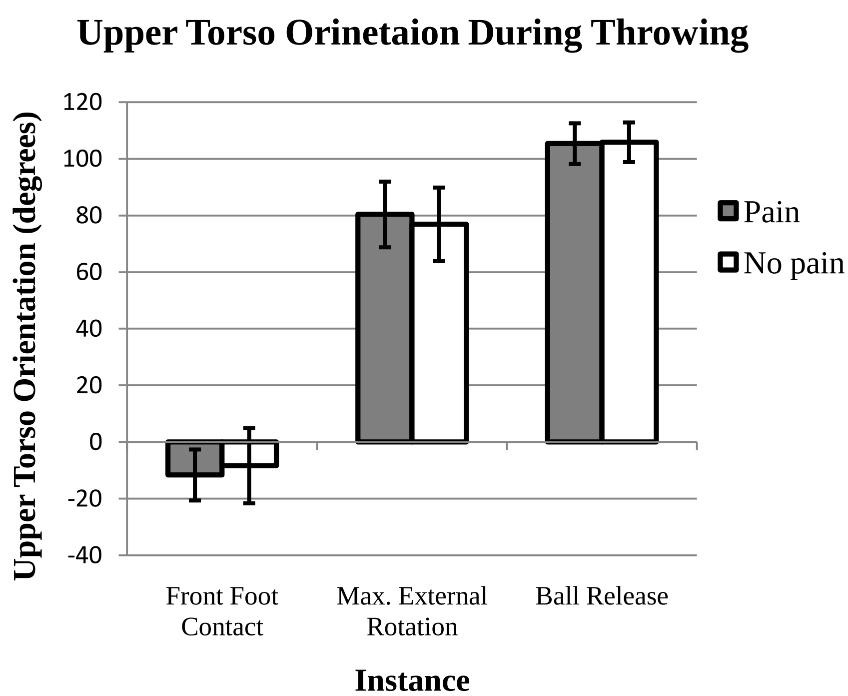


Figure 8: Pelvis Orientation at FFC, MER, and BR

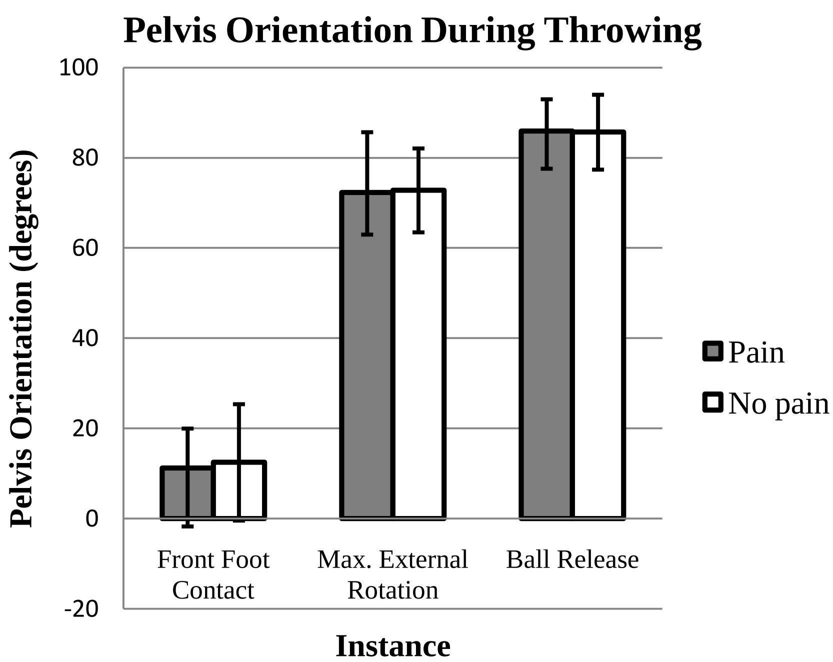


Figure 9: Upper Torso-Pelvis Separation Angle at Front Foot Contact, Maximum Shoulder External Rotation, and Ball Release

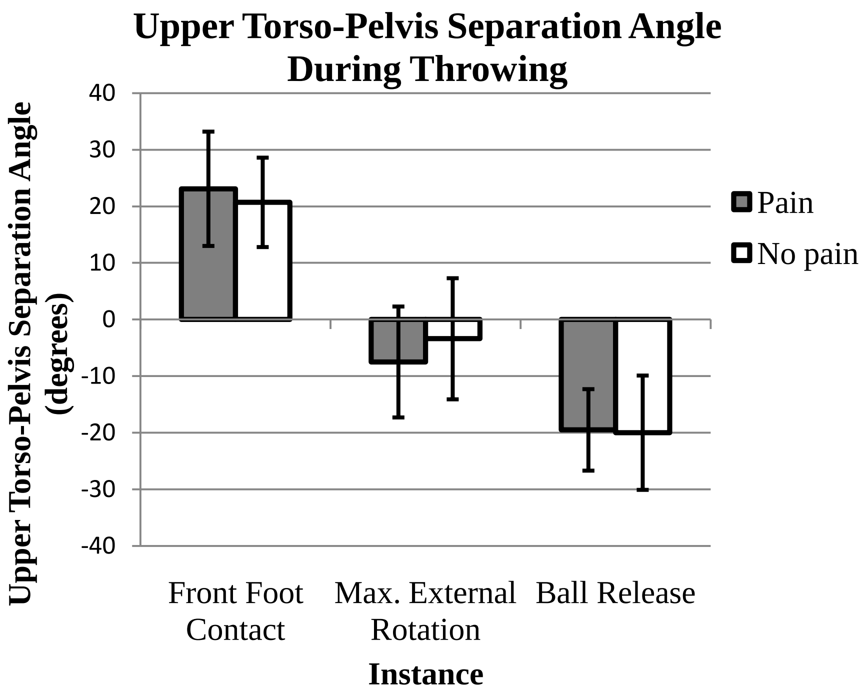


Figure 10: Initiation of Trunk Rotation during Throwing

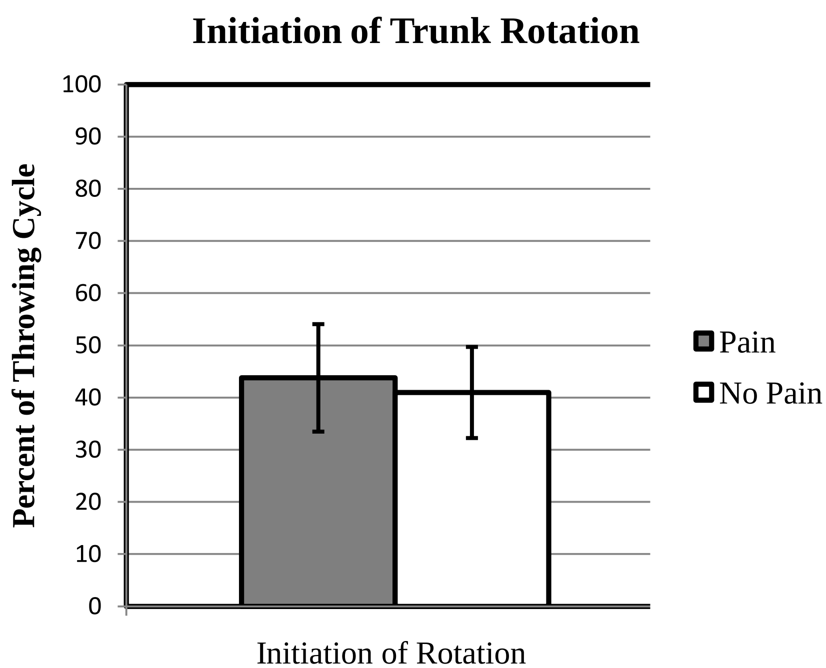
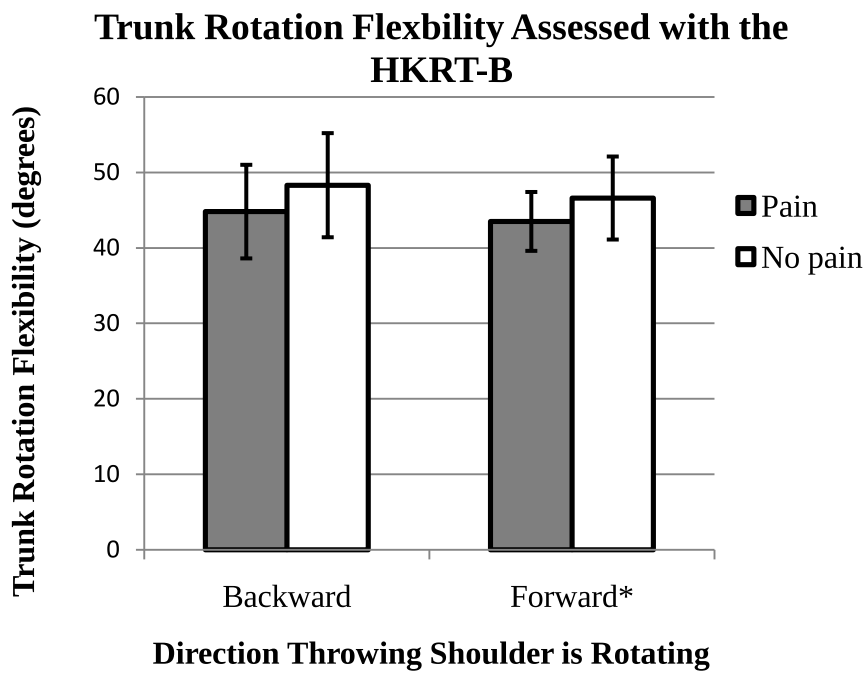


Table 6: Comparison of Clinical Measures of Trunk Flexibility between Subjects with and without a History of Shoulder or Elbow pain

	Pain (n = 19) Mean ± SD		No Pain (n = 46) Mean ± SD		*t*	*p*
Half knee rotation test with bar in back						
Throwing shoulder rotating backward (°)	44.8	6.2	48.3	6.9	-1.92	.060
Throwing shoulder rotating forward (°)	43.5	3.9	46.6	5.5	-2.24	.029*
Half knee rotation test with bar in front						
Throwing shoulder rotating backward (°)	46.2	6.6	48.6	5.5	-1.49	.141
Throwing shoulder rotating forward (°)	45.3	5.3	46.4	5.7	-.73	.470
Seated rotation test						
Throwing shoulder rotating backward (°)	46.2	6.5	46.8	5.5	-.33	.743
Throwing shoulder rotating forward (°)	44.1	7.9	43.7	8.3	.21	.833

*Significant difference between groups at an alpha level of 0.05

Figure 11: Comparison of Trunk Rotation Flexibility Assessed with Half Kneeling Rotation Test with Bar in Back



*Significant difference between groups at .05 alpha level

Figure 12: Comparison of Trunk Rotation Flexibility Assessed with Half Kneeling Rotation Test with Bar in Front

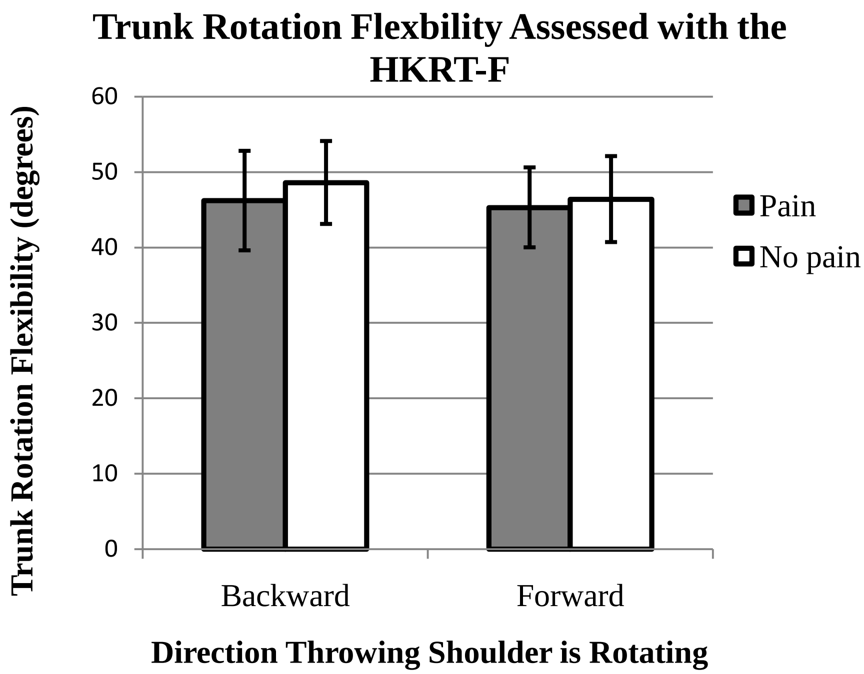


Figure 13: Comparison of Trunk Rotation Flexibility Assessed with Seated Rotation Test

