Yoga: Effects on Throwing Performance, Range of Motion, Strength, and Flexibility in a NCAA Division I Softball Team

by

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ABSTRACT

Overhead throwing is a highly dynamic, total-body motion that requires strength, range of motion, flexibility, functional stability, and neuromuscular coordination. Throwing athletes train diligently to improve these measures in order to gain a competitive advantage on the field of play. Practicing yoga has been shown to improve certain physical characteristics, such as strength, range of motion, and flexibility, and has become increasingly popular as a supplementation to training for athletes. However, the effects of athletes practicing yoga on these physical characteristics as related to the functional performance of overhead throwing, particularly during a competitive season, are still unclear. Therefore, the purpose of this research study was to investigate how implementing a 6-week yoga intervention during the fall competitive season of a NCAA Division I softball team affects lower extremity, lumbopelvic-hip complex, and upper extremity kinematics during overhead throwing, shoulder and hip range of motion, and hamstring strength and flexibility. Twenty-six collegiate softball players were assigned to a treatment (n = 13) or control group (n =13) and tested prior to and following a yoga intervention. The intervention consisted of participating in 20-minute yoga sessions three times per week. Results indicated a significant *time**group* interaction for the stride length measured during overhead throwing. The stride length of participants in the control group significantly decreased from pre- to post-intervention, whereas the treatment group was able to maintain a comparable stride length after six weeks of yoga practice. Two limitations of the current study are worth noting. First, using a collegiate softball team as the participant pool limited the sample size to the amount of players on the current playing roster. Second, all participants underwent strength/conditioning training and team-structured softball practices for the duration of this study. Future research should consider examining the biomechanical and psychophysiological effects of athletes practicing yoga with longer sessions for a longer period of time. Furthermore, supplementing an athlete’s training with a yoga practice that directly targets the functional movements associated with their particular sport or skill and examining the biomechanical effects on athletic performance may be insightful.

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To Lauren Elizabeth Brewer.

Not an acknowledgment, but a dedication.

Same, but different.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I.

INTRODUCTION

Overhead throwing is a total body motion that requires a complex interaction of body segments and necessitates substantial amounts of strength, flexibility, and range of motion. The overall goal of this research study was to investigate the effects of implementing six weeks of yoga practice during a fall competitive season for a NCAA Division I softball team on 1] lower extremity, lumbopelvic-hip complex, and upper extremity kinematics during overhead throwing, 2] shoulder and hip rotational range of motion, as well as 3] hamstring strength and flexibility. This chapter presents 1] a brief introduction to the topic of study, 2] statements of purpose, 3] significance, 4] hypotheses, 5] limitations, 6] delimitations, and 7] a glossary of pertinent terms.

Throwing Kinematics

Baseball pitching can be considered as a highly specialized, ballistic form of overhead throwing. Thus, the overhead throwing motion has been previously investigated primarily in baseball pitchers (Chu et al., 2009; Dillman et al., 1993; Dun et al., 2008; Fleisig et al., 1999; Douoguih et al., 2015; Oliver & Weimar, 2014; Seroyer et al., 2010; Robb et al., 2010; Tippett, 1986; Elliott et al., 1986; Davis et al., 2009; Oyama et al., 2013; Hurd & Kaufman, 2012; Reinold et al., 2008; Tyler et al., 2014; Shanley et al., 2015; Kibler et al., 2012; Wilk et al., 2014; Wilk et al., 2012; Case et al., 2015). For biomechanical analysis of such a dynamic skill, the pitching motion has been broken down into six phases: 1] windup, 2] stride/early arm-cocking, 3] late arm-cocking, 4] arm-acceleration, 5] arm-deceleration, and 6] follow-through (Dillman et al., 1993). While these six phases serve as the framework for analyzing the pitching motion, analysis of the overhead throwing motion can be conducted using the same template.

As overhead throwing is a total-body motion, proper throwing mechanics begin in the lower body, and lower extremity and torso function can greatly influence throwing performance. Previous research on lower body mechanics during baseball pitching has indicated that stride length (Fleisig et al., 1999; Elliott et al., 1986; Stodden et al., 2006; Chu et al., 2009; Dillman et al., 1993), knee kinematics (Chu et al., 2009; Seroyer et al., 2010), hip kinematics (Scher et al., 2010; Robb et al., 2010), as well as pelvis and trunk kinematics (Douoguih et al., 2015; Chu et al., 2009; Robb et al., 2010) all contribute to functional performance. Throwing performance can also be influenced by certain physical characteristics, such as range of motion, strength, and flexibility. Accordingly, throwing athletes train diligently to improve these physical characteristics in order to facilitate proper throwing mechanics and improve throwing performance. Practicing yoga has been shown to improve range of motion, strength, and flexibility in normal populations (Cowan & Adams, 2005; Amin & Goodman, 2014; Galantino et al., 2004; Cowan & Adams, 2005; Tran et al., 200), and athletes are beginning to use yoga as a supplemental training modality. However, the effects of throwing athletes practicing yoga on shoulder and hip range of motion, functional hamstring strength and flexibility, as well as on lower extremity lumbopelvic-hip complex, and upper extremity throwing kinematics remains largely unclear.

Shoulder Range of Motion

The two primary joints where adequate range of motion is paramount during throwing are the shoulders and the hips. A vast amount of research has examined shoulder range of motion in overhead athletes (Kibler et al., 2012; Bigliani et al., 1997; Burkhart et al., 2003a; Crockett et al., 2002; Ellenbecker et al., 2002; Meister et al., 2005; Reagan et al., 2002; Wilk et al., 2002; Oyama et al., 2013; Wilk et al., 2014; Tyler et al., 2014; Shanley et al., 2015; Case et al., 2015; Kibler et al., 1996; Reagan et al., 2002; Brown et al., 1988; Reinold et al., 2008; Hurd & Kaufman, 2012; Wilk et al., 2012; Chant et al., 2007; Dwelly et al., 2009). Adaptations in the shoulder that are known to occur as a result of repetitive throwing include decreased passive internal rotation and increased passive external rotation, even though bilateral total arc of motion remains comparable (Bigliani et al., 1997; Burkhart et al., 2003a; Crockett et al., 2002; Ellenbecker et al., 2002; Meister et al., 2005; Reagan et al., 2002; Wilk et al., 2002). Additionally, humeral retroversion, defined as the posterior twisting of the distal humerus relative to the proximal humerus (Krahl, 1947), is believed to contribute to increased shoulder external rotation (Chant et al., 2007; Crockett et al., 2002) and decreased shoulder internal rotation in baseball players (Reagan et al., 2002; Crockett et al., 2002) because the throwing humerus is repeatedly subjected to torsion forces. Also known to be present in throwers are shoulder rotational differences between the throwing arm and non-throwing arm (Oyama et al., 2013; Wilk et al., 2014; Tyler et al., 2014; Kibler et al., 1996; Reagan et al., 2002; Brown et al., 1988; Macedo & Magee, 2008; Wilk et al., 2012; Shanley et al., 2015). These side-to-side differences in shoulder range of motion are noteworthy, especially internal rotation differences greater than 20° (indicative of GIRD, glenohumeral internal rotation deficit), because a loss of shoulder internal rotation has been implicated in injury risk more than any other pathological range of motion profile (Case et al., 2015). Specifically, it is known that a 25° deficit in shoulder internal range of motion increases the risk for injury by 4.8 times (Shanley et al., 2011). Therefore, restoring proper shoulder range of motion is of utmost importance for throwing athletes, and participation in shoulder stretching programs is known to improve this range of motion (Lintner et al., 2007; Aldridge et al., 2012; Hall et al., 2012; Laudner et al., 2008). However, no studies were found that investigate the effects of practicing yoga on shoulder rotational range of motion in overhead throwers.

Hip Range of Motion

Of equal importance to healthy throwing mechanics, alongside shoulder range of motion, is sufficient hip range of motion. The substantial forces generated via the rotation of the hips are essential in the generation and transfer of energy through the kinetic chain during throwing (Burkhart et al., 2003c; Campbell et al., 2010). Research has advocated that hip rotational range of motion should be bilaterally symmetrical (Ellison et al., 1990; Simoneau et al., 1998; Ellenbecker et al., 2007; Laudner et al., 2010; Sauers et al., 2014). However, asymmetrical loading patterns in the hip, inherent to overhead throwing, may contribute to the sport-specific and limb-specific adaptive changes commonly seen in the hips of repetitive throwers (Elliot et al., 1986; Fleisig et al., 1995; Roetert & Groppel, 2001). These adaptive changes to the rotational range of motion in the hips of throwers are known to have a substantial impact on throwing kinematics (Beckman & Buchanan, 1995; Wong & Lee, 2004). Inadequate hip rotational range of motion can limit the capacity of pelvis and trunk rotation thereby diminishing energy transmission through the kinetic chain (Robb et al., 2010). Alternatively, excessive hip rotation may decrease energy production as a result of premature arm-cocking and pelvis and trunk rotations (Dillman et al., 1993; Wilk et al., 2000). Maintaining adequate hip range of motion is paramount in preserving the working relationship between lower and upper body segments; however, little is known about the effects of stretching on restoring or improving hip rotational range of motion in throwers. Moreover, to the author's knowledge, no literature exists investigating the effects of practicing yoga on hip rotational range of motion in a repetitive throwing population.

Hamstring Strength

In addition to range of motion, sufficient strength and balanced co-activation of the muscles surrounding the knee is necessary during high-speed activities and sports related tasks, such as throwing. Throwing athletes use the hamstrings to assist in stride knee extension during arm acceleration in an attempt to impart more force and increase the velocity of the thrown ball (Tippett, 1986). Knee extension via hamstring contraction is possible due to the bi-articulate nature of the hamstring group thereby allowing these muscles to assist in knee extension during closed kinetic chain activities. Proper knee kinematics during throwing involves strength in both the hamstrings and quadriceps, and this strength profile between agonist-antagonist musculature about the knee has been previously investigated using a dynamic control ratio of eccentric antagonist strength relative to concentric agonist strength (Aagaard et al., 1998; Aginsky et al., 2014). While much of literature examining the dynamic control ratio of muscles about the knee has utilized lower extremity dominate athletes (Croisier et al., 2002; Croisier et al., 2008; Aagaard et al., 1998; Aginsky et al., 2014), two studies have examined the strength profiles of knee flexors and extensors in throwing athletes (Coleman, 1982; Tippett, 1986). However, Coleman (1982) and Tippett (1986) did so using a concentric agonist to concentric antagonist ratio. A strictly concentric or eccentric strength ratio of the hamstrings and quadriceps may not be the most accurate depiction of true knee function as knee movement typically allows for eccentric hamstring contraction to be combined with concentric quadriceps function during knee extension and vice versa during knee flexion (Aagaard et al., 1998). No studies were found having used the more accurate representation of knee motion, namely a dynamic control ratio (concentric agonist muscular strength relative to eccentric antagonist strength), to investigate the strength profiles of throwing athletes. Moreover, to the author’s knowledge, no literature exists on the effects of practicing yoga on the dynamic control ratio of knee musculature in overhead throwers.

Hamstring Flexibility

In conjunction with strength about the knee, flexibility in the hamstrings is equally important to throwing athletes. Hamstring flexibility has previously been assessed in a variety of ways including the sit-and-reach test (Burkett, 1970; Stephens & Reid 1988; Orchard et al., 1997), the straight leg raise test (Jonhagen et al., 1994;

Ekstrand & Gillquist, 1982; Liemohn, 1978; Knapik et al., 1991; Witvrouw et al., 2003), and the passive knee extension test (Worrell et al., 1991; Hartig & Henderson, 1999; Lowther et al., 2012;). It has been recommended that the passive knee extension test be utilized by clinicians to assess hamstring flexibility as results of the sit-and-reach and straight leg raise tests can be affected by confounding variables (Gleim & McHugh, 1997; Worrell et al., 1991; Bohannon, 1982; Bohannon et al., 1985; Gajdosik & LeVeau, 1985). To investigate hamstring flexibility in athletic populations, athletes playing lower extremity dominated sports have primarily been used as participants, and much controversy exists in the literature pertaining to lack of flexibility as an injury risk factor (Yeung et al., 2009; Gabbe et al., 2005; Arnason et al., 2004; Gabbe et al., 2006; Engebretsen et al., 2010; Orchard, 2001; Orchard et al., 1997; Bennell et al., 1998; Henderson et al., 2010; Bradley & Portas, 2007; Witvrouw et al., 2003; Krivickas & Feinberg, 1996; Lowther et al., 2012; Worrell et al., 1991; Ekstrand et al., 1982; Jonhagen et al., 1994). Despite the controversy surrounding hamstring flexibility and injury risk, it is generally known that tight muscles are more likely to be strained (Worrell et al., 1991; Worrell & Perrin, 1992), specifically during the rapid transition from eccentric to concentric contraction (Verrall et al., 2001; Peterson & Holmich, 2005). A transition from eccentric to concentric muscle contraction is a common occurrence in the lower extremities during the stride/early arm-cocking phase of throwing. Additionally, hamstring flexibility has been associated with pathomechanics during throwing, most notably during the windup and stride phases (Chu et al., 2009; Tippett, 1986). Female throwers may already be at a predisposed disadvantage during throwing due to shorter relative stride lengths compared to males (Chu et al., 2009), and this disadvantage may only be exacerbated in those with diminished hamstring flexibility. However, to the author's knowledge, no studies to date have examined hamstring flexibility as a variable related to throwing performance in softball players performing an overhand throw.

Yoga

Yoga is an alternative movement therapy that is thousands of years old and concentrates on the physical health and wellbeing of the practitioner (Lalvani, 1996). First developed in India, yoga is historically considered an ancient movement practice striving to bring balance to the physical, mental, emotional, and spiritual dimensions of one's overall wellness (Ross & Thomas, 2010). In the Western world, yoga is now beginning to be considered a systematic training program for improving physical fitness parameters including muscular strength, flexibility, and even sports performance (Gharote et al., 1976). Multiple studies have implemented yoga interventions varying in duration and frequency in order to investigate the effects on strength and flexibility (Tran et al., 2001; Bhutkar et al., 2011; Cowen & Adams, 2005; Tracy & Hart, 2013; Pal et al., 2013; Amin & Goodman, 2014; Tran et al., 2001; Galantino et al., 2004; Cowen & Adams, 2005; Cowen, 2010; Ray et al., 2001; Bal & Kaur, 2009; Hovsepian et al., 2013; Ray et al., 1983; Gharote et al., 1976). It has been concluded that practicing yoga biweekly for as little as six weeks is an effective way to improve total body muscular strength in a normal population, specifically upper body and torso strength which are two vital parameters associated with overhand throwing (Cowan & Adams, 2005). Furthermore, practicing yoga can have substantial effects on improving flexibility in a normal population, specifically hip and shoulder flexibility, which are vital to optimal throwing mechanics. Flexibility is known to improve with yoga practice in as little as 6-8 weeks (Amin & Goodman, 2014; Galantino et al., 2004; Cowan & Adams, 2005; Tran et al., 2001). However, research on the effects of athletes practicing yoga is sparse. The biomechanical conclusions that can be drawn from the studies that do exist (Briegel-Jones et al., 2013; Brunelle et al., 2015; Donohue, et al., 2006; Goodman et al., 2014) are minimal owing to the primarily qualitative nature of the research. While yoga evidently does improve strength and flexibility in normal populations, little is known about the subsequent effects of practicing yoga on athletic performance.

Statement of Purpose

Therefore, the purpose of this research study was threefold: to investigate the effects of implementing a 6-week, yoga intervention during the fall competitive season of a NCAA Division I softball team on 1] lower extremity, lumbopelvic-hip complex, and upper extremity kinematics during overhead throwing, 2] shoulder and hip rotational range of motion, and 3] hamstring strength and flexibility.

Significance

The significance of this research study was two-fold. First, no research was found by the author that investigated how practicing yoga affects physical body parameters related to overhead throwing or to the execution of an overhead throw. Second, prior to the current study, little was known about the effectiveness of practicing yoga on improving the physical characteristics of athletes during a competitive season. Therefore, this research study filled a void in the literature related to yoga and athletic performance.

Hypotheses

The over-arching null hypothesis tested for the current research study was stated as follows: assuming no treatment effect, the variables in question for both groups (treatment and control) will not change from pre-intervention to post-intervention. The following were the primary objectives and specific alternative hypotheses tested during this research study.

The primary objective was to determine the effects of practicing yoga for six weeks during a fall competitive season on throwing kinematics in the lower extremities, lumbopelvic-hip complex, and upper extremity.

1) This objective was addressed through the evaluation of throwing kinematics prior to and following a 6-week yoga intervention.

   H_1: It was hypothesized that from pre-intervention to post-intervention, stride length during overhead throwing will change differently for the treatment group compared to the control group.

   H_2: It was hypothesized that from pre-intervention to post-intervention, stride knee flexion angle during overhead throwing will change differently for the treatment group compared to the control group.

   H_3: It was hypothesized that from pre-intervention to post-intervention, hip rotation in the stance leg and the stride leg during overhead throwing will change differently for the treatment group compared to the control group.

H_4: It was hypothesized that from pre-intervention to post-intervention, degree of torso separation during overhead throwing will change differently for the treatment group compared to the control group.

H_5: It was hypothesized that from pre-intervention to post-intervention, rotation in the throwing shoulder during overhead throwing will change differently for the treatment group compared to the control group.

H_6: It was hypothesized that from pre-intervention to post-intervention, elevation (shoulder abduction) in the throwing shoulder during overhead throwing will change differently for the treatment group compared to the control group.

H_7: It was hypothesized that from pre-intervention to post-intervention, plane of elevation (horizontal abduction) in the throwing shoulder during overhead throwing will change differently for the treatment group compared to the control group.

The secondary objective was to determine the effects of practicing yoga for six weeks during a fall competitive season on passive rotational range of motion in the shoulder and hip joints.

1) This objective was first addressed through the evaluation of bilateral passive shoulder rotational range of motion prior to and following a 6-week yoga intervention.

H_1: It was hypothesized that from pre-intervention to post-intervention, passive internal rotation in the throwing shoulder and non-throwing shoulder will change differently for the treatment group compared to the control group.

H_2: It was hypothesized that from pre-intervention to post-intervention, passive external rotation in the throwing shoulder and non-throwing shoulder will change differently for the treatment group compared to the control group.

H_3: It was hypothesized that from pre-intervention to post-intervention, passive rotational total arc of motion in the throwing shoulder and non-throwing shoulder will change differently for the treatment group compared to the control group.

2) This objective was additionally addressed through the evaluation of bilateral passive hip rotational range of motion prior to and following a 6-week yoga intervention.

H_1: It was hypothesized that from pre-intervention to post-intervention, passive hip internal rotation in the stance leg and stride leg will change differently for the treatment group compared to the control group.

H_2: It was hypothesized that from pre-intervention to post-intervention, passive hip external rotation in the stance leg and stride leg will change differently for the treatment group compared to the control group.

H_3: It was hypothesized that from pre-intervention to post-intervention, passive hip total arc of motion in the stance leg and stride leg will change differently for the treatment group compared to the control group.

The tertiary objective was to determine the effects of practicing yoga for six weeks during a fall competitive season on functional hamstring strength and flexibility.

1) This objective was first addressed through the evaluation of bilateral hamstring strength relative to quadriceps strength prior to and following a 6-week yoga intervention.

   H_1: It was hypothesized that from pre-intervention to post-intervention, the dynamic control ratio for knee extension (H_{ecc}:Q_{con}) in the stance leg and the stride leg will change differently for the treatment group compared to the control group.

   H_2: It was hypothesized that from pre-intervention to post-intervention, the dynamic control ratio for knee flexion (H_{con}:Q_{ecc}) in the stance leg and the stride leg will change differently for the treatment group compared to the control group.

2) This objective was additionally addressed through the evaluation of bilateral hamstring flexibility prior to and following a 6-week yoga intervention.

   H_1: It was hypothesized that from pre-intervention to post-intervention, hamstring flexibility in the stance leg and the stride leg will change differently for the treatment group compared to the control group.

Limitations

The limitations of the current research study were as follows:

1) The potential participant pool was limited based on the number of players active on the roster for the Division I softball team that was utilized as the sample in the current study.
2) All participants were competing in games throughout the duration of the current research study. Eight games were played over the course of four weekends during the intervention period.
3) In addition to only the treatment group performing the yoga intervention, participants in both groups (treatment and control) underwent training in the form of team-structured practices and strength/conditioning exercises throughout the duration of the current research study. During the intervention period, all participants had team-structured softball practice four days per week, strength training workouts three days per week, and conditioning workouts three days per week separate from the strength training days.

Delimitations

The delimitations of the current research were as follows:

1) Kinematic data were collected using a tethered electromagnetic tracking system.
2) Shoulder and hip range of motion were both measured passively using a digital inclinometer.
3) Hip range of motion was measured in the prone position.
4) Strength testing was performed using a Biodex Multi-joint System – Pro isokinetic dynamometer with an angular velocity of 300°/second.

5) Flexibility was assessed by means of the passive knee extension test and was measured using a digital inclinometer.
6) The intervention period lasted for six weeks and consisted of three, 20-minute yoga sessions per week.
7) All data collection and intervention protocols took place in a controlled setting inside the Auburn University Sports Medicine & Movement Laboratory located on the Auburn University campus.

Glossary

Asanas – Sanskrit word meaning *posture*, or *pose,* which is adopted during the practice of Hatha yoga.

Bikram Yoga – a type of Hatha yoga characterized by a set series of 26 postures and 2 breathing exercises performed in a room heated to 104° F.

Crow Hop – a common stepping and crossover motion typically used by outfielders in baseball and softball for increased throw velocity.

Dynamic Control Ratio – ratio calculated based on peak torque to describe the eccentric strength relative to the concentric strength of an agonist-antagonist pair of muscles.

Flexibility – a measurement of the ability of skeletal muscles and tendons to lengthen under tension (active) or in the absence of tension (passive).

GIRD – glenohumeral internal rotation deficit defined as a side-to-side difference in glenohumeral internal rotation greater than 20°.

Hatha Yoga - one of the many forms of yogic practice that involves the practice of physical postures and breathing exercises.

H_{con}:Q_{ecc} – dynamic control ratio for knee flexion that indicates concentric hamstring strength relative to eccentric quadriceps strength.

H_{ecc}:Q_{con} – dynamic control ratio for knee extension that indicates eccentric hamstring strength relative to concentric quadriceps strength.

H:Q Ratio – generic strength ratio that relates concentric hamstring strength to concentric quadriceps strength or eccentric hamstring strength to eccentric quadriceps strength.

Humeral Retroversion - the acute angle, directed in a medial and posterior direction, between the axis through the center of the humeral head and the axis of the elbow joint*;* believed to be an osseous adaptation in throwing arm resulting from repetitive throwing.

Isokinetic – type of muscular contraction in which the rate of movement is constant but the resistance across the involved joint changes throughout the range of motion.

Kinematics – branch of mechanics that describes motion without regard to the involved forces causing said motion. Variables include both linear and angular displacements, velocities, and accelerations.

Kinetic Chain – a model that describes the series of interdependent, linked body segments that 1] function in a proximal-to-distal pattern in order to impart the desired action on the most distal segment and 2] allow for execution of coordinated, efficient body movements.

Lumbopelvic-hip Complex – a component of the musculoskeletal system that includes the proximal femurs, pelvis, and lumbar vertebrae as well as all musculature originating or inserting on these body segments.

Passive Knee Extension Test – a clinical assessment for hamstring flexibility in which the involved hip is flexed to 90° and the knee joint is passively extended until end range of motion in the hamstrings is reached.

Pranayama – Sanskrit word meaning *control of breath*; performed as deep breathing exercises during yogic practice.

Range of Motion – a measurement of the degree of movement possessed by a particular joint.

Stance Leg/Hip – the leg/hip that is ipsilateral to the throwing arm.

Strength – the maximum amount of force that a muscle can exert against some form of resistance.

Stride Leg/Hip – the leg/hip that is contralateral to the throwing arm.

Stride Length – the linear distance measured in the global sagittal plane between stance foot position during windup and the stride foot position at the instant of foot contact with the ground.

Sun Salutation B – a cyclical, sequenced pattern of certain asanas that, when practiced, are synchronized with specific breathing patterns.

Torso – a segment of the body that is comprised of the pelvis and trunk body segments.

Torso separation – calculated as the angular difference between the degree of transverse pelvis rotation and transverse trunk rotation during the throwing motion.

Total arc of motion – the combined rotational range of motion of a joint calculated as sum of measured internal and external rotations.

Yoga – a spiritual and ascetic discipline that includes breath control, simple meditation, and the adoption of specific bodily postures widely practiced for health, wellness, and relaxation.

CHAPTER II.

REVIEW OF LITERATURE

The objectives of this research study were as follows: to evaluate the effects of implementing yoga practice during a fall competitive season for a NCAA Division I softball team on 1] lower extremity, lumbopelvic-hip complex, and upper extremity kinematics during overhead throwing 2] shoulder and hip rotational range of motion, and 3] hamstring strength and flexibility. This chapter presents and reviews the previous literature related to the various aspects of this research study. Specifically, the following chapter has been divided into six subsections: 1] throwing kinematics, 2] shoulder range of motion, 3] hip range of motion, 4] hamstring strength, 5] hamstring flexibility, and 6] yoga.

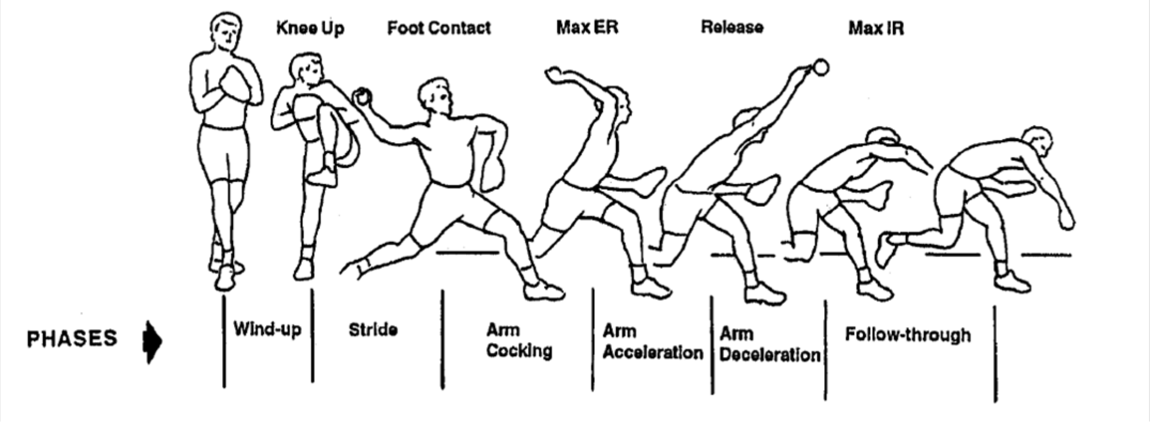
Throwing Kinematics

Overhead pitching is known to be one of the fastest motions the human body is capable of performing (Dillman et al., 1993). The highly dynamic nature of throwing is represented by the fact that the arm has to externally rotate to over 175° and then rapidly internally rotates to as far as 100° in as little as 0.42-0.58 seconds (Dillman et al., 1993; Pappas et al., 1985). The thrown ball is accelerated from four mph to upwards of 85 mph due to angular velocities in the upper extremity exceeding 7000°/second in elite throwers

(Dillman et al., 1993; Pappas et al., 1985). However, the act of throwing involves much more than just rapid movement of the throwing arm. Overhead throwing is a complex, dynamic, total body motion that requires repetitive high velocity, high load, large range of motion movements executed with a great deal of precision (Kibler et al., 2013). The optimum mechanics associated with throwing are produced by virtue of the kinetic chain: a coordinated, sequenced activation of individual body segments that places the most distal segment in an optimum position with appropriate timing while moving at maximum velocity in order to accomplish the desired task (Putnam, 1993). In an efficient kinetic chain, each individual body segment initiates its desired motion as the adjacent proximal segment reaches its maximum angular velocity, ultimately culminating with the highest velocity being present in the most distal segment (Putnam, 1993; Bunn, 1972). Following the summation of speed principle, individual angular velocities of involved body segments are summated in a proximal-to-distal manner and account for the substantial amount of angular velocity found at the hand during the throwing motion (Pappas et al., 1985; Putnam, 1993; Bunn, 1972). Proper kinetic chain sequencing during the throwing motion allows for the generation and transmission of energy from the lower extremity to the hip, pelvis, and trunk, through the shoulder to the elbow, forearm, wrist, and ultimately on to the ball (Atwater, 1979; Pappas et al., 1985). In this efficiently functioning kinetic chain, the feet are the contact points with the ground that make up the stable base of support and generate the ground reaction forces that are subsequently transferred up the kinetic chain (Beckett et al., 2014; Kibler et al., 2013). The lower extremities and torso (comprised of the pelvis and trunk segments) are designed as the primary force-developing engines during throwing and allow for small changes in rotation around the central pillar of the body to effect large changes in the distal segments, similar to cracking a whip (Kibler et al., 2006). As primary force generators, the pelvis and trunk reportedly provide around 50% of the total energy in the kinetic chain during the throwing motion (Kibler et al., 2006). The shoulder and scapula are also pivotal links in the kinetic chain but should only function to funnel forces from the larger proximal segments in the chain to smaller distal segments in the arm (Kibler, 1998). It has been reported that a 20% decrease in kinetic energy delivered to the upper extremity from the lower extremities and trunk requires a 34% increase in angular velocity at the shoulder to maintain the same resultant force at the hand that propels the ball (Kibler & Chandler, 1995). Many factors including strength, flexibility, and range of motion, can alter the efficiency of kinetic chain sequencing and can greatly influence all segments in the linked kinetic chain system (Kibler et al., 2006). Therefore, the current study will investigate these three parameters (strength, flexibility, and range of motion) in conjunction with throwing kinematics.

For effective analysis of the throwing motion, it has been broken down into six phases: 1] windup, 2] stride/early arm-cocking, 3] late arm-cocking, 4] arm-acceleration, 5] arm-deceleration, 6] and follow-through (Figure 1) (Dillman et al., 1993). The windup phase begins with first movement of the stride leg and ends at the point of maximum stride knee height during the elevation of stride leg (Seroyer et al., 2010). During the windup phase, external rotation of the stance hip allows for the stance foot to be placed parallel to the pitching rubber in order for the pelvis and trunk to rotate over that fixed leg (Tippett, 1986). The net result is internal rotation of the stance hip as the body coils over the stance leg in order to eccentrically load musculature in the hips and trunk in preparation for the stride phase. As the stance leg becomes fixed, the stride leg is elevated by a combination of hip flexion, knee flexion, and hip internal rotation in order to further eccentrically load hip and trunk musculature for the proper transfer of energy between the lower body and upper body during arm acceleration (Tippett, 1986). After fully loading the body during windup, the upper body is rotated 90° so that the non-throwing shoulder faces the target (Dillman et al., 1993).

Figure 1. Phases of the pitching motion (Fleisig et al., 1996).



ER – *External Rotation*; IR – *Internal Rotation*

Next the lower extremities align themselves with the target during the stride/early arm-cocking phase which begins at maximum stride knee height and ends at the instance of stride foot contact (Seroyer et al., 2010). Once the windup is completed, the stance knee is flexed in order to lower the body as the stride leg begins to move towards the target (Dillman et al., 1993). Proper alignment of the stride leg with the target is accomplished via knee extension, hip abduction, and external rotation whereas the stance leg simultaneously generates power for the stride via hip extension and external rotation

(Tippett, 1986). At the same time, the throwing hand/ball separate from the glove and move in a downward then upward path in rhythm with the stride leg reaching towards the target (Dillman et al., 1993). When this motion is synchronized properly, the arm is in a semi-cocked position when the stride foot first contacts the ground (Dillman et al., 1993). At this point in the stride/early arm-cocking phase, the throwing arm has only just begun its cocking motion and the instance of stride foot contact with the ground separates the early arm-cocking phase from the late arm-cocking phase (Tippett, 1986).

Late arm-cocking occurs between stride foot contact and maximal external rotation of the throwing shoulder (Seroyer et al., 2010). Once the stride is complete, the trunk slightly flexes and moves towards the target as pelvis rotation is initiated. Trunk rotation follows pelvis rotation, and once the trunk is facing the target, the throwing shoulder is in maximal external rotation i.e. a completely cocked position (Dillman et al., 1993). During the late cocking phase, the pelvis reaches its maximum angular velocity, the trunk begins to rotate and tilt towards the target, and the lead knee continues to extend in order to provide a stable base for trunk flexion (Seroyer et al., 2010). Together, the two cocking phases comprise 80% of the throwing motion (Pappas et al., 1985), last only 1.5 seconds in duration, and prepare the athlete’s body for the impending forceful arm acceleration towards home plate (Douoguih et al., 2015).

The arm-acceleration phase begins at throwing shoulder maximal external rotation, ends at the instance of ball release, and consists primarily of the throwing humerus internally rotating about the shoulder (Seroyer et al., 2010; Dillman et al., 1993). Also during arm acceleration, the trunk simultaneously rotates towards the target and the athlete continues to forcefully drive off the stance leg (Tippett, 1986). Ball release separates the arm-acceleration phase from the arm-deceleration phase, and the ball is released with the trunk in a flexed position, the stride knee extending, and the throwing arm internally rotating in an almost completely extended position (Dillman et al., 1993). The arm-deceleration phase begins after ball release, terminates at maximal shoulder internal rotation, and is considered to be the most violent phase of the throwing cycle due to the greatest amount of joint loading being present during this phase (Seroyer et al., 2010).

Finally, after ball release and maximal shoulder internal rotation, the follow-through phase begins as the thrower continues to decelerate the throwing arm with eccentric contraction of the posterior throwing shoulder musculature (Tippett, 1986). The follow-through phase consists of all accessory motion after maximal shoulder internal rotation and ends when the stance leg returns to the ground, placing the player into an athletic position for fielding (Seroyer et al., 2010). Upper and lower extremity motion during the follow-through phase consists of stride hip internal rotation, stride knee extension, continued bilateral hip flexion, shoulder adduction, shoulder horizontal adduction, elbow flexion, and forearm supination (Dillman et al., 1993; Tippett, 1986).

These aforementioned mechanics have been most accurately described during the pitching motion (Tippett, 1986; Dillman et al., 1993; Seroyer et al., 2010), but can also serve as a template for optimal overhead throwing mechanics in general. It is known that these throwing mechanics should not change as a function of age, evidenced by a study comparing the pitching motions of youth (10-15 years, n = 23), high school (15-20 years, n = 33), collegiate (17-23 years, n = 115), and professional (20-29 years, n = 60) pitchers (Fleisig et al., 1999). This study reported no significant differences in 16 of 17 kinematic and temporal variables across the four age levels examined (Fleisig et al., 1999). The results of that study highlight the importance of learning proper throwing mechanics at an early age (Fleisig et al., 1999).

Certain lower body and torso characteristics of the throwing motion are known to be critical in affecting the outcome of the throw including stride length (Fleisig et al., 1999; Elliott et al., 1986; Stodden et al., 2006; Chu et al., 2009; Dillman et al., 1993), knee kinematics (Chu et al., 2009; Seroyer et al., 2010), hip kinematics (Scher et al., 2010; Robb et al., 2010), as well as pelvis and trunk kinematics (Douoguih et al., 2015; Chu et al., 2009; Robb et al., 2010). The stride is the initial component of energy generation and transfer through the kinetic chain during advanced throwing (Stodden et al., 2006). According to Dillman et al. (1993), an adequate stride length is one that is long enough for the thrower to stretch out the body but not too long that athlete cannot properly rotate the legs and hips. Absolute stride length will vary depending on a pitchers height and build, but it has been reported that relative stride length should be approximately 80-85% of standing height regardless of the age or experience level of the thrower (Chu et al., 2009; Fleisig et al., 1999; Elliott et al., 1986; Stodden et al., 2006). A proper stride length has important implications on subsequent pelvis and trunk rotations as well as on ball velocity as each of these three measures increased with increased stride length (Stodden et al., 2006). Ball velocity and stride length are so closely related that results from the same study demonstrated that stride length accounted for 69.3% of ball velocity variations among throwers across four levels of development (Stodden et al., 2006).

Equally important to the outcome of throwing are knee kinematics from the instant of foot contact through ball release. During the stride, the stride leg absorbs the impact of ground foot contact with initial knee flexion then becomes a stable base of support and brakes forward movement of the body with slight knee extension (Chu et al., 2009). Consequently, stride knee flexion should be less at ball release compared to foot contact, and the knee should be extending at the instant of ball release (Chu et al., 2009). Rapid knee extension, as the arm approaches ball release, is performed by the thrower in conjunction with arm acceleration in order to convert total body liner momentum generated during the stride into the angular momentum for trunk flexion (Chu et al., 2009). Moreover, Chu et al. (2009) reported that peak knee extension angular velocity should occur just prior to ball release. Tippett et al. (1986) reported that in pitchers, it was not uncommon to see a posting action on the stride leg during arm acceleration as the athlete used the femur as a lever to pivot upon, effectively bringing the body weight up onto the stride leg as momentum carried the athlete forward (Tippett, 1986). The posting and pivoting on the stride leg was accomplished via stride knee extension and was an attempt by the thrower to increase velocity of the ball (Tippett, 1986). Knee extension prior to ball release reportedly is an effective mechanism to increase ball velocity as increased knee extension and knee extension angular velocity have both been associated with increased throwing velocity (Matsuo et al., 2001; Stodden et al., 2005). Contrarily, increased knee flexion at ball release is considered a breakdown in the kinetic chain sequencing and has been associated with less force generation through trunk flexion and rotation around the stride leg (Seroyer et al., 2010). Whether the thrower is using knee flexion/extension to brake, brace, or accelerate body movements, proper knee kinematics are a crucial aspect of the throwing motion.

Not only is throwing performance affected by stride length and knee kinematics, but hip kinematics play a pivotal role as well. It has been reported that the hip is the primary joint that initiates spinal rotation during throwing (Lee & Wong, 2002). Correlations have also been reported between hip range of motion and biomechanical parameters associated with throwing (Robb et al., 2010). It has been found that stance hip abduction range of motion and total arc of stance hip abduction/adduction positively correlated with torso separation velocity during arm-cocking. This relationship indicates that greater range of motion facilitates greater angular velocity of the pelvis as the stance leg is responsible for initiating forward momentum during throwing (Robb et al., 2010). Additionally, it was noted that total arc of stride hip abduction/adduction negatively correlated with stride length and with pelvic orientation at foot contact suggesting that range of motion can limit stride length as well as compromise the energy transfer from the lower extremity to the throwing arm (Robb et al., 2010). Furthermore, stance hip rotation range of motion negatively correlated with pelvis orientation indicating that with greater rotational range of motion comes a more open pelvis position at foot contact thereby promoting a premature transfer of kinetic energy from the lower extremities and a subsequent loss of upper extremity momentum (Robb et al., 2010). In contrast, diminished rotational range of motion in the hips limits the capacity of the pelvis and trunk to rotate causing the athlete to throw across the body thereby diminishing the energy contribution from the lower extremities (Robb et al., 2010; Dillman et al., 1993). It can be concluded that while adequate hip rotational range of motion is vital for proper body alignment, control of hip/pelvis motion is equally as valuable for preventing unwanted motion during throwing. Therefore, exercises designed to improve hip flexibility should be performed in conjunction with exercises that promote dynamic pelvis and hip stability within training programs for throwers. In another study by Scher et al. (2010), a significant relationship was reported between increased stance hip extension range of motion and decreased throwing shoulder external rotation in non-pitchers with a history of shoulder injury (r = -0.64). Non-pitchers may compensate for a lack of stance hip extension range of motion (potentially causing a shortened stride length) by increasing shoulder external rotation to throw long distances with high speed. Doing so increases forces applied to soft tissues in the shoulder possibly predisposing the thrower to injury (Scher et al., 2010). It seems evident that adequate hip range of motion and proper function during the throwing motion are paramount to optimal throwing mechanics.

Pathomechanics at the knee and hip joints during throwing can also have implications on pelvis and trunk rotations. One of the most critical variables to throwing performance is separation angle between the pelvis and trunk as a rotational separation in the transverse plane between these two segments is a sign of mature throwing mechanics (Stodden et al., 2001). Rotational separation between the pelvis and trunk (torso separation) is defined as the difference between the axial rotation angle of the trunk and the axial rotation angle of the pelvis. It is known that for proper kinetic chain sequencing, the proximal segment should reach its maximum angular velocity prior to the initiation of rotation of the adjacent distal segment (Putnam, 1993). It is additionally known that the rapid sequence of pelvic rotation and trunk rotation contributes to maximum shoulder external rotation (Dillman et al., 1993; Dun et al., 2007; Stodden et al., 2001; Werner et al,. 1993). Therefore, during the throwing motion, the pelvis should begin rotating towards the target before the initiation of trunk rotation (Dillman et al., 1993). It has been postulated that excessive forces in the throwing arm could be caused by an early initiation of trunk rotation (Tullos & King, 1973), and early trunk rotation reportedly significantly increases the risk for throwing arm surgery (Douoguih et al., 2015). Trunk rotation towards the target should occur prior to stride foot contact with the ground but still after pelvic rotation, and early trunk rotation dissipates some of the potential energy necessary for throwing at a given velocity (Aguinaldo & Chambers, 2009). Therefore, the proper sequence of pelvis and trunk rotation substantially contributes to throwing with optimal mechanics because poor sequencing can place the thrower at risk for injury (Douoguih et al., 2015).

The mechanics and kinematics discussed in this section are known to be beneficial to throwing as long as they are performed properly. However, literature exists reporting that female throwers present with significantly altered lower body and trunk kinematics compared to males (Chu et al., 2009). Specifically, at the instance of foot contact, females reportedly have a shorter relative stride length and less pelvis and trunk separation in addition to presenting with altered knee kinematics from foot contact to ball release (Chu et al., 2009). As a percentage of body height, females had a significantly shorter stride (70%) compared to males (78%) (Chu et al., 2009). The authors postulated that this may be a consequence of the stride leg generating less potential energy (evidenced by a smaller maximum knee height during windup), hamstring tightness, or diminished lower body strength compared to males (Chu et al., 2009). Chu et al. (2009)

additionally reported that females also demonstrate less pelvis (35°) and trunk (-5°) rotation than males (39° and -17°, respectively) at foot contact. The negative values indicate left axial rotations passed neutral and positive values represent right axial rotations passed neutral for a right handed thrower. Therefore, the separation between the pelvis and trunk for females was 40° whereas it was 56° for males (Chu et al., 2009). Less separation between the pelvis and trunk at foot contact causes less stretch of the abdominal musculature and less stored potential energy that can be utilized during rapid trunk rotation (Fleisig et al., 1996). Even with less separation between the trunk and pelvis, females still had peak trunk angular velocity and maximal shoulder external rotation angle comparable to that of males, indicative of compensations in throwing mechanics (Chu et al., 2009). Finally, Chu et al. (2009) reported that female throwers present with greater knee flexion at ball release (62°) than at foot contact (50°) indicating that these female throwers do not extend the stride knee in an effort to stop forward movement of the lower body. Additional evidence of altered knee kinematics in female throwers is indicated by females demonstrating less stride knee extension velocity compared to males at ball release (Chu et al., 2009). Furthermore, stride knee extension velocity peaked after ball release in females whereas it peaked prior to ball release in males (Chu et al., 2009). The authors concluded that females use the stride leg the most after throwing to regain balance and not to brace the body in order to facilitate the throw or in any effort to increase throwing velocity (Chu et al., 2009). Based on the aforementioned studies, it is evident that females' throwing mechanics differ from the generally accepted constructs of throwing. Optimizing these throwing mechanics may only improve females' functional performance on the field of play. Yoga has been shown to improve certain physical characteristics associated with throwing such as strength, flexibility, and range of motion (Amin & Goodman, 2014; Tran et al., 2001; Bhutkar et al., 2011; Galantino et al., 2004; Cowen & Adams, 2005). However, to the author's knowledge, no studies exist that directly investigate the effects of practicing yoga on the lower extremity, upper extremity, and trunk kinematics associated with throwing.

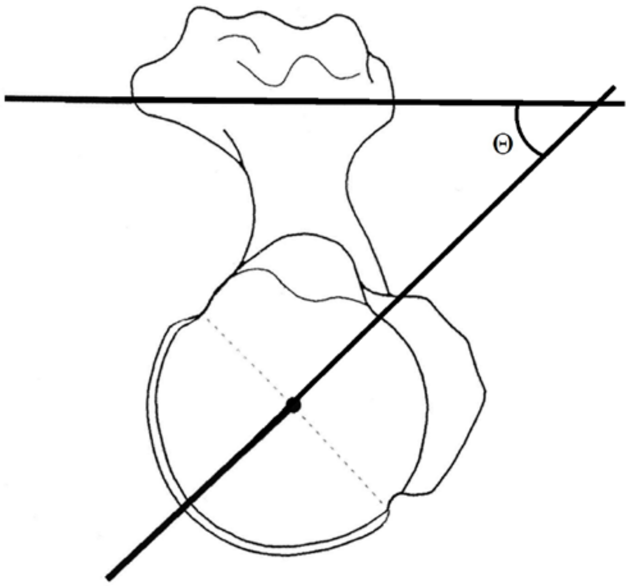
Shoulder Range of Motion

Shoulder range of motion in overhead athletes has been examined extensively in the literature (Kibler et al., 2012; Oyama et al., 2013; Wilk et al., 2014; Tyler et al., 2014; Shanley et al., 2015; Case et al., 2015; Hurd & Kaufman, 2012; Wilk et al., 2012). It has been established that repetitive throwing causes joint adaptations that can affect range of motion (Kibler et al., 2012). These adaptations include decreased passive shoulder internal rotation and increased passive shoulder external rotation, even though total arc of motion (defined as the sum of shoulder external and internal ranges of motion) remains the comparable bilaterally (Bigliani et al., 1997; Burkhart et al., 2003a; Crockett et al., 2002; Ellenbecker et al., 2002; Meister et al., 2005; Reagan et al., 2002; Wilk et al., 2002). Previous literature has proposed numerous explanations for passive shoulder range of motion adaptations including scapular position (Borich et al., 2006; Torres & Gomes, 2009), posterior shoulder capsule tightness (Reinold et al., 2008; Burkhart et al., 2003a), anterior shoulder capsule laxity (Burkhart et al., 2003a), and an osseous adaptation termed humeral retroversion (Chant et al., 2007; Crockett, et al., 2002; Meister et al., 2005; Osbahr et al., 2002; Reagan et al., 2002; Whiteley et al., 2006). These adaptations are known to be prevalent in throwers across all ages and skill levels (Brown et al., 1988;

Lintner et al., 2007; Meistner et al., 2005; Reinold et al., 2008; Trakis et al., 2008; Wilk et al., 2011).

The osseous adaptation that occurs in the throwing arm as a result of repetitive throwing is known as humeral retroversion (Figure 2). First examined by Krahl (1947), humeral retroversion is the acute angle, directed in a medial and posterior direction, between the axis through the center of the humeral head and the axis of the elbow joint (Pieper, 1998). This angle becomes increased due to the posterior rotation of the distal humerus relative to the proximal humerus (Krahl, 1947). The humerus becomes twisted in opposite directions as a result of the forces applied to it by forceful contraction of the internal rotators and passive inertia of the limb, generating a torsional stress along the long axis of the bone during the arm-cocking and acceleration phases of the throwing motion (Sabick et al., 2004; 2005). Various studies have demonstrated that humeral retroversion is greater in overhead athletes' dominant arm (arm used to throw) compared to the non-dominant arm (Crockett et al., 2002; Myers et al, 2009; Osbar et al., 2002; Pieper, 1998; Reagan et al., 2002; Schwab & Blanch, 2009; Taylor et al., 2009; Warden et al., 2009; Whiteley et al., 2009; Oyama et al., 2013). Krahl (1947) attributed the asymmetric increase of humeral retroversion in the dominant arm compared to the non-dominant arm to external forces on the proximal humerus from throwing during the critical period of growth and development (up to age 16). Krahl's conclusion (1947) has been supported by a study of youth baseball pitchers that reported the degree of humeral retroversion being greater in players who started pitching before age 11 compared to those players who started pitching at an older age (Yamamoto et al., 2006). Further supporting this conclusion by Krahl (1947) is a study by Oyama et al. (2013) examining humeral retroversion in high school baseball pitchers. These authors reported that humeral retroversion did not change over the course of a season despite greater retroversion still being present in the throwing arm compared to the non-throwing arm (Oyama et al., 2013). Therefore based on the aforementioned reports, it can be concluded that humeral retroversion may begin prior to players reaching the high school level and is unaffected by a year of competitive pitching, or perhaps one year is not a long enough time period to detect a change in degree of retroversion.

Figure 2. Humeral Retroversion (Adapted from Hernigou et al., 2002).



Superior view of the right humerus. Θ – angle between the axis through the center of the humeral head and the axis of the elbow joint; indicative of the degree of humeral retroversion.

A lack of longitudinal studies examining humeral retroversion makes it unclear exactly when this adaptation occurs throughout maturation, however it is speculated that humeral retroversion may contribute to altered shoulder range of motion in throwing athletes. It has been reported that increased humeral retroversion was associated with increased shoulder external rotation (Chant et al., 2007; Crockett et al., 2002) as well as with decreased shoulder internal rotation in baseball players (Reagan et al., 2002; Crockett et al., 2002). Though alterations in range of motion have been associated with retroversion, it is not known if these adaptations are positive or negative. From a performance standpoint, one could benefit from increased shoulder external rotation, according to Krahl (1947). It was postulated that increased retroversion allows for a thrower to have an increased capacity for shoulder external rotation without having to rely on an increase in shoulder capsular laxity (Krahl, 1947). Additionally, greater shoulder external range of motion would permit maximal external rotation during throwing to occur before the limit of available joint motion, thus resulting in decreased demand on the passive joint stabilizers and increased demand of the dynamic muscular stabilizers to control the motion of the shoulder (Hurd & Kaufman, 2012). Furthermore, it has been reported that increased shoulder external range of motion is associated with smaller elbow adduction (varus) and shoulder internal rotation moments (Hurd & Kaufman, 2012). Therefore, it can be concluded that increased shoulder external range of motion, perhaps from increased humeral retroversion, may help to protect the medial aspect of the elbow from injury and potentially decrease the stress on the anterior aspect of the shoulder (Hurd & Kaufman, 2012).

In conjunction with humeral retroversion, posterior shoulder tightness may also contribute to increased external rotation and decreased internal rotation in the throwing shoulder (Reinold et al., 2008; Burkhart et al., 2003a). The phase of throwing during which most injuries occur is the follow-through, and it is during this phase that the posterior muscles are required to eccentrically contract in order to slow down the throwing arm. Posterior shoulder musculature must slow the humerus, forearm, and wrist from rotating at speeds upwards of 7000°/second (Glousman et al., 1992; Gowan et al., 1987; Jobe et al., 1984; Sisto et al., 1987; Dillman et al., 1993; Fleisig et al., 1995), and the associated eccentric muscle contractions have been correlated with increased passive muscle tension and diminished joint range of motion (Proske & Morgan 2001). Furthermore, Osbahr et al. (2002) and Chant et al. (2007) both reported that decreased shoulder internal rotational range of motion could possibly be explained by soft tissue changes in the shoulder, such as posterior muscle tightness. Myers et al. (2006) additionally reported that those overhead athletes with diminished shoulder internal range of motion also presented with posterior shoulder muscle tightness. Therefore, the eccentric responsibility of the posterior shoulder muscles could contribute to posterior shoulder tightness and thus to diminished shoulder internal range of motion in throwers.

It is well known that repetitive throwing causes decreased shoulder internal range of motion and increased shoulder external rotational range of motion, despite the total arc of motion being preserved (Bigliani et al., 1997; Burkhart et al., 2003a; Crockett et al., 2002; Ellenbecker et al., 2002; Meister et al., 2005; Reagan et al., 2002; Wilk et al., 2002). Previous research on shoulder range of motion has focused on changes across the course of a season (Dwelly et al., 2009; Oyama et al., 2013), changes from pre- to post-pitching bouts (Kibler et al., 2012; Case et al., 2015; Reinold et al., 2008), and side-to-side differences between shoulders (Oyama et al., 2013; Wilk et al., 2014; Tyler et al., 2014; Kibler et al., 1996; Reagan et al., 2002; Brown et al., 1988; Macedo & Magee, 2008; Wilk et al., 2012; Shanley et al., 2015). Controversy exists on whether or not passive shoulder range of motion changes over the course of a season. Dwelly et al. (2009) reported that in a sample of baseball and softball players, external rotation and total arc of motion in both shoulders increased from pre-fall to post-spring. However, no increases in internal rotation were found for either the throwing or non-throwing shoulder (Dwelly et al., 2009). Contrarily, in a sample of 138 baseball players, Oyama et al. (2013) observed a small change in shoulder internal rotation over the course of a one year period (pre = 43°, post = 41°), but not in the non-throwing shoulder (pre = 50°, post = 50°). Additionally, shoulder external rotation decreased bilaterally over the course of one year (throwing shoulder: pre = 118°, post = 117°; non-throwing shoulder: pre = 115°, post = 112°) (Oyama et al., 2013). Perhaps the conflicting results of these two studies (Dwelly et al., 2009; Oyama et al., 2013) could be attributed to the fact that Dwelly et al. (2009) measured range of motion after an athletic season (from pre-fall to post-spring; not including offseason) whereas Oyama et al. (2013) measured range of motion after one complete year, which would include an offseason of minimal throwing.

Much of the previous range of motion literature in throwing athletes has focused on how shoulder range of motion is affected by pitching (Kibler et al., 2012; Case et al., 2015; Reinold et al., 2008). Pitchers are often used as subjects to examine shoulder range of motion because pitching is the most dynamic and ballistic type of all the overhead throws (Dillman et al., 1993). The pitching motion is so ballistic that elite pitchers will often externally rotate the throwing shoulder to 180° during arm-cocking (Dillman et al., 1993; Fortenbaugh et al., 2009), then internally rotate with a peak angular velocity up to 7500°/second near the time of ball release (Wilk et al., 2014). Kibler et al. (2012) measured shoulder range of motion immediately before and after a pitching bout in addition to 24 hours post, 48 hours post, and 72 hours post in 45 professional baseball pitchers. Internal rotation was significantly diminished at every time point after pitching compared to the 19° of rotation measured before pitching (Kibler et al., 2012). Additionally, Kibler et al. (2012) reported that external range of motion immediately after pitching (133°), 24 hours post (133°), and 48 hours post (133°) was significantly greater than before pitching (129°) and 72 hours post pitching (128°). The results of that study indicate that external range of motion returned to within baseline measurements after 72 hours following pitching whereas internal range of motion did not (Kibler et al., 2012). Similar to Kibler et al. (2012), Case et al. (2015) reported that measurements of external range of motion in the throwing arm post-pitching (154°) and post 24 hours (154°) were both significantly greater than the pre-pitching measurements (151°). Additionally, post-pitching internal rotation in the throwing shoulder (46°) significantly decreased compared to pre-pitching internal rotation (50°). However, in contrast to Kibler et al. (2012), internal rotational range of motion from that study returned to the baseline measurement following 24 hours post-pitching (Case et al., 2015). Reinold et al. (2008) conducted a study in which measurements of bilateral passive shoulder internal and external range of motion were taken in 67 professional baseball pitchers prior to, immediately after, and 24 hours post-pitching. Results were consistent with Kibler et al. (2012) but contrasted Case et al. (2015) in that compared to pre-pitching measurements, there was a significant reduction in throwing arm internal rotation (-9.5°) and total range of motion (-10.7°) that remained present for 24 hours after pitching. Despite controversy in these three aforementioned studies, it is well known that restoring shoulder range of motion after a pitching bout is critical in preventing the development of a future injury or potential need for surgery in the throwing arm (Wilk et al., 2012).

Perhaps the most thoroughly investigated parameter of shoulder range of motion is the side-to-side differences in athletes playing overhead, upper extremity dominated sports (Oyama et al., 2013; Wilk et al., 2014; Tyler et al., 2014; Kibler et al., 1996; Reagan et al., 2002; Brown et al., 1988; Macedo & Magee, 2008; Wilk et al., 2012; Shanley et al., 2015). It is known that range of motion should ideally be bilaterally symmetrical as put forth by Macedo & Magee (2008) who measured range of motion in 90 healthy, non-throwing women, ages 18-59. Of all 30 joint motions that were measured across the body, 14 showed a significant difference between sides of the body; only five of those motions had a side-to-side difference of greater than 5° and no motions had a difference of greater than 8° (Macedo & Magee, 2008). Notably, the greatest difference was found in shoulder internal rotation where the dominant shoulder had 7.5° less range of motion than the non-dominant shoulder (Macedo & Magee, 2008). A deficit of 7.5° is not of sufficient magnitude to be considered impairment according to the American Medical Association (Doege & Houston, 1995), who recommends that side-to-side differences less than 10° may be considered clinically insignificant. However, results of the study by Macedo & Magee (2008) do show that there is already a side-to-side difference between shoulders in the rotational range of motion of non-throwers (Macedo & Magee, 2008).

Repetitive throwing will only exacerbate bilateral shoulder range of motion differences. The following data are summarized in Table 1. Oyama et al. (2013) reported that external rotation in a sample of 138 baseball players was slightly higher in the throwing shoulder compared to non-throwing shoulder, and internal range of motion was slightly diminished in the throwing shoulder compared to the non-throwing shoulder. However, the differences in that study (Oyama et al., 2013) are not sufficient enough to be considered clinically relevant, according to the American Medical Association (Doege & Houston, 1995). In another study, preseason range of motion measurements were taken in 101 baseball pitchers (Tyler et al.; 2014). The results of that study indicated that the throwing shoulder had clinically significantly less internal range of motion but clinically significantly more external range of motion compared to the non-throwing shoulder, according to the American Medical Association standards (Doege & Houston, 1995). Moreover, in a study of 54 male collegiate baseball players, Reagan et al. (2002) reported that no statistical difference existed between total rotational range of motion of the throwing shoulder and non-throwing shoulder. However, statistically significant differences in internal and external range of motion did exist between the throwing shoulder and non-throwing shoulder (Reagan et al., 2002). Although, none of these differences (Reagan et al., 2002) were large enough to be considered clinically relevant according to the threshold set by the American Medical Association (Doege & Houston, 1995). Another study by Wilk et al. (2012) utilized a longitudinal design to examine bilateral passive shoulder range of motion in 369 professional baseball pitchers during six consecutive spring training seasons. The results indicated that mean external rotation in the throwing shoulder was statistically, though not clinically, significantly greater than the non-throwing shoulder (Wilk et al., 2012). Additionally, internal range of motion in the throwing shoulder was statistically, though not clinically significantly less than the non-throwing shoulder (Wilk et al., 2012). Last, total arc of motion was again statistically significantly lower in the in the throwing shoulder compared to the non-throwing shoulder, but a difference of 6° may not be clinically relevant (Wilk et al., 2012). Again in 2014, Wilk et al. assessed passive shoulder range of motion in 296 baseball pitchers over the course of eight competitive seasons. The authors reported that players tended to have statistically significantly less internal range of motion and total arc of motion but statistically significantly higher external range of motion in the throwing shoulder compared to the non-throwing shoulder (Wilk et al., 2014). Only side-to-side differences of shoulder internal range of motion from that study (Wilk et al., 2014) met the criteria put forth by the American Medical Association (Doege & Houston, 1995) to be considered a clinically significant impairment. There is a multitude of additional studies that have reported clinically significant differences (difference greater than 10°) between sides in shoulder internal range of motion (Chant et al., 2007; Ellenbecker et al., 2002; Myers et al., 2006; Osbahr et al., 2002; Wilk et al., 2011; Wilk et al., 2014). The clinically significant decreases in internal range of motion in the throwing shoulder from all of these aforementioned studies is noteworthy because loss of throwing shoulder internal range of motion has been implicated with injury more than any other pathological range of motion profile (Case et al., 2015).

Table 1. Summary of literature findings for shoulder range of motion profiles in baseball players.

Study	Sample	Results			Conclusion
Oyama et al., 2013	High school baseball players; (n = 138)	**Shoulder ER**			Side-to-to differences in neither ER nor IR are sufficient enough to be clinically relevant according to AMA standards.
		Throwing Arm		118°	
		Non-Throwing Arm		115°	
		Shoulder IR			
		Throwing Arm		43°	
		Non-Throwing Arm		50°	
Tyler et al., 2014	High school baseball pitchers; (n = 101)	**Shoulder ER**	a		The difference between the throwing arm and non-throwing arm for both ER and IR were statistically significant; difference was clinically relevant for IR but not for ER according to AMA standards.
		Throwing Arm vs. Non-Throwing Arm		7°	
		Shoulder IR	a, b		
		Throwing Arm vs. Non-Throwing Arm		-10°	
Reagan et al., 2002	Collegiate baseball players; (n = 54)	**Shoulder ER**	a		Side-to-side differences in ER and IR were large enough to be statistically significant; none of the side-to-side differences were large enough to be clinically relevant according to AMA standards.
		Throwing Arm		116°	
		Non-Throwing Arm		107°	
		Shoulder IR	a		
		Throwing Arm		43°	
		Non-Throwing Arm		51°	
		Total Arc of Motion			
		Throwing Arm		160°	
		Non-Throwing Arm		158°	
Wilk et al., 2012	Professional baseball pitchers; (n = 369)	**Shoulder ER**	a		Side-to-side differences in ER, IR, and total arc of motion were large enough to be statistically significant; none of the side-to-side differences were large enough to be clinically relevant according to AMA standards.
		Throwing Arm		132°	
		Non-Throwing Arm		127°	
		Shoulder IR	a		
		Throwing Arm		52°	
		Non-Throwing Arm		63°	
		Total Arc of Motion	a		
		Throwing Arm		184°	
		Non-Throwing Arm		190°	
Wilk et al., 2014	Professional baseball pitchers; (n = 296)	**Shoulder ER**	a		Side-to-side differences in ER, IR, and total arc of motion were large enough to be statistically significant; difference was clinically relevant for IR according to AMA standards.
		Throwing Arm		131°	
		Non-Throwing Arm		125°	
		Shoulder IR	a, b		
		Throwing Arm		52°	
		Non-Throwing Arm		63°	
		Total Arc of Motion	a		
		Throwing Arm		183°	
		Non-Throwing Arm		188°	

ER – *external rotation range of motion;* IR – *internal rotation range of motion;* AMA – *American Medical Association (Doege & Houston, 1995);* a – *statistically significant side-to-side difference within the cited study;* b – *clinically relevant side-to-side difference according to AMA standards.*

While only a 10° difference in bilateral shoulder range of motion is enough to be considered clinically relevant (Doege & Houston, 1995), previous work by Burkhart et al. (2003a, 2003b) has established a higher internal rotational deficit threshold as related to throwing shoulder injury known as glenohumeral internal range of motion deficit, or GIRD. GIRD is defined as a difference between internal rotation in the non-throwing shoulder and throwing shoulder of 20° or more (Burkhart et al., 2003a, 2003b). GIRD has been found to decrease from immediately before to immediately after a throwing bout (Reinold et al., 2008), from the beginning of one season to the end of one season (Freehill et al., 2011), and after years of throwing exposure (Kibler et al., 1996; Roetert et al., 2000). GIRD has also been examined as it relates to injury risk (Wilk et al., 2014; Tyler et al., 2014). In a longitudinal study conducted over eight competitive seasons in which a total of 296 pitchers were assessed for passive shoulder range of motion then subsequently tracked for injury, 18% of players had GIRD and 14% of those players suffered an elbow injury sometime after initial evaluation (Wilk et al., 2014). Comparatively, only 13% of players who suffered an elbow injury did not present with GIRD ($p = 0.55$) (Wilk et al., 2014). Furthermore, Tyler et al. (2014) reported that the injury incidence in a study of 101 baseball pitchers with greater than 20° loss of shoulder internal range of motion was 23%. While GIRD has previously been used as a threshold for increased risk of injury (Burkhart et al., 2003a, 2003b; Wilk et al., 2014; Tyler et al., 2014), more recently it has been postulated, through a prospective study, that a side-to-side deficit greater than 25° in adolescent baseball players represents a significant risk factor for arm injuries following a season (Shanley et al., 2011). In fact, the risk for injury was 4.8 times greater in players with at least a 25° deficit in shoulder internal range of motion compared to those with less than a 25° loss (Shanley et al., 2011). It is evident that deficits in shoulder internal range of motion are hazardous to throwers and represent a substantial risk factor for injury.

Upper extremity injuries are prevalent in overhead athletes, and have been reported as accounting for 75% of the time lost from sport in collegiate throwing athletes (McFarland & Wasik, 1998). Common injuries to the upper extremity in throwing athletes include rotator cuff tendinitis, superior labrum anterior-posterior (SLAP) lesions, internal impingement, and ulnar collateral ligament (UCL) injury (Wilk et al., 2009; Wilk et al., 2004). It has been hypothesized that these overuse injuries are a result of cumulative microtrauma associated with high magnitude, repetitive stresses that are caused by overhead throwing (Wilk et al., 2002). Also associated with these injuries is an alteration in shoulder range of motion. Alterations in shoulder range of motion, specifically loss of internal rotation and total arc of motion, have been linked with injury to the shoulder (Burkhart et al., 2003a; Burkhart et al., 2003b; Laudner et al., 2006; Myers et al., 2006; Wilk et al., 2009; Wilk et al., 2002; Turkel et al., 1981; Walch et al., 1992), rotator cuff internal impingement and shoulder pain (Myers et al., 2006; Ruotolo et al., 2006), as well as with injuries to the UCL (Dines et al., 2009; Garrison et al., 2012). Dines et al. (2009) reported that baseball players with a deficient UCL had less throwing shoulder internal rotation compared to healthy control players, and Garrison et al. (2012) found that baseball players with a torn UCL had less internal rotation and total arc of motion in the throwing shoulder compared to healthy controls. It has been hypothesized that throwers who lack shoulder range of motion may compensate with higher levels of elbow varus torque and shoulder internal rotation torque in order to generate ball velocity, possibly increasing the risk for injury (Werner et al., 2002).

Risk for injury associated with diminished shoulder range of motion has been examined previously in the literature (Wilk et al., 2012; Shanley et al., 2011; Shanley et al., 2015). Wilk et al. (2012) reported that baseball players who sustained elbow injuries had 52° of internal rotation in the throwing shoulder, a 12° deficit compared to the non-throwing shoulder, while non-injured players also had 52° of internal rotation in the throwing shoulder, but only a 10° deficit compared to the non-throwing shoulder. It has also been reported by Shanley et al. (2011) that decreased shoulder internal range of motion is a significant risk factor for injury in baseball and softball players as players who were subsequently injured during the season had a 12° decrease of shoulder internal range of motion compared to only a 7° decrease in non-injured players. Additionally, injured adolescent pitchers presented with a significantly greater side-to-side shoulder internal rotation difference (18°) (Shanley et al., 2015). Finally, adolescent pitchers with a side-to-side difference in shoulder internal rotation greater than 13° were six times more likely to be injured than those adolescents with a less than a 13° difference (Shanley et al., 2015). Despite the presence of GIRD representing a substantial risk for injury, the results of these studies (Wilk et al., 2012; Shanley et al., 2011; Shanley et al., 2015) highlight the importance of a side-to-side rotational range of motion difference as small as 10°, put forth by the American Medical Association (Doege & Houston, 1995), and it’s relation to risk for upper extremity injury.

Because it is known that repetitive throwing causes alterations in shoulder range of motion in overhead athletes (Bigliani et al., 1997; Burkhart et al., 2003a; Crockett et al., 2002; Ellenbecker et al., 2002; Meister et al., 2005; Reagan et al., 2002; Wilk et al., 2002) and that these alterations are associated with increased injury risk (Burkhart et al., 2003a; Burkhart et al., 2003b; Laudner et al., 2006; Myers et al., 2006; Wilk et al., 2009; Wilk et al., 2002; Turkel et al., 1981; Walch et al., 1992; Myers et al., 2006; Ruotolo et al., 2006; Dines et al., 2009; Garrison et al., 2012), restoring range of motion to the shoulder becomes paramount in reducing the risk of upper extremity injury (Wilk et al., 2012). Participation in a shoulder internal rotation stretching program has been shown to significantly increase passive internal rotation in collegiate and professional baseball and softball players (Lintner et al., 2007; Aldridge et al., 2012; Hall et al., 2012; Laudner et al., 2008). Lintner et al. (2007) examined the passive shoulder range of motion profiles in 44 professional pitchers who were enrolled in a team structured stretching program for at least three years and 41 pitchers who did not participate in the team structured stretching program. The results showed a significant difference ($p < 0.01$) in throwing shoulder internal rotation and total range of motion between those players who had taken part in the stretching program (74.4° and 206.4°, respectively) and those players who did not participate in the stretching program (55.2° and 194.2°, respectively) (Lintner et al., 2007). That study showed that an appropriate stretching program can help regain and maintain internal rotation in throwing athletes (Lintner et al. 2007). More recently, Aldridge et al. (2012) reported that participation in a 12-week posterior shoulder capsule stretching program can significantly increase throwing shoulder internal rotation and total range of motion in a sample of 28 NCAA Division I baseball players. After participation in the stretching program, shoulder internal rotation significantly increased from 48.9° to 54.1° and total arc of motion increased from 154° to 161° (Aldridge et al., 2012).

Furthermore, Hall et al. (2012) reported that participation in a 4-week stretching program comparing three different types of stretching techniques (active stretching, passive stretching, and proprioceptive neuromuscular facilitation stretching) significantly improved shoulder internal range of motion in 42 collegiate men and women. Of particular interest was that no differences were reported between the three stretching techniques in the effectiveness at improving shoulder internal range of motion and that 45% (n = 19) of the sample from that study were NCAA Division I softball players (Hall et al., 2012). Not only have various chronic stretching techniques increased shoulder range of motion (Lintner et al., 2007; Aldridge et al., 2012), but an acute stretching bout has increased range of motion in throwing athletes as well (Laudner et al., 2008). These authors reported that performing the sleeper stretch twice for 30 seconds each at the end range of motion of the throwing shoulder in 33 collegiate baseball players significantly increased passive shoulder internal range of motion (Laudner et al., 2008). For this stretch, the athlete assumes as side-lying positon with the shoulder and elbow both flexed to 90°. Downward pressure is then applied to the distal forearm to internally stretch the shoulder. The sleeper stretch is designed to isolate and stretch the posterior soft tissue in the shoulder and increased passive internal rotation by 3.1° from 43.8° to 46.9° in that study (Laudner et al., 2008). The authors attribute the small degree of increase in internal rotation to the fact that range of motion measurements and stretching occurred prior to a baseball season, and therefore the players may have not yet acquired the adaptive shoulder tightness that results from repetitive throwing throughout the course of a season. Still, although this improvement of 3.1° is clinically insignificant, it is statistically significant and resulted from an acute stretch for a total of only 60 seconds (Laudner et al., 2008). The four aforementioned studies provide evidence that certain stretching techniques can improve shoulder range of motion. However, to the author's knowledge, no studies to date have investigated the effects of an alternative stretching technique, such as yoga, on shoulder range of motion in collegiate softball players.

Hip Range of Motion

During overhead throwing, the lower extremities provide a stable base of support and generate ground reaction forces that are then transferred up the kinetic chain through the hips, trunk, shoulder, and eventually onto the hand and ball (Kibler, 1995). The total energy in the kinetic chain is summated from contributions of individually rotating body segments and accounts for the large angular velocities seen during throwing (Pappas et al., 1985; Putnam, 1993). The substantial forces generated via the rotation of the hips are essential in the initiation and transfer of energy through the kinetic chain (Burkhart et al., 2003c; Campbell et al., 2010). The lower extremities have been shown, via electromyographic analysis, to provide substantial rotational momentum for upper extremity force development, and they are known to produce 50% of the kinetic energy during overhead motions (Watkins et al., 1989). Overhead throwing sports, such as baseball and softball, require inherent asymmetrical loading patterns in the hip joints which may contribute to the sport-specific and limb-specific adaptive changes commonly seen in the hips of throwers (Elliot et al., 1986; Fleisig et al., 1995; Roetert & Groppel, 2001). Theses adaptive changes to the hips during athletic activities, such as throwing (Laudner et al., 2010), include altered hip range of motion profiles which may lead to joint contractures (Bach & Goldberg, 2006; Myers et al., 2006), structural changes

(Hreljac, 2004; Kettunen et al., 2000), and even altered kinematics of the hips and pelvis during the throwing motion (Beckman & Buchanan, 1995; Wong & Lee, 2004).

Information about the role of the hips in relation to proper throwing mechanics is prevalent in the literature (Tippett, 1986; Lintner et al., 2008; MacWilliams et al., 1998; Laudner et al., 2010; Wight et al., 2004). The windup phase of the pitching motion, which is similar although more exaggerated than that of the throwing motion, requires the trunk to rotate over the stance leg, producing internal rotation of the stance hip (Lintner et al., 2008; MacWilliams et al., 1998). Driving off the stance leg, during stride and arm-acceleration phases, requires stance hip extension and external rotation to propel the body forward (Tippett, 1986; Lintner et al., 2008; MacWilliams et al., 1998). External rotation in the stride hip, as the body is propelled forward, is necessary for proper stride foot place at foot contact (Tippett, 1986; Laudner et al., 2010). It has been reported that the proper stride foot placement consists of the foot being oriented directly towards home plate or pointed between 5-25° towards the midline of the body at foot contact (Wight et al., 2004). Hip internal rotation is additionally necessary in the stride leg as the thrower will often pivot around the lead leg after ball release and during the deceleration and follow-through phases (Tippett et al., 1986; Lintner et al., 2008; MacWilliams et al., 1998). It is apparent that adequate hip rotation is an integral piece of throwing with proper mechanics regardless if the thrower relies on stance hip extension and external rotation or relies on the posting action and pivot around the stride leg to generate power. Though much focus has been on the hip range of motion of baseball pitchers, positional players have also been examined. It has been documented that position players may rely on the lower extremities to generate power even more so than pitchers (Laudner et al., 2010; Tippett, 1986). Non-pitchers likely have a throwing motion that is more variable than pitchers and oftentimes includes a crow hop, a common stepping and crossover motion typically used by outfielders for added throw velocity (Scher et al., 2010). With a crow hop, stride hip internal rotation may be responsible for decelerating the athlete's body after ball release (Scher et al., 2010), thus highlighting the importance of proper hip range of motion in overhead throwers.

Ranges of motion profiles in the hips of overhand throwers have been examined extensively in the literature using both the seated and prone measurement positions (Scher et al., 2010; Sauers et al., 2014; Beckett et al., 2014; Laudner et al., 2010; Ellenbecker et al., 2007; Tippett, 1986; Robb et al., 2010). However, it has been reported that the prone position is perhaps a more thorough measurement technique as it better represents the pelvis-hip orientation seen during throwing (Robb et al., 2010). Seated measurements of hip range of motion may not allow for total motion due to the compressive forces about the hip exerted during the seated position (Ellison et al., 1990). In addition, the inconsistent nature of trunk-pelvis orientation during seated measurements may alter the hip's axis of rotation at the acetabulum (Ellison et al., 1990). Simoneau et al. (1998) measured hip range of motion in both the seated and prone positions in a healthy population and found a larger variability in external range of motion during the seated position compared to the prone position. The authors postulate that these results indicate the capsuloligamentous structures limiting hip external range of motion would be under greater tension in the seated position (Simoneau et al., 1998). Additionally, the lengths of the musculature surrounding the hip will undoubtedly change with 90° of hip flexion that will only further limit passive motion of the joint (Simoneau et al., 2010). Therefore it has been recommended that prone position be used when assessing hip range of motion in throwing athletes (Robb et al., 2010).

Unlike what is seen in shoulder range of motion in throwing athletes, hip range of motion is usually bilaterally symmetrical (Ellison et al., 1990; Simoneau et al., 1998; Ellenbecker et al., 2007; Laudner et al., 2010; Sauers et al., 2014). The recommended normal hip range of motion is 40° for internal rotation and 50° for external rotation (American Medical Association, 1990), but even in non-throwers, slight deviations from these recommended values have been reported. In a sample of 100 healthy subjects with a mean age of 26 years, Ellison et al. (1990) reported nearly symmetrical internal (38°) and external (35°) rotations with a total range of motion of 73°. Furthermore, in a sample of 39 healthy subjects with a mean age of 21 years, Simoneau et al. (1998) reported hip internal (36°) and external (45°) rotations with a total range of motion of 81°. Repetitive throwing seems to cause an even greater deviation from the normal hip range of motion values recommended by the American Medical Association (1990). Laudner et al. (2010) measured passive hip rotational range of motion in 40 professional baseball position players who presented with comparable bilateral hip internal (stride = 37°, stance = 37.7°) and external (stride = 42.7°, stance = 41.9°) rotation. Furthermore, in a study measuring passive hip range of motion of 99 baseball players in the seated position, Sauers et al. (2014) reported that position players averaged 36.9° of internal rotation and 33.8° of external rotation in the stance hip for a total arc of motion of 70.8°. These players averaged comparable levels of rotation in the stride hip as well: 38.4° of internal rotation and 31.5° of external rotation for a total arc of motion of 70.4° (Sauers et al., 2014). Corroborating the results of these two studies (Laudner et al., 2010; Sauers et al.,

2014) was a study by Ellenbecker et al. (2007) who reported no significant differences between sides for either stride or stance hip internal or external rotation. Stride hip internal rotation was 22°, external rotation was 34°, and total arc of motion was 57°; stance hip internal rotation was 23°, external rotation was 35°, and total arc of motion was 58° (Ellenbecker et al., 2007). The values reported by Ellenbecker et al. (2007) are lower than values reported in the aforementioned studies because they are representative of active hip range of motion, which may not allow for assessment of the entire physiological range of motion in the hip (Robb et al., 2010). By also measuring active hip range of motion in 16 collegiate baseball pitchers, Tippett (1986) reported that external rotation was bilaterally symmetrical between hips (30°) even though internal rotation was significantly different between hips (stride hip = 34°, stance hip = 38°). The bilateral asymmetry from that study (Tippett, 1986) could potentially be attributed to the playing position of the subjects. The previous studies (Ellenbecker et al., 2007; Laudner et al., 2010; Sauers et al., 2014) all examined position players while Tippett et al. (1986) examined pitchers. Regardless of how hip range of motion is assessed (passive or active), the aforementioned studies support bilateral hip rotational range of motion symmetry among baseball position players despite it being substantially less than values recommended for the normal population by the American Medical Association (1990).