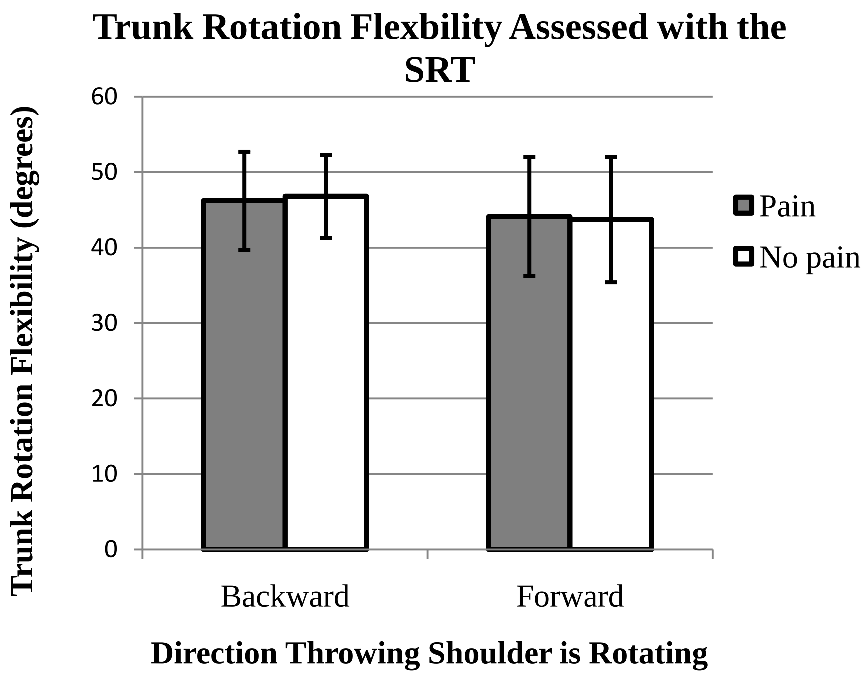


Table 7: An association between trunk rotation flexibility in a direction away from the throwing shoulder measured using the half knee rotation test with bar in back and shoulder or elbow pain

		Pain	No pain	
Trunk flexibility	Limited*	14 (42.4%)	19 (57.6%)	33
	Not limited†	5 (15.6%)	27 (84.4%)	32
		19	46	65

$\chi^2(1) = 5.640$, $p = .018$

* Limited: trunk rotation flexibility below the group median

† Not limited: trunk rotation flexibility above the group median

Table 8: Comparison of ball velocity between subjects with and without shoulder or elbow pain

	Pain (n=19)		No Pain (n=46)		t	p
	Mean	SD	Mean	SD		
Ball Velocity (mph)	52.9	4.2	54.3	4.4	-1.12	.268

Table 9: Pearson correlation coefficients between trunk rotation kinematics variables during throwing and ball velocity

	Velocity	
	Pearson Correlation Coefficient (r)	P-Value
Upper Torso Orientation		
FFC (°)	-.478	.001**
MER (°)	-.137	.278
BR (°)	.161	.199
Pelvis Orientation		
FFC (°)	-.522	.001**
MER (°)	-.118	.349
BR (°)	-.189	.131
Separation Angle		
FFC (°)	-.042	.739
MER (°)	.009	.943
BR (°)	-.288	.020*
Initiation of Rotation (% throwing cycle)	-.064	.614

*Correlation significant at .05 alpha level
**Correlation significant at .01 alpha level

Table 10: Pearson correlation coefficients (p-values in parenthesis) between the trunk rotation flexibility when the throwing shoulder is moving backward and trunk kinematic variables. The minimum upper torso orientation and minimum pelvis orientation indicates the most “closed” positions (subject’s back facing the direction of throw) for the upper torso and the pelvis, respectively. The maximum upper torso-pelvis rotation is attained when the upper torso is maximally coiled relative to the pelvis when the throwing shoulder is rotating backward.

Trunk flexibility tests	Minimum Upper Torso Orientation	Minimum Pelvis Orientation	Maximum Separation Angle
Half kneeling rotation with bar in back	.092 (.468)	.167 (.184)	.119 (.344)
Half kneeling rotation with bar in front	-.050 (.694)	.072 (.567)	.175 (.163)
Seated Rotation	.076 (.548)	.238 (.057)	.227 (.069)

Table 11: Pearson correlation coefficients (p-values in parenthesis) between trunk rotation flexibility when the throwing shoulder is rotating forward and trunk kinematic variables. The maximum upper torso orientation and maximum pelvis orientation indicates the most "open" positions (subject's anterior aspect facing the direction of the throw) for the upper torso and the pelvis, respectively. The minimum upper torso-pelvis rotation is attained when the upper torso is maximally coiled relative to the pelvis when the throwing shoulder is rotating forward.

Trunk flexibility tests	Maximum Upper Torso Orientation	Maximum Pelvis Orientation	Minimum Separation angle
Half kneeing rotation with bar in back	-.152 (.226)	.119 (.344)	.251 (.044*)
Half kneeing rotation with bar in front	-.148 (.241)	.098 (.439)	.216 (.084)
Seated Rotation	.059 (.642)	.168 (.182)	.062 (.623)

*Correlation significant at .05 alpha level

CHAPTER 5

DISCUSSION

Although typically thought of as an upper extremity movement, successful throwing results from the effective transfer of energy from the lower extremity to the upper extremity which is mediated by the trunk (Putnam 1993; Stodden, Fleisig et al. 2001). For this reason, it is theorized that suboptimal trunk rotation kinematics during throwing and or flexibility characteristics may result in inefficient transfer of energy to the upper extremity, causing the upper extremity to experience abnormal stress. However, few studies to date have investigated trunk rotation kinematics during throwing or flexibility characteristics as possible contributors to upper extremity injuries in overhead athletes. Therefore, the purpose of this study was to compare trunk rotation kinematics during throwing and trunk flexibility measures in intercollegiate softball position players with and without a history of shoulder or elbow pain. Specific kinematic variables of interest included upper torso orientation angle, pelvis orientation angle, upper torso-pelvis separation angle at front foot contact, maximum shoulder external rotation, and ball release and timing of trunk rotation initiation during throwing. Trunk rotation flexibility was measured using three flexibility tests: the half kneeling rotation test-back (HKRT-B), half kneeling rotation test-front (HKRT-F), and the seated rotation test (SRT). In addition to trunk rotation kinematics and flexibility, ball velocity was compared between softball players with and without history of shoulder or elbow pain as a measure of performance. Lastly, the relationship between trunk kinematics variables and ball velocity and the relationship between trunk flexibility measures and biomechanical variables were explored.

Trunk Rotation Kinematics

The amount of and timing at which the upper torso and pelvis rotate play an important role in the transfer of energy to the distal segments of the upper extremity (Stodden, Fleisig et al. 2001). At the time of the front foot contact, the pelvis was oriented facing the direction of the throw (open orientation) relative to the upper torso, while the upper torso was oriented away from the direction of the throw (closed orientation), which results in lagging of the upper torso behind the hips, and therefore coiling of the trunk segment (Stodden, Langendorfer et al. 2006). This coiling allows storage of elastic energy within the anterior trunk musculature, which can be transferred to the upper extremity to accelerate the throwing limb (Feltner and Dapena 1986). The more closed orientations of the pelvis and the upper torso at front foot contact permit larger range of movement for the storage and transfer of energy to take place, which facilitates greater transfer of energy to the upper extremity. The greater coiling of the trunk segments results in greater stretching of the oblique muscles and thus greater storage of the elastic energy. We hypothesized that the softball players with a history of shoulder or elbow pain would demonstrate more open pelvis and upper torso orientations at the front foot contact compared to the players without a history of shoulder or elbow pain because we theorized that the softball player’s inefficient use of trunk in storing and transferring energy to the upper extremity would contribute to upper extremity injuries.

However, contrary to our hypotheses, this study demonstrated no differences in trunk kinematic variables at the time of front foot contact between softball players with and without a history of shoulder or elbow pain.

At the instance of maximum shoulder external rotation, the upper torso is rotated slightly forward relative to the pelvis, while the upper extremity lags behind the trunk, which allows for storage of energy in the anterior shoulder structures (Aguinaldo and Chambers 2009). The pelvis at this point should be close to its maximum orientation (more open). The more open orientation of the pelvis at time of maximum shoulder external rotation permits the pelvis to become a stable base for the upper torso to rotate on, which continues the sequence of transferring energy to the upper extremity. Since this is the point at which upper torso orientation is just overcoming pelvis orientation; upper torso-pelvis separation angle will be closer to parallel. We hypothesized that softball players with a history of shoulder or elbow pain would demonstrate more closed pelvis and upper torso orientations and be more coiled (less parallel) compared to players without a history of shoulder or elbow pain because we theorized softball players' inefficient use trunk rotation would contribute to upper extremity injuries. However, contrary to our hypotheses, this study demonstrated no differences in trunk kinematic variables at the time of maximum shoulder external rotation between softball players with and without a history of shoulder or elbow pain.

During ball release both pelvis and upper torso orientations approach their maximum orientations. The more open positions of the pelvis and the upper torso permit a large coiling of the trunk, which allows the previously stored elastic energy to be transferred to the distal segment. Thus we hypothesized that softball players with a history of shoulder or elbow pain would demonstrate more closed positions at ball release compared to softball players without a history of shoulder or elbow pain. We theorized that softball players with a more closed position are unable to transfer energy effectively and result in increased stress to be placed on the upper extremity. Opposing our hypotheses, this study demonstrated no differences in trunk kinematic variables at the time of ball release between softball players with and without a history of shoulder or elbow pain.

To date no study has compared trunk rotation kinematics between softball players with and without a history of pain. Therefore, the results of this study cannot be directly compared to findings from previous studies. Aguinaldo et al has previously investigated the relationship between trunk kinematic variables and the elbow valgus torque during baseball pitching, and reported that there were no relationships between elbow valgus torque and upper torso and pelvis orientations (Fleisig, Andrews et al. 1995). Their findings are in line with the finding from our study demonstrating no difference in trunk kinematic differences between the softball players with and without pain. While Aguinaldo et al did not compare trunk rotation kinematics between pitchers with and without pain; high magnitude of valgus stress has been considered to contribute to development of elbow injuries (Fleisig, Barrentine et al. 1996; Stodden, Fleisig et al. 2001; Stodden, Langendorfer et al. 2006).

Upper torso rotation typically occurs near the time of maximum shoulder external rotation. After front foot contact, the pelvis starts to rotate forward, while the upper torso maintains a closed orientation, creating further lagging of the upper torso relative to the pelvis, thus maximizing energy storage. The upper torso then starts rotating forward (timing of trunk rotation) as the trunk musculature contracts and the transfer of momentum from the pelvis to the upper torso begins (Aguinaldo and Chambers 2009). Therefore, we hypothesized that softball players with shoulder or elbow pain would initiate trunk rotation earlier than softball players without shoulder or elbow pain. However, contrary to our hypotheses, this study demonstrated no differences in initiation of trunk rotation between softball players with and without a history of shoulder or elbow pain.

In the study by Aguinaldo et al previously discussed, the authors reported that the initiation of trunk rotation prior to FFC was significantly related to greater elbow valgus torque (Aguinaldo, Buttermore et al. 2007). Furthermore, an earlier study by Aguinaldo et al (Fleisig, Andrews et al. 1995) compared trunk rotation kinematics between pitchers from different levels and reported that younger inexperienced pitchers initiated trunk rotation earlier in the pitching cycle and produced greater shoulder internal rotation torque relative to their body mass compared to the older more experienced pitchers. These studies indicate that early initiation of trunk rotation may be associated with inexperience and greater reliance on the shoulder to produce torque, which may make an individual more susceptible to injury (Aguinaldo, Buttermore et al. 2007; Aguinaldo and Chambers 2009).

One of the potential reasons why the differences in trunk kinematic variables were not detected in this study is the high inter-subject variability in throwing kinematics, due to inclusion of infielders and outfielders and a use of crow hop. Secondary analysis demonstrated that the trunk rotation kinematics were different between infielders and outfielders. Infielders’ upper torso tended to be in a more closed position, while their pelvis tended to be in a more open position during FFC. The crow hop is a controlled movement, which is initiated by the trail leg by kicking it up and forward and passing it in front of the other leg. This strategy is more frequently used by outfielders than in infielders to quickly position a thrower after fielding a ball and gain momentum behind their throw. During this study it was observed that some subjects used a crow hop technique while others simply took a forward step to throw, which may have introduced inter-subject variability in the trunk rotation kinematics data.

Another possible reason why no differences in trunk rotation kinematics were detected between groups is because of the error introduced in the data from poor reliability in some kinematic variables. Reliability testing conducted prior to digitization of the data demonstrated moderate to high reliability and precision for upper torso and pelvis orientation angles. However, the reliability of the upper-torso orientation angle and the timing of trunk rotation were low. This can be attributed to the fact that upper torso-pelvis separation angle was calculated by subtracting the pelvis orientation value from the upper torso orientation value, and therefore the separation angle is affected by error from two variables. The low reliability of the timing of rotation was low, likely because the variable was calculated based on the separation angle. Onset time of trunk rotation was defined as the time in which the magnitude, relative to the pelvis, begins to decrease from its maximum value (Leigh and Yu 2007; Leigh, Gross et al. 2008; Leigh, Liu et al. 2009). The low reliability of the variables may be due to relatively low sampling frequency (60 Hz) used for the kinematic analysis. The 60Hz sampling frequency may have been too slow for the motion we were trying to capture, although this sampling frequency had previously been used to collect kinematic data during discus throwing (Stodden, Fleisig et al. 2001; Stodden, Langendorfer et al. 2006; Aguinaldo, Buttermore et al. 2007; Aguinaldo and Chambers 2009). Recent studies looking at baseball pitchers have used a sampling frequency of 200 -240 Hz (Stodden, Langendorfer et al. 2006). Within subject variability may have also resulted in throwing kinematics within the same subject. Although there was a small variability in ball velocity between each of the three throws, this may have influenced kinematics resulting in within subject variability.

Trunk Flexibility

Currently there is no study that compares trunk flexibility measures between subjects with or without history of shoulder or elbow pain. Thus we were interested to see if there was an easy clinical measure that can be used to indentify players who may be at increased risk for injury. We found that softball players with a history of shoulder or elbow pain exhibited significantly less trunk rotation flexibility measured using the HKRT-B when the throwing shoulder is rotating forward than subjects without history of shoulder or elbow pain. Furthermore, odds ratio analysis reveals that softball players with trunk rotation flexibility less than 45 degrees were almost 4 times more likely to have shoulder or elbow pain compared to the softball players with greater trunk flexibility when measured using the HKRT-B when the throwing shoulder is rotating forward. This finding is in agreement with our hypothesis that softball players with a history of shoulder or elbow pain would have less trunk flexibility than subjects without pain. Due to the retrospective nature of this study, this finding cannot be interpreted and cause and effect relationship. During throwing, the eccentric loading of the trunk musculature occurs as the pelvis rotates and the upper torso lags behind (Sell, Tsai et al. 2007). Limited trunk flexibility in this direction may inhibit the storage of elastic energy in the trunk musculature, which could result in greater reliance on upper extremity joints to produce torque. A study by Sell et al (Sell, Tsai et al. 2007) compares trunk rotation flexibility between three different professional levels of golfers. This study found that golfers with lower handicap scores had a significantly greater amount of trunk rotation flexibility (Stodden, Langendorfer et al. 2006). The increase in trunk rotation by golfers with a lower handicap may increase their ability to generate energy during their swing.

Interestingly, HKRT-B was the only test that demonstrated the flexibility difference between softball players with and without history of shoulder or elbow pain. The other trunk flexibility tests (HKRT-F and SRT) did not show any differences in subjects with and without shoulder or elbow pain. During the HKRT-B test, holding a bat behind the lower back results in ”locking” of the lumbar spine and scapula, which results in isolation of the rotation of the thoracic spine. On the other hand, the HKRT-F performed while holding the bat across chest does not lock the lumbar spine or the scapula, and therefore the measurement reflects combination of the rotation at the thoracic and lumbar spine and the movement of the scapula along the rib cage. Since the HKRT-F measures the rotation flexibility of the entire trunk segments, the test allows movement of the scapula along the rib cage to compensate for the limited trunk flexibility, which results in range of motion values that do not truly represent the trunk flexibility. As well as locking the pelvis in place, both the HKRT-B and the HKRT-F measures trunk rotation flexibility in a more functional position that mimics the trunk rotation occurring during throwing.

The SRT is a more traditional method of measuring trunk rotation flexibility that simply assesses flexibility while the subject is seated. Similar to the HKRT-F, the SRT measures the flexibility of the thoracic and lumbar spine and the movement of the scapula along the rib cage, and therefore may produce values that do not truly represent trunk flexibility. HKRT-B was the only test that was able to detect the difference in trunk flexibility between the softball players with and without a history of shoulder or elbow pain. Based on this finding, the HKRT-B may be more sensitive in identifying subjects who are at increased risk for developing pain, and should be used in clinical settings.

Ball Velocity

There was no difference in ball velocity between subjects with and without shoulder or elbow pain. Therefore, previous history of shoulder or elbow pain does not seem to have an effect on the ball speed. In this study, shoulder or elbow pain was operationally defined as pain in the shoulder or elbow that has limited an athlete on three or more occasions during practice or competition or has required an athlete to receive some form of treatment for more than a week within the past two years. However, any softball players who could not throw a softball as they normally would in a game situation due to shoulder or elbow pain were excluded from the study. Therefore, it was expected that subjects with a history of shoulder or elbow pain would throw similar to subjects who have not had pain.

Trunk Rotation Kinematics and Ball Velocity

The exploratory analysis of the relationship between trunk rotation kinematics and ball velocity revealed that a more “closed” orientation of the upper torso and pelvis at the time of front foot contact was related to greater ball velocity. The analysis also demonstrated that greater twisting of the upper torso relative to pelvis at the time of ball release (greater upper torso-pelvis separation angle in negative direction) was related to faster ball velocity. These findings agree with the hypotheses that subjects with a greater ball velocity will start in a more closed position and rotate their upper torso more relative to pelvis at the time of ball release. Just prior to FFC the pelvis begins to rotate while the upper torso stays behind creating a “lag effect.” This lag effects creates elastic energy which is stored in trunk musculature (Stodden, Fleisig et al. 2001). A more closed position at FFC may allow for more energy to be stored and transferred to the upper extremity resulting in a greater ball velocity. While these findings are in agreement with our hypothesis, they varied from the findings in the study by Stodden et al (Stodden, Fleisig et al. 2001) that reported greater (more open) upper torso and pelvis orientation at maximum shoulder external rotation as well as greater pelvis orientation at ball release were associated with a greater ball velocity (Fletcher and Hartwell 2004; Thompson and Osness 2004; Lephart, Smoliga et al. 2007). Differences in findings between the studies may be attributed to the difference in tasks and study population. Our study evaluated trunk rotation kinematics during throwing in collegiate softball position players and Stodden et al studied trunk rotation kinematics during baseball pitching in three different levels (professional, collegiate and high school).

Trunk Rotation Kinematics and Trunk Flexibility

The relationship between trunk rotation flexibility and the trunk kinematic variables were explored in order to examine if trunk flexibility measured using clinical tests can predict trunk rotation kinematics during throwing. While there were a few statistically significant correlations between trunk rotation kinematics and trunk flexibility, the correlations were weak, indicating that the trunk rotation kinematics during throwing was not dictated by the trunk flexibility characteristics. However, this result needs to be interpreted with caution due to the aforementioned limitation with the instrumentation used for trunk rotation kinematics during throwing assessment. Further study assessing the relationship using higher sampling frequency is warranted. Trunk rotation flexibility may not be reflected in trunk rotation kinematics during throwing because in order to play softball at the division I level, players will need to be able to rotate their trunk to a certain degree. If two people, one with good flexibility and one with bad flexibility, achieve the same amount of rotation during throwing, the more flexible person may do so easier than the one with limited flexibility. Although the person with limited flexibility is achieving the same amount of rotation during throwing, more tension may be placed on the shoulder or elbow leading to pain. This may be why no relationship was found between trunk rotation flexibility and trunk rotation kinematics during throwing.

Clinical Implications

The main finding of this study is that limited trunk rotation flexibility is strongly associated with a history of shoulder or elbow injuries, and that individuals with limited trunk flexibility measured with the HKRT-B when the throwing shoulder is rotating forward are almost 4 times more likely to have a history of shoulder or elbow injury. The HKRT-B is a simple and quick clinical test that may be used by sports medicine clinicians in preseason screenings to identify individuals with limited trunk rotation flexibility. If limitations in trunk rotation flexibility are identified, clinicians can prescribe exercises that can improve trunk flexibility. Previous studies have demonstrated that exercise training programs implemented in golfers have successfully improved trunk flexibility and performance (Ludewig and Cook 2000; Reddy, Mohr et al. 2000; Cools, Witvrouw et al. 2004; Cools, Witvrouw et al. 2005; Tyler, Cuoco et al. 2009). A strong association between limited trunk rotation flexibility suggests that an improvement in trunk rotation flexibility has the potential to lead to prevention of shoulder or elbow injuries.

While the limitation in trunk flexibility was identified as a possible contributor to the shoulder and elbow pain, there are other factors that are suggested to contribute to shoulder or elbow pain. These factors include weakness of the scapular stabilizers and rotator cuff muscles (Ludewig and Cook 2000; Cools, Witvrouw et al. 2003; Barden, Balyk et al. 2005; Hess, Richardson et al. 2005), altered activation pattern of the scapular stabilizers and rotator cuff muscles (Ludewig and Cook 2000; McClure, Bialker et al. 2004; Downar and Sauers 2005; Myers, Pasquale et al. 2005; Laudner, Myers et al. 2006; McClure, Michener et al. 2006; Laudner, Stanek et al. 2007; Oyama, Myers et al. 2008), altered scapular kinematics (Morgan, Burkhart et al. 1998; Burkhart, Morgan et al. 2003; Downar and Sauers 2005; Myers, Laudner et al. 2006; Ruotolo, Price et al. 2006; McClure, Balaicuis et al. 2007; Laudner, Sipes et al. 2008), posterior shoulder tightness (PST) and decreased internal rotation (Flyger, Button et al. 2006). Clinicians will need to assess trunk flexibility in addition to these when evaluating shoulder or elbow injuries in overhead athletes.

Although our study did not demonstrate any differences in kinematic variables between softball players with and without history of shoulder or elbow pain, more studies are needed to determine the exact relationship since this is the first study examining kinematic variables in softball position players. Considering the methodological limitation, the study results need to be interpreted with caution.

Limitations

In addition to the limitation of the study related to instrumentation for the kinematic analysis discussed above, there are a few limitations to this study that need to be discussed. In this study trunk rotation kinematics was assessed with the subjects throwing a softball a distance of 25.86 meters. While this is a common distance that all position players throw, kinematics may change when softball players throw at different distances (e.g. outfield to home, 2^{nd} to 3^{rd} base). These results should not be generalized to all throwing distances. Although athletes were instructed to throw as if in a game situation, they may have thrown differently since they knew they were being filmed. Also, player position influences throwing kinematics. Furthermore, this study only looked at division I softball position players, therefore study results cannot be generalized to pitchers or position players of different ages or competition level. In addition this study focused on a wide range of injuries. Softball players with a history of shoulder injuries may have different kinematics than softball players with elbow injuries. Also different types of injuries may result in different kinematics, such as differences that may be present between softball players with labral tears versus players with rotator cuff tendinitis. Another limitation of the study is insufficient statistical power for many of the variables. Particularly trunk rotation flexibility measured the HKRT-B, HKRT-F when the throwing shoulder is rotating forward and separation angle at MER demonstrated moderate effect sizes of .51, .40 and .41 respectively, and therefore may be demonstrated to be statistically significant between softball players with and without a history of shoulder or elbow pain given a larger sample size. The post-hoc power analysis and effect size are provided in Table 12.

Future Research

This was the first study to examine differences in trunk rotation kinematics during throwing and trunk flexibility in softball players, therefore more studies need to be conducted in order to confirm the findings of this study. Prospective studies that examine whether trunk flexibility is related to higher injury risk are needed to help determine a cause and effect relationship. Intervention studies to improve trunk flexibility in softball players are also warranted. Additionally, the study can be replicated in examining trunk rotation kinematics and flexibility characteristics in athletes participating in other overhead sports, such as baseball, tennis, javelin, and team handball, since movement of the trunk is important in these sports as well. In addition to kinematic variables, future study should examine the kinetic variables during throwing, since joint kinetics may have direct influence on the stress experienced by the joints and thus may be related to complaints of pain. More studies that examine the relationship between the kinematics and the ball velocity in softball position players may provide information that coaches can use to improve an athlete's performance.

Conclusions

No differences in trunk rotation kinematics between softball players with and without a history of pain were identified. However, this study demonstrated that softball players with history of shoulder or elbow pain had limited trunk rotation flexibility when measured using HKRT-B when the throwing shoulder is rotating forward. Screening of trunk rotation flexibility using HKRT-B during preseason screenings may be used to identify those athletes with limited trunk flexibility. Clinicians can prescribe intervention exercises to these individuals to potentially prevent shoulder or elbow injuries. This study also suggests that softball players who land in a more closed position will be able to throw a ball at a higher velocity. Coaches may use this information when instructing athletes on how to throw in order to improve ball velocity.

Table 12 Effect Size and Power

	Pain (n=19)	No pain (n=46)	SD	Effect size	Power
Half knee rotation test-back					
Forward (^{o})	44.8	48.3	6.8	0.51	0.45
Backward (^{o})	43.5	46.6	5.2	0.59	0.57
Half knee rotation test-front					
Forward (^{o})	46.2	48.6	5.9	0.40	0.30
Backward (^{o})	45.2	46.4	5.6	0.22	0.12
Seated rotation test					
Forward (^{o})	46.2	46.8	5.8	0.09	0.06
Backward (^{o})	44.1	43.7	8.1	0.06	0.06
Upper Torso Orientation					
Front Foot Contact (^{o})	-12.1	-8.3	12.2	0.31	0.20
Max. Shoulder ER (^{o})	80.4	76.9	12.7	0.28	0.17
Ball Release (^{o})	105.4	105.9	6.5	0.08	0.06
Maximum (^{o})	120.2	121.0	9.0	0.09	0.06
Minimum (^{o})	-18.9	-12.6	12.7	0.50	0.44
Pelvis Orientation					
Front Foot Contact (^{o})	11.2	12.5	11.8	0.11	0.07
Max. Shoulder ER (^{o})	72.3	72.8	10.5	0.05	0.05
Ball Release (^{o})	85.9	85.7	7.9	0.03	0.05
Maximum (^{o})	92.6	90.7	7.1	0.27	0.16
Minimum (^{o})	6.8	7.4	11.8	0.05	0.05
Separation angle					
Front Foot Contact (^{o})	23.1	20.7	8.6	0.28	0.17
Max. Shoulder ER (^{o})	-7.7	-3.4	10.5	0.41	0.32
Ball Release (^{o})	-19.5	-20.0	9.4	0.06	0.06
Maximum (^{o})	31.5	28.1	7.7	0.44	0.36
Minimum (^{o})	-30.6	-33.6	9.4	0.32	0.21
Rotation (% throwing cycle)	43.8	41.0	9.2	0.31	0.20
Velocity (mph)	52.9	54.3	4.38	0.30	0.19

APPENDIX A

Section I: Screening of the inclusion and exclusion criteria

Do you currently have shoulder or elbow pain that prevents you from throwing as you normally would in a game situation?	Y or N
Do you currently have any neck or back pain that prevents you from throwing as you normally would in a game situation?	Y or N
Within the past three days have you experienced numbness or tingling in your throwing arm that prevented you from throwing as you normally would in a game situation?	Y or N
Have you ever been diagnosed by a physician as having a neurological disorder?	Y or N
Have you had any surgery to your arm including the shoulder, elbow, wrist or fingers within the past **six months**?	Y or N
Have you recently (within the past week) been diagnosed by a physician or athletic trainer as having a strain of any trunk muscles that prevents you from throwing as you normally would in a game situation?	Y or N
Do you pitch more than 50% of either practice or game time?	Y or N

Section II: Demographic Information

1. How old are you? ___

2. How long have you been playing softball?

3. What is your primary position?

    a. If applicable what is your secondary position?