Although bilateral hip range of motion symmetry is recommended, additional literature has reported significant bilateral differences between age groups and genders in both non-throwers (Svenningsen et al., 1989; Simoneau et al., 1998) and throwers (Robb et al., 2010; Tippett, 1986; Scher et al., 2010; Beckett et al., 2014). It has been reported that female non-throwers have significantly greater active hip internal (38°) and external

(46°) rotation when measured in the prone position compared to male non-throwers (internal = 32°, external = 44°) (Simoneau et al., 1998). Additionally, it was also found that female non-throwers had greater hip rotational range of motion when measured in the seated position (Svenningsen et al., 1989). Adult females had higher bilateral average values of internal hip rotation (52°) and total hip rotation (92°) compared to males (38° and 81°, respectively) (Svenningsen et al., 1989). Additionally, age appears to have a significant effect on total hip range of motion because there were marked reductions in hip motion up to age 15 (Svenningsen et al., 1989). In support of Svenningsen et al. (1989), Beckett et al. (2014) assessed hip range of motion in the prone position for 108 preadolescent (ages 7-12) and adolescent (ages 13-18) baseball players. There was a significant difference in stride hip internal rotation between adolescents (33.1°) and preadolescents (40.8°) as well as a significant difference in total hip rotational range of motion between adolescents (71.6°) and preadolescents (78.5°) (Beckett et al., 2014). However, no differences were found between age groups in stride or stance hip external rotation (Beckett et al., 2014). It has been postulated that the hip rotational range of motion differences between age groups could result from muscular growth as the player matures and possibly from longer exposure to repetitive throwing (Beckett et al., 2014).

Finally, side-to-side differences in hip passive, prone range of motion were reported in a study assessing 19 male professional baseball players (Robb et al., 2010). The stance hip had more range of motion than the stride hip internally (50.8° and 31.3°, respectively), externally (44° and 35.6°, respectively), and in total arc of motion (94.8° and 67°, respectively) (Robb et al., 2010). The authors postulate that the smaller amount of range of motion in the stride hip may be attributed to the repetitive exposure to high landing forces associated with throwing (Robb et al., 2010; MacWilliams et al., 1998). It is evident that throwers have altered hip rotational range of motion profiles, potentially due to the accumulation of forces exerted on the hips during throwing (Laudner et al., 2010). The asymmetrical loading patterns of the hips inherent in throwing may contribute to these limb-specific adaptive changes commonly seen in the hips of repetitive throwers (Elliot et al., 1986; Fleisig et al., 1995; Roetert & Groppel, 2001).

The adaptive changes to the rotational range of motion in the hips of throwers are also known to affect throwing kinematics (Beckman & Buchanan, 1995; Wong & Lee, 2004). Adequate hip motion is vital to developing the necessary torque and velocity required for overhead throwing (Dillman et al., 1993; Kibler, 1995; MacWilliams et al., 1998). Additionally, appropriate hip rotational range of motion is necessary as it allows for proper positioning of the feet during the throw as well as optimal pelvis orientation and rotation, creating a smooth and efficient energy transfer through the kinetic chain (Dillman et al., 1993; Wight et al., 2004). It has been reported that insufficient rotational range of motion in the hips can alter kinetic chain functioning thereby reducing the amount of energy transfer from the lower body to the upper body (Dillman et al., 1993; Wilk et al., 2000). Inadequate stride hip rotational range of motion may result in closed stride foot and pelvis position at foot contact thereby limiting the capacity for pelvis and trunk rotation (Robb et al., 2010). Proper stride foot position at foot contact is vital because it allows for optimal rotation of the hips, pelvis, and trunk which are crucial for providing the most effective transfer of energy from the lower body to the upper body (Dillman et al., 1993; Fleisig et al., 1998). It has been reported by Robb et al. (2010) that total arc of rotational motion in the stride hip was correlated with trunk separation velocity which is the rate of change between the trunk and pelvic rotations. This correlation between stride hip rotational range of motion and trunk separation velocity indicates that restrictions in hip rotation limits upper body angular velocities, which ultimately could be detrimental to throwers. Excessive hip rotation may also be detrimental to throwers. Excessive external rotation in the stride hip can cause the foot to land too much in an open position consequently causing premature arm-cocking as well as premature pelvis and trunk rotations and thereby decreasing energy production by the thrower (Dillman et al., 1993; Wilk et al., 2000).

Restrictions in hip rotational range of motion not only cause alterations in lower body mechanics, but may cause alterations in kinetic chain movements at other segments proximal and distal to the hip joint (Sciascia & Cromwell, 2012). A lack of full hip range of motion in the stance leg during the cocking and arm-acceleration phases may cause increased lumbar extension, trunk rotation, and shoulder external rotation in order for the thrower to achieve full power and maintain throwing performance (Fleisig et al., 1995; MacWilliams et al., 1998). During ball release and arm deceleration, diminished stance hip internal rotation may result in the inability of the thrower to position the body towards the target, and compensations will occur in the form of increased trunk rotation and shoulder internal rotation (Sauers et al., 2014). Additionally, limitations in stride hip internal rotation after ball release could diminish the ability of the leg to absorb force, implementing a greater demand on the posterior shoulder musculature to eccentrically absorb the load and slow down the motion of the arm (Anz et al., 2010; Dillman et al., 1993; Fleisig et al., 1995; MacWilliams et al., 1998; Pappas et al., 1985). Using the lower extremity to dissipate force may be especially important to long distance overhead throwers, as it has been reported that when throwing with a crow hop, stride hip internal rotation may be responsible for decelerating the athlete’s body (Scher et al., 2010). A lack of stride hip internal rotation may transfer some of the demands of deceleration from the hip to the shoulder resulting in less force dissipation by the lower extremity and more stress to the upper extremity, thereby possibly increasing the risk for shoulder injury (Scher et al., 2010). Not only do range of motion restrictions in the hip contribute to pathomechanics in throwing, but they also place the athlete at an increased risk for developing an overuse upper extremity injury.

Improper pelvis and trunk kinematics due to altered range of motion in the hip may result in greater stress being placed on the shoulder and potentially heightens the risk for upper extremity injury (Dillman et al., 1993; Wilk et al., 2000; Stodden et al., 2005; Wight et al., 2004). It has been reported that proper alignment of the pelvis with the intended target at foot contact and maximal shoulder external rotation reduces maximum torques at the shoulder (Stodden et al., 2005; Wight et al., 2004; Dillman et al., 1993; Wilk et al., 2000). Not only does proper pelvic rotation reduce injury risk, but it is also important for optimized throwing performance. It has been documented that despite torques decreasing in the shoulder with proper rotation of the pelvis, ball velocity actually increased (Stodden et al., 2005; Wight et al., 2004). Additionally, Wight et al. (2004) reported that pitchers with a more open (facing more towards the batter) pelvis position at foot contact (accomplished via adequate hip rotational range of motion) had diminished forces and torques in the throwing arm. It is hypothesized that premature rotation of the pelvis and trunk during the throwing motion increases the stress on anterior shoulder structures (Scher et al., 2010). This will potentially increase the likelihood of upper extremity injury to the thrower because the shoulder must make up for the energy loss in the lower body in order to maintain velocity on the ball (Scher et al., 2010). It is known that the lower extremity and trunk should be the primary energy generators and the shoulder should remain as an energy funnel during optimal throwing mechanics (Kibler, 1998). Maintaining adequate hip range of motion is critical in preserving this working relationship between lower and upper body segments during the dynamic and ballistic throwing motion.

It has been recommended that training of the throwing shoulder be accompanied by improving hip rotational flexibility, specifically stride hip internal range of motion (Scher et al., 2010). However, little is known on the effects of stretching on restoring or improving hip rotational range of motion. To the author’s knowledge, no literature exists investigating the effects of practicing yoga on the hip rotational range of motion in a repetitive throwing population. Overhand throwers are in particular need for restoring and improving hip rotational range of motion due to their altered hip range of motion profiles as well as the known importance of hip range of motion to injury prevention and proper throwing kinematics.

Hamstring Strength

The hamstring muscle group is located in the posterior compartment of the upper leg and consists of the biceps femoris, semitendinosus, and semimembranosus muscles. As the functional antagonist to the knee extensors, co-contraction of the hamstrings muscles with the quadriceps assist the ligaments about the knee in providing dynamic stability to the knee joint (Li, 1999; Renstrom, 1986; Withrow, 2008). Forceful, active contraction of the quadriceps during knee extension creates significant anterior tibial translation and shear forces at the knee, and co-activation of the hamstrings significantly contributes to counterbalancing these forces (Baratta et al., 1988). Sufficient strength and balanced co-activation in the muscles surrounding the knee is needed in order to help protect the joint during high-speed activities and sports related tasks, such as throwing. Though primarily knee flexors, the hamstrings are bi-articulate muscles, crossing both the knee and hip joints, and also contribute to knee extension in closed kinetic chain activities (Tippett, 1986). The ability of the hamstrings to function as knee extensors in a closed kinetic chain is especially important to throwing athletes. After foot contact in the throwing motion, the hamstrings in the stride leg act to extend the knee around the time of ball release, causing the femur to function as a lever in order to bring the player's body weight forward up over the top of the planted leg (Tippett, 1986). It is common for throwing athletes to use this knee extension during arm-acceleration to their advantage in an attempt to impart more force onto and increase the velocity of the thrown ball (Tippett, 1986). Therefore, sufficient strength in the hamstrings could be a key component of successful performance in throwing.

Isokinetic dynamometry has long been used to assess the strength profiles of the hamstrings and quadriceps in athletes (Aginsky et al., 2014; Costain & Williams, 1984; Croisier et al., 2008; Croisier et al., 2002; Devan et al., 2004; Jonhagen et al., 1994; Parker et al., 1983; Smith et al., 1981). By controlling the velocity of joint motion, isokinetic movements allow for maximum resistance to be applied to a muscle throughout the entire range of motion of the involved joint (Costain & Williams, 1984). Two primary parameters that have been used to assess lower extremity muscular strength are the ipsilateral reciprocal ratio between the hamstrings and quadriceps, known as the H:Q ratio, and the dynamic control ratio.

The H:Q ratio is calculated by dividing maximal knee flexion strength by maximal knee extension strength at a given angular velocity and muscular contraction type (concentric or eccentric) (Aagaard et al., 1998). This ratio has been investigated principally in lower extremity dominated sports such as soccer (Devan et al., 2004; Croisier et al., 2002; Croisier et al., 2008; Costain & Williams, 1984; Croisier et al., 2003; Myer et al., 2009), track and field (Croisier et al., 2002; Aagaard et al., 1998), basketball (Devan et al., 2004) and football (Aginsky et al., 2014; Parker et al., 1983). Much of the focus of these studies is aimed at identifying an imbalance between quadriceps and hamstring strength. However, controversy exists on what H:Q ratio qualifies as normal and what constitutes a strength deficiency. Normal conventional H:Q ratios have been reported by Aagaard et al. (1995) as 40-50%, based on peak knee moments and independent of contraction type and velocity. Accounting for contraction velocity, the absolute values for normal concentric H:Q ratios are proposed to be 60-69% at 30°/second and 80-95% at 300°/second (Wilk, 1998). Furthermore, Croisier et al. (2002, 2003, 2008) established that a significant strength deficiency is present in the hamstrings if the H:Q is less than 47%. However, it has been reported that in order to maintain a strength balance around the knee, collegiate athletes must maintain an H:Q ratio of at least 60% (Coplin, 1971) Additionally, Heiser et al. (1994) suggested that a low H:Q ratio, specifically less than 60%, indicated a predisposition for injury.

Depending on which of the previously described thresholds is used to assess an athlete’s muscular strength profile, H:Q imbalances and hamstring strength deficits are alarmingly common among athletes. In an assessment of 53 collegiate, female athletes, Devan et al. (2004) reported that 45% (n = 24) presented with an H:Q ratio below 60% at 60°/second, suggesting a lack of hamstring strength. Additionally, the mean right and left H:Q ratio at 300°/second were 73.6% and 74.7%, respectively, both below the range suggested by Wilk (1998). Aagaard et al. (1998) evaluated nine sprinters during concentric contractions at 30°/second and the mean H:Q ratio reported in that study (50%) was well below the range suggested by Wilk (1998). Using the 47% threshold established by Croisier et al. (2002, 2003, 2008), 25% of the 462 soccer athletes evaluated presented with a hamstring strength deficiency at 60°/second and 17% presented with a deficiency at 240°/second (Croiser et al., 2008). Similarly, nine out 26 (35%) soccer and track and field athletes evaluated by Croisier et al. (2002) presented with a H:Q ratio below 47%. It is apparent that lack of hamstring strength is a prevalent issue among athletes playing lower extremity dominated sports.

However, the concentric or eccentric strength ratio of the hamstrings and quadriceps may not be the most accurate representation of true knee function. By nature of the conventional H:Q ratio, it implies that concentric or eccentric contraction of the hamstrings and quadriceps occur simultaneously. True knee motion during open chain movements only allows for eccentric hamstring contraction to be combined with concentric quadriceps function during knee extension and vice versa during knee flexion (Aagaard et al., 1998). Therefore, a more thorough representation of the agonist-antagonist strength profile around the knee may be shown by the dynamic control ratio, also known as the functional H:Q ratio (Aagaard et al., 1998; Aginsky et al., 2014). For example, by using the dynamic control ratio, Croisier et al. (2002) discovered an eccentric strength imbalance in 23% of subjects that a conventional isokinetic protocol would have completely neglected. The dynamic control ratio is calculated by measuring maximal eccentric hamstring strength and dividing it by the measured maximal concentric quadriceps strength (Hecc:Qcon) for knee extension or by dividing maximal concentric hamstring strength by maximal eccentric quadriceps strength (Hcon:Qecc), representative of knee flexion. Dynamic control ratios have been reported near and even above 100% in athletes (Aagaard et al., 1998; Aginsky et al., 2014; Croisier et al., 2002; Croisier et al., 2008) indicating the ability of the hamstrings to help provide stability to the knee during ballistic movements. A dynamic control ratio of 100% would indicate that eccentric hamstring strength is equal to that of concentric quadriceps strength. Previous research has suggested that a dynamic control ratio of less than 80% is representative of a significant strength deficiency in the hamstrings (Croisier et al., 2002; Croisier et al., 2008). In evaluating the strength profile of 26 male athletes, Croisier et al. (2002) reported a staggering 62% presented with a dynamic control ratio of less than 80%. Additionally, 40% of 462 soccer athletes presented with a significant hamstring strength deficiency, as determined by the dynamic control ratio (Croisier et al., 2008).

The dynamic control ratio around the knee is a useful measure in throwing athletes as the hamstrings and quadriceps must function together during the forward stride of the throwing motion. As the player steps forward, the quadriceps muscles act to extend the stride leg while the ipsilateral hamstrings must activate eccentrically in order to slow knee extension and prepare the leg for foot contact (Tippett, 1986). Subsequent concentric activation of the hamstrings extends the knee and brings the players body forward over the planted leg (Tippett, 1986). It has been reported that knee flexion in the stride leg should be less at ball release than at foot contact (Chu et al., 2009). In a study comparing the pitching motions of male and female baseball players, Chu et al. (2009) reported that female pitchers were unable to accomplish even minimal knee extension after foot contact and the stride knee actually remained flexed throughout the pitch cycle. The authors postulated that the lack of knee extension in females is a consequence of the muscles in the leg not being strong enough to firmly brace the body after foot contact (Chu et al., 2009). Therefore, it appears necessary to investigate the strength profile around the knee using a dynamic control ratio, especially in female throwers, as a balanced strength profile around the knee is paramount to throwers for optimal performance and injury prevention.

Previous literature has investigated lower extremity strength profiles as related to injury in almost exclusively lower extremity dominated sports (Aginsky et al, 2014; Jonhagen et al., 1994; Croisier et al., 2008; Croisier et al., 2002; Croisier, 2004; Croisier et al., 2003). Hamstring muscle strains are among the most common muscular injuries in athletes (Agre, 1985; Clanton, 1998; Ekstrand, 1983). Etiological factors attributed to an increased risk of muscular strain injury include poor muscular strength, particularly eccentric strength deficits, and ipsilateral muscular strength imbalances (Mjolsnes et al., 2004). Croisier et al. (2008) reported muscle strength disorders (bilateral strength differences greater than 15%, a concentric H:Q ratio less than 47%, or a dynamic control ratio was less than 80%) were detected in 70% of cases after a hamstring strain. Orchard et al. (1997) concluded that preseason isokinetic testing in professional football players could be used to identify at-risk players for hamstring injury. Those players who subsequently went on to sustain a hamstring injury during the season had hamstring strength that was 16% less than those players who were non-injured (Orchard et al., 1997). Jonhagen et al. (1994) discovered that sprinters who had suffered from a hamstring rupture were significantly weaker in eccentric contractions of the hamstrings at 30°/second, 180°/second, and 230°/second than those sprinters who did not suffer an injury. In a study of athletes with a history of hamstring injury, Croisier et al. (2002) reported that the dynamic control ratio was significantly reduced in the injured limb (73%) compared to the non-injured limb (90%). Consequently, injury appears to be linked to strength deficits in athletes playing lower extremity dominated sports.

Only two studies were found examining the H:Q ratio in throwing athletes (Coleman, 1982; Tippett, 1986). In compiling the physiological characteristics of Major League Baseball players, Coleman (1982) reported that the dominant leg (throwing side) H:Q ratio for players across all positions was 74%, and the H:Q ratio in the non-dominant leg (non-throwing side) was 73%. Tippett (1986) reported that collegiate baseball pitchers have an H:Q ratio of 80% in their stance leg and 81% in their stride leg. These values suggest that professional and collegiate baseball players are not at risk for sustaining a hamstring injury according to the at-risk thresholds discussed previously. In spite of this, during an analysis of all injuries in Major League Baseball from 2001-2010, it was reported that hamstring injuries are a common lower body injury among baseball pitchers, second only to knee injuries (Enad, 2014; Posner et al., 2011). It has additionally been suggested that hamstring injuries are actually even more prevalent in baseball position players compared to pitchers (Posner et al., 2011). The prevalence of hamstring injuries in throwers implies a necessity to investigate the role of the lower extremities, specifically strength in the hamstrings and quadriceps, in a throwing population as it relates to optimal mechanics.

Hamstring Flexibility

A factor accompanying muscular strength as related to athletic performance is muscular flexibility. Measures of flexibility can be either static or dynamic and are performed in order to assess the ability of skeletal muscle and tendons to lengthen (Gleim & McHugh, 1997). Static flexibility is defined as the range of motion of a specific joint or series of joints while dynamic flexibility refers to a joint’s ease of movement within a particular range of motion (Gleim & McHugh, 1997). Various protocols exist for assessing the flexibility of different muscles, but three common tests are routinely used for measuring the flexibility of the hamstring muscle group in athletes: the sit-and-reach test (Burkett, 1970; Stephens & Reid 1988; Orchard et al., 1997), the straight leg raise test (Jonhagen et al., 1994; Ekstrand & Gillquist, 1982; Liemohn, 1978; Knapik et al., 1991; Witvrouw et al., 2003), and the passive knee extension test (Worrell et al., 1991; Hartig & Henderson, 1999; Lowther et al., 2012;). Perhaps the most viable of these three assessments is the passive knee extension test. It has been recommended by Gajdosik & Lustin (1983) that the passive knee extension test be utilized by clinicians to assess hamstring flexibility because the results of the sit-and-reach test and straight leg raise test can be affected by confounding variables. When attempting to assess lower body flexibility, it is difficult to distinguish vertebral flexibility from hip flexibility using the sit-and-reach test (Gleim & McHugh, 1997) as the results can be influenced by upper body, thoracic, and lumbar laxity (Worrell et al., 1991). Methodology used in performing the straight leg raise test creates some controversy because this test can be confounded by pelvic rotation (Bohannon, 1982; Bohannon et al., 1985) and foot position (Gajdosik & LeVeau, 1985). Additionally, the passive knee extension test could be viewed as superior because coefficients of reliability for this test have been reported as high as r = 0.98 (Hartig & Henderson, 1999) compared to only r = 0.77 for the passive straight leg raise and r = 0.84 for a modified sit-and-reach test (Ayala et al., 2012).

Hamstring flexibility has been investigated extensively in lower extremity dominated sports (Ekstrand & Gillquist, 1983; Jonhagen et al., 1994; Liemohn, 1978; Worrell et al., 1991; Knapik et al., 1991; Hennessy & Watson, 1993; Witvrouw et al., 2003; Krivickas & Feinberg 1996; Lowther et al., 2012; Yeung et al., 2009; Gabbe et al., 2005; Arnason et al., 2004; Gabbe et al., 2006; Engebretsen et al., 2010; Orchard, 2001; Bennell et al., 1998; Henderson et al., 2010; Bradley & Portas, 2007). However, much controversy still exists in the literature on the relationship between flexibility and injury. In review of literature prior to 1984, Sutton (1984) reported no clear connection between flexibility and injury. More recent prospective studies have also demonstrated no relationship between hamstring flexibility and hamstring injury in sprinters, football players, and soccer players (Yeung et al., 2009; Gabbe et al., 2005; Arnason et al., 2004; Gabbe et al., 2006; Engebretsen et al., 2010; Orchard, 2001; Orchard et al., 1997; Bennell et al., 1998). Additionally, in a sample of 34 rugby, hurling, and Gaelic football players grouped by previous history of hamstring strain, Hennessy & Watson (1993) indicated that the mean right and left leg flexibility was not significantly different between the injured group (77.8°) and the non-injured group (77.1°). These results support findings by Stephens & Reid (1988) who reported that hamstring flexibility was not different among hamstring injured and non-injured football players. Also corroborating these results are studies by Ekstrand & Gillquist (1982), Liemohn (1978), and Burkett (1970) but flexibility measures were taken using the straight leg raise test (Ekstrand & Gillquist, 1982; Lieholm, 1978) and sit-and-reach test (Burkett, 1970). These aforementioned studies support the notion that flexibility in the hamstrings is not associated with risk for injury in the lower extremities.

Contrarily, previous research does exist that links hamstring flexibility with injury (Henderson et al., 2010; Bradley & Portas, 2007; Witvrouw et al., 2003; Krivickas & Feinberg, 1996; Lowther et al., 2012; Worrell et al., 1991; Ekstrand et al., 1982; Jonhagen et al., 1994). In professional soccer players, a relationship has been found between preseason flexibility measures and subsequent injuries suffered during the season (Henderson et al., 2010; Bradley & Portas, 2007; Witvrouw et al., 2003). Also in soccer players, Witvrouw et al. (2003) used the straight leg raise test to evaluate hamstring flexibility and reported that players who were injured exhibited significantly less mean flexibility that the non-injured players ($p = 0.02$). These results are consistent with Krivickas & Feinberg (1996) who reported a significant correlation between flexibility and the development of injuries in collegiate athletes. In a retrospective study, Lowther et al. (2012) utilized the more reliable passive knee extension test to evaluate two groups of Gaelic football players: those who had a previous hamstring injury and those who did not. The authors reported that non-injured hamstrings were statistically more flexible than the injured hamstrings within the injured group while there was no significant difference between limbs in the non-injured group, thus it was concluded that hamstring flexibility is reduced in limbs that have previously sustained a hamstring injury

(Lowther et al., 2012). The passive knee extension test was also used to assess hamstring flexibility in a group of highly skilled male athletes (Worrell et al., 1991). The authors reported that the hamstring flexibility of athletes in their injured leg was significantly less (37° from full extension) than in the non-injured hamstring (32° from full extension). Additionally, the hamstring-injured subjects were less flexible in both extremities compared to non-injured subjects (Worrell et al., 1991). Hamstring tightness has also been associated with subsequent lower extremity injuries in a prospective study of 180 soccer players (Ekstrand et al., 1982). These authors discovered that 24% (n = 44) of players suffered a muscle strain or tendinitis in the lower extremity during the course of a season, and 34 of these injured athletes had tight hamstring muscles (Ekstrand et al., 1982). Finally, sprinters with a history of hamstring injury had significantly tighter hamstrings than those sprinters who had not suffered a hamstring injury in the previous two seasons; although flexibility in that study was assessed using the less reliable straight leg raise test (Jonhagen et al., 1994). The aforementioned studies contribute to the controversy surrounding injury risk and hamstring flexibility as they support the notion that decreased flexibility is a risk factor for sustaining a lower extremity injury.

Perhaps also contributing to the controversy associated with hamstring flexibility and injury risk is the difficult nature of generalizing flexibility patterns across various sports. The demands of different sports and even the demands between positions within a particular sport vary considerably. Despite this variability in flexibility patterns, specific levels of hamstring flexibility as related to risk of injury have been established in an active sample of military recruits during basic training using the passive knee extension test (Seto, 1995). Hamstring flexibility less than 30° from neutral (extended knee, 0°)

indicated minimal risk for hamstring injury; hamstring flexibility between 30-35° from neutral indicated a non-significant increased risk for hamstring injury, and hamstring flexibility greater than 35° from neutral indicated a significantly increased risk for hamstring injury (Seto, 1995). As the passive knee extension test is a reliable method for assessing level of flexibility (Hartig & Henderson, 1999) and has been used as a tool for associating flexibility level with injury in an active sample (Seto, 1995), it could also be a useful tool in examining flexibility in other active populations, such as overhead throwers. To the author's knowledge, no studies to date have utilized the passive knee extension test to assess hamstring flexibility in softball players.

Despite the controversy surrounding the relationship between hamstring flexibility and incidence of injury, one of the most commonly stated notions in the literature is that tight muscles are more likely to be strained (Worrell et al., 1991; Worrell & Perrin, 1992). Athletes with a lack of hamstring muscle flexibility have a shorter optimal muscle length as compared to athletes with normal hamstring flexibility (Alonso et al., 2009). A shorter optimal muscle length can result in higher muscle strains for the same range of motion compared to a more compliant muscle, thus increasing the risk of injury in the shorter, stiffer muscle (Peterson & Holmich, 2005). Studies suggest that a muscle is most vulnerable to injury as it generates tension during the rapid transition from eccentric to concentric contraction (Verrall et al., 2001; Peterson & Holmich, 2005). In running, this transition occurs during the late swing phase of the running stride (Thelen et al., 2005; Yu et al., 2008) when the hamstrings muscles must eccentrically decelerate knee extension and brace the leg for foot contact. The muscle group must then transition to concentric contraction in order to rapidly extend the hip and bring the body forward during the stance phase of gait (Peterson & Holmich, 2005).

A similar eccentric to concentric contraction pattern of the hamstring muscle occurs in throwing athletes as well. During the drive phase of the throwing motion as the player steps forward towards the target, the stride leg quadriceps extend the knee while the ipsilateral hamstrings must subsequently activate in order to slow knee extension and prepare the stride leg for ground foot contact (Tippett, 1986). The forward stride is critical to the throwing motion because the stride is the initial factor of energy generation and ideally should cause the smooth, efficient transfer of force through the kinetic chain needed to impart high velocities on the ball during advanced throwing (Stodden et al., 2006). In fact, the importance of having a good stride as related to throwing performance has been shown with the results of a linear regression which indicted that stride length accounted for 69.3% of ball velocity variations among throwers across four levels of development (Stodden et al., 2006). Research on baseball pitchers has put forth that relative stride length should be approximately 80% of standing height (Thurston, 1984), and this is unaffected by level of pitching experience. Studies have shown that the relative stride lengths of youth, high school, and collegiate baseball pitchers were 85% of their respective heights (Fleisig et al., 1999) while professional pitchers had a stride length of 86% of standing height (Fleisig et al., 1999; Schultzler & Atwater, 1980). Based on these aforementioned studies, it can be concluded that regardless of age or experience level, a thrower’s stride length should be 85% of standing height for optimal performance.

However, stride length does appear to be significantly affected by gender according to a study comparing the kinematic parameters of 11 male and 11 female baseball pitchers (Chu et al., 2009). That study concluded that females had a significantly shorter relative stride length (70%) compared to their male counterparts (78%) (Chu et al., 2009). The authors suspect that the shorter stride in females may be a consequence of the stride leg generating less potential energy to be used during the drive phase as the females had a significantly shorter maximum knee height during windup (Chu et al., 2009). The importance of proper hip and knee flexion during the windup phase of the pitch cycle as related to optimal performance has been discussed by Tippett (1986). Hip and knee flexion in the stride leg during the windup provides significant momentum to the large mass of the lower body and produces a sufficient rotation, or coiling, of the pelvis and trunk around the stance leg (Tippett, 1986). This coiling of the pelvis and trunk around the stance leg eccentrically stretches the musculature in the hip and trunk and allows the thrower to load as they prepare for the stride (Tippett, 1986). Proper windup mechanics could then lead to a longer, more powerful stride. Longer stride lengths have been strongly associated with faster pelvis and upper torso rotational velocities as well as with faster throwing velocity (Stodden et al., 2006). Although hamstring flexibility was not measured in the study by Chu et al. (2009), the authors suspect that a lack of hip and knee flexion during the windup could be a consequence of a lack of hamstring flexibility. Therefore, hamstring tightness in throwers could potentially lead to the development of pathomechanics during throwing. Female throwers may be at a predisposed disadvantage during throwing due to shorter relative stride lengths compared to males, and this disadvantage may only be exacerbated in those with diminished hamstring flexibility. To the author's knowledge, only one study (Tippett, 1986) has investigated hamstring flexibility as related to throwing performance. However, that study by Tippett (1986) used a sample of collegiate male baseball pitchers. No studies to date were found to have examined hamstring flexibility as a variable related to throwing performance in softball players performing an overhead throw.

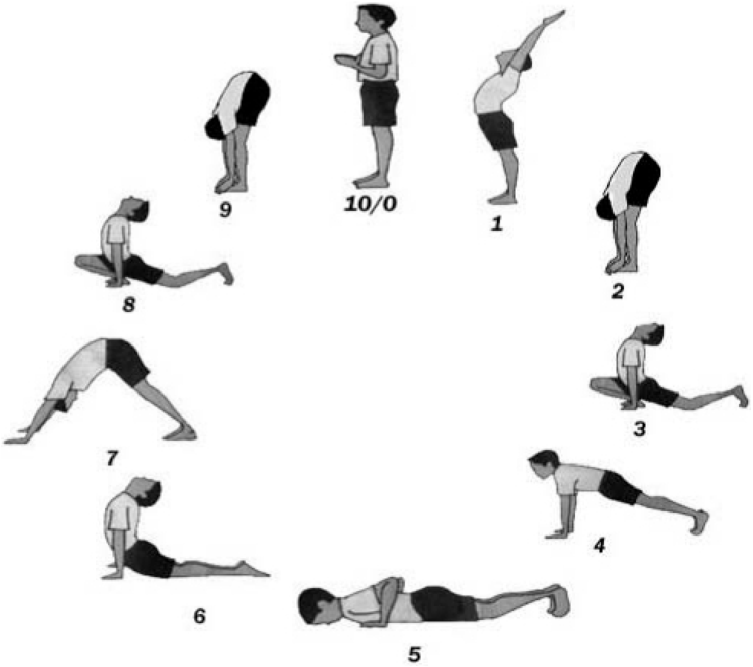
Yoga

Yoga is an ancient discipline that strives to bring balance to the physical, mental, emotional, and spiritual dimensions of one's overall wellness and being (Ross & Thomas, 2010). Originating in India, yoga is believed to be approximately 4000-8000 years old and was first developed as an ancient science of movement in order to improve life physically and mentally (Lalvani, 1996). The word *yoga* is derived from an ancient Sanskrit word meaning *unify* or *join*, and the daily practice of yoga is believed to cause equilibrium between or unifying of the body and mind (Briegel-Jones et al., 2013). Although it has been practiced in the eastern world for thousands of years, yoga is beginning to become increasingly popular in the western world evidenced by a 2003 survey of 1,208 health clubs in North America that reported 83% of clubs offer yoga programs (Club Programs, 2003). The aspects of yoga practice that have generally become synonymous with the term *yoga* in the western world are more accurately referred to as Hatha yoga, one of the many forms of yogic practice (Garfinkel & Schumacher, 2000). Hatha yoga concentrates on the physical health and wellbeing of the practitioner, and involves the practice of physical postures, or *asanas*, for strength and flexibility; breathing techniques known as *pranayama* for increased self-awareness; and often meditation, or *chanda*, for the calming of the mind (Lalvani, 1996). Additionally, Hatha yoga provides an introduction to basic yoga asanas and is often practiced at a slow and gentle pace (Briegel-Jones et al., 2013). Learning how to listen and respond to individual bodily sensations is the primary message taught to beginners in yoga, and this awareness can help the individual arrive at a comfortable mental and physical place while still challenging the body (Shiffmann, 1996). Not surprisingly then, yoga asanas are described in Sanskrit as *sthira suk ham asanas* meaning a stable, comfortable, state of the body (Gupta & Awasthi, 2014). Additionally, asanas are considered the subtle physical practices that release physical and mental energy blockages in the body in order to prepare the body-mind for the deeper practices of yoga, such as meditation (Saraswati, 1993). Asanas are different from other physical exercises as yogic exercises are synchronous postures that require minimal energy consumption while maximizing the rehabilitation effects on physiological body systems in order to facilitate awareness, relaxation, concentration, and mediation (Gupta & Awasthi, 2014). In addition to cultivating body awareness and mental concentration, yoga has come to be considered a systematic training program for improving physical fitness parameters including muscular strength, flexibility, and even sports performance (Gharote et al., 1976).

Much of the previous literature investigating the effects of yoga has done so utilizing yoga interventions of various durations and frequencies (Amin & Goodman, 2014; Tran et al., 2001; Bhutkar et al., 2011; Galantino et al., 2004; Cowen & Adams, 2005; Cowen, 2010; Ray et al., 2001; Bera & Rajapurkar, 1993; Bal & Kaur, 2009; Briegel-Jones et al., 2013; Brunelle et al., 2015; Donohue, et al., 2006; Goodman et al., 2014; Pal et al., 2013; Hovsepian et al., 2013; Ray et al., 1983; Gharote et al., 1976).

Muscular strength is a common measure that has been routinely reported as improving as a result of practicing yoga (Tran et al., 2001; Bhutkar et al., 2011; Cowen & Adams, 2005; Tracy & Hart, 2013; Pal et al., 2013) because yoga asanas are specifically designed as an approach to align and strengthen segments of the body (Robert-McComb, 2009). The isometric muscular contractions from static holding of the asanas and the controlled movement between asanas are believed to be responsible for strength increases commonly reported (Pal et al., 2013; Tran et al., 2001). Tran et al. (2001) reported that yoga significantly increased isokinetic muscular strength for elbow extension by 31%, elbow flexion by 19%, and knee extension by 28% in a population of ten healthy, untrained, sedentary males and females (18-27 years). The intervention used by Tran et al., 2001 lasted eight weeks during which the participants attended 90-minute yoga sessions four times per week. Additionally, Bhutkar et al. (2011) reported significant improvements in knee extension strength following regular performance of Sun Salutation cycles (Figure 3) six days a week for 24 weeks in 79 (49 male, 30 female) healthy, untrained, sedentary college students. The Sun Salutation is a cyclical event that is synchronized with specific breathing patterns, and the specific asanas within a Sun Salutation sequence are known to individually cause specific strength improvements in muscles surrounding the spine as well as muscles within the abdomen, chest, shoulders, arms, and legs (Bhutkar et al., 2011). In another study examining 26 (20 females, six males) healthy, untrained individuals who performed 75 minutes of yoga twice weekly for six weeks, Cowan & Adams (2005) reported that upper body and trunk strength increased by 47% and 54%, respectively. Furthermore, eight weeks of Bikram yoga, consisting of 24 total sessions, has been shown to improve lower limb strength in healthy young adults (Tracy & Hart, 2013). Finally, Pal et al. (2013) assessed back and leg muscle strength in 60 healthy, male paramilitary personnel prior to and following a 3-month yoga intervention consisting of performing Hatha yoga asanas for 90 minutes daily. A 10.9% increase in back and leg strength following the yoga intervention was reported (Pal et al., 2013). It was thus concluded that performing yoga is effective at improving total body muscular strength. Specifically, upper body and trunk strength, two vital parameters associated with overhead throwing, can be improved in as little as six weeks as a result of biweekly yoga practice (Cowan & Adams, 2005).

Figure 3. Sun Salutation Cycle (Bhutkar et al., 2011).



In conjunction with improving strength, regular practice of yoga has also been implicated as effective in improving flexibility (Amin & Goodman, 2014; Tran et al., 2001; Galantino et al., 2004; Cowen & Adams, 2005; Cowen, 2010; Ray et al., 2001; Bal & Kaur, 2009; Hovsepian et al., 2013; Ray et al., 1983; Gharote et al., 1976). The improvements in flexibility generally seen as a result of yoga practice have been attributed to the repetitive static stretching and force-resistance movements associated with the asanas (Gharote et al., 1976; Amin & Goodman, 2014). Amin & Goodman (2014) assessed hamstring and low back flexibility using a sit-and-reach test in 16 healthy, low-to-moderately active females (40-65 years) with at least two years of yoga practice. After six weeks of once a week, 90-minute yoga sessions, post-intervention scores of hamstring flexibility (30.87 cm) were significantly greater than pre-intervention scores (29.50 cm) (Amin & Goodman, 2014). Also using the sit-and-reach test, Galantino et al. (2004) reported an improvement from 13.91 cm to 16.43 cm after a total of six weeks of 60-minute biweekly yoga sessions. Another study by Cowen & Adams (2005) also used the sit-and-reach test to evaluate hamstring flexibility and reported a significant 17% improvement compared to baseline assessments in a yoga intervention group that performed 75-minute sessions twice weekly for six weeks (Cowan & Adams, 2005). Furthermore, Cowen (2010) used the sit-and-reach test as well as a measure of trunk flexibility, and significant improvements were found between prior to (26.46 cm) and following (28.06 cm) a yoga intervention consisting of six weeks of optional yoga sessions. Participants in that study attended an average of four sessions over the entire 6-week intervention, and 62% of participants reported feeling more flexible post-intervention (Cowan, 2010). In another study, Tran et al. (2001) reported a 188% improvement in trunk extension flexibility, 14% increase in trunk flexion flexibility, and an improvement of 155% in shoulder elevation flexibility in ten healthy, untrained, sedentary males and females (18-27 years) after an 8-week yoga intervention consisting of 4, 90-minute sessions per week. Furthermore, Ray et al. (2001) assessed body flexibility in 54 healthy, untrained but active college aged students. Subjects were randomly assigned to one of two groups, yoga and control, and the yoga group received Hatha yoga training for one hour every alternate day in a week (3 times per week) for 10 months (Ray et al., 2001). After five months, males showed significant improvements in shoulder, hip, and trunk flexibility and it increased further after month 10 of yoga practice; females only demonstrated a significant increase in trunk flexibility after 10 months, although shoulder and hip flexibility did improve after 10 months as well (Ray et al., 2001). The authors do not speculate as to a reason for the differences between genders. Lastly, Gharote et al. (1976) recruited 98 subjects to investigate the effects on flexibility of a 9-week yoga intervention consisting of 45-minute sessions performed six days per week. Backward extension (+6.2 cm) and shoulder flexibility (+7.45 cm) tests showed significant improvement from pre- to post-intervention (Gharote et al., 1976). These aforementioned studies provide evidence that performing yoga can have substantial effects on improving flexibility. Specifically, hip and shoulder flexibility which are vital to optimal throwing mechanics, are known to improve with yoga practice in as little as 6-8 weeks (Amin & Goodman, 2014; Galantino et al., 2004; Cowan & Adams, 2005; Tran et al., 2001).