4. What year are you? a. freshmen b. sophomore c. junior d. senior e. fifth year senior

5. With which arm do you throw? Right or Left

6. Which direction do you bat? Right or Left

Section III: Past Medical History Screening

Have you been diagnosed by an athletic trainer, family physician, orthopedic physician, or other medical professional with any of the following injuries **as a result of throwing within the past two years**? (***check all that apply***)

___ **Superior labral anterior to posterior (SLAP) lesion** (if checked, answer the following questions)

When did this injury occur? _______________(Month/Year)

How did the injury happen?

Did this injury require surgery? Y or N

Were you asked by your athletic trainer or physician to limit your throws during practice? Y or N

If yes, how many practice/games were you limited in?

a. 5 or fewer practices/games b. 6 or more practices/games

Were you expected to report for rehabilitation with your athletic trainer because of this injury?

Y or N, If yes how long were you expected to report for rehab?

a. Less than a week b. Over a week

Did this injury prevent you from throwing? Y or N

If yes, how long were you not throwing because of pain?

a. 2 or fewer days b. 3 or greater than 3 days

___ **Rotator cuff strain or tendinitis** (if checked, answer the following questions)

When did this injury occur? _______________(Month/Year)

How did the injury happen?

Did this injury require surgery? Y or N

Were you asked by your athletic trainer or physician to limit your throws during practice? Y or N

If yes, how many practice/games were you limited in?

a. 5 or fewer practices/games b. 6 or more practices/games

Were you expected to report for rehabilitation with your athletic trainer because of this injury?

Y or N, If yes how long were you expected to report for rehab?

b. Less than a week b. Over a week

Did this injury prevent you from throwing? Y or N

If yes, how long were you not throwing because of pain?

a. 2 or fewer days   b. 3 or greater than 3 days

___ **Biceps tendinitis (Shoulder)** (if checked, answer the following questions)

When did this injury occur? _______________(Month/Year)

How did the injury happen?

Did this injury require surgery? Y or N

Were you asked by your athletic trainer or physician to limit your throws during practice? Y or N

If yes, how many practice/games were you limited in?

a. 5 or fewer practices/games   b. 6 or more practices/games

Were you expected to report for rehabilitation with your athletic trainer because of this injury?

Y or N, If yes how long were you expected to report for rehab?

b. Less than a week   b. Over a week

Did this injury prevent you from throwing? Y or N

If yes, how long were you not throwing because of pain?

a. 2 or fewer days   b. 3 or greater than 3 days

___ **Shoulder Impingement** (if checked, answer the following questions)

When did this injury occur? _______________(Month/Year)

How did the injury happen?

Did this injury require surgery? Y or N

Were you asked by your athletic trainer or physician to limit your throws during practice? Y or N

If yes, how many practice/games were you limited in?

a. 5 or fewer practices/games   b. 6 or more practices/games

Were you expected to report for rehabilitation with your athletic trainer because of this injury?

Y or N, If yes how long were you expected to report for rehab?

b. Less than a week   b. Over a week

Did this injury prevent you from throwing? Y or N

If yes, how long were you not throwing because of pain?

a. 2 or fewer days   b. 3 or greater than 3 days

___ **Medial Epicondylitis** (if checked, answer the following questions)

When did this injury occur? ________________(Month/Year)

How did the injury happen?

Did this injury require surgery? Y or N

Were you asked by your athletic trainer or physician to limit your throws during practice? Y or N

If yes, how many practice/games were you limited in?

a. 5 or fewer practices/games b. 6 or more practices/games

Were you expected to report for rehabilitation with your athletic trainer because of this injury?

Y or N, If yes how long were you expected to report for rehab?

b. Less than a week b. Over a week

Did this injury prevent you from throwing? Y or N

If yes, how long were you not throwing because of pain?

a. 2 or fewer days b. 3 or greater than 3 days

___ **Lateral Epicondylitis** (if checked, answer the following questions)

When did this injury occur? ________________(Month/Year)

How did the injury happen?

Did this injury require surgery? Y or N

Were you asked by your athletic trainer or physician to limit your throws during practice? Y or N

If yes, how many practice/games were you limited in?

a. 5 or fewer practices/games b. 6 or more practices/games

Were you expected to report for rehabilitation with your athletic trainer because of this injury?

Y or N, If yes how long were you expected to report for rehab?

b. Less than a week b. Over a week

Did this injury prevent you from throwing? Y or N

If yes, how long were you not throwing because of pain?

a. 2 or fewer days b. 3 or greater than 3 days

___ **Ulnar Collateral Ligament Sprain** (if checked, answer the following questions)

When did this injury occur? ________________(Month/Year)

How did the injury happen?

Did this injury require surgery? Y or N

Were you asked by your athletic trainer or physician to limit your throws during practice? Y or N

If yes, how many practice/games were you limited in?

a. 5 or fewer practices/games   b. 6 or more practices/games

Were you expected to report for rehabilitation with your athletic trainer because of this injury?

Y or N, If yes how long were you expected to report for rehab?

b. Less than a week   b. Over a week

Did this injury prevent you from throwing? Y or N

If yes, how long were you not throwing because of pain?

a. 2 or fewer days   b. 3 or greater than 3 days

___ **Biceps Tendinitis (Elbow)** (if checked, answer the following questions)

When did this injury occur? ________________(Month/Year)

How did the injury happen?

Did this injury require surgery? Y or N

Were you asked by your athletic trainer or physician to limit your throws during practice? Y or N

If yes, how many practice/games were you limited in?

a. 5 or fewer practices/games   b. 6 or more practices/games

Were you expected to report for rehabilitation with your athletic trainer because of this injury?

Y or N, If yes how long were you expected to report for rehab?

b. Less than a week   b. Over a week

Did this injury prevent you from throwing? Y or N

If yes, how long were you not throwing because of pain?

a. 2 or fewer days   b. 3 or greater than 3 days

___ ____(If your injury was not listed above please write it in. ONLY shoulder or elbow injuries)

When did this injury occur? ________________(Month/Year)

How did the injury happen?

Did this injury require surgery? Y or N

Were you asked by your athletic trainer or physician to limit your throws during practice? Y or N

If yes, how many practice/games were you limited in?

a. 5 or fewer practices/games   b. 6 or more practices/games

Were you expected to report for rehabilitation with your athletic trainer because of this injury?

Y or N, If yes how long were you expected to report for rehab?

b. Less than a week   b. Over a week

Did this injury prevent you from throwing? Y or N

If yes, how long were you not throwing because of pain?

a. 2 or fewer days   b. 3 or greater than 3 days

APPENDIX B

Manuscript

A Comparison of Trunk Rotation Flexibility and Trunk Rotation Kinematics during Throwing between Division I Collegiate Softball Position Players with and without a History of Shoulder or Elbow Pain

Context: Throwing is a whole body movement that requires the transfer of energy via the trunk from the lower extremity to the upper extremity. Ineffective transfer of energy sometimes referred to as "throwing with too much arm" is thought to cause abnormal stresses on the joints of the throwing arm.

Objective: To compare trunk rotation kinematics during throwing and trunk rotation flexibility between softball players with and without shoulder/elbow pain. To establish the relationship between trunk rotation kinematics during throwing and ball velocity. Lastly, to establish the relationship between trunk rotation flexibility and trunk rotation kinematics during throwing.

Design: Cross sectional design

Setting: Five division I schools in central North Carolina

Participants: Sixty five healthy female division I softball position players

Data Collection: Trunk rotation flexibility was measured with three clinical tests, while trunk kinematic variables during throwing were obtained by manual digitization of two-dimensional video clips that were transformed into three-dimensional coordinates with the direct linear transformation (DLT) procedure.

Main Outcome measure: Trunk rotation kinematics was analyzed using a one way ANOVA. Trunk rotation flexibility was analyzed using independent samples *t*-test. Pearson correlations coefficients were run to establish the relationship between trunk rotation kinematics during throwing and ball velocity and trunk rotation kinematics during throwing and trunk rotation flexibility. Statistical significance was set a priori at $\alpha = 0.05$.

Results: Softball players with a history of shoulder/elbow pain have limited trunk flexibility measured using the half kneeling rotation test-bar back. Softball players with a more closed upper torso and pelvis orientation at front foot contact showed an increase in ball velocity.

Conclusion: The clinical test may be use by sports medicine staff to identify softball players who may be at increased risk for developing shoulder/elbow.

Key Words: Softball, Trunk rotation kinematics, trunk rotation flexibility, Shoulder pain, Elbow Pain

Introduction: The sport of softball began in 1880 as a derivation of baseball and was officially named softball in 1930 (Flyger, Button et al. 2006). Over the years softball has continued to grow and the International Softball Federation now recognizes 122 national federations (Marshall, Hamstra-Wright et al. 2007). It can be estimated that there are about 16,079 participants at the collegiate level in the United States (Bonza, Fields et al. 2009).

Currently there is little epidemiological data available for softball injuries in position players. A recent epidemiologic study in high school athletes reports that girls are more likely to sustain upper extremity injuries as a result of overuse/chronic mechanisms versus boys who are more likely to sustain shoulder injuries from contact with playing surface or noncontact mechanisms. High school epidemiology research also demonstrates that for baseball (24.3%) and softball (50.2%), shoulder injuries are a result from throwing not including pitching. Sprains and strains were found to be the most common shoulder injuries accounting for 52.9% in softball players (Ludewig and Cook 2000; Cools, Witvrouw et al. 2003; Barden, Balyk et al. 2005; Hess, Richardson et al. 2005).

With a high percentage of upper extremity injuries occurring in softball players, it is important to identify potential risk factors so that appropriate intervention programs can be developed. Weakness of the scapular stabilizers and rotator cuff muscles (Ludewig and Cook 2000; McClure, Bialker et al. 2004; Downar and Sauers 2005; Myers, Pasquale et al. 2005; Laudner, Myers et al. 2006; McClure, Michener et al. 2006; Laudner, Stanek et al. 2007; Oyama, Myers et al. 2008), altered activation pattern of the scapular stabilizers and rotator cuff muscles (Morgan, Burkhart et al. 1998; Burkhart, Morgan et al. 2003; Downar and Sauers 2005; Myers, Laudner et al. 2006; Ruotolo, Price et al. 2006; McClure, Balaicuis et al. 2007; Laudner, Sipes et al. 2008), altered scapular kinematics (Aguinaldo, Buttermore et al. 2007; Aguinaldo and Chambers 2009), posterior shoulder tightness (PST) and decreased internal rotation (Fleisig, Barrentine et al. 1996; Stodden, Fleisig et al. 2001) have previously been investigated and suggested as possible factors contributing to upper extremity injuries. One area that has received little attention and may significantly contribute to shoulder and elbow pain is trunk flexibility and trunk rotation kinematics. Decreased trunk flexibility, limited trunk rotation and altered timing of trunk rotation during throwing may have an implication in shoulder or elbow pain because of its role of transferring energy to the upper extremity during throwing (Dillman, Fleisig et al. 1993).

Three instances that stand out in the throwing cycle are front foot contact (FFC), instance of maximal shoulder external rotation (MER), and ball release (BR) (Stodden, Fleisig et al. 2001). FFC marks the end of the stride phase during which the upper body and the lower body move in synchrony, and the beginning of the late cocking phase when transfer of energy occurs as the pelvis rotates first followed by rotation of the upper torso (Kibler 1998). Proper execution of this phase allows for transfer of energy (Feltner and Dapena 1986). MER marks the end of the arm cocking phase. The instance of MER is referred to as the instance of "full tank of energy" due to the tension on the anterior shoulder musculature, and at this instance allows storage of energy that is used to accelerate the upper limb during the arm acceleration phase (Aguinaldo, Buttermore et al. 2007; Aguinaldo and Chambers 2009). BR occurs at the end of the arm acceleration phase during which the upper torso motion acts as the major contributor to ball speed

(Rose, Phillips et al. 2008). Thus if the pelvis and upper torso do not move effectively, contribution would only come from the arm which would result in a potential increase in stress at the shoulder or elbow (Lephart, Smoliga et al. 2007). The trunk has been shown to be important in the transfer of energy during throwing, hence it was important to begin to investigate differences in the trunk rotation flexibility and pelvis and the upper torso kinematics in individuals with and without history shoulder and elbow pain.