Yoga has additionally been cited as more effective than aerobic exercise and stretching exercises in improving hip, hamstring, and shoulder flexibility (Ray et al., 1983; Hovsepian et al., 2013). In a study by Ray et al. (1983), 40 healthy older men (40-48 years) were assigned to a yoga group (n = 20) or physical exercise group (n = 20). The yoga group performed six months of regular yoga practice consisting of two minutes of prayer, 50 minutes of asanas, five minutes of pranayama, and five minutes of meditation whereas the exercise group participated in regular physical exercise consisting of running, stretching exercises and pull ups for the same duration of time (Ray et al., 1983). Flexion and extension measurements were taken in the trunk, shoulders and hips pre- and post-intervention (Ray et al., 1983). Shoulder flexion and extension improved significantly in the yoga group from pre-intervention (195.8°) to post-intervention (205.7°) but not in the exercise group (Ray et al., 1983). Additionally, hip flexion and extension improved significantly in the yoga group from pre-intervention (106.7°) to post-intervention (120.4°) but again not in the exercise group (Ray et al., 1983). Hovsepian et al. (2013) recruited 57 healthy female students to compare the effects of yoga (n = 27) vs. aerobic training (n = 30) on certain physical bodily characteristics including hip flexibility that was assessed using the modified sit-and-reach test. Participants either exercised via aerobics or yoga for one hour twice a week over the course of three months (Hovsepian et al., 2013). The yoga group performed 15-20 different asanas each session in addition to relaxation and meditation practices, and results showed greater increases in hamstring flexibility in the yoga group post-intervention (+8.5 cm) compared to the aerobics group (+3.2 cm), although the differences were non-significant (Hovsepian et al., 2013). Based on the results of the aforementioned studies demonstrating yoga's effectiveness in improving flexibility, it has been recommended that yoga be implemented in athletic populations in order to reduce the risk of sports injuries (Hovsepian et al., 2013).

Despite the apparent physical benefits of yoga and the suggestion that it should be implemented into the training regimen of athletes (Hovsepian et al., 2013), minimal scientific research exists that investigates the effects of yoga in athletic populations. To the author's knowledge, only four studies exist that utilize athletes to investigate the effects of yoga practice (Briegel-Jones et al., 2013; Brunelle et al., 2015; Donohue et al., 2006; Goodman et al., 2014), and it is difficult to draw biomechanical conclusions from these studies due to the qualitative nature of the research or the lack of biomechanical measures being taken. Briegel-Jones et al. (2013) utilized 21 elite youth swimmers as a sample to investigate the effects of 10 weeks of yoga practice in an athletic population. However, no biomechanical data were reported as only qualitative data were collected (Briegel-Jones et al. (2013). Five participants reported feeling stronger in the upper body, lower body, and the core following the yoga intervention; two participants reported feeling improvements in flexibility level following the yoga intervention, and six participants reported feeling improved in both training and competition from a performance stand point following the yoga intervention (Briegel-Jones et al. (2013). While these data are subjective, they do lend to the notion that yoga practice can improve strength, flexibility, and even athletic performance (Briegel-Jones et al. (2013). In another study, 36 yoga sessions (19 yoga stretch classes, 17 athletic yoga classes) over the course of eight weeks were implemented into the established training regimen of an Italian Olympic speed skating team (n = 15) (Brunelle et al., 2015). The intervention was structured such that no two sessions were the same, but each session averaged 41 minutes in duration (Brunelle et al., 2015). Three postures were analyzed pre- and post-intervention, although no measures of flexibility or strength were taken so conclusions cannot be drawn from this study relating to the effects of yoga on the physical characteristics of this athletic sample (Brunelle et al., 2015). However, the head coaches of the speed skating team did report feeling that the athletes were more capable of separating hip and trunk rotations during skating, thus increasing the efficiency of the skating stride (Brunelle et al., 2015). This observation by the coaches again lends to the notion that yoga can have positive effects on athletic performance and perhaps have even bigger implications for throwing athletes based on the known importance of proper hip and trunk rotations in throwing (Dillman et al., 1993; Wilk et al., 2000; Stodden et al., 2005; Wight et al., 2004). The effects of yoga on athletic performance, in the form of a timed run, have also been examined in a sample of 90 high school long-distance runners. In that study by Donohue et al. (2006), a treatment group of runners were given an acute yoga intervention lasting only 20 minutes and consisting of 11 basic asanas prior to performing a timed run. The treatment group showed significant improvement in run performance compared to a control group ($t[1,5] = 2.17$, $p < 0.05$), thus the current study showed that a brief period of yoga practice prior to running can cause significant, albeit small improvements in performance (Donohue et al., 2006). Finally, a study by Goodman et al. (2014) implemented a 5-week yoga intervention in an athletic population made up of 26 collegiate male athletes. Thirteen NCAA Division I athletes comprised the treatment group while 13 matched club sport athletes comprised the control group (Goodman et al., 2014). The intervention consisted of biweekly 60-minute yoga sessions, but no biomechanical measures were taken in that study (Goodman et al., 2014). Therefore, no conclusions could be drawn on the physical effects of yoga in this athletic population (Goodman et al., 2014). Consequently, research on the effects of yoga in athletes is sparse, and the biomechanical conclusions that can be drawn from the studies that do exist (Briegel-Jones et al., 2013; Brunelle et al., 2015; Donohue, et al., 2006; Goodman et al., 2014) are minimal.

The effects of yoga practice on physical fitness parameters such as strength, flexibility, and range of motion are readily apparent. However, it remains to be seen how yoga practice can affect these physical fitness parameters in an athletic population, specifically overhead throwers. To the author’s knowledge, there is an obvious void in the literature pertaining to the beneficial effects of practicing yoga on hamstring strength and flexibility, hip and shoulder range of motion, and subsequently throwing performance in elite softball players.

CHAPTER III.

METHODOLOGY

The objectives of this research study were as follows: to evaluate the effects of implementing yoga practice during a fall competitive season for a NCAA Division I softball team on 1] lower extremity, lumbopelvic-hip complex, and upper extremity kinematics during overhead throwing, 2] shoulder and hip rotational range of motion, and 3] hamstring strength and flexibility. This chapter aims to outline and describe the methodology to be used to address these objectives. Methodology has been divided into the following subsections: 1] participants, 2] setting, 3] instrumentation, 4] procedures, 5] data analysis, and 6] experimental design.

Participants

Thirty female, collegiate softball players were recruited to participate in this study. The number of recruited participants was limited based on the size of the collegiate softball team used as the participant pool, and all recruited participants were on the current playing roster. The recruiting protocols used allowed for the implications of this study to be delimited across a larger population of overhead throwing athletes. Recruited participants completed a health-history questionnaire (Appendix A) in order to determine eligibility for participation in this study. Criteria for inclusion required participants to be active on the current playing roster and free of any current or recent (within the previous six months) injury and surgery to the lower extremity, pelvis, trunk, or upper extremity. After completion of the health-history questionnaire, 28 participants were eligible for participation. Two of the eligible 28 participants were subsequently injured during fall season competition, one from the treatment group and one from the control group, and were removed from the study. In total, 26 participants completed the study. Each participant signed an informed consent document approved by the Auburn University Institutional Review Board (Appendix B) prior to any testing or implementation of data collection procedures.

Power Analysis

G*Power v.3.1.9.2 (Faul et al., 2007) was used in order to compute the statistical power for the current study. The results of a power analysis indicated that a sample of 26 participants (number of rostered players on the NCAA Division I team examined in the current study) had a power of 0.88 to detect a within-subject between-group interaction with a medium effect size (Cohen's f = 0.23) and an α-level set *a priori* to 0.05, assuming a strong correlation (r = 0.70) between dependent variables from pre- to post-intervention. Additionally, results of the power analysis indicated that statistical testing had an 80% chance of detecting a clinically significant 10° difference (Doege & Houston, 1995) in shoulder range of motion with 13 participants per group, assuming the standard deviation within each group averaged 11.4. Furthermore, results of the power analysis indicated that statistical testing had a 99% chance of detecting a clinically significant 10° difference (Doege & Houston, 1995) in hip range of motion with 13 participants per group, assuming the standard deviation within each group averaged 7.7. Standard deviations were determined post-hoc using data from the current study.

Setting

All data collection and intervention regimes took place in a controlled setting inside the Sports Medicine & Movement Laboratory located on the Auburn University campus. This location contained the necessary space and equipment required to satisfy the objectives of this study.

Instrumentation

Throwing Kinematics

All kinematic data were collected using an electromagnetic tracking system (trakSTAR™, Ascension Technologies, Inc., Burlington, VT, USA; Figure 4) synced with The MotionMonitor™ (Innovative Sports Training, Chicago, IL, USA; Figure 5). The electromagnetic tracking system used in this study has been previously validated for measuring humeral movements, and interclass correlation coefficients for axial humeral rotation in both loaded and non-loaded conditions have been reported greater than 0.96 (Ludwig & Cook, 2000). Field distortion associated with electromagnetic tracking systems has been reported to be the cause of error greater than 5° at distance of two meters from the extended range transmitter (Day et al., 2000), but instrument sensitivity increases have reduced this error from near 10° prior to system calibration to as low as 2° following calibration (Day et al., 2000; Mesker et al., 1999; Perie et al., 2002). Consequently, the current system was calibrated using previously established protocols prior to the collection of any data (Day et al., 2000; Perie et al., 2002; Plummer & Oliver, 2013a; Plummer & Oliver, 2013b; Oliver, 2013; Keeley et al., 2012; Oliver & Plummer, 2011; Oliver et al., 2010; Oliver & Keeley, 2010b). After calibration, the error in determining position and orientation of the electromagnetic sensors with the current calibrated world axis system was less than 0.01 m and 3°, respectively. A sampling rate of 100 Hz was used for all kinematic data describing position and orientation (Oliver & Keeley, 2010a; Plummer & Oliver, 2013a; Oliver, 2013; Oliver & Plummer, 2011; Wicke et al., 2013). A 40 cm x 60 cm Bertec force plate (Bertec Corp., Columbus, OH) was built into the surface from which all throws were made (Figure 6) such that the participant's stride foot would land on the force plate during the throwing motion. Force plate data were only used to measure the instance of stride foot contact during the throwing motion and were sampled at a rate of 1000 Hz.

Figure 4. trakSTAR™ electromagnetic tracking system.

Figure 5. The MotionMonitor™ 3D motion capture system.

Figure 6. Force platform and throwing surface for overhead throwing test protocol.

Range of Motion and Flexibility

A digital inclinometer (Baseline® Evaluation Instruments, White Plains, NY, USA; Figure 7) was used in order to assess the shoulder and hip range of motion profiles as well as hamstring flexibility measures for all participants. Similar studies measuring range of motion and flexibility have utilized a goniometer (Shanley et al., 2011; Scher et al., 2010; Crockett et al., 2002; Tokish et al., 2008; Anloague et al., 2012) or inclinometer (Dwelly et al., 2009; Ribeiro et al., 2013; Mair et al., 2004; Laudner et al., 2010) to collect these data. The inclinometer was chosen for use in the current study because of familiarity and ease of use for the primary investigator, who collected these data. In order to ensure accurate measurements, the inclinometer was calibrated to the standards recommended by the manufacture prior to collection of any range of motion data (Baseline, 2008).

Figure 7. Baseline® digital inclinometer.

Strength

The isokinetic strength profiles of the hamstrings and quadriceps for participants in this study were evaluated using a Biodex Multi-Joint System – Pro dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA; Figure 8). Isokinetic dynamometry has been used extensively in previous research and is a valid and reliable method for measuring strength (Aginsky et al., 2014; Costain & Williams, 1984; Croisier et al., 2008; Croisier et al., 2002; Devan et al., 2004; Jonhagen et al., 1994; Parker et al., 1982; Smith et al., 1981; Pincivero et al., 1997; Feiring et al., 1990; Gross et al., 1991). Prior to any data collection, the dynamometer was calibrated based upon the manufacturer's recommended standards.

Figure 8. Biodex Multi-Joint System – Pro dynamometer.

Procedures

Throwing kinematics, range of motion, flexibility, and strength were measured prior to and following a 6-week yoga intervention during a fall competitive softball season. Prior to any measurements being taken, each participant completed the health history questionnaire and signed the Informed Consent document approved by the Auburn University Institutional Review Board. Participants were instructed to report to the laboratory wearing athletic shorts and a t-shirt in order to allow for the palpitation of necessary anatomical landmarks during testing. This type of clothing also allowed for easy placement of motion capture sensors on the participant and additionally allowed the investigator to note movement compensations exhibited by the participants during range of motion testing. Pre- and post-intervention measurements of range of motion, flexibility, and strength were obtained on the same day for each participant. The overhead throwing test protocol was performed pre- and post-intervention by each participant on a day separate from range of motion, flexibility, and strength tests.

Overhead Throwing Test Protocol

For the overhead throwing test protocol, each participant had a series of 11 electromagnetic sensors (Figure 9) attached to the body at the following locations (Figure 10): 1] the posterior aspect of the torso at the first thoracic vertebrae (T1) spinous process; 2] the posterior aspect of the pelvis at the first sacral vertebrae (S1); 3] the flat, broad portion of the acromion on the throwing scapula; 4] the lateral aspect of the throwing upper arm at the deltoid tuberosity; 5] the posterior aspect of the distal throwing forearm, centered between the radial and ulnar styloid processes; 6-7] the lateral aspect of each thigh, centered between the greater trochanter and the lateral condyle of the knee; 8-9] the lateral aspect of each shank, centered between the head of the fibula and the lateral malleolus; 10-11] the dorsal aspect of each foot on top of the shoe (Oliver & Keeley, 2010a; Oliver & Keeley, 2010b; Plummer & Oliver, 2013a; Plummer & Oliver, 2013b; Oliver, 2013; Keeley et al., 2012; Oliver & Plummer, 2011; Myers, 2005). All sensors were affixed to the participant's skin using PowerFlex cohesive tape (Andover Healthcare, Inc., Salisbury, MA, USA) to ensure secure placement throughout testing. A twelfth, moveable sensor was attached to a plastic stylus used for the digitization of bony landmarks described in Table 2 (Oliver & Keeley, 2010a; Oliver & Keeley, 2010b; Myers, 2005; Oliver, 2011; Wu et al., 2002; Wu et al., 2005). In order to ensure accurate identification and palpitation of bony landmarks, the participant stood in anatomical neutral throughout the duration of the digitization process. Using the digitized joint centers for the ankle, knee, hip, shoulder, T12-L1, and C7-T1, a link segment model was developed (Figure 11). Joint centers were determined by digitizing the medial and lateral aspect of a joint then calculating the midpoint between those two points (Oliver & Keeley, 2010a; Plummer & Oliver, 2013b; Oliver & Plummer, 2011; Wu et al., 2002; Blackburn et al., 2003). Thus the ankle and knee joints were defined as the midpoint between the digitized medial and lateral malleoli and medial and lateral femoral condyles, respectively, whereas the spinal column was defined as the digitized space between C7-T1 and T12-L1 (Oliver & Keeley, 2010a; Plummer & Oliver, 2013b; Oliver, 2013; Oliver & Plummer, 2011; Oliver & Keeley, 2010b). A rotation method, validated as capable of providing accurate positional data (Huang et al., 2010; Veeger, 2000), was utilized to estimate the joint centers of the shoulders and hips. The shoulder joint center was calculated from the rotation of the humerus relative to the scapula while the hip joint centers were calculated from the rotation of the femur relative to the pelvis. The rotation method consisted of the investigator stabilizing the joint then passively moving the limb into six different positions in a small, circular pattern (Huang et al., 2010). Raw data regarding sensor position and orientation were transformed to locally based coordinate systems for each of the respective body segments. The longitudinal axis of each segment was represented by two points and a third point defined the plane of the segment (Oliver, 2013; Holt & Oliver, 2015). For the world axis, the y-axis represented the vertical direction; horizontal and to the right of y was the z-axis; anterior and orthogonal to the plane defined by y and z was the x-axis (Oliver, 2013; Holt & Oliver, 2015). Position and orientation of the body segments were described using Euler angle decomposition sequences (Oliver & Keeley, 2010a; Oliver, 2013; Holt & Oliver, 2015). Kinematic data were obtained using Euler angle sequences that were consistent with the International Society of Biomechanics standards and joint conventions (Wu et al., 2002; Wu et al., 2005). More specifically, ZY'X" sequence was used to describe knee motion; ZX'Y" sequence was used to describe hip motion; ZX'Y" sequence was used to describe pelvis motion; ZX'Y" sequence was used to describe trunk motion; YX'Y" sequence was used to describe shoulder motion (Table 3). All raw data were independently filtered along each global axis using a 4th order Butterworth filter with a cutoff frequency of 13.4 Hz (Oliver & Keeley, 2010a; Plummer & Oliver, 2013a; Oliver, 2013; Oliver & Plummer, 2011; Wicke et al., 2013). All data was time stamped through The MotionMonitor™ and passively synchronized using a data acquisition board.

Figure 9. Flock of Birds™ electromagnetic sensors.

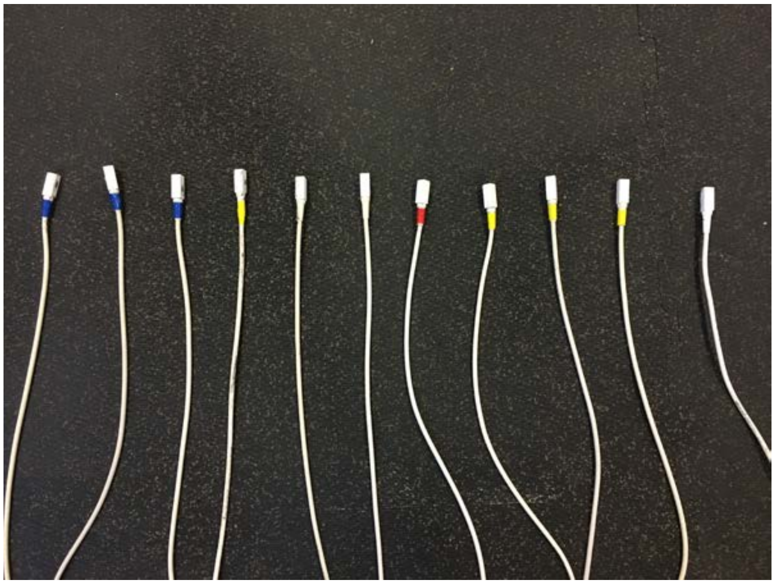


Figure 10. Motion capture sensor placement locations.

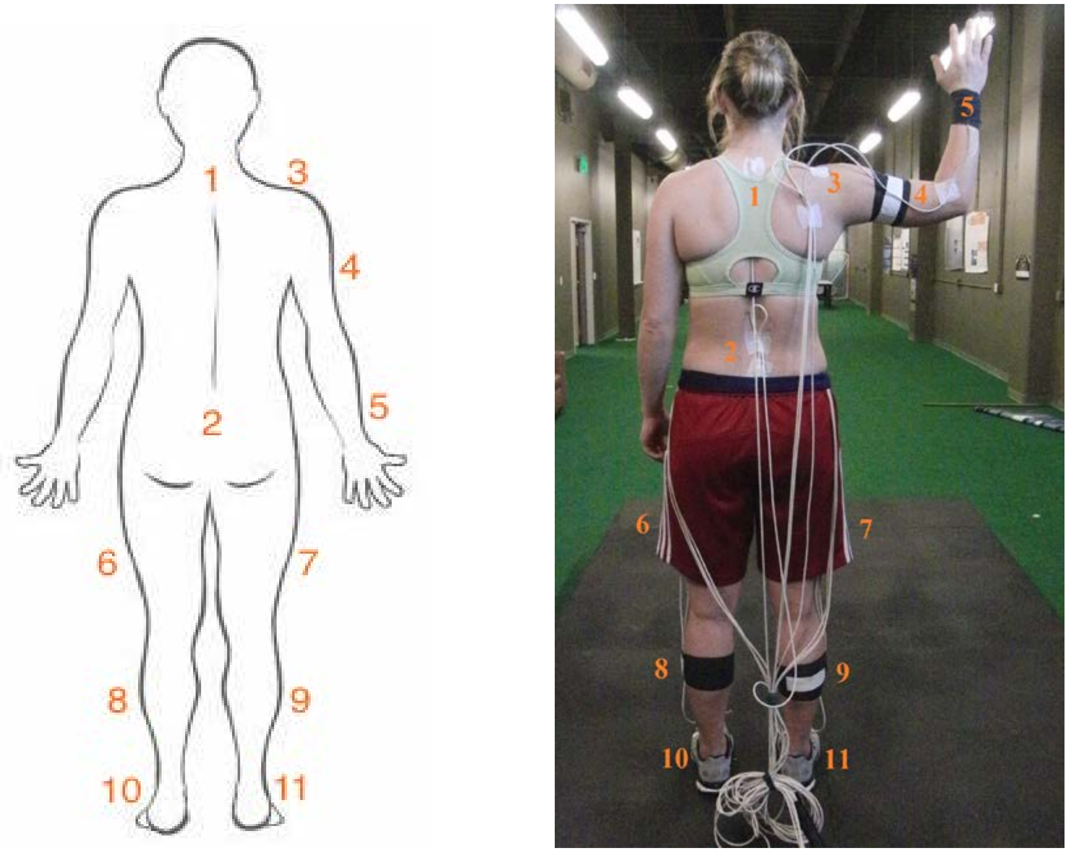


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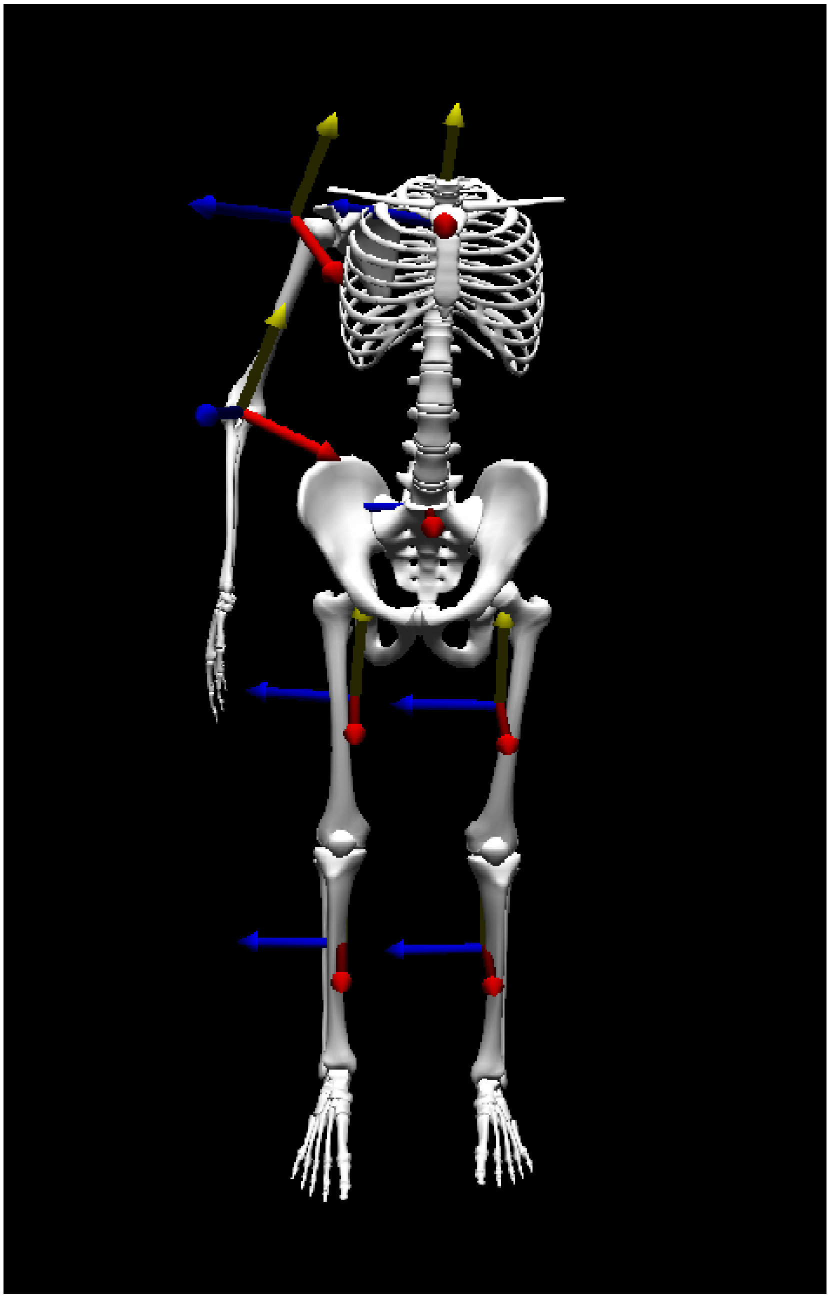
Table 2. Description of bony landmarks palpated and digitized.

Bony Landmark	Bony Process Palpated & Digitization
Thorax	
Seventh Cervical Vertebra [C7]	Most dorsal aspect of the spinous process
Twelfth Thoracic Vertebra [T12]	Most dorsal aspect of the spinous process
Eighth Thoracic Vertebra [T8]	Most dorsal aspect of the spinous process
Suprasternal Notch	Most cranial aspect of sternum
Xiphoid Process	Most distal aspect of sternum
Humerus	
Medial Epicondyle	Medial/distal aspect of condyle
Lateral Epicondyle	Lateral/distal aspect of condyle
Shoulder Joint Rotation Center	Rotation method*
Forearm	
Radial Styloid Process	Lateral/distal aspect of radial styloid
Ulnar Styloid Process	Medial/ distal aspect of ulnar styloid
Thigh	
Medial Femoral Condyle	Medial/distal aspect of condyle
Lateral Femoral Condyle	Lateral/distal aspect of condyle
Hip Joint Rotation Center	Rotation method*
Shank	
Medial Malleolus	Medial/distal aspect of malleolus
Lateral Malleolus	Lateral/distal aspect of malleolus

** Centers of shoulder rotation and hip rotation were not digitized. The rotation method estimated joint center using lest of squares algorithm for the point moving the least during a series of short rotational movements (Meskers et al., 1999).*

Figure 11. Link segment model created from digitized segment end points.



Arrows represent the local based coordinate systems for each body segment; red – x direction, yellow – y direction, blue – z direction.

Table 3. Angle and orientation decomposition sequences.

Segment	Axis of Rotation	Angle
Knee		
Rotation 1	Z	Flexion [-] / Extension [+]
Rotation 2	Y’	Left Tibial Rotation [+] / Right Tibial Rotation [-]
Rotation 3	X”	Left: Varus [-] / Valgus [+] Right: Varus [+] / Valgus [-]
Hip		
Rotation 1	Z	Flexion [+] / Extension [-]
Rotation 2	X’	Left: Adduction [+] / Abduction [-] Right: Adduction [-] / Abduction [+]
Rotation 3	Y”	Left: Internal Rotation [-] / External Rotation [+] Right: Internal Rotation [+] / External Rotation [-]
Pelvis		
Rotation 1	Z	Anterior Tilt [-] / Posterior Tilt [+]
Rotation 2	X’	Left Lateral Tilt [-] / Right Lateral Tilt [+]
Rotation 3	Y”	Left Axial Rotation [+] / Right Axial Rotation [-]
Trunk		
Rotation 1	Z	Flexion [-] / Extension [+]
Rotation 2	X’	Left Lateral Flexion [-] / Right Lateral Flexion [+]
Rotation 3	Y”	Left Axial Rotation [+] / Right Axial Rotation [-]
Shoulder		
Rotation 1	Y	Plane of Elevation [0° = Abduction; 90° = Flexion]
Rotation 2	X’	Internal Rotation [+] / External Rotation [-]
Rotation 3	Y”	Elevation [-]

Prime [‘] *and double prime* [“] *notations – represent previously rotated axes due to the rotation of the local coordinate system resulting in all axes within that system being rotated. [Rotation about the X axis also results in rotation of both Y and Z axes resulting in a new system of X’Y’Z’.] Subsequent rotation are then about those axes.*

After sensor attachment and digitization, each participant was allotted an unlimited amount of time to warm-up and become familiar with all testing procedures. The testing began only once the participant was self-declared warm and ready. For testing, each participant performed five maximal effort overhead throws using an NCAA regulation-sized softball (circumference = 31.12 cm [12 ¼ in]; weight = 198.45 g [7 oz]) across a distance of 25.60 m (84 ft) (Abrahamson, 2014). The distance of 25.60 m was chosen because that is the distance across the diamond of a NCAA regulation-sized softball field (Abrahamson, 2014). Participants were instructed not to crow-hop when throwing but instead to use a simple step-and-throw action. All trials were recorded, but only accurate throws were saved. A throw was judged as accurate if the investigator catching each throw could do so with both feet remaining firmly planted to the ground. The pre-intervention overhead throwing protocol concluded once the participant had completed five maximal-effort accurate throws. Post-intervention overhead throwing testing was completed following the 6-week intervention period using the same protocols and procedures previously described.

Shoulder Rotational Range of Motion Test Protocol

On a day separate from the overhead throwing test protocol, range of motion, flexibility, and strength measurements were taken for each participant. Shoulder range of motion measurements were taken in both the throwing and non-throwing shoulders with the participant lying supine on a standard athletic training table. The supine position allowed for the table to assist in stabilizing the scapula during range of motion testing. For testing, the arm of the participant was placed in 90° of abduction with the elbow flexed to 90° in such a way that the forearm will be aligned perpendicular to the plane of the table. In order to minimize shoulder horizontal abduction during testing, a rolled towel was placed under the distal end of the measured humerus (Dwelly et al., 2009). A digital inclinometer was then used to measure internal and external range of motion values. The inclinometer was placed along the anterior aspect of the measured distal forearm, and the investigator passively rotated the shoulder into maximal internal rotation

(Figure 12). The same procedure was then repeated for maximal external rotation of the shoulder (Figure 13). Visual inspection was used to control for scapulothoracic motion using a technique described by Dwelly et al. (2009). Therefore, shoulder range of motion measurements from the current study were indicative of isolated glenohumeral rotation. The method used to control for scapulothoracic motion in the current study has been previously validated as reliable when measuring isolated glenohumeral motion (Dwelly et al., 2009; Awan et al., 2002). This measurement technique consisted of the investigator measuring range of motion until a firm capsular end-feel was reached or the acromion elevated off the table (Dwelly et al., 2009).

Figure 12. Passive shoulder internal rotation.

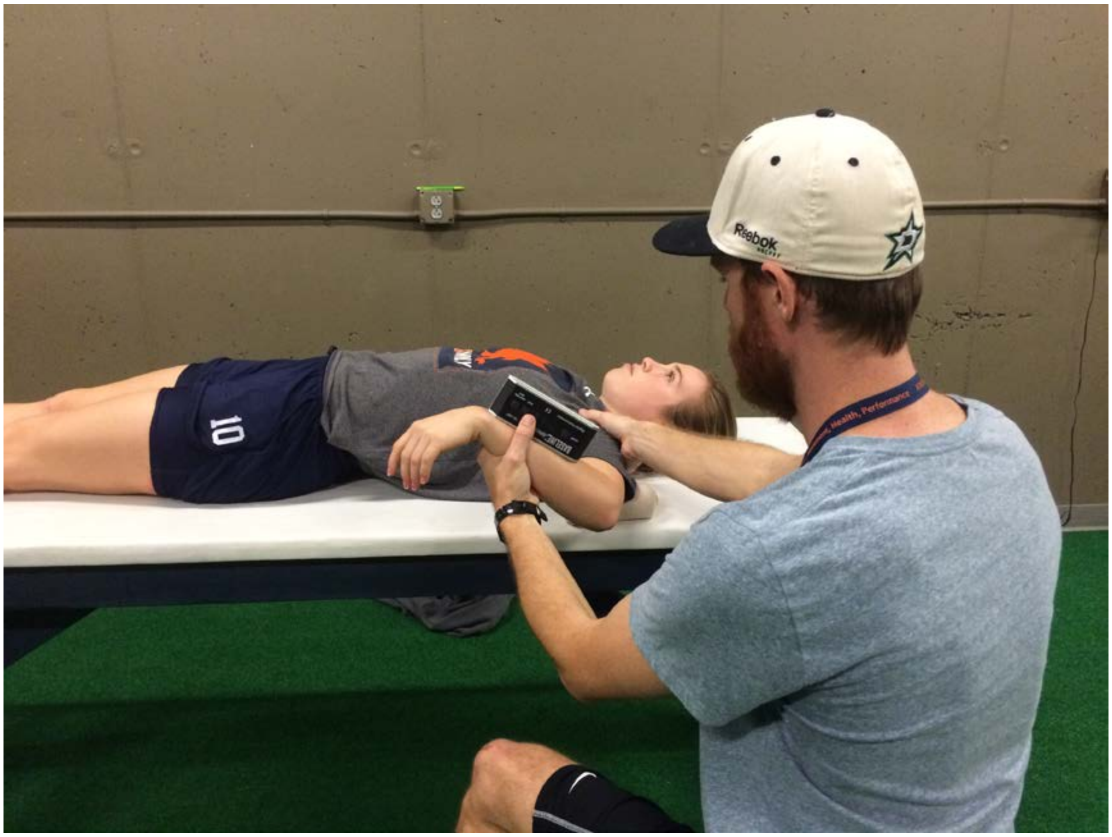


Figure 13. Passive shoulder external rotation.

Hip Rotational Range of Motion Test Protocol

For the purpose of measuring hip range of motion, it was necessary to define each hip relative to the throwing arm. Regardless of throwing handedness, the stance leg was defined as the leg ipsilateral to the throwing arm, and the stride leg was defined as the leg contralateral to the throwing arm (Laudner et al., 2010; Tippett, 1986; Ellenbecker et al., 2007). Hip range of motion has typically been measured in the seated or prone position (Robb et al., 2010; Laudner et al., 2010; Ellenbecker et al., 2007; Sauers et al., 2013; Holt & Oliver, 2015; Scher et al., 2010; Oliver & Weimar, 2014). However, it has been reported that the prone measurement position more accurately represents the pelvis-hip orientation during throwing, thus this position has been recommended for range of motion measurements in overhead throwers (Robb et al., 2010; Sauers et al., 2013; Holt & Oliver, 2015). Therefore, the prone position was selected for use in the current study to measure hip internal and external range of motion. Measurements were taken following the protocol established by Beckett et al. (2014) and were as follows: the participant lied prone on the athletic training table and an investigator manually stabilized the pelvis by placing two hands over the posterior sacroiliac spine. The hip being measured was placed into 0° of abduction while the contralateral hip was moved to 30° of abduction in order to provide adequate space for motion of the measured hip. The knee ipsilateral to the hip being measured was flexed to 90°, and a second investigator aligned the inclinometer along the medial aspect of the participant's shank. The second investigator then passively rotated the thigh to produce maximal external rotation of the hip (Figure 14). The same procedure was then repeated for maximal internal rotation of the hip joint (Figure 15). End range of motion occurred when a resistive end-feel was first achieved, and the investigator applied no overpressure once this position was reached.

Figure 14. Passive hip external rotation.

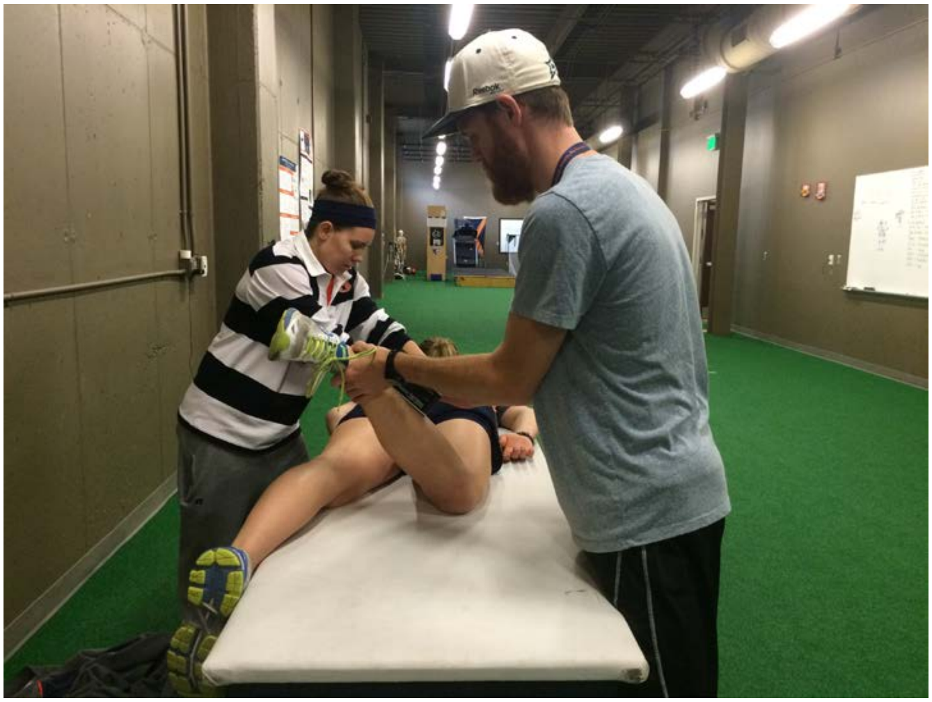


Figure 15. Passive hip internal rotation.

Hamstring Flexibility Test Protocol

Following range of motion testing, the passive knee extension test (Worrell et al., 1991; Hartig & Henderson, 1999; Lowther et al., 2012) was utilized to assess bilateral hamstring flexibility. The test has previously demonstrated reliability when measuring hamstring flexibility with a Pearson Product Moment coefficient of r = 0.98 (Worrell et al., 1991; Hartig & Henderson, 1999). For testing, the participant lied supine on the athletic training table with the measured hip flexed to 90°. The participant stabilized the measured leg in 90° of hip flexion by placing both hands around the distal thigh, just proximal to the knee, and interlocking the fingers. An investigator used a standard goniometer in order to ensure 90° of hip flexion was maintained throughout testing. The stationary arm of the goniometer was aligned parallel with the long axis of the trunk, the moveable arm was aligned parallel with the lateral midline of the femur, and the axis was placed over the greater trochanter. The participant's contralateral hip remained at 0° of flexion throughout testing. A second investigator aligned the digital inclinometer parallel with the anterior aspect of the shank ipsilateral to the measured hip. The second investigator then placed the foot ipsilateral to the measured hip into maximal plantarflexion and passively extended the knee until a resistive end-feel was first achieved in the hamstrings (Figure 16). The investigator applied no overpressure once this position was reached. Hamstring flexibility measurements were recorded as the number of degrees from complete knee extension (0°).