The half kneeling rotation test (bar back (HKRT-B) and bar front (HKRT-F)) (Fletcher and Hartwell 2004; Fradkin, Sherman et al. 2004; Thompson and Osness 2004; Lephart, Smoliga et al. 2007) and seated rotation test (SRT) (Leigh and Yu 2007) are clinical tests that are used to assess trunk rotation flexibility, which have been used in golfers to identify limitations in trunk range of motion. The half kneeling rotation test may be better to use on throwers because it puts a person into a position in which they must also remain balanced. With the feet in line with each other, it may better represent throwing posture than the traditional seated rotation measurement. Several studies have been conducted to evaluate effectiveness of exercise programs that focus on the trunk flexibility and strength as well as other exercises on golfers (Escamilla, Fleisig et al. 1998). All these studies found that there was either an increase in trunk range of motion, trunk strength, or golf performance after completion of the program. Thus if trunk rotation flexibility is limited in softball players it can be corrected with exercises.

With the sport of softball increasing in popularity and prevalence of upper extremity injuries increasing as more people participate, it was important to begin to study the biomechanics of these athletes in order to understand etiology and develop prevention strategies. Since trunk rotation is important in transferring energy to the shoulder and elbow during ball propulsion and absorbing stresses at the joints during limb deceleration, it is becoming an area of greater interest. As of yet, there was no study looking at the relationship between trunk rotation kinematics and upper extremity pain. Therefore the primary purpose of this study was to compare the amount of trunk rotation and timing of trunk rotation during throwing between collegiate softball players with and without shoulder or elbow pain. The secondary purpose of this study was to compare the trunk flexibility characteristics measured using the half kneeling rotation test (bar in front and bar in back) and seated trunk rotation test between collegiate softball players with and without shoulder or elbow pain. The relationship between trunk rotation kinematics during throwing and ball velocity was explored to see if trunk rotation kinematics during throwing can predict performance. Lastly, the relationship between the clinical measures of trunk rotation flexibility and trunk rotation kinematics during throwing was explored to see if clinical measures of trunk flexibility may be used as predictors of trunk rotation kinematics during throwing.

Methods

Subjects: Eighty healthy female division I softball position players were recruited for this study. Five intercollegiate softball teams from schools in central North Carolina were contacted for participation in this study. Subjects were included in the study if 1) they were able to throw as they normally would in a game situation, and 2) they play a position other than pitcher for at least fifty percent of their total playing time. Fifteen players reported that they play pitcher for more than fifty percent of their total playing and were thus excluded from the study. Therefore, data from a total of sixty-five position players were used in the data analysis. Pitchers were excluded in order to avoid the influence of shoulder and elbow injuries that may be potentially due to the underhand pitch.

Instrumentations: Four Video Home System (VHS) video camcorders (Panasonic, Kadoma, Japan: Model; PV-GS35) were used to collect throwing data at a rate of 60 frames per second and a shutter speed of 1/1000 seconds (Rose, Phillips et al. 2008). The four cameras (figure 1) were centered around the throwing circle. The cameras were placed 45 degrees at the front right (figure 1, camera 1), back right (figure 1, camera 1), back left (figure 1, camera 3), and front left (figure 1, camera 4) centered around the throwing circle. The two cameras on the right side were used to film right handed subjects, and the two cameras on the left side were used to film left handed subjects. A ten by ten inch box was taped to the ground centered around the origin. A 2 x 1.5 x 1 m three dimensional calibration frame(Peak Performance Technologies, Inc., Englewood Colorado) was placed in the center of the throwing circle, which was set in an open area in the outfield, and videotaped prior to data collection (Aguinaldo, Buttermore et al. 2007). Additionally, one object was placed at the origin and another object about meter away was used to represent the direction of the x-axis during calibration to establish a global reference frame during data reduction.

Procedures: Prior to subject arrival, the cameras were set up and calibration frame was videotaped as described in the instrumentation section.

Subjects reported to the stadium of the school that was tested. Prior to participation, subjects signed an informed consent form that was approved by the University of North Carolina-Chapel Hill Biomedical Institutional Review Board. Participants were screened for inclusion and exclusion criteria using section I of the questionnaire (Appendix A). Subjects were excluded if the reported that they pitched for more than 50% of their total playing time. Subjects were also excluded if they (1) reported currently having shoulder, elbow, neck or back pain that would prevent them from throwing in a game situation, experienced numbness or tingling in their throwing arm within the past three days or have been diagnosed with a neurological disorder, reported having surgery on their throwing arm within the past six months, and/or (4) if they were diagnosed by a physician or athletic trainer as having a strain of any trunk muscles within the past week. If participants met the criteria, they proceeded to complete the rest of the questionnaire to provide demographic information (section II) and past medical history (section III). The past medical history was used to determine if the subject was placed in a shoulder/elbow pain or no shoulder/elbow pain group (Appendix A). Subjects were classified into the shoulder/elbow pain group or the no shoulder/elbow pain group based on the past medical history questionnaire. Subjects were placed in the shoulder/elbow pain group if they (1) have sustained an injury in which they were unable to throw for three or more days, sustained an injury in which they were only allowed to participate in a limited number of throws for more than a week, and/or sustained an injury in which they were asked to receive treatment for more than a week. All subjects were asked to wear a tank top to aid in visualization of bony landmarks. Sixteen subjects from one of the five schools were tested in practice uniforms due to cold weather.

Subjects underwent three screening tests for trunk flexibility 1) Half kneeling rotation test bar in the back (HKRT-B), 2) half kneeling rotation test bar in front (HKRT-F) and 3) Seated trunk rotation test (SRT). These screening tests assessed the participant's trunk flexibility.(Abdel-Aziz and Karara 1971) In our laboratory, moderate to high reliability was obtained through pilot data. The intraclass correlation coefficient and standard error of measurement (SEM) for HKRT-B to the right and left were $ICC_{(2,k)}$ = .672 / SEM = 5.8 deg and $ICC_{(2,k)}$ = .868 / SEM = 3.7 deg, respectively. The ICC and SEM values for HKRT-F to the right and left were $ICC_{(2,k)}$ = .811 / SEM = 5.0 deg and $ICC_{(2,k)}$ = .856 / SEM = 4.0 deg, respectively. The ICC and SEM values for SRT to the right and left were $ICC_{(2,k)}$ = .798 / SEM = 4.1 deg and $ICC_{(2,k)}$ = .727 / SEM = 5.0 deg, respectively.

Once a subject completed the questionnaire and the trunk screening tests, she was given ample time to warm up as she normally would, including stretching, non throwing drills and warm up throws. As soon as the subject felt adequately warmed up to make a throw, pre-wrap and tape were placed just above the elbow and at the wrist to aid in the identification of elbow and wrist joint centers during digitization. Once the tape was placed on the subject they were allowed 1-3 practice throws.

Subjects threw a straight line a distance of 25.86 m in the outfield. This distance was chosen because it is the distance from home base to second base, which is a common distance that position players throw during practices and games. Subjects were instructed to throw as hard and accurate as if in a game situation. They were also instructed to make their front foot land within the 10 inch by 10 inch box. The ball was thrown to the subject. The subject then caught the ball and threw back to researcher who was 25.86 m away down a straight line. The subject completed five throws with as much time in between each throw for rest as the subject required.

Subjects rated each of their throws on a scale of 1-5 with 1 being the worst throw and 5 being the best throw based on subjective criteria of accuracy of throw and how good the throw felt (Stodden, Fleisig et al.). The speed of each throw was recorded using Jugs (*JK-RG-Gun-R1010)* radar gun. A combination of the highest rated throws and the greatest velocity were chosen for digitization.

Data Reduction: The Direct Linear Transformation (DLT) procedure was used to calculate three dimensional (3-D) coordinates of the bony landmarks (Yu and Andrews 1998). The markers on the calibration frame and two additional markers from two camera views were manually digitized using Peak Motus software (Peak Performance Technology, Inc., Englewood, CO) to obtain the Direct Linear Transformation (DLT) parameters, and to define the global coordinate system. The global reference frame was defined such that the X was pointing toward the direction of throwing, Z was the vertical component pointing upward, and Y was the cross-product of Z and X pointing toward the left when facing the direction of throwing (Stodden, Fleisig et al.). For each throw, six bony landmarks were digitized in each frame for each camera view, starting at five frames before front foot contact to five frames after the instant of ball release. The two camera views were synchronized using a frequency modulated analog audio signal simultaneously transmitted to the cameras. When the 2-D coordinates were synchronized, the DLT procedure was used to obtain the 3-D coordinates. The 3-D coordinates were filtered using a 4^{th} order Butterworth filter with an estimated optimal cutoff frequency of 7.14 (Stodden, Fleisig et al.), and then were used to calculate upper torso orientation, pelvis orientation, and upper torso-pelvis separation angle. Additionally shoulder external rotation angle was calculated to determine the instance of maximal humeral external rotation during throwing.

Three throws were digitized for each subject and then was averaged. Image quality had an influence on digitization, due to some images being clearer than others. Image quality was influenced by the amount of lighting present during the day of testing. Three throws were to be analyzed for each subject but due to tape malfunction, only one or two throws were useable for some subjects. Tape malfunction occurred when the tape would skip frames and thus result in inaccurate synchronization. Only two trials were analyzed for nine subjects and one trial was analyzed for two subjects. The remaining 54 subjects had three trials analyzed.

Moderate to high intra-rater reliability was found during pilot testing for the kinematic variables. Upper torso orientation at FFC, MER, and BR revealed values of $ICC_{(2,k)}$ = .947, SEM = 2.52, $ICC_{(2,k)}$ = .749, SEM = 6.80, $ICC_{(2,k)}$ = .732, SEM = 5.77. Pelvis orientation at FFC, MER, and BR revealed values of $ICC_{(2,k)}$ = .72, SEM = 2.70, $ICC_{(2,k)}$ = .59, SEM = 9.11, $ICC_{(2,k)}$ = .757, SEM = 4.83. Upper torso-pelvis separation angle at FFC, MER, and BR revealed values of $ICC_{(2,k)}$ = .897, SEM = 3.05, $ICC_{(2,k)}$ = .642, SEM = 9.05, $ICC_{(2,k)}$ = .472, SEM = 8.06. Initiation of trunk rotation revealed values of $ICC_{(2,k)}$ = .318, SEM = 12.96.

Pelvis orientation (figure 2) was defined as the angle between the line connecting the two ASIS and the global X-axis in the XY plane in a global reference frame. Pelvis orientation was positive when the anterior aspect of the pelvis was visible to the throwing target. Positive orientation was considered the open position of the pelvis. Pelvis orientation is negative when the posterior aspect of the pelvis was visible to the throwing target. Negative orientation was considered the closed position of the pelvis (Myers, Lephart et al. 2008).

Upper torso orientation (figure 3) was the angle between the line connecting the bilateral acromion processes and the global X-axis in the XY plane in a global reference frame. Upper torso orientation was positive when the anterior aspect of the upper torso was visible to the throwing target. Positive orientation was considered the open position of the upper torso. Upper torso orientation was negative when the posterior aspect of the upper torso was visible to the throwing target. Negative orientation was the considered the closed position of the upper torso (Graichen, Hinterwimmer et al.).

Upper torso-pelvis separation angle was the acute angle between the line connecting the acromion and the line connecting the ASIS (Stodden, Fleisig et al. 2001). Upper torso-pelvis separation angle was neutral (0 degrees) when upper torso orientation and pelvis orientation were parallel to one another. Upper torso-pelvis separation angle was negative when the upper torso orientation lags behind the pelvis orientation and positive when the upper torso orientation surpasses the pelvis orientation.

Three trunk kinematic variables (upper torso orientation, pelvis orientation, and upper torso-pelvis separation angle) were analyzed at three instances, 1) instant of front foot contact, 2) instant of maximum shoulder external rotation (Werner, Fleisig et al. 1993; Fleisig, Escamilla et al. 1996; Escamilla, Fleisig et al. 1998) , and 3) instant of ball release (Aguinaldo, Buttermore et al. 2007; Aguinaldo and Chambers 2009). The instances of front foot contact and ball release were identified visually and maximum shoulder external rotation was determined based on the shoulder kinematic data.

In order to identify the timing of upper torso rotation initiation, the three trunk kinematic variables were normalized to the throwing cycle such that 0% is front foot contact and 100% is ball release (Putnam 1991; Putnam 1993; Aguinaldo, Buttermore et al. 2007; Aguinaldo and Chambers 2009). Onset time of trunk rotation was defined as the time in which the magnitude, relative to the pelvis, begins to decrease from its maximum value (Putnam 1993; Stodden, Fleisig et al. 2001). Calculation of all dependent variables from the 3-D coordinate data was performed using a custom-written program using MatLab software (The MathWorks Inc, Natick MA).

Data Analysis

Three separate one-between (group), one-within (instance) factor analysis of variance (ANOVA) were run to compare the means of upper torso orientation angle, pelvis orientation angle, upper torso-pelvis separation angle at FFC, MER, BR between subjects with and without shoulder/elbow pain. Additionally, independent samples *t*-tests were run to compare the means of initiation of trunk rotation, trunk flexibility test (HKRT-B, HKRT-F, and SRT when the throwing shoulder is rotating backward and when the throwing shoulder is rotating forward) and ball velocity between subjects with and without shoulder/elbow pain. In case significant mean differences were identified, median dichotomy was used to categorize the subjects into limited vs. not limited flexibility or movements groups. Chi-square analysis was used to further analyze the association between the variable and the shoulder/elbow pain and to calculate the odds ratio. In order to explore the relationships between ball velocity and trunk rotation kinematics during throwing, Pearson correlation coefficients were calculated between the trunk kinematic variables and the ball velocity. Additionally, Pearson correlation coefficients were also calculated to explore the relationship between trunk rotation flexibility measured using HKRT-B, HKRT-F, and SRT, and the trunk rotation kinematics during throwing, specifically the maximum and minimum upper torso orientation, pelvis orientation, and upper torso-pelvis separation angles.