Measurements were taken twice during all range of motion and flexibility tests, and the average of the two measurements was calculated for use in all subsequent statistical analysis (Dwelly et al., 2009). Pilot testing was performed to assess the intra-rater and inter-rater reliability of the primary investigator, who performed all range of motion and flexibility measurements throughout the duration of this study. Median interclass correlation coefficients across all pre-intervention range of motion and flexibility variables was strong (r = 0.869), with a strong positive minimum (r = 0.752) and strong positive maximum (r = 0.970). Additional pilot testing was performed to assess intra-rater and inter-rater reliability of the primary investigator prior to all post-testing due to the large time lapse in between pre- and post-testing. Median interclass correlation coefficients across all post-intervention range of motion and flexibility variables was strong (r = 0.983), with a strong positive minimum (r = 0.983) and strong positive maximum (r = 0.995).

Figure 16. Passive knee extension test.

Hamstring Strength Test Protocol

After range of motion and flexibility testing were complete, the isokinetic strength profile of the hamstrings and quadriceps was assessed. Strength testing was performed on the stance leg and stride leg using a Biodex Multi-Joint System – Pro isokinetic dynamometer. Strength testing was performed using an adapted version of the protocols developed by Aagaard et al. (1998) and Croisier et al. (2002, 2008). Those adapted protocols were as follows: participants first warmed up with five minutes of cycling on an ergonomic bicycle at a speed of 80 rpm (Figure 17). Participants were then seated on the chair of the dynamometer with the hips flexed to 90° and the trunk reclined 10° (Figure 18). The hips, thighs, and trunk were firmly strapped to the chair of the dynamometer. The axis of rotation for the lever arm of the dynamometer was visually aligned with the lateral femoral condyle, and the lower leg was strapped to the lever arm of the dynamometer at the level of the lateral malleolus. Prior to testing, participants were made aware of the importance of exerting maximal effort, and the investigator provided standardized verbal encouragement throughout all strength testing. Testing consisted of five maximal effort concentric and five maximal effort eccentric contractions of the quadriceps followed by five maximal effort concentric and five maximal effort eccentric contractions of the hamstrings all at an angular velocity of 300°/second. An isokinetic speed of 300°/second was chosen for strength testing as pilot data indicated that peak stride knee extension angular velocity during the forward stride of a 18.28 m (60 ft) overhead throw averaged 305°/second in a sample of 39 collegiate-aged softball players. All sets of testing were separated by one minute of rest, and each set was preceded by three submaximal contractions in order for the participant to gain familiarity with the testing protocol. The outcome measure for strength testing was the dynamic control ratio for the bilateral knee flexion (H_{con}:Q_{ecc}) and extension (H_{ecc}:Q_{con}). This ratio was calculated based on the measured peak torque during the five contractions of concentric and eccentric flexion and extension movements. For knee flexion, the dynamic control ratio was calculated by dividing maximal concentric hamstring torque by maximal eccentric quadriceps torque (H_{con}:Q_{ecc}). For knee extension, the dynamic control ratio was calculated by dividing maximal eccentric hamstring torque by maximal concentric quadriceps torque (H_{ecc}:Q_{con}). Strength testing was terminated once the participant had performed five eccentric and five concentric flexion and extension movements on both legs (total of 40 repetitions). Post-intervention range of motion, flexibility, and strength testing were completed following the 6-week intervention period using the same protocols and procedures previously described.

Figure 17. Hamstring strength test warmup on the ergonomic bicycle.

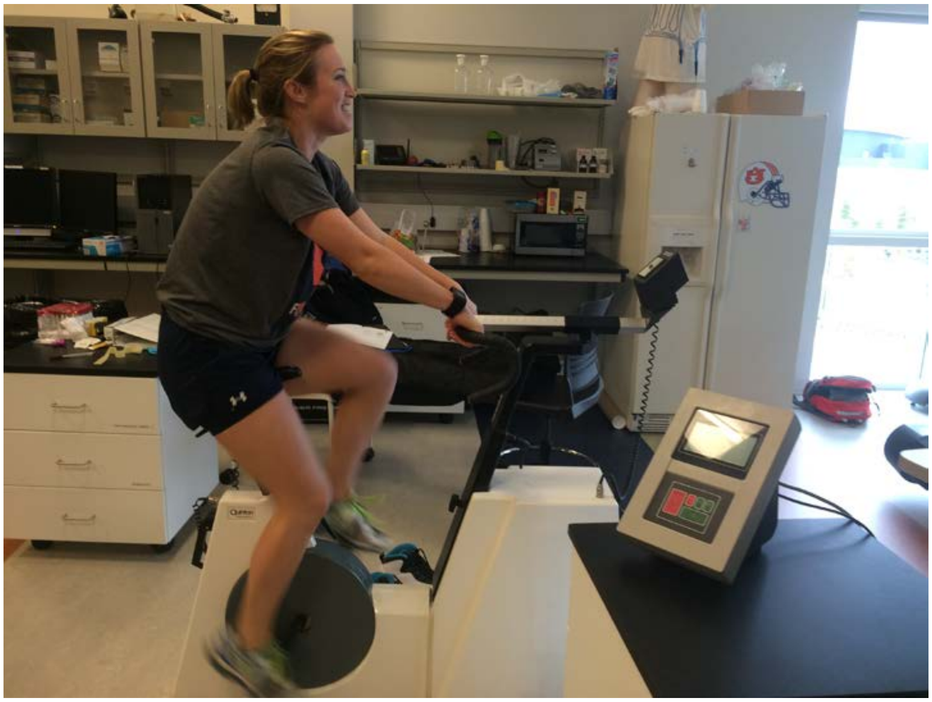


Figure 18. Hamstring strength test.

Yoga Intervention

For the intervention, participants were assigned to a treatment group or a control group using a convenience method. A convenience assignment method was chosen in order to best combat attrition associated with long-term intervention studies. The participants were first stratified by position (pitcher or position player) prior to being assigned a group in order to ensure that an equal number of pitchers and position players were in each group. Next, those participants deemed most capable of completing the intervention, solely based on class/workout schedule, were assigned to the treatment group (n = 13), and the remaining participants were assigned to the control group (n = 13). The treatment group participated in the 6-week yoga intervention in addition to the team-structured practices and strength/conditioning exercises, while the control group participated only in the team-structured practices and strength/conditioning exercises. Team-structured softball practices took place four days per week; strength training workouts took place three days per week, and conditioning workouts took place three days per week separate from the strength training days. Additionally, all participants competed in eight softball games over the course of four weekends during the intervention period.

The yoga intervention was implemented during the fall season of competition for a NCAA Division I softball team. The intervention consisted of performing a 20-minute series of Hatha yoga postures three days per week for six weeks. Each session was treated as an abbreviated yoga class and consisted of a period of relaxation and warm-up exercises, followed by a series of static stretches and isometric holds known as asanas, and ended with another brief period of relaxation. A yoga instructor trained in Hatha yoga instruction with two years of yoga practice, one year of yoga instruction, and an instructor certification level of RYT200 (registered yoga teacher with at least 200 hours of instructor training) was present at each session in order to provide guidance, instruction, and feedback to the participants. Attendance was recorded at each session and participant completion of all 18 sessions was required in order to maintain enrollment in the study.

Each specific exercise and posture was chosen based on consultation with and recommendation from a trained yoga instructor with 21 years of yoga practice, 11 years of yoga instruction, and an instructor certification level of RYT500 (registered yoga teacher with at least 500 hours of instructor training). The chosen yoga poses within the intervention were designed to target the legs, hips, and shoulders. The chosen postures are represented in Figures 19-40, and the protocol for each session is described below. During all movements and transitions between exercises and postures, participants were instructed to always move with inhalations or exhalations of the breath.

Participants began in a comfortable, supine position and a 1-minute deep breathing exercise was performed during quiet lying (Figure 19). The deep breathing exercise consisted of participants expanding the chest and belly during deep inhalations and collapsing the chest and belly during deep exhalations. Next, the participants remained supine and performed a bilateral knee-to-chest stretch for 30 sec on each leg (Figure 20). The participants then performed a supine spinal twist exercise known as Wringing the Organs (Figure 21). This exercise was performed for one minute with 30 seconds being devoted to each side of the body. Next, participants remained supine but transitioned into Old Fashioned Typewriter (Figure 22) for 30 seconds with movements occurring on alternating sides of the body. The last warmup exercise, Cat-Cow pose, (Figure 23), was performed next for 30 seconds. These first five relaxation and warmup exercises (Figures 19-23) were designed to focus the attention of the participants to their own body and to the present moment in time in addition to lengthening and loosening the spine, hips, and shoulders. Directly following the warmup exercises, the participants transitioned into a series of dynamic movements known as Sun Salutation B (Figures 24-32) and performed two cycles through the following sequence: began in Mountain pose (Figure 24), inhaled into Chair pose (Figure 25), exhaled into Forward Fold (Figure 26), inhaled into Half Lift (Figure 27), exhaled into Chatarunga (Figure 28), inhaled into Upward Dog (Figure 29), exhaled into Downward Dog (Figure 30), inhaled into Warrior

I with the left leg forward (Figure 31), exhaled into Chatarunga, inhaled into Upward Dog, exhaled into Downward Dog, inhaled into Warrior I with the right leg forward (Figure 32), exhaled into Chatarunga, inhaled into Upward Dog, exhaled into Downward Dog, inhaled into Half Lift, exhaled into Forward Fold, inhaled into Chair pose, exhaled into Mountain pose. Next, 30 seconds of rest were spent in Childs pose (Figure 33) followed by the participants transitioning into Thread the Needle (Figure 34) for 30 seconds with 15 seconds devoted to each arm. The participants then transitioned into Lizard pose (Figure 35) for one minute with 30 seconds dedicated to each leg followed by Pigeon pose (Figure 36) for one minute again with 30 seconds spent on each leg. Next, the participants moved to a prone lying position to transition into Bow pose (Figure 37) and held that pose for 30 sec on each side of the body. Participants then assumed a standing position and transitioned into Dancer pose (Figure 38) for one minute, holding on each leg for 30 sec. Next, the participants transitioned into a short series of lumbopelvic-hip complex strengthening and stabilizing exercises. Pelvic Bridges (Figure 39) were first be performed 30 seconds in a supine position with the knees bent, feet flat on the ground, and hands by the side. The participants were then instructed to raise and lower the pelvis with inhalations and exhalations, respectively. This was followed by a Single Leg Pelvic Bridge (Figure 40) for 30 seconds with a 15-second isometric hold on each leg. Finally, for rest, recovery, and relaxation, the participants lied comfortably supine on the ground in Corpse pose for one minute (Figure 19). Participants were instructed to perform each pose to the best of their ability without incurring any pain or discomfort. The trained yoga instructor present at each session provided verbal and tactile instruction and feedback to the participants. Emphasis was placed on proper alignment of body segments and proper body posture during all poses.

Figure 19. Corpse Pose; deep breathing exercise.

Figure 20. Knee-to-chest stretch.

Figure 21. Wringing the Organs.

Figure 22. Old Fashioned Typewriter.

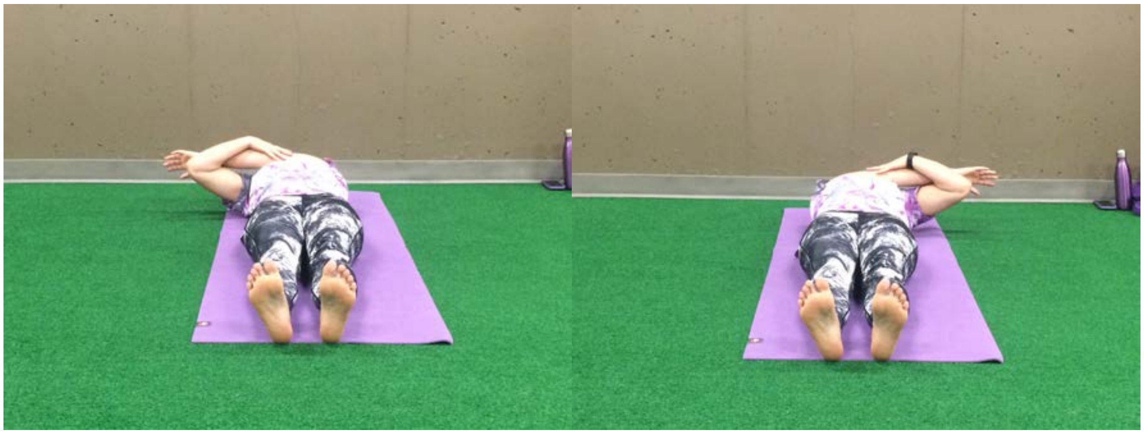


Figure 23. Cat-Cow Pose.

Figure 24. Mountain Pose.

Figure 25. Chair Pose.

Figure 26. Forward Fold Pose.

Figure 27. Half Lift Pose.

Figure 28. Chatarunga Pose.

Figure 29. Upward Dog Pose.

Figure 30. Downward Dog Pose.

Figure 31. Warrior I Pose with the left leg forward.

Figure 32. Warrior I Pose with the right leg forward.

Figure 33. Childs Pose.

Figure 34. Thread the Needle Pose.

Figure 35. Lizard Pose.

Figure 36. Pigeon Pose.

Figure 37. Bow Pose.

Figure 38. Dancer Pose.

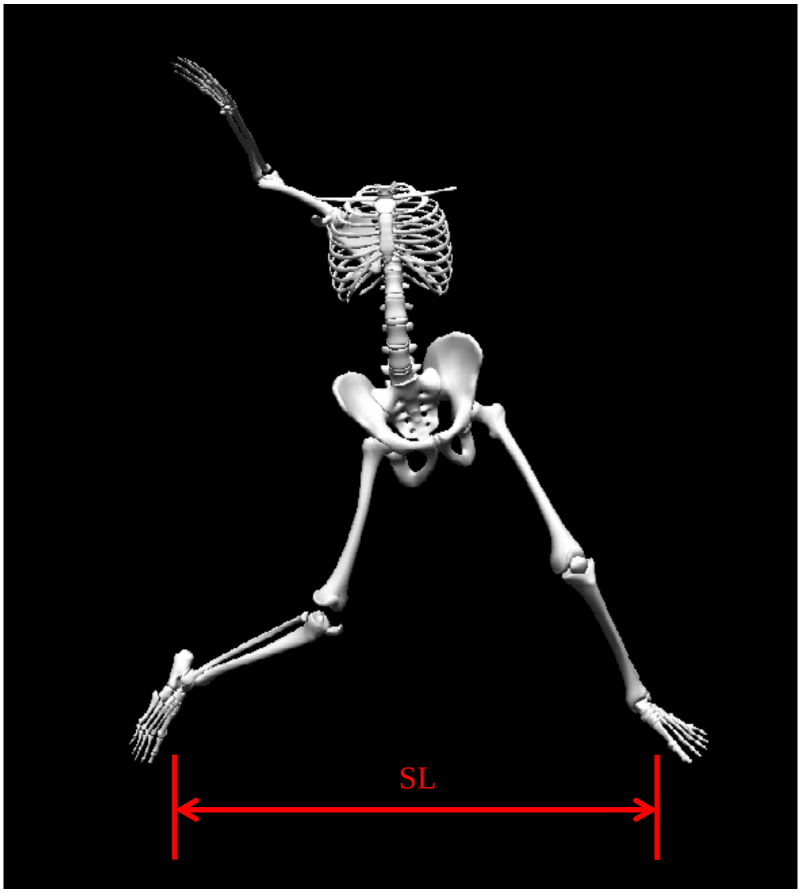
Figure 39. Pelvic Bridges.

Figure 40. Single Leg Pelvic Bridges.

Data Analysis

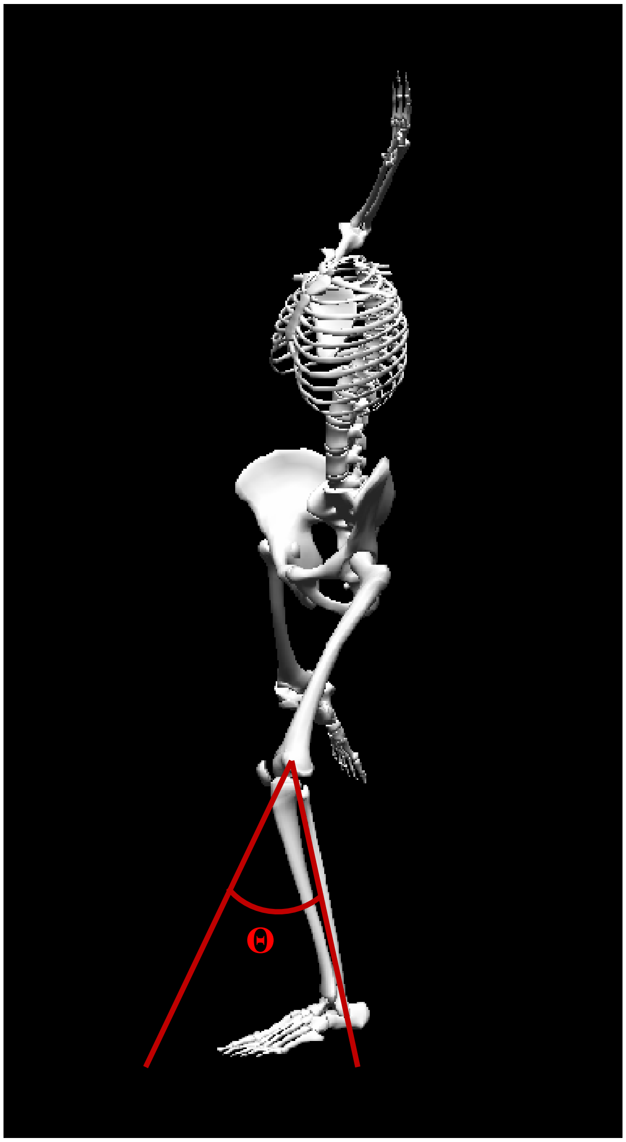
All statistical analyses for the current study were performed using IBM SPSS Statistics 22 software (IBM corp., Armonk, NY) with an alpha level set *a priori* at $\alpha = 0.05$. All data were compiled in a spreadsheet using Microsoft Excel to prepare for statistical analysis. Descriptive statistics were calculated for the demographics of all participants in addition to all pre- and post-intervention kinematic, range of motion, flexibility, and strength parameters. Kinematic data were averaged across all five overhead throws for analysis in order to limit variability between trials. Kinematic data were reduced using The MotionMonitor™ software, and the kinematic variables examined in this study were be stride length (Figure 41), stride knee flexion (Figure 42), bilateral hip rotation (Figure 43), torso separation (Figure 44), throwing-arm shoulder rotation (Figure 45), throwing-arm shoulder elevation (shoulder abduction; Figure 46) and throwing-arm shoulder plane of elevation (horizontal abduction; Figure 47).

Figure 41. Stride length during overhead throwing.



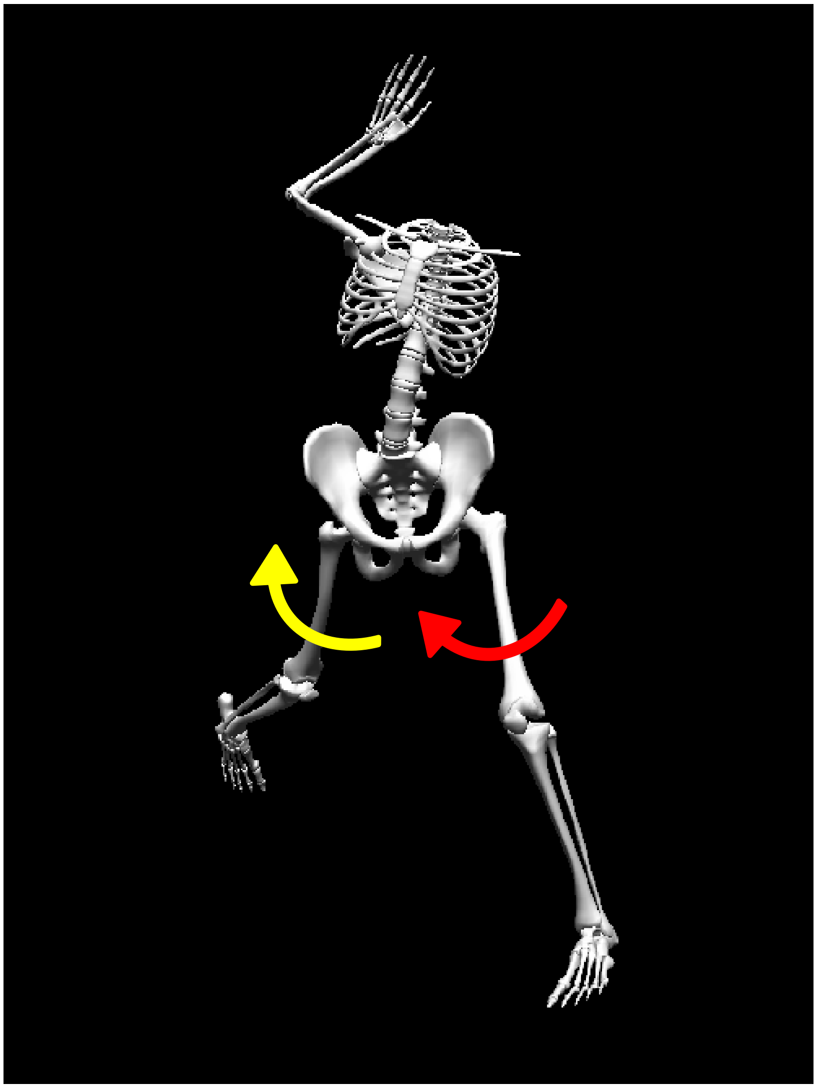
SL – *stride length measured at foot contact as the linear displacement of the center of mass of the stride foot relative to the center of mass of stance foot in the global x direction.*

Figure 42. Stride knee flexion angle during overhead throwing.



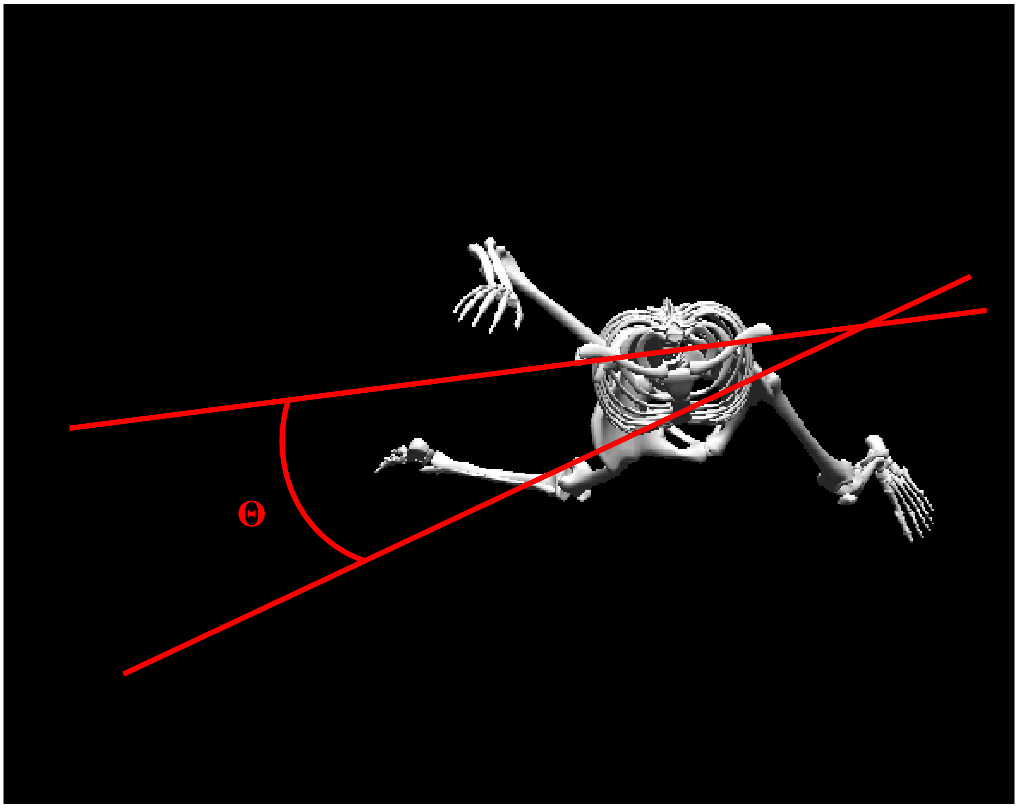
Θ – *stride knee flexion angle of the shank relative to the femur.*

Figure 43. Hip rotation during overhead throwing.



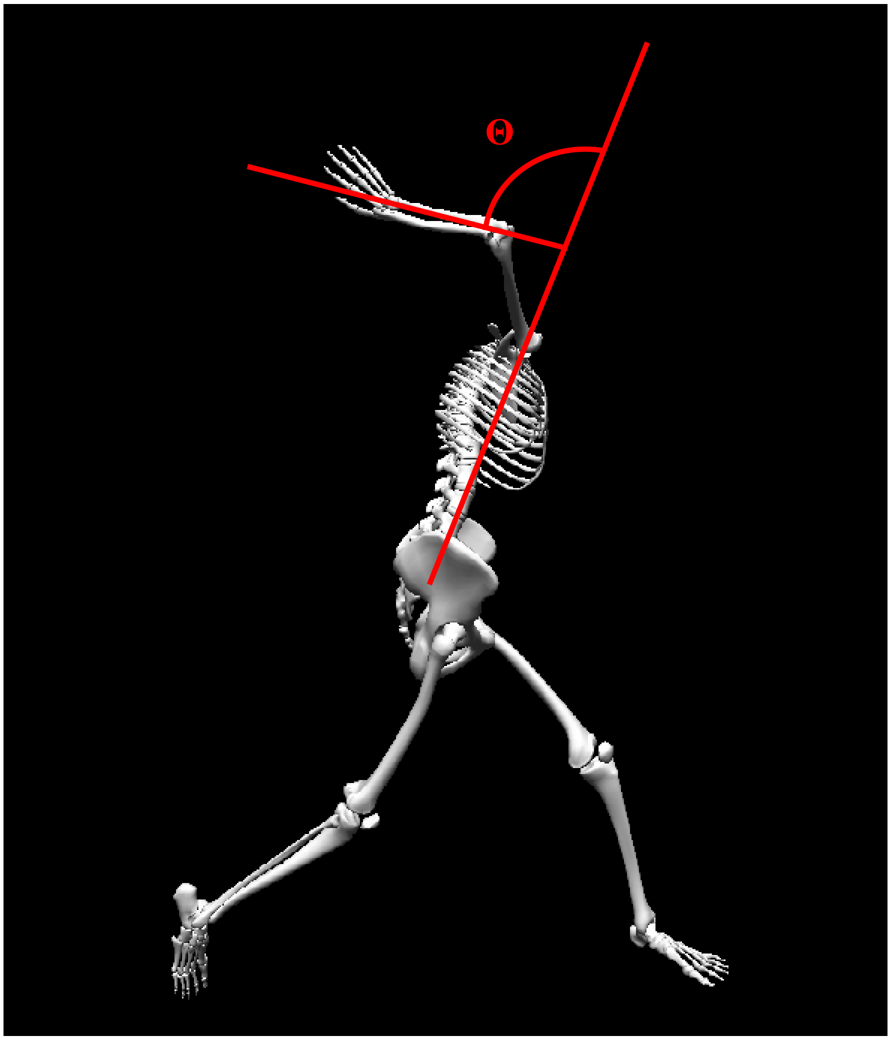
Yellow arrow indicates external rotation of the femur relative to the pelvis; red arrow indicates internal rotation of femur relative to the pelvis.

Figure 44. Torso separation during overhead throwing.



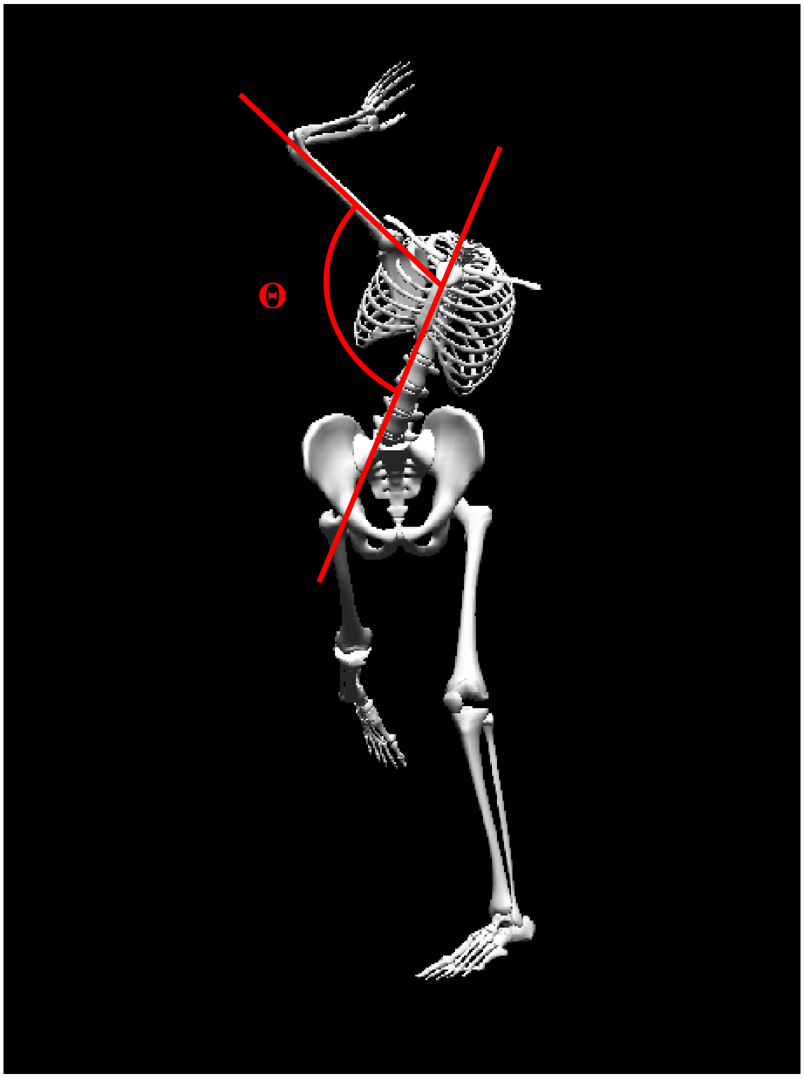
Θ – *torso separation angle measured in the transverse plane as the difference between axial rotation of the pelvis and axial rotation of the torso.*

Figure 45. Shoulder rotation during overhead throwing.



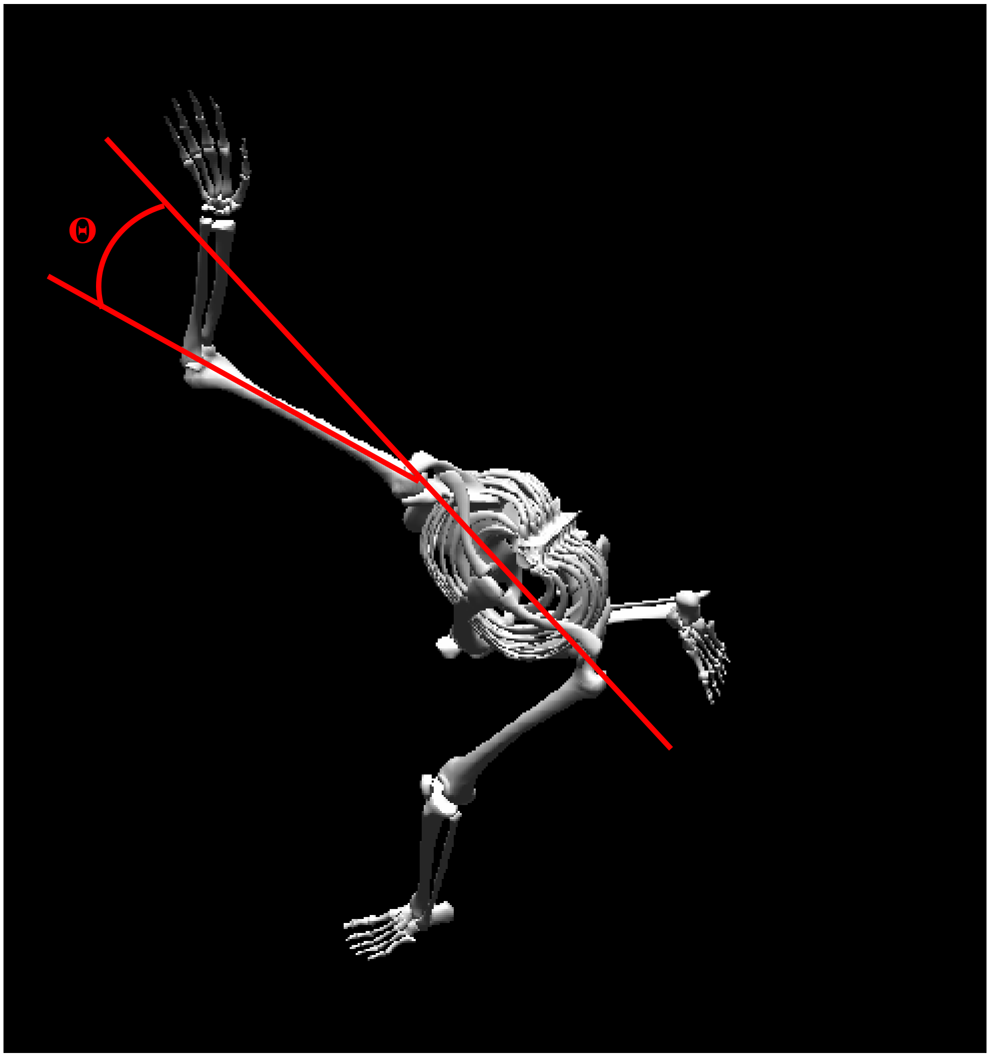
Θ – *shoulder rotation angle of the humerus relative to the trunk.*

Figure 46. Shoulder elevation (abduction) during overhead throwing.



Θ – *shoulder elevation angle of the humerus relative to the trunk.*

Figure 47. Shoulder plane of elevation (horizontal ab/adduction) during overhead throwing.



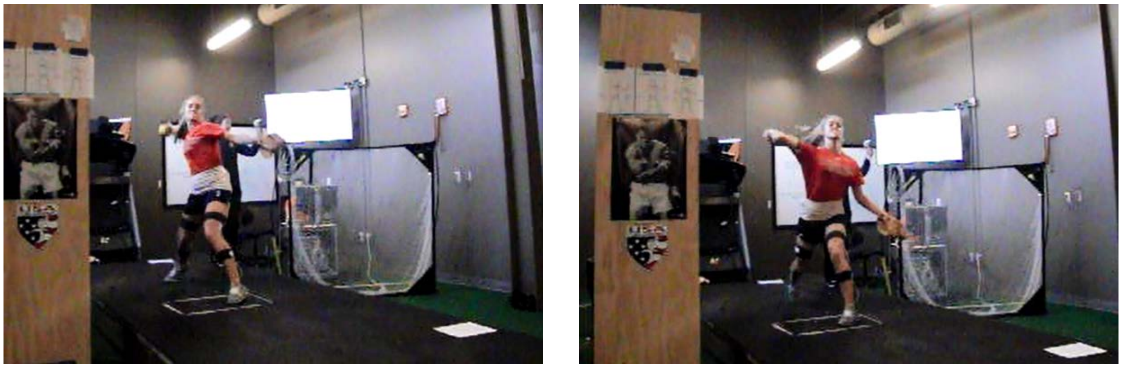
Θ *– shoulder plane of elevation angle of the humerus relative to the trunk.*

Experimental Design

Statistical testing utilized a series of mixed-factorial analyses of variance, ANOVAs, in order to determine if throwing kinematics, shoulder range of motion, hip range of motion, hamstring strength, and hamstring flexibility were significantly different following a 6-week yoga intervention during a fall season of competition. Separate analyses were performed for 1] stride length, 2] stride knee flexion, 3] hip rotation, 4] torso separation, 5] shoulder kinematics, 6] passive shoulder rotational range of motion, 7] passive hip rotational range of motion, 8] hamstring strength, and 9] hamstring flexibility. For certain variables to meet the assumption of normality associated with an ANOVA, three data transformations were necessary. Passive shoulder rotational range of motion and hamstring flexibility data were transformed using a square root transformation whereas hamstring strength data were transformed using a base-10 log transformation. Subsequent statistical analyses for these three variables were performed on the transformed data, but the presentation and discussion of these results utilized the untransformed group means. For all statistical analyses, the independent variable *group* contained the levels of treatment and control while the independent variable *time* contained the levels of pre-intervention and post-intervention.

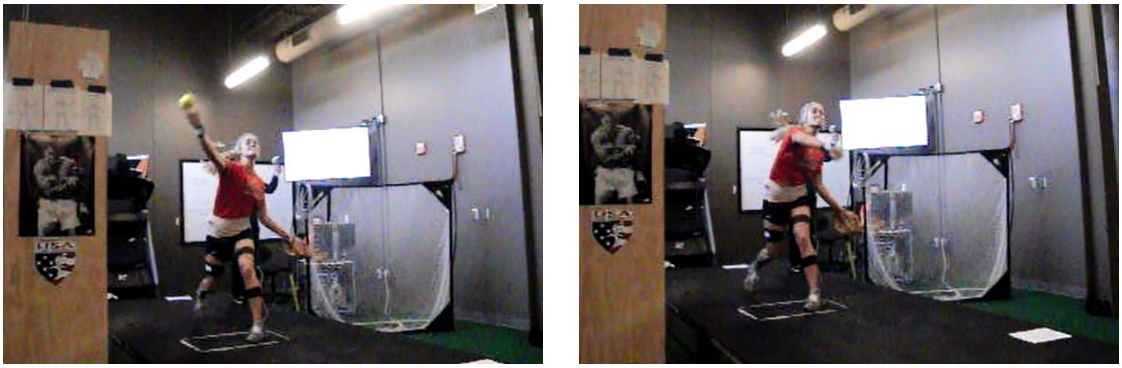
For throwing kinematics, separate analyses were performed for the various segments of the body. For the purpose of this study, the throwing motion was broken down into the following four events (Figure 48a-d): 1] stride foot contact (FC), 2] maximal shoulder external rotation (MER), 3] ball release (BR), and 4] maximal shoulder internal rotation (MIR). For all kinematic analyses except for stride length, the independent variable *event* contained the four levels of FC, MER, BR, and MIR. A within-subjects 2 (group) x 2 (time) design was used for the stride length analysis. The dependent variable was the measured stride length calculated into a percent of the respective participant's body height. For stride knee flexion, a within-subjects 2 (group) x 2 (time) x 4 (event) design was utilized with knee flexion angle in the stride leg serving as the dependent variable. Hip rotation during throwing was analyzed using a within-subjects 2 (group) x 2 (time) x 4 (event) x 2 (limb) design. The two levels of the independent variable *limb* were the stance leg and stride leg. Torso separation was analyzed using a within-subjects 2 (group) x 2 (time) x 4 (event) design. The dependent variable for this analysis was the degree of torso separation calculated as the difference between degree of pelvis axial rotation and trunk axial rotation. A within-subject 2 (group) x 2 (time) x 4 (event) x 3(direction) design was utilized for shoulder kinematics. The independent variable of *direction* contained the three levels of shoulder rotation, shoulder elevation, and shoulder plane of elevation.

Figure 48. Events of the throwing motion.



a. *Foot contact (FC)*

b. *Maximal external rotation (MER)*



c. *Ball release (BR)*

d. *Maximal internal rotation (MIR)*

A separate within-subjects 2 (group) x 2 (time) x 3 (direction) x 2 (limb) design was implemented for both shoulder and hip rotational range of motion. For the independent variable *direction*, the levels were internal rotation, external rotation, and total arc of motion (the sum of external and internal range of motions) for both analyses. Throwing shoulder and non-throwing shoulder were used as the levels of the independent variable *limb* for the shoulder analysis whereas stance leg and stride leg were used as the levels for the hip analysis. The dependent variables for these analyses were the passive range of motion measures. For hamstring strength, a within-subjects 2 (group) x 2 (time) x 2 (limb) x 2 (direction) design was utilized. Stance leg and stride leg side were used as the levels for the independent variable *limb*. Additionally, *direction* was included as an independent variable, and the two levels were knee flexion and knee extension. The calculated dynamic control ratios served as the dependent variables for this analysis. Finally, a within-subjects 2 (group) x 2 (time) x 2 (limb) design was used for hamstring flexibility. The levels for the independent variable *limb* were the same as for hamstring strength. The dependent variable for this analysis was the measurements from the passive knee extension test. In any ANOVA where the independent variables of *group* or *time* had a significant effect on the dependent variables, paired-samples *t* tests were conducted as post-hoc analyses in order to determine where the effect occurred.

CHAPTER IV.

RESULTS

The objectives of this research study were to evaluate the effects of implementing yoga practice during the fall competitive season for a NCAA Division I softball team on 1] lower extremity, lumbopelvic-hip complex, and upper extremity kinematics during overhead throwing, 2] shoulder and hip rotational range of motion, and 3] hamstring strength and flexibility. This chapter presents the results of the current research study and is divided into the following subsections: 1] participant demographics, 2] the effect of yoga on lower extremity, lumbopelvic-hip complex, and upper extremity kinematics during overhead throwing, 3] the effect of yoga on passive shoulder and hip rotational range of motion, 4] the effect of yoga on hamstring strength and flexibility and 5] yoga exit survey responses.

Participant Demographics

Thirty female, collegiate softball players were recruited to participate in the current research study. Twenty-eight participants met the initial criteria for inclusion based on responses to the health-history questionnaire. After pre-intervention testing, two of the 28 participants, one from each group, were injured during softball competition and consequently removed from the study. In total, 26 participants completed the duration of the research study, and all subsequent results and conclusions are based on those 26 participants. A summary of the participant demographics is presented in Table 4. Separate paired-samples *t* tests were conducted for age, height, and weight to investigate differences between groups. Results revealed no significant differences between groups for these demographic parameters.

Table 4. Participant demographics.

Demographic (mean ± standard deviation)	**Group**	
	Control (n = 13)	**Treatment (n = 13)**
Age	19.64 ± 1.57 years	20.01 ± 1.12 years
Height	167.55 ± 7.04 cm	170.20 ± 7.79 cm
Weight	68.24 ± 8.44 kg	74.23 ± 12.00 kg
Throwing Arm		
Right	n = 12	n = 12
Left	n = 1	n = 1
Class		
Freshman	n = 6	n = 2
Sophomore	n = 2	n = 3
Red Shirt Sophomore	n = 0	n = 1
Junior	n = 1	n = 3
Red Shirt Junior	n = 0	n = 1
Senior	n = 3	n = 3
Red Shirt Senior	n = 1	n = 0
Position		
Pitcher	n = 2	n = 3
Position Player	n = 11	n = 10

Throwing Kinematics

In attempt to understand the effect of yoga on overhead throwing performance, a series of mixed-factorial ANOVAs were conducted for the different kinematic parameters with an alpha level set *a priori* at $\alpha = 0.05$. For all kinematic analyses, the independent variable *group* contained the two levels of treatment and control, and the independent variable *time* contained the two levels of pre- and post-intervention. All descriptive statistics for overhead throwing kinematics are summarized in Table 5.

Table 5. Descriptive statistics for overhead throwing kinematics.

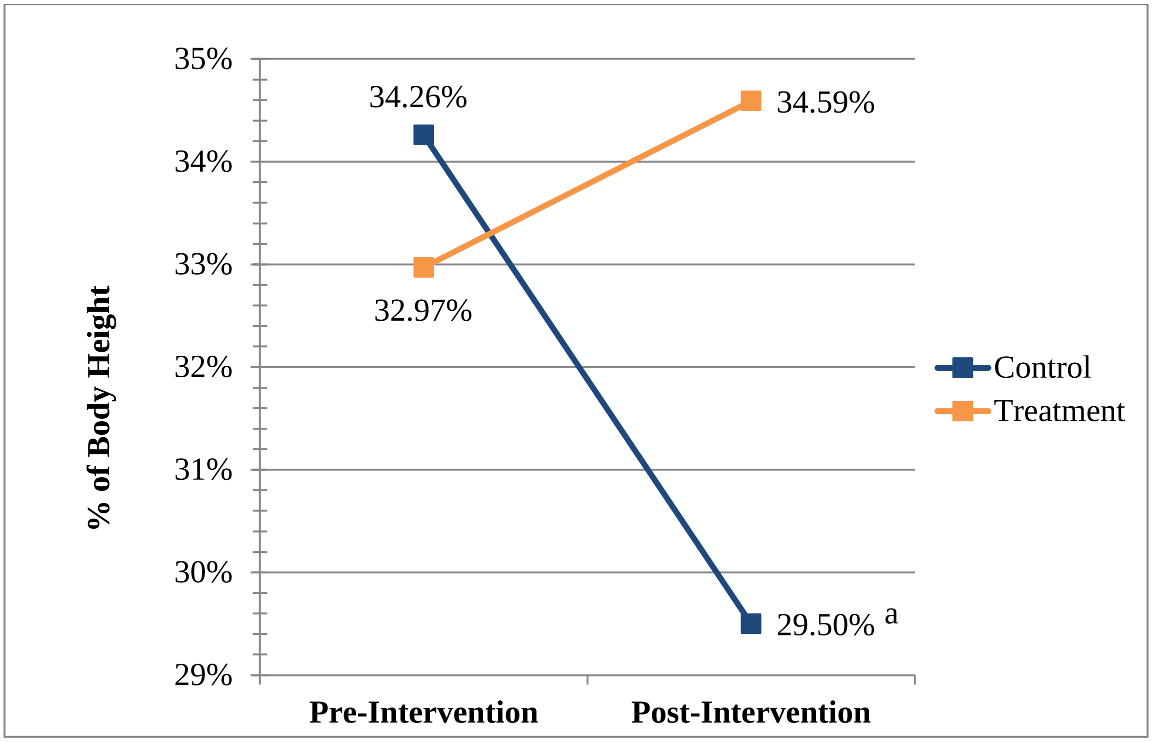
Variable (mean ± standard deviation)	**Event**	**Control**		**Treatment**	
		Pre	**Post**	**Pre**	**Post**
Stride Length (% of body height)	FC	34.26 ± 9.89	29.50 ± 12.20 [a]	32.97 ± 13.16	34.59 ± 11.35
Stride Knee Flexion (°) 0° = extension -90° = flexion	FC	-31.70 ± 11.84	-31.31 ± 11.57	-24.96 ± 15.77	-27.44 ± 13.45
	MER	-34.29 ± 11.73	-29.40 ± 7.86	-35.69 ± 14.98	-34.68 ± 10.69
	BR	-22.34 ± 14.08	-16.20 ± 11.38	-25.86 ± 15.65	-23.71 ± 14.97
	MIR	-12.74 ± 15.45	-8.60 ± 12.63	-16.23 ±16.05	-14.21 ± 18.68
Hip Rotation Stride Hip (°) [+] = ER; [-] = IR	FC	4.69 ± 13.14	4.99 ± 9.85	7.81 ± 6.34	5.86 ± 9.79
	MER	-15.82 ± 7.23	-18.39 ± 8.67	-13.74 ± 6.18	-13.06 ± 6.39
	BR	-14.13 ± 7.56	-16.36 ± 9.83	-12.18 ± 7.12	-10.13 ± 6.81
	MIR	-10.40 ± 6.95	-11.40 ± 11.54	-9.99 ± 6.84	-8.37 ± 6.10
Stance Hip (°) [+] = IR; [-] = ER	FC	1.32 ± 9.05	1.10 ± 15.08	0.99 ± 11.19	1.33 ± 10.38
	MER	-12.22 ± 8.68	-14.25 ± 9.34	-14.86 ± 10.13	-13.24 ± 10.69
	BR	-12.19 ± 7.83	-14.17 ± 9.26	-12.71 ± 11.26	-11.00 ± 11.99
	MIR	-11.16 ± 8.92	-12.27 ± 9.45	-12.31 ± 10.86	-11.38 ± 11.10
Torso Separation (°) [+] = trunk Θ >pelvis Θ [-] = trunk Θ< pelvis Θ	FC	19.07 ± 9.45	21.97 ± 10.84	23.97 ± 10.81	21.38 ± 10.32
	MER	1.05 ± 11.23	2.52 ± 8.95	6.72 ± 8.30	6.23 ± 5.79
	BR	-5.32 ± 9.23	-5.21 ± 8.70	-2.94 ± 8.16	-5.71 ± 5.39
	MIR	-5.93 ± 9.99	-6.42 ± 10.35	-5.27 ± 9.05	-7.46 ±7.13
Shoulder Kinematics Rotation (°) [+] = IR, [-] = ER	FC	-77.26 ± 19.88	-87.70 ± 24.37	-84.78 ± 27.52	-89.26 ± 22.64
	MER	-127.38 ± 20.21	-147.42 ± 15.44	-137.35 ±19.19	-143.78 ± 14.71
	BR	-101.89 ± 25.29	-113.00 ± 19.87	-106.82 ± 24.12	-112.97 ± 17.58
	MIR	-50.20 ± 22.31	-57.54 ± 27.93	-50.02 ± 34.68	-55.35 ± 23.63
Elevation (°) 0° = neutral; 90° = abduction	FC	-103.97 ± 17.06	-102.00 ± 15.34	-94.56 ± 14.59	-97.04 ± 14.18
	MER	-97.61 ± 12.46	-97.06 ± 13.38	-97.50 ± 14.29	-95.75 ± 12.98
	BR	-88.09 ± 9.65	-88.15 ± 11.46	-84.58 ± 13.15	-81.98 ± 11.07
	MIR	-81.55 ± 10.02	-81.74 ± 9.99	-78.66 ± 11.03	-76.76 ± 9.41
Plane of Elevation (°) 0° = abduction 90° = flexion	FC	-7.56 ± 18.52	-7.43 ± 16.68	-1.49 ± 14.80	-9.18 ± 16.54
	MER	19.50 ± 16.29	23.72 ± 13.67	26.90 ± 17.37	20.81 ± 12.17
	BR	22.43 ± 13.76	24.68 ±13.24	30.59 ± 13.47	23.01 ± 9.96
	MIR	42.44 ± 13.59	41.14 ± 12.89	45.86 ±15.31	36.74 ± 10 67

a – *significant difference ($p < 0.05$) from pre-intervention period value;* FC – *stride foot contact;* MER – *throwing shoulder maximum external rotation;* BR – *ball release;* MIR – *throwing shoulder maximum internal rotation;* Pre – *value measured prior to yoga intervention period;* Post – *value measured after yoga intervention period;* IR – *internal rotation;* ER – *external rotation;* Θ – *angular displacement in the transverse plane;* neutral – *anatomical position.*

Stride Length

A within-subjects 2 (group) x 2 (time) design was utilized to analyze stride length during overhead throwing. The dependent variable was the measured stride length calculated into a percent of the respective participant's body height. The null hypothesis tested stated that assuming no treatment effect, the stride length during overhead throwing for both the control group and the treatment group will not change from pre- to post-intervention. This null hypothesis was rejected given the significant *time***group* interaction [$F(1, 24) = 10.790$, $p = 0.003$, $\eta^2 = 0.310$]. These results indicated that *time* (from pre- to post-intervention) affected the treatment and control groups' stride length during overhead throwing differently. Post-hoc paired-samples t tests revealed that the control group's stride length significantly decreased from pre- to post-testing [$p = 0.008$], whereas the stride length for the treatment group did not change significantly from pre- to post-intervention [$p = 0.215$] (Figure 49). Results also yielded a non-significant main effect of *time* [$F(1, 24) = 2.624$, $p = 0.118$, $\eta^2 = 0.099$] and a non-significant main effect of *group* [$F(1, 24) = 0.179$, $p = 0.676$, $\eta^2 = 0.007$]. A comprehensive list of statistical results pertaining to stride length during overhead throwing is presented in Appendix C.

Figure 49. Stride length during overhead throwing from pre- to post-intervention.



a – *significant difference ($p < 0.05$) from pre-intervention value.*

Stride Knee Flexion

For analysis of stride knee flexion during overhead throwing, a within-subjects 2 (group) x 2 (time) x 4 (event) design was utilized with knee flexion angle in the stride leg serving as the dependent variable. For the independent variable *event*, the four levels were FC, MER, BR, and MIR. The null hypothesis tested stated that assuming no treatment effect, knee flexion angle in the stride leg during overhead throwing for both the control group and the treatment group will not change from pre- to post-intervention. Results indicated a failure to reject this null hypothesis due to a non-significant *time*group* interaction effect [$F(1, 24) = 0.334$, $p = 0.569$, $\eta^2 = 0.014$]. These results suggested that the effect of *time* (from pre- to post-intervention) on stride knee flexion angle during overhead throwing was similar for both *groups* (treatment and control). The results also yielded a significant *time***event* interaction effect [$F(1.5595, 38.291) = 9.753$, $p = 0.001$, $\eta^2 = 0.289$] suggesting that *time* (from pre- to post-intervention) and *event* (from FC to MER to BR to MIR) together affected the stride knee angle of the sample as a whole. Post-hoc paired-samples *t* tests revealed that the stride knee angle did not change significantly from pre- to post- intervention at FC [$p = 0.719$], MER [$p = 0.295$], BR [$p = 0.157$], nor MIR [$p = 0.274$]. Results of the post-hoc testing suggested that the stride knee flexion angle differences across the four events were driving the interaction between *time* and *event* and not differences from pre- to post-intervention. Furthermore, results yielded a non-significant main effect of *time* [$F(1, 24) = 0.677$, $p = 0.419$, $\eta^2 = 0.027$] and non-significant main effect of *group* [$F(1, 24) = 0.339$, $p = 0.566$, $\eta^2 = 0.014$]. A comprehensive list of statistical results pertaining to stride knee flexion angle during overhead throwing is presented in Appendix C.

Hip Rotation

Hip rotation during overhead throwing was analyzed using a within-subjects 2 (group) x 2 (time) x 4 (event) x 2 (limb) design. The four levels of the independent variable *event* were FC, MER, BR, and MIR, whereas the two levels of the independent variable *limb* were the stance leg and stride leg. The null hypothesis tested stated that assuming no treatment effect, hip rotation in the stance leg and the stride leg for both the treatment group and the control group will not change from pre- to post-intervention. Results indicated a failure to reject this null hypothesis due to a non-significant *group***time* interaction effect [$F(1, 24) = 1.373$, $p = 0.253$, $\eta^2 = 0.054$]. These results suggested that the effect of *time* (from pre- to post-intervention) on the hip rotations during overhead throwing was similar for both *groups* (treatment and control). Furthermore, results yielded a non-significant main effect of *time* [$F(1, 24) = 0.058$, $p = 0.811$, $\eta^2 = 0.002$] and non-significant main effect of *group* [$F(1, 24) = 0.666$, $p = 0.422$, $\eta^2 = 0.027$]. A comprehensive list of statistical results pertaining to hip rotation during overhead throwing is presented in Appendix C.

Torso Separation

A within-subjects 2 (group) x 2 (time) x 4 (event) design was utilized to analyze torso separation during overhead throwing. The four levels of the independent variable *event* were FC, MER, BR, and MIR. The dependent variable for this analysis was the degree of torso separation calculated as the difference between degree of pelvis axial rotation and trunk axial rotation in the transverse plane. The null hypothesis tested stated that assuming no treatment effect, the degree of torso separation for both the treatment group and the control group will not change from pre- to post-intervention. Results indicated a failure to reject this null hypothesis due to a non-significant *group***time* interaction effect [$F(1, 24) = 1.200$, $p = 0.284$, $\eta^2 = 0.048$]. These results suggested that the effect of *time* (from pre- to post-intervention) on the degree of torso separation during overhead throwing was similar for both *groups* (treatment and control). Furthermore, results yielded a non-significant main effect of *time* [$F(1, 24) = 0.137$, $p = 0.714$, $\eta^2 = 0.006$] and non-significant main effect of *group* [$F(1, 24) = 0.636$, $p = 0.433$, $\eta^2 = 0.026$]. A comprehensive list of statistical results pertaining to torso separation during overhead throwing is presented in Appendix C.

Shoulder Kinematics

For analysis of shoulder kinematics during overhead throwing, a within-subject 2 (group) x 2 (time) x 4 (event) x 3(direction) design was utilized. The independent variable *event* contained the four levels FC, MER, BR, and MIR while shoulder rotation, shoulder elevation, and shoulder plane of elevation comprised the three levels for the independent variable *direction*. The null hypothesis tested stated that assuming no treatment effect, shoulder rotation, shoulder elevation, and shoulder plane of elevation for both the treatment group and the control group will not change from pre- to post-intervention. The results indicated a failure to reject this null hypothesis due to a non-significant *group***time* interaction effect [$F(1, 24) = 0.024$, $p = 0.887$, $\eta^2 = 0.001$]. These results suggested that the effect of *time* (from pre- to post-intervention) on shoulder kinematics during overhead throwing was similar for both *groups* (treatment and control). Furthermore, results yielded a non-significant main effect of *time* [$F(1, 24) = 3.322$, $p = 0.080$, $\eta^2 = 0.122$] and non-significant main effect of *group* [$F(1, 24) = 0.205$, $p = 0.655$, $\eta^2 = 0.008$]. A comprehensive list of statistical results pertaining to shoulder kinematics during overhead throwing is presented in Appendix C.

Range of Motion

In attempt to understand the effect of yoga on passive rotational range of motion, separate mixed-factorial ANOVAs were conducted for the shoulder and hip joints with an alpha level set *a priori* at $\alpha = 0.05$. For both range of motion analyses, the independent variable *group* contained the two levels treatment and control, and the independent variable *time* contained the two levels pre- and post-intervention. All descriptive statistics for shoulder and hip rotational range of motion are summarized in Table 6.

Table 6. Descriptive statistics for shoulder and hip rotational range of motion.

Variable (mean ± standard deviation)	**Side**	**Control**		**Treatment**	
		Pre	**Post**	**Pre**	**Post**
Shoulder					
Internal Rotation (°)	Throwing Shoulder	43.56 ± 12.00	44.90 ± 5.95	45.86 ± 8.64	50.02 ± 7.04
	Non-Throwing Shoulder	50.54 ± 11.11	50.01 ± 10.07	53.29 ± 11.06	53.42 ± 5.05
External Rotation (°)	Throwing Shoulder	98.30 ± 9.55	100.43 ± 7.59	96.64 ± 11.08	94.72 ± 12.55
	Non-Throwing Shoulder	93.90 ± 10.63	98.44 ± 6.15	91.56 ± 14.92	93.04 ± 15.42
Total Arc (°)	Throwing Shoulder	141.76 ± 11.82	145.33 ± 9.43	142.50 ± 12.66	144.75 ± 13.48
	Non-Throwing Shoulder	144.44 ± 15.91	148.45 ± 7.51	139.25 ± 27.35	146.46 ± 16.47
Hip					
Internal Rotation (°)	Stance Hip	33.68 ± 10.47	35.12 ± 8.83	34.88 ± 11.36	35.12 ± 10.53
	Stride Hip	31.75 ± 7.23	32.76 ± 5.98	32.46 ± 7.16	31.84 ± 7.16
External Rotation (°)	Stance Hip	32.68 ± 5.72	33.26 ± 6.64	35.86 ± 6.84	36.77 ± 7.57
	Stride Hip	36.28 ± 4.65	36.16 ± 4.54	36.17 ± 7.54	37.24 ± 7.71
Total Arc (°)	Stance Hip	66.36 ± 10.79	68.37 ± 7.42	70.75 ± 7.53	71.89 ± 10.70
	Stride Hip	68.02 ± 8.78	68.92 ± 6.61	68.62 ± 6.31	69.08 ± 5.93

Pre – *value measured prior to yoga intervention period;* Post – *value measured after yoga intervention period;* Total Arc – *summation of internal and external rotational range of motions;* Stance Hip – *hip ipsilateral to the throwing arm;* Stride Hip – *hip contralateral to the throwing arm.*

Shoulder Range of Motion

Passive shoulder rotational range of motion was analyzed using a within-subjects 2 (group) x 2 (time) x 3 (direction) x 2 (limb) design. The independent variable *direction* contained the levels internal rotation, external rotation, and total arc of motion (the sum of external and internal range of motions). Throwing shoulder and non-throwing shoulder were used as the levels of the independent variable *limb*. The null hypothesis tested stated that assuming no treatment effect, passive shoulder internal rotation, external rotation, and total arc of motion in the throwing shoulder and non-throwing shoulder for both the treatment group and the control group will not change from pre- to post-intervention. The conclusion drawn based on the results was a failure to reject the null hypothesis due to a non-significant *group**time* interaction effect [$F(1, 24) = 0.014$, $p = 0.908$, $\eta^2 = 0.001$]. These results suggested that the effect of *time* (from pre- to post-intervention) on passive range of motion measured in both shoulders was similar for both *groups* (treatment and control). Results also yielded a significant main effect of *time* [$F(1, 24) = 8.605$, $p = 0.007$, $\eta^2 = 0.264$] suggesting that *time*, from pre- to post-intervention had an effect on shoulder passive range of motion for the sample as a whole. However, results yielded a non-significant main effect of *group* [$F(1, 24) = 0.000$, $p = 0.996$, $\eta^2 = 0.000$]. A comprehensive list of statistical results pertaining to passive shoulder range of motion is presented in Appendix C.

Hip Range of Motion

For passive hip rotational range of motion, a within-subjects 2 (group) x 2 (time) x 3 (direction) x 2 (limb) design was used. The independent variable *direction* contained the levels internal rotation, external rotation, and total arc of motion (the sum of external and internal range of motions). Stance hip and stride hip were used as the levels for the independent variable *limb*. The null hypothesis stated that assuming no treatment effect, passive hip internal rotation, external rotation, and total arc of motion in the stance hip and stride hip for both the treatment group and the control group will not change from pre- to post-intervention. The conclusion drawn based on these results was a failure to reject the null hypothesis due to a non-significant *group***time* interaction effect [$F(1, 24) = 0.136$, $p = 0.716$, $\eta^2 = 0.006$]. These results suggested that the effect of *time* (from pre- to post-intervention) on passive range of motion measured in both hips was similar for both *groups* (treatment and control). Furthermore, results yielded a non-significant main effect of *time* [$F(1, 24) = 1.613$, $p = 0.216$, $\eta^2 = 0.063$] and non-significant main effect of *group* [$F(1, 24) = 0.633$, $p = 0.434$, $\eta^2 = 0.026$]. A comprehensive list of statistical results pertaining to passive hip range of motion is presented in Appendix C.

Strength and Flexibility

In attempt to understand the effect of yoga on hamstring strength and flexibility, separate mixed-factorial ANOVAs were conducted for these two variables with an alpha level set *a priori* at $\alpha = 0.05$. For both the hamstring strength analysis and hamstring flexibility analysis, the independent variable *group* contained the two levels treatment and control, and the independent variable *time* contained the two levels pre- and post-intervention. All descriptive statistics for hamstring strength and hamstring flexibility are summarized in Table 7.

Table 7. Descriptive statistics for hamstring strength and flexibility.

Variable (mean ± standard deviation)	**Side**	**Control**		**Treatment**	
		Pre	**Post**	**Pre**	**Post**
Dynamic Control Ratio					
Extension (Hecc:Qcon)	Stance Leg	1.20 ± 0.73	1.03 ± 0.32	1.51 ± 0.74	1.07 ± 0.32
	Stride Leg	1.28 ± 1.01	0.96 ± 0.20	1.41 ± 0.31	1.14 ± 0.73
Flexion (Hcon:Qecc)	Stance Leg	0.43 ± 0.17	0.61 ± 0.35	0.53 ± 0.27	0.48 ± 0.16
	Stride Leg	0.39 ± 0.13	0.63 ± 0.26	0.42 ± 0.17	0.58 ± 0.32
Passive Knee Extension Test (°) 0° = knee extension 90° = knee flexion	Stance Leg	54.31 ± 11.22	55.28 ± 8.83	40.97 ± 15.13	48.39 ± 15.96
	Stride Leg	52.00 ± 12.58	57.66 ± 12.08	42.37 ± 17.08	45.35 ± 17.87

Pre – *value measured prior to yoga intervention period;* Post – *value measured after yoga intervention period;* Stance Leg – *leg ipsilateral to the throwing arm;* Stride Leg – *leg contralateral to the throwing arm.* Dynamic Control Ratio Extension – *ratio calculated based on peak torque to describe the eccentric hamstring strength relative to the concentric quadriceps strength during maximal effort knee extension;* Dynamic Control Ratio Flexion – *ratio calculated based on peak torque to describe the concentric hamstring strength relative to the eccentric quadriceps strength during maximal effort knee flexion;* Passive Knee Extension Test – *higher values indicate lesser hamstring flexibility, lower values indicate greater hamstring flexibility.*

Hamstring Strength

For hamstring strength, a within-subjects 2 (group) x 2 (time) x 2 (limb) x 2 (direction) design was utilized. Stance leg and stride leg were used as the levels for the independent variable *limb*. Additionally included as an independent variable was *direction,* and the two levels were knee flexion and knee extension. The null hypothesis stated that assuming no treatment effect, the dynamic control ratios for knee extension (H_{ecc}:Q_{con}) and knee flexion (H_{con}:Q_{ecc}) in the stance leg and the stride leg for both the treatment group and the control group will not change from pre- to post-intervention. The conclusion drawn based on the results was a failure to reject the null hypothesis due to a non-significant *group**time* interaction effect [$F(1, 19) = 1.705$, $p = 0.207$, $\eta^2 = 0.082$]. These results suggested that the effect of *time* (from pre- to post-intervention) on the calculated strength profiles of the hamstrings in the stride and stance legs was similar for both *groups* (treatment and control). Furthermore, results yielded a non-significant main effect of *time* [$F(1, 19) = 0.125$, $p = 0.727$, $\eta^2 = 0.007$] and non-significant main effect of *group* [$F(1, 19) = 2.185$, $p = 0.156$, $\eta^2 = 0.103$]. A comprehensive list of statistical results pertaining to hamstring strength is presented in Appendix C.

Hamstring Flexibility

Finally, a within-subjects 2 (group) x 2 (time) x 2 (limb) design was used for analysis of hamstring flexibility. For the independent variable *limb*, stance leg and stride leg comprised the two levels. The null hypothesis stated that assuming no treatment effect, hamstring flexibility in the stance leg and the stride leg for both the treatment group and the control group will not change from pre- to post-intervention. Results of statistical testing led to the conclusion of a failure to reject this null hypothesis based on a non-significant *group***time* interaction effect [$F(1, 24) = 0.324$, $p = 0.574$, $\eta^2 = 0.013$]. These results suggested that the effect of *time* (from pre- to post-intervention) on the measured hamstring flexibility in the stride and stance legs was similar for both *groups* (treatment and control). Furthermore, results yielded a non-significant main effect of *time* [$F(1, 24) = 0.201$, $p = 0.658$, $\eta^2 = 0.008$] but a significant main effect of *group* [$F(1, 24) = 5.088$, $p = 0.033$, $\eta^2 = 0.175$]. This significant main effect of group suggested that the two groups differed in degree of hamstring flexibility, but the changes over time were comparable. A comprehensive list of statistical results pertaining to hamstring strength is presented in Appendix C.

Yoga Exit Survey Responses

In an attempt to gauge the participants' subjective experience practicing yoga, a Likert Questionnaire (Appendix D) was completed by each participant following the yoga intervention. Participants were asked to rate their level of agreement on a 1-5 scale with statements pertaining to yoga and hip flexibility, shoulder flexibility, spinal mobility, lower body strength, softball functional performance, body mindfulness, mental relaxation, physical relaxation, enjoyment, and continuation of practice. Descriptive statistics for each question are presented in Table 8.

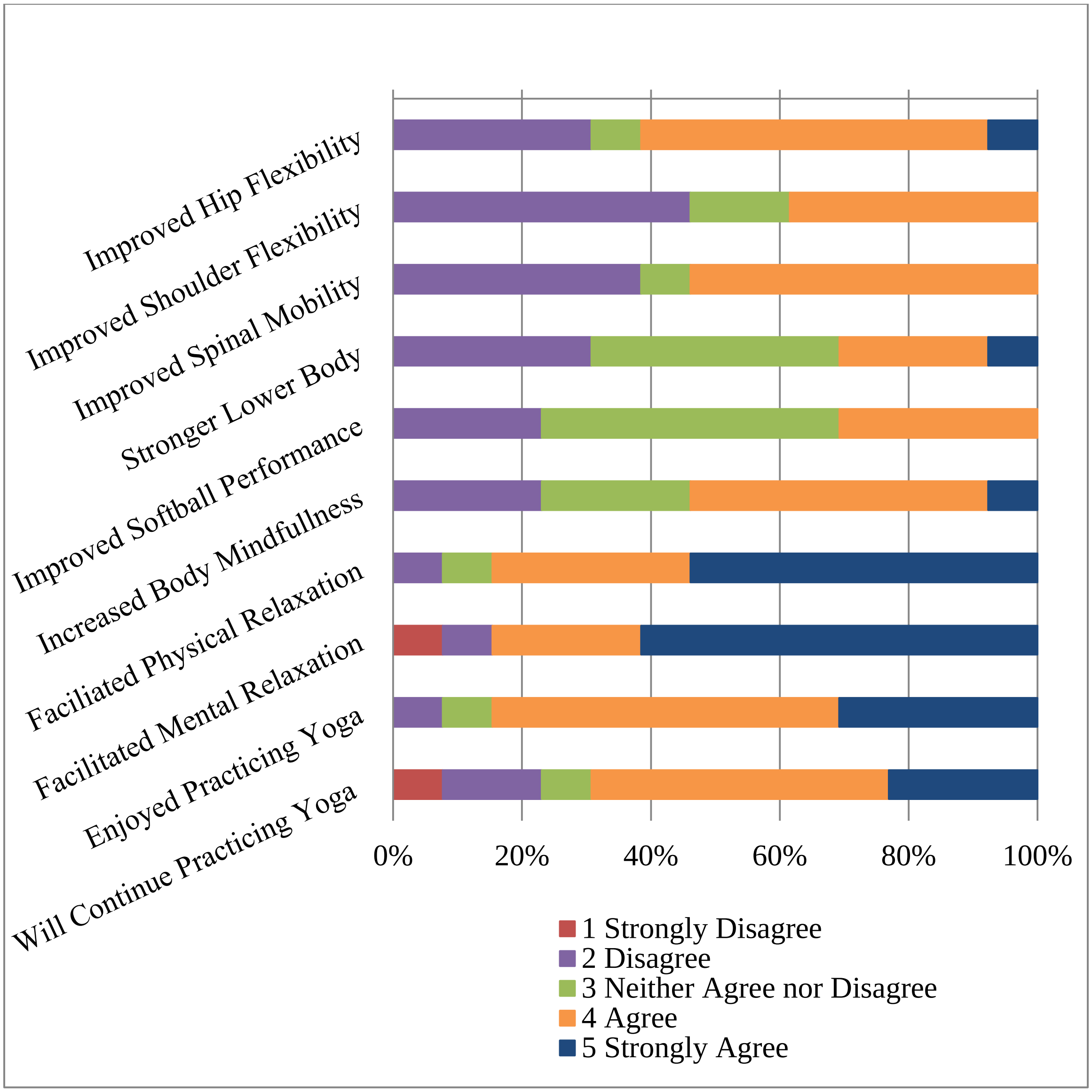
Table 8. Descriptive statistics for yoga exit survey responses.

Statement	Mode	Mean ± Standard Deviation
I felt more flexible in my hips as a direct result of practicing yoga for six weeks.	4	3.38 ± 1.04
I felt more flexible in my shoulders as a direct result of practicing yoga for six weeks.	2	2.92 ± 0.95
I felt more flexible in my spine as a direct result of practicing yoga for six weeks.	4	3.15 ± 0.99
I felt stronger in my lower body as a direct result of practicing yoga for six weeks.	3	3.08 ± 0.95
Practicing yoga improved my functional performance on the softball field.	3	3.08 ± 0.76
I am more mindful and aware of my body as a result of practicing yoga for six weeks.	4	3.38 ± 0.96
Practicing yoga allowed me to physically decompress and relax after softball training.	5	4.31 ± 0.95
Practicing yoga allowed me to mentally decompress and relax after softball training.	5	4.23 ± 1.30
I enjoyed my time spent practicing yoga for six weeks.	4	4.08 ± 0.86
If given the opportunity, I would continue practicing yoga to supplement my softball training.	4	3.62 ± 1.27

Mode: 1 – *Strongly Disagree;* 2 – *Disagree;* 3 – *Neither Agree nor Disagree;* 4 –*Agree;* 5 – *Strongly Agree.*

The categorical breakdowns of what percentage of participants agreed with or disagreed with each statement are presented in Figure 50. Participants generally reported feeling more flexible in the hips as 61.53% of participants agreed or strongly agreed that hip flexibility improved as a direct result of practicing yoga for six weeks. By comparison, only 30.77% of participants disagreed or strongly disagreed with this statement. In terms of shoulder flexibility, participants were generally split on the effectiveness of yoga at improving shoulder flexibility: 46.15% of participants disagreed or strongly disagreed, 38.46% agreed or strongly agreed, and 15.38% neither agreed nor disagreed with the statement that shoulder flexibility directly improved as a result of practicing yoga for six weeks. A similar trend was shown in the effectiveness of yoga on improving spinal mobility: 53.84% of participants agreed or strongly agreed, 38.46% disagreed or strongly disagreed, and 7.69% of participants neither agreed nor disagreed that practicing yoga for six weeks directly improved spinal mobility. Participants were also generally split on the effectiveness of practicing yoga on improving lower body strength: 30.76% agreed or strongly agreed, 30.77% disagreed or strongly disagreed, and 38.46% neither agreed nor disagreed with the statement that practicing yoga for six weeks directly improved lower body strength. Additionally, participants generally reported that practicing yoga for six weeks neither positively nor negatively affected functional softball performance. Responses indicated that 46.15% neither agreed nor disagreed, 30.77% either agreed or strongly agreed, and 23.08% either disagreed or strongly disagreed with the statement pertaining to yoga and softball performance. Body mindfulness seemingly was affected by practicing yoga as 53.84% of participants reported agreeing or strongly agreeing with the statement that body mindfulness directly improved as a result of practicing yoga for six weeks. In contrast, only 23.07% disagreed or strongly disagreed with that statement. Perhaps the most substantial effect as reported by the participants was the effect of yoga on facilitating both mental and physical relaxation. For mental relaxation, 84.60% of participants agreed or strongly agreed with the statement that practicing yoga for six weeks facilitated mental relaxation, whereas only 15.38% reported disagreeing or strongly disagreeing with that statement. For physical relaxation, 84.61% of participants agreed or strongly agreed with the statement that practicing yoga for six weeks facilitated physical relaxation, whereas only 7.69% reported disagreeing or strongly disagreeing with that statement. A strong majority of participants, 84.61%, reported agreeing or strongly agreeing with the statement that they enjoyed the six weeks spent practicing yoga. Only 7.69% of participants reported disagreeing with or strongly disagreeing with that statement. Finally, 69.22% of participants reported that they would continue practicing yoga, if given the opportunity, whereas 23.07% reported that they do not wish to continue yoga practice.

Figure 50. Yoga exit survey responses as a percentage of the surveyed sample.



CHAPTER V.

DISCUSSION

The primary objectives of this research study were to evaluate the effects of implementing yoga practice during the fall competitive season for a NCAA Division I softball team on 1] lower extremity, lumbopelvic-hip complex, and upper extremity kinematics during overhead throwing, 2] shoulder and hip rotational range of motion, and 3] hamstring strength and flexibility. This chapter presents the discussion and conclusions drawn from the current research study and is divided into the following subsections: 1] the effect of yoga on lower extremity, lumbopelvic-hip complex, and upper extremity kinematics during overhead throwing, 2] the effect of yoga on passive shoulder and hip rotational range of motion, 3] the effect of yoga on hamstring strength and flexibility and 5] conclusions and suggestions for future research.

Throwing Kinematics

Overhead throwing is a total body motion that requires a complex interaction of body segments and necessitates substantial amounts of strength, flexibility, and range of motion in order to be performed with optimal mechanics. Sports training programs are designed to target athletes’ strength, flexibility, and range of motion with the goal of translating these parameters directly to the field of play. Yoga in the Western world has become a systematic training program for improving physical characteristics related to fitness and even improving sports performance (Gharote et al., 1976). Previous research on athletes practicing yoga has indicated that yoga can improve running time for track and field athletes (Donohue et al., 2006) and may improve hip and trunk rotations during the skating stride of the Olympic speed skaters (Brunelle et al., 2015). These two studies support the claim that practicing yoga may either directly or indirectly improve sport performance for athletes. A primary component of sports performance for collegiate softball players is the overhead throw. Softball athletes work diligently on and off the field to perfect their throwing mechanics in order to gain a competitive advantage by improving functional performance and preventing injury. However, to the author’s knowledge, yoga had not been investigated as a training tool for collegiate softball athletes prior to the current study. It was hypothesized that practicing yoga may be beneficial to throwing athletes based on the known positive effects of yoga on strength and range of motion as well as the known importance of these two physical characteristics to the overhead throwing motion. The current study investigated the effects of a NCAA Division I softball team practicing yoga during a fall competitive season. Specifically, this section examines the effects of practicing yoga on overhead throwing kinematics including: stride length, stride knee flexion, hip rotation, torso separation, shoulder rotation, shoulder elevation, and shoulder plane of elevation. A statistically significant *time*group* interaction effect was discovered for stride length at foot contact during the throwing motion. While no other statistically significant effects were found, noteworthy trends were shown for stride knee flexion, shoulder rotation, and shoulder plane of elevation.