All statistical analyses were run using Statistical Package for Social Science (SPSS) 16 (SPSS Inc, Chicago IL). The level of significance was set at an alpha level of .05.

Results: A total of eighty division I softball players from five schools in Central North Carolina were tested for this study. Fifteen subjects reported pitching more than 50% of their total playing time, thus were excluded from data analysis. Data from a total of sixty-five subjects were included in the statistical analysis. Of the 65 study subjects, 19 reported a history of shoulder or elbow pain and 46 reported no history of shoulder or elbow pain. A total of twenty eight injuries were reported by 19 subjects. Two subjects reported four injuries, one subject reported three injuries, one subject reported two injuries, and the remaining 15 subjects reported one injury. Types of injuries reported by the athletes are reported in Table 2, and the number of individuals with shoulder or elbow pain is listed by position and by throwing/hitting sides in Table 3 and 4, respectively.

Means and standard deviations of the biomechanical variables at the instances of front foot contact (FFC), maximal shoulder external rotation (MER), and ball release (BR) are presented in Table 5. No significant group by instance interaction was found for upper torso orientation ($F_{(1,126)}$=1.786, p=.172), pelvis orientation ($F_{(1,126)}$=.145, p=.865), or separation angle ($F_{(1,126)}$=2.160, p=.120). Additionally, the timing of initiation of trunk rotation was not different between the subjects with and without shoulder or elbow pain ($t_{(63)}$ = 1.127, p = .264). Means and standard deviations for clinical measures of trunk rotation flexibility are presented in Table 6. Subjects with shoulder or elbow pain had significantly less trunk rotation when the throwing shoulder is moving forward than subjects with no pain when tested with the half kneeling rotation test with bar in the back (HKRT-B) ($t_{(63)}$ = -2.24, p = .029).

The chi-square analysis demonstrated that having less trunk rotation flexibility when the throwing shoulder is moving forward is significantly associated with a history of shoulder or elbow pain ($\chi 2_{(1)}$ =5.640, p =.018) when measured using the HKRT-B (Table 7). Subjects with trunk rotation flexibility less than the group median (45.0 deg) were 3.98 times more likely to have shoulder or elbow pain. However, trunk rotation flexibility when the throwing shoulder is moving forward was not different between subjects with and without pain when trunk rotation flexibility was tested with half kneeing rotation test with bar in front (HKRT-F) ($t_{(63)}$ = -1.49, p = .141) or with seated rotation test (SRT) ($t_{(63)}$ = .21, p = .833).

There were no between-group differences in trunk rotation flexibility when the throwing shoulder is moving back when tested with the HKRT-B ($t_{(63)}$ = -1.92,p = .060), HKRTBF ($t_{(63)}$ = -.73, p = .470), or SRT ($t_{(63)}$ = -.33, p = .743).

Pearson correlations were run to explore the relationship between trunk rotation kinematics variables during throwing and ball velocity. Pearson correlation coefficients among the variables are reported in table 9. A moderate inverse relationship was found between both upper torso (r = -.478, p = .001) and pelvis orientations (r = -.522, p = .001) at FFC and ball velocity. The more closed the upper torso and pelvis orientations were at front foot contact, the faster the ball velocity. A weak inverse relationship was found between separation angle at BR (r = -.288, p = .020) and ball velocity. The more “coiled” the upper torso is relative to the pelvis, the faster the ball velocity. No other correlations were statistically significant.

Pearson correlations were run to explore the relationship between clinical measures of trunk flexibility and trunk kinematic variables during throwing. Pearson correlation coefficients among the variables are reported in table 10 and 11. A weak positive relationship was found between the HKRT-B when the throwing shoulder is rotating forward and minimum separation angle ($r = .251$, $p = .044$). The minimum separation angle is attained when the upper torso is maximally “coiled” relative to pelvis towards the non-throwing shoulder. No other correlations were statistically significant ($p>.05$).

Discussion

Although typically thought of as an upper extremity movement, successful throwing results from the effective transfer of energy from the lower extremity to the upper extremity which is mediated by the trunk (Stodden, Fleisig et al. 2001). For this reason, it is theorized that suboptimal trunk rotation kinematics during throwing and or flexibility characteristics may result in inefficient transfer of energy to the upper extremity, causing the upper extremity to experience abnormal stress. However, few studies to date have investigated the trunk rotation kinematics during throwing or flexibility characteristics as possible contributors to upper extremity injuries in overhead athletes.

Trunk Rotation Kinematics: The amount and timing at which the upper torso and pelvis rotate play an important role in the transfer of energy to the distal segments of the upper extremity (Stodden, Langendorfer et al. 2006). At the time of the front foot contact, the pelvis was oriented facing the direction of the throw (open orientation) relative to the upper torso, while the upper torso was oriented away from the direction of the throw (closed orientation), which results in lagging of the upper torso behind the hips, and therefore coiling of the trunk segment (Feltner and Dapena 1986). This coiling allows storage of elastic energy within the anterior trunk musculature, which can be transferred to the upper extremity to accelerate the throwing limb (Aguinaldo and Chambers 2009). The more closed orientations of the pelvis and the upper torso at front foot contact permit larger range of movement for the storage and transfer of energy to take place, which facilitates greater transfer of energy to the upper extremity. The greater coiling of the trunk segments results in greater stretching of the oblique muscles and thus greater storage of the elastic energy. We hypothesized that the softball players with a history of shoulder or elbow pain would demonstrate more open pelvis and upper torso orientations at the front foot contact compared to the players without a history of shoulder or elbow pain because we theorized that the softball player’s inefficient use of trunk in storing and transferring energy to the upper extremity would contribute to upper extremity injuries. However, contrary to our hypotheses, this study demonstrated no differences in trunk kinematic variables at the time of front foot contact between softball players with and without a history of shoulder or elbow pain.

At the instance of maximum shoulder external rotation, the upper torso is rotated slightly forward relative to the pelvis, while the upper extremity lags behind the trunk, which allows for storage of energy in the anterior shoulder structures (Fleisig, Andrews et al. 1995). The pelvis at this point should be close to its maximum orientation (more open). The more open orientation of the pelvis shoulder external rotation permits the pelvis to become a stable base for the upper torso to rotate on, which continues the sequence of transferring energy to the upper extremity. Since this is the point at which upper torso orientation is just overcoming pelvis orientation; upper torso-pelvis separation angle will be closer to parallel. We hypothesized that softball players with a history of shoulder or elbow pain would demonstrate more closed pelvis and upper torso orientations and be more coiled (less parallel) compared to players without a history of shoulder or elbow pain because we theorized softball players' inefficient use trunk rotation would contribute to upper extremity injuries. However, contrary to our hypotheses, this study demonstrated no differences in trunk kinematic variables at the time of maximum shoulder external rotation between softball players with and without a history of shoulder or elbow pain.

During ball release both pelvis and upper torso orientation approach their maximum orientations. The more open positions of the pelvis and the upper torso permit a large coiling of the trunk, which allows the previously stored elastic energy to be transferred to the distal segment. Thus we hypothesized that softball players with a history of shoulder or elbow pain would demonstrate more closed positions at ball release compared to softball players without a history of shoulder or elbow pain. We theorized that softball players with a more closed position will not be able to transfer energy effectively and result in increase stress place on the upper extremity. Opposing our hypotheses, this study demonstrated no differences in trunk kinematic variables at the time of ball release between softball players with and without a history of shoulder or elbow pain.

To date no study has compared trunk rotation kinematics between softball players with and without a history of pain. Therefore, the results of this study cannot be directly compared to findings from previous studies. Aguinaldo et al has previously investigated the relationship between trunk kinematic variables and the elbow valgus torque during baseball pitching, and reported that there were no relationships between elbow valgus torque and upper torso and pelvis orientations (Fleisig, Barrentine et al. 1996; Stodden, Fleisig et al. 2001; Stodden, Langendorfer et al. 2006). Their findings are in line with the finding from our study demonstrating no difference in trunk kinematic differences between the softball players with and without pain. While Aguinaldo et al did not compare trunk rotation kinematics between pitchers with and without pain; high magnitude of valgus stress has been considered to contribute to development of elbow injuries (Aguinaldo and Chambers 2009).

Upper torso rotation typically occurs near the time of maximum shoulder external rotation. After front foot contact, the pelvis starts to rotate forward, while the upper torso maintains a closed orientation, creating further lagging of the upper torso relative to the pelvis, thus maximizing energy storage. The upper torso then starts rotating forward (timing of trunk rotation) as the trunk musculature contracts and the transfer of momentum from the pelvis to the upper torso begins (Aguinaldo, Buttermore et al. 2007). Therefore, we hypothesized that softball players with shoulder or elbow pain would initiate trunk rotation earlier than softball players without shoulder or elbow pain. However, contrary to our hypotheses, this study demonstrated no differences in initiation of trunk rotation between softball players with and without a history of shoulder or elbow pain.

In the study by Aguinaldo et al previously discussed, the authors reported that the initiation of trunk rotation prior to FFC was a significantly related to greater elbow valgus torque (Fleisig, Andrews et al. 1995). Furthermore, an earlier study by Aguinaldo et al (Aguinaldo, Buttermore et al. 2007; Aguinaldo and Chambers 2009) compared trunk rotation kinematics between pitchers from different levels and reported that younger inexperienced pitchers initiated trunk rotation earlier in the pitching cycle and produced greater shoulder internal rotation torque relative to their body mass compared to the older more experienced pitchers. These studies indicate that early initiation of trunk rotation may be associated with inexperience and greater reliance on the shoulder to produce torque, which may make an individual more susceptible to injury (Leigh and Yu 2007; Leigh, Gross et al. 2008; Leigh, Liu et al. 2009).

One of the potential reasons why the differences in trunk kinematic variables were not detected in this study is the high inter-subject variability in the throwing kinematics, due to inclusion of infielders and outfielders and a use of crow hop. Secondary analysis demonstrated that the trunk rotation kinematics were different between infielders and outfielders. Infielders' upper torso tended to be in a more closed position, while their pelvis tended to be in a more open position during FFC. The crow hop is a controlled movement, which is initiated by the trail leg by kicking it up and forward and passing it in front of the other leg. This strategy is more frequently used by outfielders than in infielders to quickly position a thrower after fielding a ball. During this study it was observed that some subjects used a crow hop technique while others simply took a forward step to throw, which may have introduced inter-subject variability in the trunk rotation kinematics data.

Another possible reason why no differences in trunk rotation kinematics were detected between groups is because of the error introduced in the data from poor reliability in some kinematic variables. Reliability testing conducted prior to digitization of the data demonstrated moderate to high reliability and precision for upper torso and pelvis orientation angles. However, the reliability of the upper-torso orientation angle and the timing of trunk rotation were low. This can be attributed to the fact that upper-torso orientation angle was calculated by subtracting the pelvis orientation value from the upper torso orientation value, and therefore the separation angle is affected by error from two variables. The low reliability of the timing of rotation was low, likely because the variable was calculated based on the separation angle. Onset time of trunk rotation was defined as the time in which the magnitude, relative to the pelvis, begins to decrease from its maximum value (Stodden, Fleisig et al. 2001; Stodden, Langendorfer et al. 2006; Aguinaldo, Buttermore et al. 2007; Aguinaldo and Chambers 2009). The low reliability of the variables may be due to relatively low sampling frequency (60 Hz) used for the kinematic analysis. The 60Hz sampling frequency may have been too slow for the motion we were trying to capture, although this sampling frequency had previously been used to collect kinematic data during discus throwing (Stodden, Langendorfer et al. 2006). Recent studies looking at baseball pitches have used a sampling frequency of 200 -240 Hz (Sell, Tsai et al. 2007). Within subject variability may have also resulted in changes between throws within the same subject. Subjects may have slightly difference mechanics between each of their three throws analyzed.

Trunk Flexibility: Currently there is no study that compares trunk flexibility measures between subjects with or without history of shoulder or elbow pain. Thus we were interested to see if there was an easy clinical measure that can be used to indentify players who may be at increased risk for injury. We found that softball players with a history of shoulder or elbow pain exhibited significantly less trunk rotation flexibility measured using the HKRT-B when the throwing shoulder is rotating forward than subjects without history of shoulder or elbow pain. Furthermore, odds ratio analysis reveals that softball players with trunk rotation flexibility less than 45 degrees were almost 4 times more likely to have shoulder or elbow pain compared to the softball players with greater trunk flexibility when measured using the HKRT-B when the throwing shoulder is rotating forward. This finding is in agreement with our hypothesis that softball players with a history of shoulder or elbow pain would have less trunk flexibility than subjects without pain. During throwing, the eccentric loading of the trunk musculature occurs as the pelvis rotates and the upper torso lags behind (Sell, Tsai et al. 2007). Limited trunk flexibility in this direction may inhibit the storage of elastic energy in the trunk musculature, which could result in greater reliance on upper extremity joints to produce torque. A study by Sell et al (Stodden, Langendorfer et al. 2006) compares trunk rotation flexibility between three different professional levels of golfers. This study found that golfers with lower handicap scores had a significantly greater amount of trunk rotation flexibility (Stodden, Fleisig et al. 2001). The increase in trunk rotation by golfers with a lower handicap may increase their ability to generate energy during their swing.