Stride Length

The stepping motion of the forward stride during an overhead throw is a primary mechanism used to generate forward momentum as it helps to direct subsequent movements towards the intended target. A sufficient stride length must be long enough to passively stretch muscles in the lower extremities and torso, but not too long that the athlete loses ability to control motion of these segments (Dillman et al., 1993). Much of the previous research examining stride length during overhead throwing has utilized baseball pitchers, and the consensus in the literature is that during a baseball pitch, stride length should be approximately 80-85% of standing height (Chu et al., 2009; Fleisig et al., 1999; Elliott et al., 1986; Stodden et al., 2006a). Additionally, research that examined position players instead of pitchers supports an optimal stride length of 80-85%, although throws were made using a crow-hop (Fleisig et al., 2011). The crow-hop has been examined previously during long-toss throws and utilizes a sequence of steps with the stride foot, stance foot, then stride foot again in an effort to facilitate lower extremity motion during the throw (Fleisig et al. 2011; Slenker et al., 2014). Although, there is no published description of the exact footwork during the crow-hopping motion, thus no consensus among clinicians and coaches as to what is pattern of footwork is most beneficial to the athlete (Slenker et al., 2014). To the author’s knowledge, no previous studies have examined stride length during overhead throwing utilizing a simple step-and-throw action. Therefore, in terms of stride length, comparisons of data from the current study to previous research that examined pitchers and position players throwing with a crow-hop were not appropriate. However, the current study began to establish normative data for relative stride length using a step-and-throw action during maximal effort overhead throwing.

Results of the current study suggested that practicing yoga for six weeks during a fall competitive season had a significant effect on relative stride length during overhead throwing. Relative stride length significantly decreased for the control group from 34.26% prior to the intervention period to 29.50% following the 6-week intervention period. By comparison, relative stride length for the treatment group actually increased from 32.97% pre-intervention to 34.59% after six weeks of yoga practice. Because this was not a statistically significant increase, it was postulated that the treatment group maintained a stride length comparable to the pre-intervention percentage of standing height. In contrast, the control group was unable to maintain a stride length comparable to pre-intervention period. In fact, a 4.76% deficit in relative stride length equals a 7.98 cm decrease in absolute stride length for the control group. Thus, the important conclusion that was drawn from these results was that practicing yoga during a competition and training period appeared to have a maintenance effect on stride length for these participants.

In the fall season during which the testing and intervention protocols for the current study were implemented, the participants underwent a rigorous training regimen. The participants had 3-hour long softball practices four days per week in addition to 1-hour long conditioning workouts three days per week and 1-hour long strength training workouts on three days per week separate from the conditioning workouts. Participants also competed in eight games over the course of four weekends throughout the duration of this study. This demanding training load can deplete the athletes' associated physical and physiological systems and limit the desired training effect. The desired adaptation to training can be accelerated, and functional performance thereby improved, when the residual fatigue effect from training is minimized (Calder, 2005). Helping to minimize this residual, acute effect of fatigue are recovery practices such as active rest and dynamic stretching (Calder, 2005). Yoga practice includes active rest in the form of light movement and deep breathing exercises as well as dynamic stretching in the form of transitioning into and out of the asanas, or yoga poses. Furthermore, Calder (2005) proposed that the end of a training session is the ideal time for active recovery methods in order to maximize benefits. In the current study, yoga was practiced immediately following morning strength/conditioning workouts, and 84.61% of participants reported that yoga helped facilitate physical relaxation after a workout. Therefore, the addition of yoga to a training program may have assisted in the active recovery of the participants after a strenuous practice or workout, and may have allowed certain aspects of throwing performance, such as stride length, to be maintained over the course of a competition season despite the training load.

Stride Knee Flexion

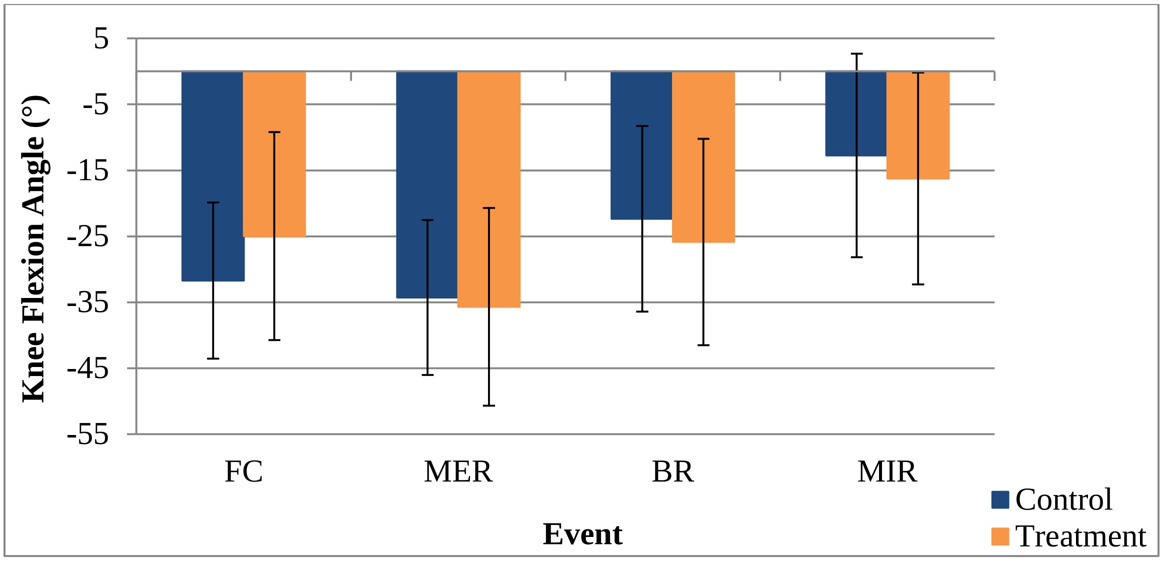
The role the stride knee plays in transmitting forces through the kinetic chain has been previously described in baseball pitchers (Chu et al., 2009; Tippett, 1986). After ground foot contact, the stride knee initially flexes in order to absorb the impact of foot contact with the ground and to slow down forward motion of the lower body (Chu et al., 2009). The stride knee then begins to extend in order to brace the lower body for forceful arm acceleration, and this knee extension allows the femur to function as a lever for the athlete to pivot upon (Tippett, 1986). This posting action on the stride leg, commonly seen in pitchers, is believed to be a consequence of the athlete attempting to gain ball velocity (Tippett et al., 1986).

Knee kinematics during throwing have been studied primarily in baseball pitchers (Chu et al., 2009; Tippett, 1986; Matsuo et al., 2001; Stodden et al., 2005; Seroyer et al., 2010) who have an exaggerated stride compared to the step-and-throw action utilized in the current study. Because of this exaggerated stride, some differences were to be expected in knee kinematics when comparing pitchers to the participants in the current study. Male baseball pitchers presented with 55° (Chu et al., 2009) and 49° (Stodden et al., 2005) of knee flexion at the instance of stride foot contact, whereas female baseball pitchers presented with 50° of knee flexion (Chu et al., 2009). Furthermore, during long-toss throwing, pitchers reportedly have 46°, 44°, and 42° of stride knee flexion at foot contact for a 37 m, 55 m, and a maximum distance throw (Fleisig et al., 2011). By comparison, the participants in the control group, from the current study, presented with 31.70° of knee flexion at foot contact pre-intervention and 31.31° post-intervention whereas these values were 24.96° and 27.44°, respectively, for the treatment group during a 25.60 m throw. It was postulated that the participants, in the current study, had a more extended knee at foot contact compared to data from previous literature due to the abbreviated stride length. A shortened stride length could have caused the athlete to be more upright with the weight of the body more over the stride foot as it contacted the ground.

It is known that from foot contact to maximal external rotation, stride knee flexion should occur to assist in absorption of force and the slowing of lower body forward motion (Chu et al., 2009). Results of the current study revealed a similar trend. Participants in the control group demonstrated a 2.59° increase in knee flexion from foot contact to maximal external rotation prior to the intervention period. This increase in knee flexion from foot contact to maximal external rotation was also present in the treatment group prior to the intervention, although the increase was a slightly larger 10.73°. Previous research has indicated that from foot contact during long-toss throwing, pitchers extended the stride knee to 36°, 33°, 31° at ball release during a 37 m, 55 m, and a maximum distance throw, respectively (Fleisig et al., 2011). Stride knee flexion data at maximal external rotation were not reported in that study so conclusions cannot be drawn about initial knee flexion after foot contact. Additionally, research has shown that male pitchers' stride knee continually extends from the instant of maximal external rotation through the termination of the pitch in an effort to increase ball velocity, although, that same study suggested that this was not the case for female baseball pitchers (Chu et al., 2009). Females continually flex the stride knee from foot contact to ball release as the knee flexion angle was 62° at ball release compared to 50° at foot contact (Chu et al., 2009). Thus, it was speculated by Chu et al. (2009) that these females absorbed too much energy in the lower extremity instead of effectively transferring it up the kinetic chain to the pelvis and trunk. Data, from the current study, indicated that the participants' stride knee flexion pattern more closely mirrored that of the male pitchers from the Chu et al. (2009) study. The males in that study extended the stride knee from 55° at foot contact to 41° at ball release. The control group participants prior to the intervention period flexed the knee from 31.70° at foot contact to 34.29° at maximal external rotation then extended to 22.34° at ball release. The treatment group followed a similar trend prior to the intervention: flexed the knee from 24.96° at foot contact to 35.69° at maximal external rotation then extended to 25.86° at ball release. Flexing the knee after foot contact and prior to knee extension during arm acceleration could be a mechanism used by the athlete to eccentrically load the quadriceps in preparation for forceful knee extension. Chu et al. (2009) speculated that female baseball pitchers used the stride knee more to regain balance after the stride instead of to facilitate torso and upper extremity motion. This explanation was plausible due to the substantially longer stride length seen in the female pitchers (Chu et al., 2009) compared to the female throwers using a step-and-throw action in the current study. It is possible that over-striding may require additional knee flexion in order to slow forward momentum. With a shorter stride, as present in the current study, the thrower may have been capable of decreasing forward momentum with less knee flexion, thus was able to forcefully extend the knee during arm acceleration.

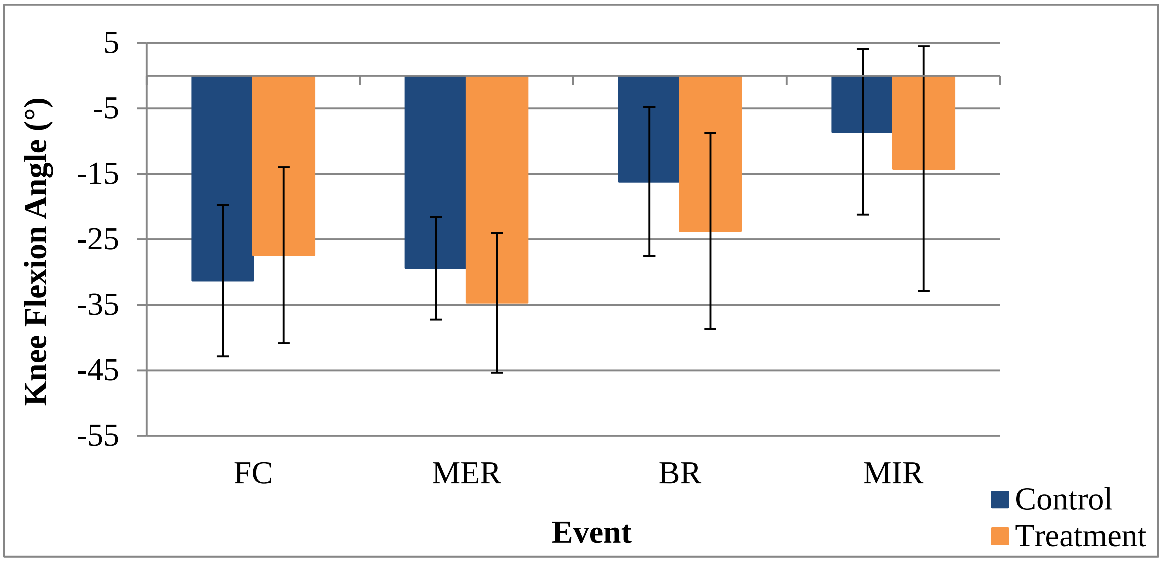
Practicing yoga for six weeks may have had a small maintenance effect in terms of stride knee flexion during overhead throwing for the participants in the treatment group. Although no statistically significant differences were found in either group from pre- to post-intervention, a noteworthy trend in the data was discovered (Figures 51-52). Following the intervention period, the control group may have no longer initially flexed the stride knee after foot contact but instead continually extended the knee from foot contact all the way through ball release. By comparison, the treatment group maintained the pattern of stride knee flexion from foot contact to maximal external rotation then knee extension through ball release following the yoga intervention. It was speculated by the author that the absence of any knee flexion after foot contact in the control group may have reduced the ground reaction force absorption by the knee musculature. Additionally, the lack of knee flexion in this group may have diminished the eccentric loading of the quadriceps thus decreased the amount of force generated by the lower extremity. However, it was difficult to draw conclusions from these data because of the lack of statistical support, but this trend may be more evident in a larger sample. Regardless, practicing yoga for six weeks during a fall competitive season potentially had a small maintenance effect for the athletes in terms of knee kinematics during overhead throwing.

Figure 51. Pre-intervention period stride knee flexion angles across four events in the throwing cycle.



FC – *stride foot contact;* MER – *throwing shoulder maximum external rotation;* BR – *ball release;* MIR – *throwing shoulder maximum internal rotation. 0° = knee extension; -90° = knee flexion.*

Figure 52. Post-intervention period stride knee flexion angles across four events in the throwing cycle.



FC – *stride foot contact;* MER – *throwing shoulder maximum external rotation;* BR – *ball release;* MIR – *throwing shoulder maximum internal rotation. 0° = knee extension; -90° = knee flexion.*

Hip Rotation

The hips are crucial joints to an effective throwing motion as the lower extremities and pelvis provide approximately 50% of the total energy in the kinetic chain during overhead throwing (Kibler, 2006). Hip kinematics during overhead throwing have been previously investigated in baseball pitchers (Dillman et al., 1993; Tippett, 1986) and these authors have described it as follows: during the windup phase, internal rotation of the stance hip allows for the torso to rotate around the planted leg, effectively loading pelvis and trunk musculature in preparation for the stride phase. Following windup, the lower extremities begin to align themselves with the intended target and this is accomplished via stride and stance hip external rotation. Stride hip external rotation prepares the stride leg for foot contact whereas stance hip external rotation assists with generating the necessary power for the forward striding motion. As the throwing arm cocks back into maximal external rotation, pelvic rotation towards the intended target is initiated and is achieved via stride hip internal rotation in conjunction with stance hip external rotation. Though these hip kinematics have only been described in pitchers, the pattern can be used as a template for general overhead throwing.

The participants from both groups, in the current study, followed the pattern of hip motion during overhead throwing previously described by Dillman et al. (1993) and Tippett (1986) for pitchers. For the control group, prior to the intervention period, the stride hip was externally rotated 4.69° at foot contact, internally rotated to 15.82° at maximal shoulder external rotation, and then remained internally rotated 14.13° at ball release. The treatment group followed a comparable pattern prior to the intervention: the stride hip was externally rotated 7.81° at foot contact, internally rotated to 13.74° at maximal shoulder external rotation, and then remained internally rotated 12.18° at ball release. The stance hip for the control group, prior to the intervention, was internally rotated 1.32° at foot contact, externally rotated 12.22° at maximal shoulder external rotation, and then remained externally rotated 12.19° at ball release. Again, the treatment group followed a similar pattern prior to the intervention: the stance hip was internally rotated 0.99° passed neutral at foot contact, externally rotated to 14.86° passed neutral at maximal shoulder external rotation, and then remained externally rotated 12.71° at ball release.

Proper hip range of motion, strength, stability, and neuromuscular control are paramount for optimal throwing mechanics (Robb et al., 2010; Dillman et al., 1993; Tippett, 1986). Therefore, exercises that promote mobility, flexibility, and dynamic stability of the hips and pelvis are crucial to the training programs for throwing athletes. For this reason, yoga was implemented into the training regimen of softball athletes in the current study. Results revealed no evidence that practicing yoga for six weeks, as a supplementation to current softball training protocols, had an effect on the hip rotation during overhead throwing. After six weeks, participants still demonstrated the same hip rotational pattern described above and reported previously by Dillman et al. (1993) and Tippett, (1986). Additionally, the degrees of hip rotation did not significantly change from the pre-intervention values for either group. The participants in the current study, on average, have been playing competitive softball for 12.28 years. Thus, it was logical to believe that practicing yoga for six weeks was not a sufficient amount of time to elicit a change in throwing mechanics. As the yoga intervention was designed to target the hips, it was possible that the intervention caused a change in hip kinematics outside the parameters of this study. It was also possible that the yoga intervention may not have specifically targeted hip rotation, therefore the hip rotational pattern during overhead throwing was unaffected by the intervention. Additionally, the training load during the fall season may have included adequate stretching and strengthening exercises such that all participants, from the current study, were able to maintain comparable hip rotational patterns after six weeks despite the rigorous training volume. Such a large training load may have also prevented the participants from partaking in the yoga intervention with enough vigor for a change in hip rotation during overhead throwing to be realized.

Torso Separation

Torso separation is defined as the rotational separation, in the transverse plane, between the pelvis and trunk segments. Alternatively stated, torso separation is the degree of trunk axial rotation subtracted from the degree of pelvis axial rotation. Torso separation is a critical component of optimal kinetic chain sequencing during throwing and is additionally an indicator of mature throwing mechanics (Chu et al., 2009; Stodden et al., 2006a). During the stride phase of the throwing motion, the pelvis should begin rotating towards the intended target before the initiation of trunk rotation (Dillman et al., 1993). When sequenced properly, the rotation of the pelvis and trunk allowed for energy to be transferred through the body in a proximal-to-distal fashion such that the greatest angular velocity is realized in the most distal segment, the hand (Pappas et al., 1985; Putnam, 1993; Bunn, 1972). The outcome of this pelvis and trunk rotational sequencing was a *lag-effect* in which the trunk remained closed, or rotated away from the target, whereas the pelvis had already opened up, or rotated towards the intended target. The lagging of the trunk was allegedly due to the inertial characteristics of the combined mass of the upper body resisting angular motion towards the target and eccentrically loaded trunk musculature in preparation for trunk and shoulder rotation (Stodden et al., 2006a).

Previous research has examined torso separation in baseball pitchers (Chu et al., 2009; Stodden et al., 2001). As baseball pitching is the most ballistic type of overhead throw, it was expected that the degrees of torso separation would be greater in baseball pitchers compared to those observed during the step-and-throw action utilized in the current study. At the instant of stride foot contact, Chu et al. (2009) reported a torso separation angle of 56° for males and a significantly diminished angle of 40° in females.

Stodden et al. (2001) corroborated these results and reported that male baseball pitchers' torso separation angle was 46°. These values indicated that the trunk rotationally lagged behind the pelvis for a right-handed pitcher; the pelvis faced more towards home plate while the trunk faced more towards third base. In the current study, prior to the intervention period, participants exhibited less torso separation than baseball pitchers from previous research: 19.07° for the control group and 23.97° for the treatment group. As the throwing motion progressed passed foot contact, data from the current study illustrated that the participants followed a similar pelvis and trunk rotational sequencing pattern when compared to existing literature. Stodden et al. (2001) previously described this rotational sequencing pattern in baseball pitchers and reported that the trunk initially lagged behind the pelvis at foot contact but overcame it as the arm was accelerated forward and the ball was released. Corroborating this rotational sequencing pattern of the pelvis and trunk was data from the current study: in the control group, prior to the intervention, the torso separation angle decreased from 19.07° at foot contact to 1.05° at maximal external rotation then the trunk rotated to 5.32° passed the pelvis at ball release. Similarly, in the treatment group, the torso separation angle decreased from 23.97° at foot contact to 6.72° at maximal external rotation then the trunk rotated to 2.94° passed the pelvis at ball release. The attenuated degrees, in the current study, seem logical because pitching consists of an exaggerated motion compared to the step-and-throw action; thus greater values of separation between the pelvis and trunk were expected during pitching.

Results of the current study revealed no evidence that practicing yoga for six weeks had an effect on the torso separation angle during overhead throwing. The pattern of the trunk initially lagging behind the pelvis at foot contact and maximal external rotation, and then rotating passed the pelvis at ball release and maximal internal rotation remained similar for both groups from pre- to post-intervention. Furthermore, there were no statistically significant changes in magnitude of separation over time at any of the four events examined. It was postulated that brief, 20-minute yoga sessions three days per week for six weeks were perhaps of insufficient duration to cause any substantial changes to throwing mechanics in a sample that had been throwing for 12+ years. There was also the possibility that the yoga intervention did not specifically target spinal and pelvic rotation that could, theoretically over time, cause a change in the torso separation pattern during throwing. Finally, there is an important temporal relationship between segments associated with this torso rotational sequencing. Torso separation promotes the storage then recovery of potential energy in the trunk musculature as long as trunk rotation immediately follows the eccentric loading of trunk musculature. The rapid transition from eccentric to concentric contraction of a muscle has been shown to enhance concentric muscle action as a result of the stretch reflex within the muscle and is known as the stretch shortening cycle (Newton et al., 1997). Therefore, torso separation may only be beneficial to the thrower if the stretch shortening cycle is taken advantage of and the rotations of the pelvis and trunk are appropriately timed. It was possible that the yoga intervention may not have targeted the temporal relationship between the pelvis and trunk, thus there were no changes in torso separation magnitude or the rotational sequencing pattern in either group from pre- to post-intervention.

Shoulder Kinematics

Overhead throwing is a highly ballistic motion that requires gross, dynamic movements of the shoulder. It has been reported that during pitching, the throwing shoulder externally rotates to over 175° and then rapidly internally rotates to as far as 100° in as little as 0.42-0.58 seconds (Dillman et al., 1993; Pappas et al., 1985). Angular velocities in the upper extremity reportedly exceed 7000°/second in elite pitchers in order to accelerate the ball (Dillman et al., 1993; Pappas et al., 1985). The biomechanics of the pitching motion has been extensively described previously (Dillman et al., 1993; Tippett, 1986; Fleisig et al., 1996; Wilk et al., 2000; Fortenbaugh et al., 2009; Nissen et al., 2009; Davis et al., 2009; Dun et al., 2008), and this literature can serve as a template to describe upper extremity motion during maximal effort overhead throwing. Dillman et al. (1993) has thoroughly described the motion of the shoulder during baseball pitching as follows: as the hands separate during the windup, the throwing shoulder begins to elevate (abduct) slightly. The shoulder then continually elevates and externally rotates as the pitcher strides forward towards the target. When the stride and shoulder motion up to this point in the pitch cycle are coordinated properly, the shoulder should be in a semi-cocked (elevated, slightly externally rotated, and horizontally abducted) position at foot contact. From foot contact, the shoulder continues to elevate, externally rotate, and horizontally adducts until a completely arm-cocked position is achieved. Forceful shoulder internal rotation, slight shoulder adduction, and horizontal abduction occur as the arm is then accelerated forward until ball release. After ball release, rapid shoulder adduction occurs in conjunction with continued shoulder internal rotation and horizontal adduction.

Table 9 presents a description of shoulder kinematic data from the current study compared to previous literature describing shoulder kinematics during pitching and overhead throwing. In general, participants in the current study exhibited shoulder kinematics during overhead throwing comparable to that described by Dillman et al. (1993) for pitchers. At stride foot contact, the throwing shoulder for participants in both groups was in a position of elevation, external rotation, and horizontal abduction. The exact degree of external rotation and plane of elevation (horizontal ab/adduction) at foot contact varies amongst different sports and types of throws, but shoulder elevation should remain at approximately 90° (Fleisig et al., 1996). Pre-intervention values of shoulder elevation at foot contact for participants in both groups in the current study were slightly greater than 90°, but still well within the safe, 80°-120° range recommended by Dillman et al., (1993). This range of shoulder elevation is believed to be the strongest, most dynamic position for the shoulder as angular deviations outside this range between foot contact and ball release during throwing are indicative of pathomechanics (Dillman et al., 1993). There were no deviations outside the 80°-120° range observed in the current study prior to or following the intervention. From foot contact to maximal external rotation, the throwing shoulder for participants in both groups substantially externally rotated and horizontally adducted such that the humerus was now anterior to the frontal plane of the trunk, consistent with existing literature (Dillman et al., 1993; Fleisig et al., 1996). The arm was next accelerated forward to ball release. In the current study, participants in both groups exhibited shoulder internal rotation, slight shoulder adduction, and horizontal adduction of the shoulder during this acceleration phase. The difference in shoulder kinematics, between what was observed in the current study and what has been previously reported, occurred as the thrower approached ball release. Previous literature has reported that the shoulder horizontally abducts to near 0° during forceful internal rotation in the acceleration phase (Dillman et al., 1993; Fleisig et al., 1996). Prior to the intervention, participants in both groups exhibited continual horizontal adduction from foot contact through shoulder maximal internal rotation. Excessive horizontal adduction at ball release can place an increased load on the posterior shoulder musculature that is responsible for decelerating the humerus after the ball has been released (Fleisig et al., 1996). Consequently, it has been found that rotator cuff tears are most common during arm deceleration as a result of tensile failure from these muscles attempting to slow the internally rotating and horizontally adducting humerus (Fleisig et al., 1996). Shoulder horizontal abduction prior to ball release may function to reduce the amount of force required of the rotator cuff to slow the arm during the arm deceleration phase.

Table 9. Shoulder kinematics during overhead throwing from the current study compared to existing literature.

Reference	**Sample**	**Event**	**Shoulder Rotation (°)**		**Shoulder Elevation (°) [Abduction]**		**Plane of Elevation (°) [Horizontal Ab/Adduction]**	
			Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
Current Study *	Collegiate Softball Players; Control Group (n = 13)	FC	77.26	87.70	103.97	102.00	-7.56	-7.43
		MER	127.38	147.42	97.61	97.06	19.50	23.72
		BR	101.89	113.00	88.09	88.15	22.43	24.68
		MIR	50.20	57.54	81.55	81.74	42.44	41.14
	Treatment Group (n =13)	FC	84.78	89.26	94.56	97.04	-1.49	-9.18
		MER	137.35	143.78	97.50	95.75	26.90	20.81
		BR	106.82	112.97	84.58	81.98	30.59	23.01
		MIR	50.02	55.35	78.66	76.76	45.86	36.74
Fleisig et al., 1996	High school and collegiate baseball pitchers; (n = 26)	FC	67 ± 21		93 ± 12		-17 ± 12	
		Max	173 ± 10				18 ± 8	
		BR			93 ± 9		7 ± 7	
Dillman et al., 1993	Collegiate and professional baseball pitchers; (n = 29)	FC	53				-30	
		Max	178		100		14	
		BR	105		95		0	
Sakurai et al., 1993	Baseball pitchers; (n = 6)	FC	106 ± 22		83 ± 12		-20 ± 8	
		Max	181 ± 7				11 ± 12	
		BR	133 ± 23		79 ± 10		6 ± 7	
Feltner & Dapena, 1986	Collegiate baseball pitchers; (n = 8)	FC	46 ± 23		76 ± 9		-18 ± 8	
		Max	170 ± 10					
		BR	113 ± 23		92 ± 6		2 ± 9	
Oliver & Keeley, 2010	High school baseball pitchers; (n = 12)	FC	50 ± 27		92 ± 22		-38 ± 13	
		MER	132 ± 22		99 ± 17		0 ± 9	
		BR	60 ± 42		102 ± 18		3 ± 15	
		MIR	-9 ± 20		101 ± 22		44 ± 13	
Stodden et al., 2006b	Adolescent throwers; (n = 26)	FC	66.83 ± 27.29		96.30 ± 6.25		-15.87 ± 13.76	
		Max	176.43 ± 12.27					
		BR			91.98 ± 10.70		12.83 ± 11.08	
Dun et al., 2008	Youth baseball pitchers; (n = 29)	FC	80.4 ± 22.5					
		Max	178.2 ± 12.3				19.8 ± 8.2	
		BR			87.4 ± 7.7		10.6 ± 8.0	
Chu et al., 2009	Olympic baseball pitchers Male (n = 11)	FC	54 ± 24		91 ± 7		22 ± 15	
		Max	171 ± 8					
		BR	122 ± 29		90 ± 10		7 ± 15	
	Female (n = 11)	FC	59 ± 35		99 ± 13		19 ± 18	
		Max	180 ±10					
		BR	136 ± 14		86 ± 6		9 ± 8	

FC – *stride foot contact;* MER – *throwing shoulder maximum external rotation;* BR – *ball release;* MIR – *throwing shoulder maximum internal rotation;* Max – *maximum value between FC and BR*; Pre – *value measured prior to yoga intervention period;* Post – *value measured after yoga intervention period*; * – *signs were changed for consistency when comparing to existing literature, reference Table 5 (Chapter IV) for standard deviations.*

Results of the current study suggested that the volume of yoga practiced for six weeks during a fall competitive softball season had no effect on shoulder kinematics during overhead throwing. However, data did reveal a notable trend relating to shoulder plane of elevation during throwing. After the intervention, the two groups demonstrated different trends in the progression of shoulder plane of elevation during throwing. While both groups still continually horizontally adducted from foot contact onward, the degree of shoulder plane of elevation tended to be less (less horizontal adduction) in the treatment group following six weeks of practicing yoga (Table 5; Chapter IV). By contrast, the control group tended to be more horizontally abducted at maximal external rotation and ball release compared to pre-intervention values (Table 5; Chapter IV). It appeared as though participants in the treatment group horizontally adducted the shoulder less as they progressed from foot contact to maximal external rotation to ball release. Nevertheless, without statistical support, this conclusion warrants further investigation to determine if this trend was a result of practicing yoga, or was simply evidence of variability in the data.

With no statistically significant differences in either group from pre- to post-intervention, it was postulated that the volume of the intervention may have been insufficient in order to elicit some change in shoulder kinematics during overhead throwing in a sample of softball players with 12+ years of throwing experience. Additionally, the notion that the yoga intervention did not adequately target shoulder strength, flexibility, muscular coordination, or neuromuscular efficiency cannot be ignored. These facets are paramount to the complex task of throwing, and must be trained in order to promote optimal mechanics. Finally, the training load that all participants were subjected to during the fall season may have included appropriate exercises that allowed all participants to maintain pre-intervention shoulder kinematics during overhead throwing despite the rigorous training volume.

Summary

It was concluded that practicing yoga during a fall competitive softball season had either no effect on or had a small maintenance effect on overhead throwing mechanics that may be altered as a function of a rigorous training load. The absence of an effect was evidenced by no *time* or *group* main effects or *time***group* interactions for stride knee flexion, hip rotation, torso separation, or shoulder kinematics thereby suggesting that there was no change in these variables for either group over time. The maintenance effect of yoga was supported by a significant *time***group* interaction effect for stride length. The stride length for the control group significantly decreased over time, whereas a comparable stride length was maintained from pre- to post-intervention for the treatment group. A possible explanation of this observation was that practicing yoga helped to minimize the residual fatigue associated with softball training and assisted in the active recovery of the athlete. Further evidence of the yoga’s maintenance effect was the notable trends discovered in the data for stride knee flexion and shoulder plane of elevation. Practicing yoga may have helped these participants maintain proper knee kinematics during throwing that may have become altered as a result of training. Moreover, practicing yoga may have helped improve shoulder motion in the transverse plane as the throwing motion progressed from foot contact to ball release. Although there was a lack of statistical significance, these trends suggest notable relationships that warrant further investigation, particularly in the absence of such a large strength and conditioning training load. Perhaps these trends would become more apparent in a larger sample or following a longer, more frequent yoga intervention that directly targets functional motion and coordination of the lower extremities, lumbopelvic-hip complex, and throwing arm.

Range of Motion

The two joints in the body where range of motion is most critical to overhead throwing are the shoulders and the hips. Overhead throwing necessitates a great deal of shoulder range of motion as the humerus has been shown to externally rotate to as far as 181° then internally rotate to as far as 9° during the most ballistic of the throwing motions: baseball pitching (Sakurai et al., 1993, Oliver & Keeley, 2010). Hip range of motion is equally important as it affects the rotation of the pelvis during the throwing motion and thus affects the transmission of energy throughout the kinetic chain (Robb et al., 2010; Dillman et al., 1993; Wilk et al., 2000). Consequently, throwing athletes must focus on maintaining proper range of motion and the dynamic stability of these joints in order to preserve the functional relationship between lower extremity, upper extremity, and lumbopelvic body segments. Practicing yoga has become increasingly popular in the athletic community as a supplementation to training, but scientific evidence is lacking pertaining to the effects of yoga practice, particularly in overhead throwing athletes. The current study highlighted the effects of a NCAA Division I softball team practicing yoga for six weeks during a fall competitive season. Specifically, this section discusses the effects of practicing yoga on passive rotational range of motion in the shoulder and hip joints. A statistically significant main effect of *time* was discovered for passive shoulder rotational range of motion. While no other statistically significant effects were found, notable trends were additionally observed for shoulder internal range of motion.

Shoulder Rotational Range of Motion

Repetitive performance of the overhand throwing motion is known to cause adaptations in the shoulder joint evidenced by a posterior shift in the total arc of motion: increased external rotation and decreased internal rotation (Wilk et al., 2002; Ellenbecker et al., 2002; Burkhart et al., 2003a). Efforts to restore internal range of motion are vital to the throwing athlete because a deficit in internal range of motion in the shoulder joint reportedly increases risk for upper extremity injury (Case et al., 2015). Stretching programs that target shoulder rotation are known to improve range of motion (Lintner et al., 2007; Aldridge et al., 2012; Hall et al., 2012; Laudner et al., 2008) and therefore should be included in the training programs for throwing athletes. Practicing yoga has also been shown to improve shoulder range of motion in terms of elevation and flexion/extension (Tran et al., 2001; Ray et al., 2001; Gharote et al., 1976 Ray et al., 1983), but these studies did not examine shoulder rotation. The current study directed focus specifically to the effects of practicing yoga on passive shoulder rotational range of motion.

Table 10 presents a comparison of passive shoulder rotational range of motion measured in the current study to that of existing literature. Measures of internal rotation are comparable to what has been previously reported, although measures of external rotation appear to be relatively less than what has been reported. A plausible explanation for this inconsistency was that the majority of previous research has focused on baseball pitchers, while the current study examined softball athletes. Pitchers make a substantially greater number of maximal effort throws compared to position players, and therefore are expected to possess greater degrees of shoulder external range of motion. This claim was supported by data from the current studied compared to existing literature.

Table 10. Passive shoulder rotational range of motion from the current study compared to existing literature.

Reference	**Sample**	**Internal Rotation (°)**				**External Rotation (°)**			
		Throwing Shoulder		**Non-throwing Shoulder**		**Throwing Shoulder**		**Non-throwing Shoulder**	
		Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
Current Study *	Collegiate softball players; Control (n = 13)	43.56	44.90	50.54	50.01	98.30	100.43	93.90	98.44
	Treatment (n = 13)	45.86	50.02	53.29	53.42	96.64	94.72	91.56	93.04
Oyama et al., 2013	High school baseball players; (n = 138)	43.3 ± 9.9		49.7 ± 12.3		117.4 ± 13.6		114.9 ± 12.3	
Reagan et al., 2002	Collegiate baseball players; (n = 54)	43.0 ± 7.4		51.2 ± 7.3		116.3 ± 11.4		106.6 ± 11.2	
Wilk et al., 2012	Professional baseball pitchers; (n = 369)	52 ± 12		63 ± 12		132 ± 11		127 ± 11	
Wilk et al., 2014	Professional baseball pitchers; (n = 296)	52.3 ± 10.2		62.8 ± 10.0		131.2 ± 9.5		124.9 ± 9.8	
Hurd & Kaufman, 2012	High school baseball pitchers; (n = 27)	59 ± 9				127 ± 10			
Reinhold et al., 2008	Professional baseball pitchers; (n = 67)	54.1 ± 11.4		63.1 ± 14.3		136.5 ± 9.8		124.2 ± 9.1	
Shanley et al., 2015	Baseball pitchers; Youth (n = 47)	43 ± 10				135 ± 13			
	Adolescents (n = 68)	47 ± 13				130 ± 14			
Dwelly et al., 2009	Collegiate baseball pitchers & position players; (n = 29)	48 ± 9				104 ± 17			
Freehill et al., 2011	Professional baseball pitchers; (n = 21)	71 ± 12				125 ± 20			
Sauers et al., 2013	Professional baseball pitchers & position players; (n = 99)	41.0 ± 6.5		50.3 ± 7.5		94.9 ± 10.9		88.4 ± 9.9	
Laudner et al., 2008	Collegiate baseball players; (n = 33)	43.8 ± 9.5				118.6 ± 10.9			
Case et al., 2015	Professional baseball pitchers; (n = 9)	49.4 ± 12		59.7 ± 15.4		150.7 ± 11.2		140.1 ± 13.6	

* Pre – *value measured prior to yoga intervention period;* Post – *value measured after yoga intervention period*; *reference Table 6 (Chapter IV) for standard deviations.*

Results revealed no evidence that practicing yoga had an effect on passive shoulder rotational range of motion due to the absence of a significant *time*group* interaction. However, the main effect of *time* suggested that this variable changed over time for the sample as a whole. After six weeks, the combined external rotation in the non-throwing shoulder for the two groups increased from 92.73° to 95.74°; combined internal rotation in the throwing shoulder also increased from 44.66° to 47.47°. Increased external rotation in the non-throwing shoulder as well as increased internal rotation in the throwing shoulder both produced more bilateral symmetry for shoulder rotation in these directions. Repetitive throwing can cause or exacerbate a pre-existing range of motion difference between limbs, but it appeared as though this sample of participants were bilaterally symmetrical in terms of shoulder rotational range of motion both before and after arduously training for six weeks. Before the intervention period, the greatest bilateral difference was a 7.25° deficit in throwing-arm internal rotation compared to the non-throwing arm. After six weeks, this deficit was reduced to 4.25°. While these changes for internal and external rotation cannot be attributed to practicing yoga, it could be that the training regimen for the athletes during the fall season included adequate shoulder stretching that mitigated the pathological changes commonly associated with repetitive throwing.