Interestingly, HKRT-B was the only test that demonstrated the flexibility difference between softball players with and without history of shoulder or elbow pain. The other trunk flexibility tests (HKRT-F and SRT) did not show any differences in subjects with and without shoulder or elbow pain. During the HKRT-B test, holding a bat behind the lower back results in ”locking” of the lumbar spine and scapula, which results in isolation of the rotation of the thoracic spine. On the other hand, the HKRT-F performed while holding the bat across chest does not lock the lumbar spine or the scapula, and therefore the measurement reflects combination of the rotation at the thoracic and lumbar spine and the movement of the scapula along the rib cage. Since the HKRT-F measures the rotation flexibility of the entire trunk segments, the test allows movement of the scapula along the rib cage to compensate for the limited trunk flexibility, which results in range of motion values that do not truly represent the trunk flexibility. As well as locking the pelvis in place, both the HKRT-B and the HKRT-F measures trunk rotation flexibility in a more functional position that mimics the trunk rotation occurring during throwing.

The SRT is a more traditional method of measuring trunk rotation flexibility that simply assesses flexibility while the subject is seated. Similar to the HKRT-F, the SRT measures the flexibility of the thoracic and lumbar spine and the movement of the scapula along the rib cage, and therefore may produce values that do not truly represent trunk flexibility. HKRT-B was the only test that was able to detect the difference in trunk flexibility between the softball players with and without a history of shoulder or elbow pain. Based on this finding, the HKRT-B may be more sensitive in identifying subjects who are at increased risk for developing pain, and should be used in clinical settings.

Trunk Rotation Kinematics and Ball Velocity: The exploratory analysis of the relationship between trunk rotation kinematics and ball velocity revealed that a more “closed” orientation of the upper torso and pelvis at the time of front foot contact was related to greater ball velocity. The analysis also demonstrated that greater twisting of the upper torso relative to pelvis at the time of ball release (greater upper torso-pelvis separation angle in negative direction) was related to faster ball velocity. These findings agree with the hypotheses that subjects with a greater ball velocity will start in a more closed position and rotate their upper torso more relative to pelvis at the time of ball release. Just prior to FFC the pelvis begins to rotate while the upper torso stays behind creating a "lag effect." This lag effects creates elastic energy which is stored in trunk musculature (Stodden, Fleisig et al. 2001). A more closed position at FFC may allow for more energy to be stored and transferred to the upper extremity resulting in a greater ball velocity. While these findings are in agreement with our hypothesis, they varied from the findings in the study by Stodden et al (Fletcher and Hartwell 2004; Thompson and Osness 2004; Lephart, Smoliga et al. 2007) that reported greater (more open) upper torso and pelvis orientation at maximum shoulder external rotation as well as greater pelvis orientation at ball release were associated with a greater ball velocity (Ludewig and Cook 2000; Reddy, Mohr et al. 2000; Cools, Witvrouw et al. 2004; Cools, Witvrouw et al. 2005; Tyler, Cuoco et al. 2009). Differences in findings between the studies may be attributed to the difference in tasks and study population. Our study evaluated trunk rotation kinematics during throwing in collegiate softball position players and Stodden et al studied trunk rotation kinematics during baseball pitching in three different levels (professional, collegiate and high school.

Trunk Rotation Kinematics and Trunk Flexibility: The relationship between trunk rotation flexibility and the trunk kinematic variables were explored in order to examine if trunk flexibility measured using clinical tests can predict trunk rotation kinematics during throwing. While there were a few statistically significant correlations between trunk rotation kinematics and trunk flexibility, the correlations were weak, indicating that the trunk rotation kinematics during throwing was not dictated by the trunk flexibility characteristics. However, this result needs to be interpreted with caution due to the aforementioned limitation with the instrumentation used for trunk rotation kinematics during throwing assessment. Further study assessing the relationship using higher sampling frequency is warranted. Trunk rotation flexibility may not be reflected in trunk rotation kinematics during throwing because it order to play softball at the division I level, players will need to be able to rotate their trunk to a certain degree. If two people, one with good flexibility and one with bad flexibility, achieve the same amount of rotation during throwing, the more flexible person may do so easier than the one with limited flexibility. Although the person with limited flexibility is achieving the same amount of rotation during throwing, more tension may be placed on the shoulder or elbow leading to pain. This may be why no relationship was found between trunk rotation flexibility and trunk rotation kinematics during throwing.

Clinical Implications: The main finding of this study is that limited trunk rotation flexibility is strongly associated with a history of shoulder or elbow injuries, and that individuals with limited trunk flexibility measured with the HKRT-B when the throwing shoulder is rotating forward are almost 4 times more likely to have a history of shoulder or elbow injury. The HKRT-B is a simple and quick clinical test that may be used by sports medicine clinicians in preseason screenings to identify individuals with limited trunk rotation flexibility. If the limitation in trunk rotation flexibility is identified, clinicians can prescribe exercises that can improve trunk flexibility. Previous studies have demonstrated that exercise training programs implemented in golfers have successfully improved trunk flexibility and performance (Ludewig and Cook 2000; Cools, Witvrouw et al. 2003; Barden, Balyk et al. 2005; Hess, Richardson et al. 2005). A strong association between limited trunk rotation flexibility suggests that an improvement in trunk rotation flexibility has potential to lead to prevention of shoulder or elbow injuries.

While the limitation in trunk flexibility was identified as a possible contributor to the shoulder and elbow pain, there are other factors that are suggested to contribute to shoulder or elbow pain. These factors include weakness of the scapular stabilizers and rotator cuff muscles (Ludewig and Cook 2000; McClure, Bialker et al. 2004; Downar and Sauers 2005; Myers, Pasquale et al. 2005; Laudner, Myers et al. 2006; McClure, Michener et al. 2006; Laudner, Stanek et al. 2007; Oyama, Myers et al. 2008), altered activation pattern of the scapular stabilizers and rotator cuff muscles (Morgan, Burkhart et al. 1998; Burkhart, Morgan et al. 2003; Downar and Sauers 2005; Myers, Laudner et al. 2006; Ruotolo, Price et al. 2006; McClure, Balaicuis et al. 2007; Laudner, Sipes et al. 2008), altered scapular kinematics , posterior shoulder tightness (PST) and decreased internal rotation . Clinicians will need to assess trunk flexibility in addition to these when evaluating shoulder or elbow injuries in overhead athletes.

Although our study did not demonstrate any differences in kinematic variables between softball players with and without history of shoulder or elbow pain, more studies are needed to determine the exact relationship since this is the first study examining kinematic variables in softball position players. Considering the methodological limitation, the study results need to be interpreted with caution.

Limitations: In addition to the limitation of the study related to instrumentation for the kinematic analysis discussed above, there are a few limitations to this study that need to be discussed. In this study trunk rotation kinematics was assessed with the subjects throwing a softball a distance of 25.86 meters. While this is a common distance that all position players throw, kinematics may change when softball players throw at different distances (e.g. outfield to home, 2nd to 3rd base). These results should not be generalized to all throwing distances. Although athletes were instructed to throw as if in a game situation, they may have thrown differently since they knew they were being filmed. Also, player position influences throwing kinematics. Furthermore, this study only looked at division I softball position players, therefore study results cannot be generalized to pitchers or position players of different age or competition level.

Future Research: This was the first study to examine differences in trunk rotation kinematics during throwing and trunk flexibility in softball players, therefore more studies need to be conducted in order to confirm the findings of this study. Prospective studies that examine whether trunk flexibility is related to higher injury risk are needed to help determine a cause and effect relationship. Intervention studies to improve trunk flexibility in softball players are also warranted. Additionally, the study can be replicated in examining trunk rotation kinematics and flexibility characteristics in athletes participating in other overhead sports, such as baseball, tennis, javelin, and team handball, since movement of the trunk is important in these sports as well. In addition to kinematic variables, future study should examine the kinetic variables during throwing, since joint kinetics may have direct influence on the stress experienced by the joints and thus may be related to complaints of pain. More studies that examine the relationship between the kinematics and the ball velocity in softball position players may provide information that coaches can use to improve an athlete's performance.

Conclusions: No differences in trunk rotation kinematics between softball players with and without a history of pain were identified. However, this study demonstrated that softball players with history of shoulder or elbow pain had limited trunk flexibility measured using HKRT-B when the throwing shoulder is moving forward. Screening of the trunk flexibility using HKRT-B during preseason screenings may be used to identify those athletes with limited trunk flexibility. Clinicians can prescribe intervention exercises to these individuals to potentially prevent shoulder or elbow injuries. This study also suggests that softball players who land in a more closed position will be able to throw a ball at a higher velocity. Coaches may use this information when instructing athletes on how to throw in order to improve ball velocity.

REFERENCES

Abdel-Aziz, Y. I. and H. M. Karara (1971). Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. ASP Symposium on Close Range Photogrammetry. Falls Church: American Society of Photogrammetry**:** 1-18.

Aguinaldo, A. L., J. Buttermore, et al. (2007). "Effects of upper trunk rotation on shoulder joint torque among baseball pitchers of various levels." J Appl Biomech **23**(1): 42-51.

Aguinaldo, A. L. and H. Chambers (2009). "Correlation of Throwing Mechanics With Elbow Valgus Load in Adult Baseball Pitchers." Am J Sports Med.

Andrews, J. R., W. G. Carson, Jr., et al. (1985). "Glenoid labrum tears related to the long head of the biceps." Am J Sports Med **13**(5): 337-41.

Atwater, A. E. (1979). "Biomechanics of overarm throwing movements and of throwing injuries." Exerc Sport Sci Rev **7**: 43-85.

Barden, J. M., R. Balyk, et al. (2005). "Atypical shoulder muscle activation in multidirectional instability." Clin Neurophysiol **116**(8): 1846-57.

Barnes, D. A. and H. S. Tullos (1978). "An analysis of 100 symptomatic baseball players." Am J Sports Med **6**(2): 62-7.

Barrentine, S. W., G. S. Fleisig, et al. (1998). "Biomechanics of windmill softball pitching with implications about injury mechanisms at the shoulder and elbow." J Orthop Sports Phys Ther **28**(6): 405-15.

Bonza, J. E., S. K. Fields, et al. (2009). "Shoulder injuries among United States high school athletes during the 2005-2006 and 2006-2007 school years." J Athl Train **44**(1): 76-83.

Bradley, J. P. and J. E. Tibone (1991). "Electromyographic analysis of muscle action about the shoulder." Clin Sports Med **10**(4): 789-805.

Brown, L. P., S. L. Niehues, et al. (1988). "Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players." Am J Sports Med **16**(6): 577-85.

Burkhart, S. S., C. D. Morgan, et al. (2003). "The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics." Arthroscopy **19**(4): 404-20.

Burkhart, S. S., C. D. Morgan, et al. (2003). "The disabled throwing shoulder: spectrum of pathology Part III: The SICK scapula, scapular dyskinesis, the kinetic chain, and rehabilitation." Arthroscopy **19**(6): 641-61.

Cain, P. R., T. A. Mutschler, et al. (1987). "Anterior stability of the glenohumeral joint. A dynamic model." Am J Sports Med **15**(2): 144-8.

Chen, F. S., A. S. Rokito, et al. (2001). "Medial elbow problems in the overhead-throwing athlete." J Am Acad Orthop Surg **9**(2): 99-113.

Clarkson, H. (2005). Trunk Rotation: Thoracolumbar Spine. Joint Motion and Function Assessment A Research-Based Practical Guide Philadelphia, Lippincott Williams & Wilkins**:** 260.

Cools, A. M., E. E. Witvrouw, et al. (2003). "Scapular muscle recruitment patterns: trapezius muscle latency with and without impingement symptoms." Am J Sports Med **31**(4): 542-9.

Cools, A. M., E. E. Witvrouw, et al. (2004). "Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms." Br J Sports Med **38**(1): 64-8.

Cools, A. M., E. E. Witvrouw, et al. (2005). "Isokinetic Scapular Muscle Performance in Overhead Athletes With and Without Impingement Symptoms." J Athl Train **40**(2): 104-110.

Crockett, H. C., L. B. Gross, et al. (2002). "Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers." Am J Sports Med **30**(1): 20-6.

Davidson, P. A., M. Pink, et al. (1995). "Functional anatomy of the flexor pronator muscle group in relation to the medial collateral ligament of the elbow." Am J Sports Med **23**(2): 245-50.

DiGiovine, N. (1992). "An electromyographic analysis of the upper extremity in pitching " Journal of Elbow Surgery **1**: 15-25.

Dillman, C. J., G. S. Fleisig, et al. (1993). "Biomechanics of pitching with emphasis upon shoulder kinematics." J Orthop Sports Phys Ther **18**(2): 402-8.

Downar, J. M. and E. L. Sauers (2005). "Clinical Measures of Shoulder Mobility in the Professional Baseball Player." J Athl Train **40**(1): 23-29.

Dun, S., G. S. Fleisig, et al. (2007). "The relationship between age and baseball pitching kinematics in professional baseball pitchers." J Biomech **40**(2): 265-70.

Ebaugh, D. D., P. W. McClure, et al. (2006). "Effects of shoulder muscle fatigue caused by repetitive overhead activities on scapulothoracic and glenohumeral kinematics." J Electromyogr Kinesiol **16**(3): 224-35.

Ebaugh, D. D., P. W. McClure, et al. (2006). "Scapulothoracic and glenohumeral kinematics following an external rotation fatigue protocol." J Orthop Sports Phys Ther **36**(8): 557-71.

Escamilla, R. F., G. S. Fleisig, et al. (1998). "Kinematic Comparisons of Throwing Different Types of Baseball Pitches." Journal of Applied Biomechanics **14**: 1-23.

Feltner, M. and J. Dapena (1986). "Dyanmics of the shoulder and elbow joints of the throwing arm during a baseball pitch." International journal of sport biomechanics **2**: 235-259.

Fleisig, G. S., J. R. Andrews, et al. (1995). "Kinetics of baseball pitching with implications about injury mechanisms." Am J Sports Med **23**(2): 233-9.

Fleisig, G. S., S. W. Barrentine, et al. (1996). "Biomechanics of overhand throwing with implications for injuries." Sports Med **21**(6): 421-37.

Fleisig, G. S., S. W. Barrentine, et al. (1999). "Kinematic and kinetic comparison of baseball pitching among various levels of development." J Biomech **32**(12): 1371-5.

Fleisig, G. S., R. F. Escamilla, et al. (1996). "Kinematic and Kinetic Comparison of Between Baseball Pitching and Football Passing " Journal of Applied Biomechanics **17**: 207-224.

Fletcher, I. M. and M. Hartwell (2004). "Effect of an 8-week combined weights and plyometrics training program on golf drive performance." J Strength Cond Res **18**(1): 59-62.

Flyger, N., C. Button, et al. (2006). "The science of softball: implications for performance and injury prevention." Sports Med **36**(9): 797-816.

Fradkin, A. J., C. A. Sherman, et al. (2004). "Improving golf performance with a warm up conditioning programme." Br J Sports Med **38**(6): 762-5.

Graichen, H., S. Hinterwimmer, et al. (2005). "Effect of abducting and adducting muscle activity on glenohumeral translation, scapular kinematics and subacromial space width in vivo." J Biomech **38**(4): 755-60.

Hamilton, C. D., R. E. Glousman, et al. (1996). "Dynamic stability of the elbow: electromyographic analysis of the flexor pronator group and the extensor group in pitchers with valgus instability." J Shoulder Elbow Surg **5**(5): 347-54.

Herring, R. M. and A. E. Chapman (1992). "Effects of changes in segmental values and timing of both torque and torque reversal in simulated throws." J Biomech **25**(10): 1173-84.

Hess, S. A., C. Richardson, et al. (2005). "Timing of rotator cuff activation during shoulder external rotation in throwers with and without symptoms of pain." J Orthop Sports Phys Ther **35**(12): 812-20.

Hill, J. L., B. Humphries, et al. (2004). "Female collegiate windmill pitchers: influences to injury incidence." J Strength Cond Res **18**(3): 426-31.

Hirashima, M., H. Kadota, et al. (2002). "Sequential muscle activity and its functional role in the upper extremity and trunk during overarm throwing." J Sports Sci **20**(4): 301-10.

Hotchkiss, R. N. and A. J. Weiland (1987). "Valgus stability of the elbow." J Orthop Res **5**(3): 372-7.

Jobe, F. W. and M. G. Ciccotti (1994). "Lateral and Medial Epicondylitis of the Elbow." J Am Acad Orthop Surg **2**(1): 1-8.

Jobe, F. W., H. Stark, et al. (1986). "Reconstruction of the ulnar collateral ligament in athletes." J Bone Joint Surg Am **68**(8): 1158-63.

Jobe, F. W., J. E. Tibone, et al. (1983). "An EMG analysis of the shoulder in throwing and pitching. A preliminary report." Am J Sports Med **11**(1): 3-5.

Kibler, W. B. (1998). "The role of the scapula in athletic shoulder function." Am J Sports Med **26**(2): 325-37.

King, J., H. J. Brelsford, et al. (1969). "Analysis of the pitching arm of the professional baseball pitcher." Clin Orthop Relat Res **67**: 116-23.

Kronberg, M., L. A. Brostrom, et al. (1990). "Retroversion of the humeral head in the normal shoulder and its relationship to the normal range of motion." Clin Orthop Relat Res(253): 113-7.

Laudner, K. G., J. B. Myers, et al. (2006). "Scapular dysfunction in throwers with pathologic internal impingement." J Orthop Sports Phys Ther **36**(7): 485-94.

Laudner, K. G., R. C. Sipes, et al. (2008). "The acute effects of sleeper stretches on shoulder range of motion." J Athl Train **43**(4): 359-63.

Laudner, K. G., J. M. Stanek, et al. (2007). "Differences in scapular upward rotation between baseball pitchers and position players." Am J Sports Med **35**(12): 2091-5.

Leigh, S., M. T. Gross, et al. (2008). "The relationship between discus throwing performance and combinations of selected technical parameters." Sports Biomech **7**(2): 173-93.

Leigh, S., H. Liu, et al. (2009). "Individualized optimal release angles in discus throwing." J Biomech **43**(3): 540-5.

Leigh, S. and B. Yu (2007). "The associations of selected technical parameters with discus throwing performance: a cross-sectional study." Sports Biomech **6**(3): 269-84.

Lephart, S. M., J. M. Smoliga, et al. (2007). "An eight-week golf-specific exercise program improves physical characteristics, swing mechanics, and golf performance in recreational golfers." J Strength Cond Res **21**(3): 860-9.

Ludewig, P. M. and T. M. Cook (2000). "Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement." Phys Ther **80**(3): 276-91.

Ludewig, P. M., T. M. Cook, et al. (1996). "Three-dimensional scapular orientation and muscle activity at selected positions of humeral elevation." J Orthop Sports Phys Ther **24**(2): 57-65.

Lukasiewicz, A. C., P. McClure, et al. (1999). "Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement." J Orthop Sports Phys Ther **29**(10): 574-83; discussion 584-6.

Marshall, S. W., K. L. Hamstra-Wright, et al. (2007). "Descriptive epidemiology of collegiate women's softball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2003-2004." J Athl Train **42**(2): 286-94.

McClure, P., J. Balaicuis, et al. (2007). "A randomized controlled comparison of stretching procedures for posterior shoulder tightness." J Orthop Sports Phys Ther **37**(3): 108-14.

McClure, P. W., J. Bialker, et al. (2004). "Shoulder function and 3-dimensional kinematics in people with shoulder impingement syndrome before and after a 6-week exercise program." Phys Ther **84**(9): 832-48.

McClure, P. W., L. A. Michener, et al. (2006). "Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome." Phys Ther **86**(8): 1075-90.

McLeod, W. D. and J. R. Andrews (1986). "Mechanisms of shoulder injuries." Phys Ther **66**(12): 1901-4.

McQuade, K. J., J. Dawson, et al. (1998). "Scapulothoracic muscle fatigue associated with alterations in scapulohumeral rhythm kinematics during maximum resistive shoulder elevation." J Orthop Sports Phys Ther **28**(2): 74-80.

Meister, K. (2000). "Injuries to the shoulder in the throwing athlete. Part one: Biomechanics/pathophysiology/classification of injury." Am J Sports Med **28**(2): 265-75.

Miller, C. D. and F. H. Savoie, 3rd (1994). "Valgus Extension Injuries of the Elbow in the Throwing Athlete." J Am Acad Orthop Surg **2**(5): 261-269.

Moore, K. and A. Dalley (2006). Clinically Oriented Anatomy. L. W. Wilkins. Philadelphia.

Morgan, C. D., S. S. Burkhart, et al. (1998). "Type II SLAP lesions: three subtypes and their relationships to superior instability and rotator cuff tears." Arthroscopy **14**(6): 553-65.

Morrey, B. F. (1986). "Applied anatomy and biomechanics of the elbow joint." Instr Course Lect **35**: 59-68.

Morrey, B. F. and K. N. An (1983). "Articular and ligamentous contributions to the stability of the elbow joint." Am J Sports Med **11**(5): 315-9.

Morrey, B. F. and K. N. An (1985). "Functional anatomy of the ligaments of the elbow." Clin Orthop Relat Res(201): 84-90.

Myers, J., S. Lephart, et al. (2008). "The role of upper torso and pelvis rotation in driving performance during the golf swing." J Sports Sci **26**(2): 181-8.

Myers, J. B., K. G. Laudner, et al. (2005). "Scapular position and orientation in throwing athletes." Am J Sports Med **33**(2): 263-71.

Myers, J. B., K. G. Laudner, et al. (2006). "Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement." Am J Sports Med **34**(3): 385-91.

Myers, J. B., M. R. Pasquale, et al. (2005). "On-the-Field Resistance-Tubing Exercises for Throwers: An Electromyographic Analysis." J Athl Train **40**(1): 15-22.

Neer, C. S., 2nd (1972). "Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report." J Bone Joint Surg Am **54**(1): 41-50.

Norkin, C. and D. White (1995). Rotation. Measurement of Joint Motiong A Guide to Goniometry. Philadelphia, F.A. Davis Company**:** 213.

Osbahr, D. C., D. L. Cannon, et al. (2002). "Retroversion of the humerus in the throwing shoulder of college baseball pitchers." Am J Sports Med **30**(3): 347-53.

Oyama, S., J. B. Myers, et al. (2008). "Asymmetric resting scapular posture in healthy overhead athletes." J Athl Train **43**(6): 565-70.

Powell, J. W. and K. D. Barber-Foss (2000). "Sex-related injury patterns among selected high school sports." Am J Sports Med **28**(3): 385-91.

Putnam, C. A. (1991). "A segment interaction analysis of proximal-to-distal sequential segment motion patterns." Med Sci Sports Exerc **23**(1): 130-44.

Putnam, C. A. (1993). "Sequential motions of body segments in striking and throwing skills: descriptions and explanations." J Biomech **26 Suppl 1**: 125-35.

Reagan, K. M., K. Meister, et al. (2002). "Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players." Am J Sports Med **30**(3): 354-60.

Reddy, A. S., K. J. Mohr, et al. (2000). "Electromyographic analysis of the deltoid and rotator cuff muscles in persons with subacromial impingement." J Shoulder Elbow Surg **9**(6): 519-23.

Regan, W. D., S. L. Korinek, et al. (1991). "Biomechanical study of ligaments around the elbow joint." Clin Orthop Relat Res(271): 170-9.

Rose, G., D. Phillips, et al. (2008). TPI Certified Golf Fitness Instructor 1. Oceanside, CA, Titleist Performance Institute.

Ruotolo, C., E. Price, et al. (2006). "Loss of total arc of motion in collegiate baseball players." J Shoulder Elbow Surg **15**(1): 67-71.

Sakurai, G., J. Ozaki, et al. (1998). "Electromyographic analysis of shoulder joint function of the biceps brachii muscle during isometric contraction." Clin Orthop Relat Res(354): 123-31.

Sell, T. C., Y. S. Tsai, et al. (2007). "Strength, flexibility, and balance characteristics of highly proficient golfers." J Strength Cond Res **21**(4): 1166-71.

Stodden, D. F., G. S. Fleisig, et al. (2001). "Relationship of Pelvis and Upper Torso Kinematics to Pitched Baseball Velocity " J Appl Biomech **17**: 164-172.

Stodden, D. F., S. J. Langendorfer, et al. (2006). "Kinematic constraints associated with the acquisition of overarm throwing part I: step and trunk actions." Res Q Exerc Sport **77**(4): 417-27.

Stodden, D. F., S. J. Langendorfer, et al. (2006). "Kinematic constraints associated with the acquisition of overarm throwing part II: upper extremity actions." Res Q Exerc Sport **77**(4): 428-36.

Thompson, C. J. and W. H. Osness (2004). "Effects of an 8-week multimodal exercise program on strength, flexibility, and golf performance in 55- to 79-year-old men." J Aging Phys Act **12**(2): 144-56.

Tsai, N. T., P. W. McClure, et al. (2003). "Effects of muscle fatigue on 3-dimensional scapular kinematics." Arch Phys Med Rehabil **84**(7): 1000-5.

Tyler, T. F., A. Cuoco, et al. (2009). "The effect of scapular-retractor fatigue on external and internal rotation in patients with internal impingement." J Sport Rehabil **18**(2): 229-39.

Walch, G., P. Boileau, et al. (1992). "Impingement of the deep surface of the supraspinatus tendon on the posterior superior gelnoid rim: An arthroscopic study." Journal of Elbow Surgery **1**: 238-245.

Wang, Q. (2006). "Baseball and softball injuries." Curr Sports Med Rep **5**(3): 115-9.

Werner, S. L., G. S. Fleisig, et al. (1993). "Biomechanics of the elbow during baseball pitching." J Orthop Sports Phys Ther **17**(6): 274-8.

Werner, S. L., T. J. Gill, et al. (2001). "Relationships between throwing mechanics and shoulder distraction in professional baseball pitchers." Am J Sports Med **29**(3): 354-8.

Werner, S. L., D. G. Jones, et al. (2006). "Kinematics and Kinetics of Elite Windmill Softball Pitching." Am J Sports Med **34**(4): 597-603.

Yu, B. and J. G. Andrews (1998). "The relationship between free limb motions and performance in the triple jump. ." Journal of Applied Biomechanics (14): 223-227.