Although practicing yoga did not have a significant effect on shoulder range of motion, a favorable trend was produced in the treatment group for internal rotation. After six weeks of yoga practice, internal rotation in the throwing arm increased by 4.16° from 45.86° to 50.02°. By contrast, this measure for the control group only increased by 1.34°. Unfortunately, without statistical support, it was difficult to conclude whether or not this result was a consequence of practicing yoga or was simply due to variability in the data. Furthermore, these small degrees of change were not clinically significant, but did imply a need for further investigation. It is possible that the volume of yoga practice was insufficient to cause a clinically or statistically significant change in shoulder range of motion. Perhaps a yoga intervention with sessions lasting longer than 20 minutes would be more beneficial. Moreover, the intervention from the current study, while designed to target the shoulders, may not have specifically affected rotational motion. It was possible that shoulder range of motion changes occurred outside the delimitations of this study, such as in flexion/extension or ab/adduction range of motion. Designing and implementing a longer yoga practice into the existing training program of overhead throwers, one that aims to internally and externally stretch the shoulder joint, may be insightful.

Hip Rotational Range of Motion

Equally important to a successful throw is hip rotational range of motion as the forces generated via hip and pelvis rotation are responsible for the generation and transmission of energy through the kinetic chain (Burkhart et al., 2003c; Campbell et al., 2010). The axial rotation of the pelvis during the throw is accomplished in part by hip rotation. Insufficient hip rotational range of motion can cause the stride foot to land in a closed position at foot contact, thereby constraining pelvis and torso rotations (Robb et al., 2010). Alternatively, excessive hip rotational range of motion can cause premature arm-cocking as well as early pelvis and torso rotations, which can decrease the amount of energy transferred from the lower body to the upper body (Dillman et al., 1993; Wilk et al., 2000). In essence, optimal throwing mechanics requires not only proper hip range of motion but also coordination, stability and control over hip/pelvis rotations.

Passive hip rotational range of motion has primarily been assessed either in the prone position or in the seated position. Robb et al. (2010) recommended that prone position was superior for assessing throwing athletes because this position more closely mimicked the orientation of the pelvis and femur during overhead throwing. Table 11 presents a summary of existing literature that assessed passive hip rotational range of motion compared to data from the current study. The data collected currently suggests that the hip rotational range of motion profile of these participants is consistent with previously reported literature. To the author’s knowledge, no literature exists that reports the hip rotational range of motion profiles of collegiate softball players. Therefore, the current study was novel in that it began to establish normative hip rotational range of motion data for collegiate softball players.

Table 11. Passive hip rotational range of motion from the current study compared to existing literature.

Reference (measurement position)	**Sample**	**Internal Rotation (°)**				**External Rotation (°)**			
		Stance Hip		**Stride Hip**		**Stance Hip**		**Stride Hip**	
		Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
Current Study * (prone)	Collegiate softball players; Control (n = 13)	33.68	35.12	31.75	32.76	32.68	33.26	36.28	36.16
	Treatment (n = 13)	34.88	35.12	32.46	31.84	35.86	36.77	36.17	37.24
Beckett et al., 2014 (prone)	Adolescent baseball players; (n = 34)	33.09		34.35		38.54		38.85	
Ellenbecker et al., 2007 (prone)	Professional baseball players; (n = 101)	23.0 ± 8.3		22.0 ± 8.9		35.0 ± 9.1		34 ± 10.6	
Laudner et al., 2010 (seated)	Professional baseball position players; (n = 40)	37.7 ± 5.8		37.0 ± 4.8		41.9 ± 7.3		42.7 ± 6.8	
Robb et al., 2010 (prone)	Professional baseball pitchers; (n = 19)	50.8 ± 9.2		31.3 ± 6.2		44.0 ± 9.0		35.6 ± 5.8	
Oliver & Weimar, 2014 (seated)	youth baseball pitchers; (n = 19)	34.9 ± 8.7		28.9 ± 6.4		35.1 ± 5.8		37.6 ± 6.6	
Sauers et al., 2103 (seated)	Professional baseball position players; (n = 49)	36.9 ± 4.9		38.4 ± 4.7		33.8 ± 4.5		31.5± 4.5	

* Pre – *value measured prior to yoga intervention period;* Post – *value measured after yoga intervention period*; *reference Table 6 (Chapter IV) for standard deviations.*

Hip range of motion is vital to overhead throwing; therefore, training programs for throwing athletes should include exercises that target hip range of motion as well as exercises that promote dynamic pelvis and hip stability. In the current study, the training regimen for a collegiate softball team was supplemented with yoga practice that aimed to target both hip mobility and stability. Results suggested that practicing yoga for six weeks during a fall competitive season had no effect on hip rotational range of motion evidenced by non-significant *time**group* interaction effect. In fact, the largest change in hip rotation from pre- to post-intervention that occurred in the treatment group was a 1.07° increase in stride hip external rotation. While this parameter is vital for stride foot placement during overhead throwing, a 1° increase was neither clinically nor statistically significant. It should also be noted that largest change in the hip rotational profile for the control group was only a 1.44° increase in stance hip internal rotation. As the values for neither group changed significantly, it was plausible that the current softball training program utilized by the collegiate team, in this study, contained appropriate stretching and strengthening exercises such that the players were able to maintain hip mobility despite the rigorous training volume. Furthermore, because the yoga intervention was designed to target hip mobility, it was possible that yoga affected some characteristic of hip motion that was outside the delimitations this study. Designing and implementing a yoga intervention into the current training program for athletes, one that directly targets hip internal and external range of motion in addition to the dynamic stability of the hip and pelvis, may be beneficial for future research.

Summary

The primary conclusion that was drawn from the range of motion data was that rotational range of motion of the shoulder and hip joints were not affected by practicing yoga for six weeks during a fall competitive season. This finding was evidenced by an absence of a significant *time*group* interaction effect for neither shoulder nor hip rotational range of motion. However, the main effect of *time* on the passive rotation of the shoulder joint suggested that this parameter does change as a function of softball training. The change was beneficial to the participants in that it functioned to promote bilateral symmetry between the shoulders. The conclusion was that the training program utilized by the collegiate softball team, in the current study, contained shoulder stretches and dynamic stability exercises that were sufficient enough to attenuate the pathological range of motion alterations that are known to be associated with repetitive throwing. Even still, this claim requires further investigation. It may also be that the volume and intensity of throwing during a one-month, fall competitive season was not sufficient enough to significantly diminish range of motion. The promising trend observed in the data was that practicing yoga may have helped to restore some degree of internal range of motion that was lost as a result of repetitive throwing. Although this trend was not statistically significant, it may be more apparent following a longer, more rigorous yoga intervention that directly focuses on internally and externally stretching the shoulder in addition to training the dynamic stability of the shoulder joint. Last, this research was novel in that it began to establish normative range of motion data for softball players.

Strength and Flexibility

Strength and flexibility in the musculature about the knee is important for efficient function of the lower extremity during dynamic activities, such as overhead throwing. The hamstring muscle group functions both concentrically and eccentrically during the throwing motion, but the strength profile of these muscles compared to the quadriceps group has previously only been examined in throwers using a concentric agonist to concentric antagonist ratio (Coleman, 1982; Tippett, 1986). Using a dynamic control ratio, or the eccentric antagonist strength relative to the concentric agonist strength, may provide more insight into true knee motion during overhead throwing. In addition to strength, flexibility of the hamstring group is equally important to overhead throwing. In order to minimize confounding variables when assessing hamstring strength, it has been suggested that the passive knee extension test was superior to the two other common tests: the sit and reach test and the active straight leg raise test (Gleim & McHugh, 1997; Worrell et al., 1991; Bohannon et al., 1985; Gajdosik & LeVeau, 1985). Previous literature that has investigated hamstring muscular strength using a dynamic control ratio and hamstring flexibility using the passive knee extension test in athletes is exclusive to those playing lower extremity dominated sports. Yoga is known to cause improvements in strength and flexibility and has become an increasing popular practice among athletes as a supplement to training. However, biomechanical data are inconclusive on the effects of athletes practicing yoga related to lower extremity strength and flexibility, particularly in the hamstring muscle group. The current study highlighted the effects of a NCAA Division I softball team practicing yoga for six weeks during a fall competitive season. Specifically, this section directs focus to the effects on hamstring strength relative to quadriceps strength assessed using a dynamic control ratio and on hamstring flexibility as assessed using the passive knee extension test. The lone significant effect discovered was a main effect of *group* on the hamstring flexibility measures, but a noteworthy trend in the hamstring flexibility data was also observed.

Hamstring Strength

Because the hamstring muscle group is biarticulate, it can function concentrically and eccentrically at both the knee and hip joints. Investigating the dynamic control ratio of the hamstrings relative to the quadriceps in throwing athletes may be insightful as these muscle groups function together during the stride phase and subsequent arm acceleration. The quadriceps concentrically extend the knee as the thrower steps towards the target, and the ipsilateral hamstring muscles contract eccentrically in order to slow angular motion of the shank and prepare the stride leg for foot contact (Tippett, 1986). After foot contact, the stride leg becomes a closed kinetic chain, thus the hamstring muscles assist in subsequent extension of the stride knee. Concentric activation of the hamstring muscles during arm acceleration can assist stride knee extension in order to shift the thrower’s body weight forward onto the planted leg. This posting action on the stride leg is a common way throwers attempt to impart more force onto the ball and increase the throwing velocity (Tippett, 1986).

Dynamic control ratios for knee extension in athletes have been reported in excess of 100%, indicating that eccentric strength of the hamstring muscles is equal to or greater than concentric quadriceps strength, thus highlighting the ability of the hamstring muscle group to help provide stability to the knee during ballistic movements (Aagaard et al., 1998; Aginsky et al., 2014; Croisier et al., 2002; Croisier et al., 2008). To the author's knowledge, only athletes playing lower extremity dominated sports have been assessed for functional hamstring strength using dynamic control ratios as no studies were found having investigated this measure in the lower extremity of throwing athletes. Table 12 presents a summary of existing literature of dynamic control ratios for athletes playing lower extremity dominated sports compared to data gathered in the current study. In general, dynamic control ratios from the current study were greater than what has been reported previously. However, caution should be taken when comparing dynamic control ratios that are measured at different angular velocities. The angular velocity chosen for the current study, 300°/second, was greater than any velocity employed by previous research. Nevertheless, the dichotomy present when comparing dynamic control ratios at various angular velocities was to be expected as it has been reported that faster angular velocities elicit greater dynamic control ratios (Aginsky et al., 2014). This claim was supported by data in Table 7 (Chapter IV).

Table 12. Dynamic control ratios from the current study compared to existing literature.

Reference (angular velocity)	**Sample**	**Dominant Leg**				**Non-dominant Leg**			
		Flexion (Hcon:Qecc)		**Extension (Hecc:Qcon)**		**Flexion (Hcon:Qecc)**		**Extension (Hecc:Qcon)**	
		Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*	*Pre*	*Post*
Current Study * (300°/sec)	Collegiate softball players; Control (n = 13)	0.43	0.61	1.20	1.03	0.39	0.63	1.28	0.96
	Treatment (n = 13)	0.53	0.48	1.51	1.07	0.42	0.58	1.41	1.14
Aagaard et al., 1998 (240°/sec)	Track and field athletes; (n = 9)	0.33 ± 0.04		0.61 ± 0.08					
Daneshjoo et al., 2013 (120°/sec)	Professional soccer players; (n = 36)			0.74 ± 0.35				0.75 ± 0.33	
Hadzic et al., 2010 (60°/sec)	Elite, male volleyball players; (n = 127)			0.64 ± 0.12 Right leg				0.64 ± 0.12 Left leg	
Dauty et al., 2003 (60°/sec)	Professional soccer players; (n = 33)			0.80 ± 0.14 Uninjured leg					
Rahnama et al., 2005 (120°/sec)	Elite soccer players; (n = 41)			0.79 ± 0.13				0.84 ± 16	
Tourny-Chollet et al., 2000 (120°/sec)	Amateur soccer players; (n = 21)			0.78 Right				0.80 Left	
Houweling et al., 2009 (60°/sec)	Professional soccer players; (n = 21)			0.77 ± 0.15 Right				0.74 ± 0.13 Left	

* Pre – *value measured prior to yoga intervention period;* Post – *value measured after yoga intervention period*; Dominant leg – *stance leg;* Non-dominant leg – *stride leg; reference Table 7 (Chapter IV) for standard deviations.*

Results of the current study indicated that practicing yoga for six weeks during a fall competitive season did not have an effect on the functional, relative strength of the hamstring muscles due to the absence of a significant *time*group* interaction. However, it appeared that relative hamstring strength compared to quadriceps strength for knee extension in both legs tended to decrease after six weeks of softball training, though the changes were not significant. It was postulated that this decrease may have been a consequence of residual muscular fatigue associated with training since participants were required to perform maximal effort strength testing as part of the softball training schedule during the same week that post-testing measurements of hamstring strength occurred for the current study. However, as the changes from pre- to post-intervention were not statistically significant, it was certainly possible that changes were simply an effect of variability in the data. Furthermore, any beneficial effect that practicing yoga may have had on the functional strength of the hamstring muscles for the treatment group may have been occluded by residual muscle fatigue from the physically demanding softball training schedule. It was also plausible the volume and the nature of the yoga intervention did not facilitate improvements in lower body muscular strength. Designing and implementing a yoga intervention into the current training program for athletes, one that includes more isometric and dynamic strengthening poses, may be beneficial for future research.

Hamstring Flexibility

In conjunction with muscular strength, flexibility is additionally important in overhead throwing. A lack of hamstring flexibility is known to cause pathomechanics during throwing, most commonly during the wind-up and stride phases (Chu et al., 2009; Tippett, 1986). Tightness in the hamstring can affect the relative stride length as the thrower steps forward towards the intended target and can increase injury risk during the rapid transition from eccentric contraction to concentric contraction as the thrower progresses into the arm-acceleration phase (Chu et al., 2009; Verrall et al., 2001; Peterson & Holmich, 2005). Particularly in females, who have been shown to have altered lower body throwing mechanics compared to males, hamstring flexibility is paramount as tightness is this muscle may only exacerbate pre-existing pathomechanics (Chu et al., 2009).

Previous research has investigated hamstring flexibility primarily in athletes that play lower extremity dominated sports. Additionally, two studies have reported absolute values of hamstring flexibility in active or athletic populations using the passive knee extension test (Hartig & Henderson, 1999; Worrell et al., 1991). Hartig & Henderson (1999) reported that, in a sample of active military personnel, the mean hamstring flexibility for both legs was 45.9° short of complete knee extension. Worrell et al. (1991) reported that the mean degree of hamstring flexibility in the non-injured leg of highly-skilled male athletes was 32° short of complete knee extension. By contrast, the participants, from the current study, presented with substantially less hamstring flexibility (Table 7; Chapter IV). Granted, it can be misleading to compare athletes from the current study, who play an upper extremity dominated, to those participants from previous research, who play lower extremity dominated sports or are active military. Nevertheless, the participants, in the current study, presented with hamstring flexibility measures that represent a significant risk for lower extremity injury according to thresholds proposed by

Seto (1995). This author reported that a hamstring flexibility level, assessed using the passive knee extension test, greater than 35° from complete knee extension corresponded to a significantly increased risk for hamstring injury. The largest amount of hamstring flexibility observed in the current study was 40.92°, measured as the mean for the treatment group prior to the intervention period. Consequently, tight hamstrings appeared to be a prevalent issue in this sample of collegiate softball players. Therefore, yoga was implemented into the fall season training regimen for these softball athletes with the goal of improving hamstring flexibility.

Results of the current study indicated that practicing yoga for six weeks during a fall competitive season did not have an effect on hamstring flexibility evidenced by the absence of a significant *time**group* interaction. However, a main effect for *group* was discovered for this variable suggesting that the two groups differed in the degree of hamstring flexibility, but the changes in either group were comparable over time. A plausible explanation of this main effect was that there were a different number position players and pitchers in either group. The demands of different positions within a sport can vary considerably and may have caused the dissimilar pattern of hamstring flexibility observed between groups. Efforts were made to assign an equal number of position players and pitchers to either group, but the treatment group contained three pitchers and 10 position players, whereas the control contained two pitchers and 11 position players. Moreover, the eight different positions on the softball diamond, other than the pitcher, were all grouped together into the stratification of *position player*. Further stratifying the players based on position (i.e. outfield, infield, catcher, and pitcher) prior to group assignment may have been more appropriate, and possibly would have prevented a group difference in hamstring flexibility.

Observation of the group means for hamstring flexibility revealed a notable trend in the data despite the lack of a *group*time* interaction. For the control group, the hamstring flexibility in the stride leg decreased, following the intervention period, by 5.66°, from 52.00° to 57.66°. Comparatively, this measure only decreased by 2.98°, from 42.37° to 45.35°, in the treatment group following six weeks of yoga practice. Because both groups exhibited a decrease in flexibility, this trend could be attributed the rigorous softball training the participants underwent during the fall season. Although, because the decrease was slightly less in the treatment group, it could be that practicing yoga was beneficial for these athletes in terms of flexibility. This claim warrants further investigation, however, as the large variability of the data may suggest that the participants are in some sort of the muscular transition point. A longer intervention, during a less strenuous time frame, on a larger number of participants, may allow the changes to take effect and be noted.

Summary

The primary conclusion drawn from this facet of the current research study was that practicing yoga during a fall competitive season had no effect on functional hamstring strength or flexibility. These conclusions were evidenced by non-significant *group*time* interactions observed for both variables. The main effect of *group* on hamstring flexibility suggested that the two groups differed on the degree of hamstring flexibility even though the changes over time were comparable. It was possible that the stratification method during the group assignment process was not effective at ensuring an equal number of positions were in either group. Observation of group means pertaining to hamstring flexibility data revealed that practicing yoga may have had the beneficial effect of staving off acute hamstring tightness that is associated with strength training. Though, the data are inconclusive, and this conclusion needs further investigation. Perhaps having athletes practice yoga for a longer period of time or including certain poses in the practice that aim to train isometric and dynamic muscular strength as well as poses that specifically target flexibility of the hamstrings would be more insightful into the effectiveness of yoga on lower extremity strength and flexibility. Last, this study was novel in that it began to establish normative data for functional hamstring strength as well as hamstring flexibility in an overhead throwing population.

Conclusions and Future Research

The final section will summarize the primary conclusions drawn from the current study and present suggested directions of future research. The purpose of the current study was to investigate the effects of athletes practicing yoga for six weeks during a fall competitive softball season on overhead throwing kinematics, passive shoulder and hip rotational range of motion, and hamstring strength and flexibility.

Softball athletes perform a wide range of functional movements including running, batting, and throwing. The overhead throw is vital to effective defensive performance in softball therefore athletes work diligently to optimize throwing mechanics in order to gain a competitive advantage on the field. Yoga has become a common training technique used by athletes to supplement standard training regimens, but the effects on physical characteristics and sports performance, particularly in softball athletes, were largely unknown prior to this study. The primary finding related to throwing mechanics was that practicing yoga as a supplement to fall season training had either no effect or a small maintenance effect for the participants. The maintenance effect was represented by the finding that the participants who practiced yoga were able to maintain a comparable stride length during overhead throwing from pre- to post-intervention, whereas the participants who did not practice yoga exhibited a significant decrease in stride length. It was postulated that practicing yoga as a supplementation to training may have assisted in the active recovery of the athlete and accelerated the desired training effect. Non-significant, though still notable, trends observed in stride knee flexion and shoulder plane of elevation data further purport that practicing yoga had a maintenance effect for the participants. Knee and shoulder kinematics may have become acutely altered as a function of a strenuous training load and practicing yoga may have helped the athlete to mitigate these negative effects and maintain optimal mechanics. Without statistical support, though, these trends are only indicative of a notable relationship that necessitates further investigation.

Overhead throwing necessitates a great deal of shoulder and hip rotational range of motion, thus throwing athletes train to maintain proper range of motion profiles as well as dynamic stability of these joints. Yoga is known to improve range of motion, but the effects on rotational range of motion in shoulder and hip joints, particularly in throwing athletes, were still inconclusive prior to the current study. The primary finding was that practicing yoga may have helped promote bilateral symmetry for shoulder rotational range of motion. This observation was notable because repetitive throwing is known to cause alterations to the rotational range of motion profiles for the shoulder. Additionally, practicing yoga may have helped to restore some degree of internal rotation deficit that is associated with repetitive throwing. However, this conclusion was only evidenced by an observed trend within the data. While there was a lack of statistical significance, the trends pertaining to range of motion suggest notable relationships that warrant further investigation. In terms of hip range of motion, results of this research study suggested that practicing yoga did not have any effect on passive hip rotational range of motion.

Hamstring strength and flexibility are paramount to lower extremity function during dynamic activities such as overhead throwing. Practicing yoga is known to be beneficial to both strength and flexibility, and the current study directed focus to these effects for the lower extremity in softball athletes. It was concluded that practicing yoga during a fall competitive softball season had no effect on functional hamstring strength or hamstring flexibility. However, it was noted that this sample of collegiate softball players exhibited some degree of hamstring tightness. To the author's knowledge, this was the first study that investigated hamstring flexibility in an overhead throwing population. Therefore, it can be concluded that exercises targeting hamstring flexibility should be included in the training programs for overhead athletes due to the known importance of this muscle group to lower extremity throwing mechanics as well as the increased risk for lower extremity injury known to be associated with hamstring tightness.

This research study was significant in several ways. First, it advanced the literature in terms of the physical effects of softball athletes practicing yoga in addition to supplementing literature on the functional performance of overhead throwing motion. Second, this study was novel in that it began to establish normative data for softball athletes in terms of relative stride length during the step-and-throw action, hip rotational range of motion, and functional hamstring strength and flexibility patterns. Last, it highlighted avenues for future research pertaining to yoga and athletic performance.

Future Research

The author recommends that future research should continue to implement yoga interventions in athletic populations in order to establish scientific data for the effects of athletes practicing yoga. For the overhead throwing athlete, it is recommended by the author, based on the results of this study, that the yoga intervention implemented into the training routines of athletes contain poses and movements that mimic the functional movement pattern associated with overhead throwing. Specifically, the yoga intervention should target internal and external motion of the hips and shoulders, the dynamic strength and stability of the lower and upper extremities, and the flexibility of the hamstring musculature.

Future research should also investigate other parameters associated with overhead throwing that were beyond the delimitations of the current study. It may be useful to examine additional kinematic variables associated with overhead throwing (such as stride foot placement at foot contact, hip flexion/extension and ab/adduction, as well as pelvis and torso kinematics) and how these variables are affected by yoga practice. Furthermore, physical characteristics related to overhead throwing, such as hip and shoulder strength, should be investigated in athletes as to how they are affected by yoga practice.

It may be additionally insightful to investigate yoga interventions that are longer in duration both in terms of the individual sessions and the intervention period. The 6-week intervention period was comparable to existing literature, but those studies utilized longer, more frequent yoga sessions in order to elicit the desired effect of practicing yoga.

Expanding the duration of the intervention period may uncover additional significant effects that were only present in the current study as trends within the data. Last, in order to best investigate the effects that practicing yoga has on athletic populations, the training load outside of practicing yoga must be controlled. Therefore, it would insightful to implement a yoga intervention for athletes during the off-season when the training dosage for those athletes can be better controlled for. While further research is necessary, this study was successful in highlighting promising effects of yoga practice related to athletic performance.

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APPENDIX A

AUBURN UNIVERSITY
COLLEGE OF EDUCATION

SCHOOL OF KINESIOLOGY

301 Wire Road
Auburn, AL 36849
(334) 884-4483

HEALTH and SPORT HISTORY QUESTIONNAIRE

Part 1. Participant Information

[Please print]

Participant ID: ____________ Date: _____________

Phone: _____________________ Email: ____

Experiment Group: _________________________ Position (circle one): Pitcher Fielder

Part 2. Athletic Participation

(Circle or fill in your responses)

1. Are you currently medically cleared to participate in throwing activities?

YES **NO**

2. What arm do you use to throw? **RIGHT** **LEFT**

3. What position is your primary position?

PITCHER **CATCHER** **1st** **2nd** **3rd** **SS** **OF**

4. What is your current NCAA grade level? ___________________________

5. For how many years have you been a member of the Auburn University Softball team?
________ **years**

6. Do you play in every game? **YES** **NO**

7. What is the average number of games you play per week ________?

8. At what age did you begin playing competitive softball? __________

9. During the season, how many hours per week do you spend doing the following activities?
    a. Playing softball: ________ **hours/week**
    b. Upper extremity training/conditioning: ________ **hours/week**
    c. Lower extremity training/conditioning: _________ **hours/week**

10. During the off-season, how many hours per week do you spend doing the following activities?
    a. Playing softball: _________ **hours/week**
    b. Upper extremity training/conditioning: _________ **hours/week**
    c. Lower extremity training/conditioning: _________ **hours/week**

11. Estimate the total amount of throws you make (warm-up through cool-down) during a typical:
    a. In-season practice: _________**throws**
    b. Game-day: _________**throws**

12. Estimate the number of throws you make at an effort greater than 90% of your maximal effort during
    a. In-season practice: ________ **throws**
    b. Game-day: ________ **throws**

Part 3. Medical History

(Circle or fill in your responses)

13. Are you allergic to adhesive tape or other adhesive products? **YES** **NO**

If YES, explain:

____

14. In the past 6 months, have you had any *INJURY* to your upper-extremity, lower extremity or torso that has caused you to miss a practice or game?

YES **NO**

If YES, explain:

____

____

If YES, on what part(s)? **SHOULDER** **ELBOW** **WRIST**

HAND/FINGER **HIP** **KNEE** **ANKLE** **FOOT/TOE**

BACK **PELVIS**

15. In the past 6 months, have you had any *SURGERY* to your upper-extremity, lower extremity or torso that has caused you to miss a practice or game?

YES **NO**

If YES, explain:

____

____

If YES, on what part(s)? **SHOULDER** **ELBOW** **WRIST**

HAND/FINGER **HIP** **KNEE** **ANKLE** **FOOT/TOE**

BACK **PELVIS**

16. Do you currently experience pain/stiffness in your throwing arm before, during or after throwing?

YES **NO**

If YES, please explain and continue onto question 17:

____

____

If NO, please sign on page 4.

***IF* you answered YES to question 16:**

17. For how long have you been experiencing pain? (Indicate a number next to 1 category)

_____Years **_____Months** **_____ Days**

18. When you do experience pain, how would you describe the onset of pain?

SUDDEN GRADUAL

19. When you do experience pain, how is it related to activity?

ASSOCIATED WITH USE INTERMITTENT ALL THE TIME

20. Have you changed your training/competition habits because of your pain? **YES NO**
If YES, explain:

____

____

21. Have your activities of daily living been effected by your pain? **YES NO**
If YES, explain:

____

____

22. Has your pain disrupted your sleep? **YES NO**
If YES, explain:

____

____

23. Have you sought medical consultation because of your pain? **YES NO**
If YES, explain:

____

____

24. Have you been given treatment for your pain? **YES NO**
If YES, explain:

____

____

25. When you do experience pain, what is the intensity of the pain (Circle one number)?

1 2 3 4 5 6 7 8 9 10

NO PAIN UNBEARABLE PAIN

I hereby state, to the best of my knowledge, my answers to the above questions are complete and correct.

____ ____________________

Signature of Participant Date

APPENDIX B

AUBURN UNIVERSITY
COLLEGE OF EDUCATION

SCHOOL OF KINESIOLOGY

301 Wire Road
Auburn, AL 36849
(334) 884-4483

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMED CONSENT for a Research Study entitled
Yoga: Effects on Throwing Performance, Range of Motion, Strength and Flexibility in a NCAA Division I Softball Team

Explanation and Purpose of the Research

You are being asked to participate in a research study for the Sports Medicine & Movement Laboratory in the School of Kinesiology. Before agreeing to participate in this study, it is vital that you understand certain aspects of what might occur. This statement describes the purpose, methodology, benefits, risks, discomforts, and precautions of this research. This statement describes your right to anonymity and your right to discontinue your participation at any time during the course of this research without penalty or prejudice. No assurances or guarantees can be made concerning the results of this study.

This study is designed to examine the effects of practicing yoga for 6 weeks on overhead throwing performance, shoulder and hip range of motion, and hamstring strength and flexibility. To investigate this: range of motion, flexibility, strength, and kinematic data during overhead throwing will be collected before and after a 6-week yoga intervention in NCAA Division I softball athletes.

Research Procedures

To be considered for this study, you must be on the active roster of the Auburn University softball team. You must also be deemed free of injury or surgery for the last 6 months. Additionally, you must not have an allergy to adhesive tape. Throwing arm dominance will not be a factor of selection for participants in this study.

Testing will require the evaluation of height, body mass, and age as well as range of motion, flexibility, strength, and throwing performance prior to and following a 6-week yoga intervention. Age will be determined from this consent form and will be recorded to the nearest month. Range of motion and flexibility will be measured with a digital inclinometer and will be recorded to the nearest tenth of a degree. Strength will be measured with an isokinetic dynamometer and will be recorded as peak torque in N * m. Throwing performance will be measured with a 3D Motion Capture system.

Once all preliminary paperwork has been completed, you will need to be dressed in only a pair of shorts, t-shirt, socks, and tennis shoes for pre-testing. Once properly dressed, range of motion of the shoulder and hip will be measured and recorded. Next, flexibility will be measured and recorded followed by strength being assessed and recorded.

On a separate day, electromagnetic sensors will be placed on your legs, arms, torso, and neck. Placement of the sensors at these locations will allow the movement of the joint centers to be properly monitored during testing. Following the placement of the sensors, you will perform your own specified pre-competition warm-up routine. During the warm-up period, we ask that you contribute at least five minutes to throwing and progressively work your way up to throwing the total distance required for testing. After completing the warm-up, the overhead throwing test will begin. The test will consist of you throwing 5 maximal effort, accurate throws across a distance of 84 feet to a cut-off man. Throws will judged as accurate if the cut-off man can catch the throw in the air while keeping the feet firmly planted to the ground. At the completion of the throwing test, water will be provided to you and you will be asked to perform you own specified post-competition cool-down.

After completion of all pre-intervention tests, you will be conveniently assigned to a treatment group or a control group. The treatment group participants will practice yoga 3 times per week for 6 weeks by following a 15-minute series developed specifically for this research study. Specific dates and times will be made available for you to practice yoga under the supervision and guidance of a qualified yoga instructor. Additionally, a video will be supplied to you for personal practice during the invention period, if you so choose. You will be required to document all time spent practicing yoga, and you must practice the study-specific yoga series at least 3 times per week for 6 weeks (18 total sessions) in order to remain enrolled in the study. Participants in the control group will not be permitted to practice yoga during the 6-week intervention period.

Following the 6-week intervention period, all testing protocols detailed above will be performed again in order to assess post-intervention values.

<u>Potential Risks</u>

As with any movement research, certain risks and discomforts may arise. The possible risks and discomforts associated with this study are no greater than those involved in competitive softball or in the practice of yoga and may include: muscle strain, muscle soreness, ligament and tendon damage, and general overuse injury to the throwing arm. Every effort will be made to minimize these risks and discomforts by selecting participants who are currently playing competitive softball. It is your responsibility, as a participant, to inform the investigators if you notice any indications of injury or fatigue, or feel symptoms of any other possible complications that might occur during testing or the intervention.

To reduce the risk of injury, certain precautions will be taken. During the throwing test protocol, two board certified athletic trainers will be present to monitor participants as they throw. Ample warm-up and cool-down periods will be required of you, and water will be provided to you as needed.

Confidentiality

All information gathered in completing this study will remain confidential. Your individual performance will not be made available for public use, and will not be disclosed to any person(s) outside of the research team. The results of this study will primarily be written as a dissertation to satisfy the degree requirements for a PhD in the School of Kinesiology at Auburn University. Additionally, supplemental results may be published or presented as scientific research. No participants' name or identity shall be revealed should such publication occur.

The researcher will try to prevent any problem that could occur because of this research. If at any time there is a problem, you should let the researcher know and he or she will help you. Should an emergency arise, we will call 911 and follow our Emergency Action Plan. You are responsible for any cost associated with medical assistance.

Participation and Benefits

Participation in this research is strictly voluntary, and refusal to participate will result in no penalty. You will be allowed to withdraw consent and discontinue your participation in this research at any time without bias or prejudice from Auburn University, the School of Kinesiology, or the Sports Medicine & Movement group.

Participants that are assigned to treatment group will potentially benefit from this research study by improving in hip and shoulder range of motion, hamstring strength and flexibility, as well as throwing performance as a result of practicing yoga for 6 weeks. There exists no direct benefit for participants in the control group.

Questions Regarding the Study

If you have any questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-884-5966 or email at irbadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

____	______ years ______ months
Printed Name of Participant	Age
____	________________
Signature of Participant	Date

The above consent form was read, discussed, and signed in my presence. In my opinion, the person signing said consent form did so freely and with full knowledge of its contents.

____	________________
Signature of Investigator	Date

APPENDIX C.

Comprehensive summary of results from statistical testing.

ANOVA	Degrees of Freedom	F Statistic	Significance	Partial Eta Squared
Stride Length				
Main Effects				
Time	(1, 24)	2.624	0.118	0.990
Group	(1, 24)	0.179	0.676	0.007
Interaction Effects	(1, 24)	10.790	0.003 [a]	0.310
Time*Group				
Stride Knee Flexion				
Main Effects				
Time	(1, 24)	0.677	0.419	0.027
Group	(1, 24)	0.339	0.566	0.014
Event	(1.296, 31.112)	26.627	0.000 [a]	0.526
Interaction Effects				
Time*Group	(1, 24)	0.334	0.569	0.014
Event*Group	(3, 72)	2.059	0.113	0.079
Time*Event	(1.595, 38.291)	9.753	0.001 [a]	0.289
Time*Event*Group	(3, 72)	0.361	0.782	0.015
Hip Rotation				
Main Effects				
Time	(1, 24)	0.058	0.811	0.002
Group	(1, 24)	0.666	0.422	0.027
Event	(1.355, 32.520)	111.089	0.000 [a]	0.822
Limb	(1, 24)	0.247	0.623	0.010
Interaction Effects				
Time*Group	(1, 24)	1.373	0.253	0.054
Event*Group	(3, 72)	0.296	0.828	0.012
Limb*Group	(1, 24)	0.483	0.494	0.020
Time*Event	(1.682, 40.379)	0.177	0.801	0.007
Time*Event*Group	(3, 72)	2.554	0.062	0.096
Time*Limb	(1, 24)	0.011	0.917	0.000
Time*Limb*Group	(1, 24)	0.012	0.913	0.001
Event*Limb	(1.476, 35.433)	4.111	0.036 [a]	0.146
Event*Limb*Group	(3, 72)	0.189	0.093	0.008
Time*Event*Limb	(1.810, 43.443)	0.248	0.760	0.010
Time*Event*Limb* Group	(3, 72)	0.524	0.667	0.021

Significance – *alpha level set a priori = 0.05;* Power – *computed using alpha level set a priori = 0.05;* a – *significant effect (p < 0.05).*

ANOVA	Degrees of Freedom	F Statistic	Significance	Partial Eta Squared
Torso Separation				
Main Effects				
Time	(1, 24)	0.137	0.714	0.006
Group	(1, 24)	0.636	0.433	0.026
Event	(1.605, 38.530)	114.517	0.000 [a]	0.827
Interaction Effects				
Time*Group	(1, 24)	1.200	0.284	0.048
Event*Group	(3, 72)	0.765	0.517	0.031
Time*Event	(1.538, 36.906)	0.699	0.468	0.028
Time*Event*Group	(3, 72)	0.560	0.643	0.023
Shoulder Kinematics				
Main Effects				
Time	(1, 24)	3.332	0.080	0.122
Group	(1, 24)	0.205	0.655	0.008
Event	(1.729, 41.492)	314.227	0.000 [a]	0.929
Direction	(2, 48)	778.697	0.000 [a]	0.970
Interaction Effects				
Time*Group	(1, 24)	0.024	0.877	0.001
Event*Group	(3, 72)	0.198	0.898	0.008
Direction*Group	(2, 48)	0.470	0.628	0.019
Time*Event	(1.909, 45.819)	0.233	0.783	0.010
Time*Event*Group	(3, 72)	0.740	0.532	0.030
Time*Direction	(1.359, 32.607)	1.908	0.174	0.074
Time*Direction*Group	(2, 48)	1.240	0.299	0.049
Event*Direction	(3.336, 80.072)	135.060	0.000 [a]	0.849
Event*Direction*Group	(6, 144)	0.518	0.794	0.021
Time*Event*Direction	(4.093, 98.233)	2.632	0.038 [a]	0.099
Time*Event*Direction* Group	(6, 144)	1.583	0.156	0.062

Significance – *alpha level set a priori = 0.05;* Power – *computed using alpha level set a priori = 0.05;* a – *significant effect ($p < 0.05$).*

ANOVA	**Degrees of Freedom**	**F Statistic**	**Significance**	**Partial Eta Squared**
Shoulder Range of Motion				
Main Effects				
Time	(1, 24)	8.605	0.007 [a]	0.264
Group	(1, 24)	0.000	0.996	0.000
Limb	(1, 24)	0.003	0.958	0.000
Direction	(1.425, 34.199)	5.061	0.020 [a]	0.174
Interaction Effects				
Time*Group	(1, 24)	0.014	0.908	0.001
Limb*Group	(1, 24)	0.096	0.759	0.004
Direction*Group	(2, 48)	1.304	0.281	0.052
Time*Limb	(1, 24)	1.766	0.196	0.069
Time*Limb*Group	(1, 24)	0.002	0.964	0.000
Time*Direction	(2, 48)	1.347	0.270	0.053
Time*Direction*Group	(2, 48)	0.973	0.238	0.039
Limb*Direction	(1.522, 36.529)	10.448	0.001 [a]	0.303
Limb*Direction*Group	(2, 48)	0.067	0.935	0.003
Time* Limb*Direction	(1.566, 37.573)	0.170	0.792	0.007
Time* Limb*Direction* Group	(2, 48)	0.678	0.513	0.027
Hip Range of Motion				
Main Effects				
Time	(1, 24)	1.613	0.216	0.063
Group	(1, 24)	0.633	0.434	0.026
Limb	(1, 24)	0.332	0.570	0.014
Direction	(1.187, 28.498)	310.093	0.000 [a]	0.928
Interaction Effects				
Time*Group	(1, 24)	0.136	0.716	0.006
Limb*Group	(1, 24)	2.300	0.142	0.087
Direction*Group	(2, 48)	0.211	0.810	0.009
Time*Limb	(1, 24)	0.259	0.616	0.011
Time*Limb*Group	(1, 24)	0.015	0.904	0.001
Time*Direction	(1.394, 33.448)	0.315	0.653	0.013
Time*Direction*Group	(2, 48)	0.887	0.419	0.036
Limb*Direction	(1.140, 27.362)	2.697	0.108	0.101
Limb*Direction*Group	(2, 48)	0.318	0.729	0.013
Time* Limb*Direction	(1.370, 32.868)	0.099	0.831	0.004
Time* Limb*Direction* Group	(2, 48)	0.109	0.897	0.005

Significance – *alpha level set a priori = 0.05;* Power – *computed using alpha level set a priori = 0.05;* a – *significant effect ($p < 0.05$).*

ANOVA	Degrees of Freedom	F Statistic	Significance	Partial Eta Squared
Hamstring Strength				
Main Effects				
Time	(1, 19)	0.125	0.727	0.007
Group	(1, 19)	2.185	0.156	0.103
Limb	(1, 19)	0.249	0.624	0.013
Direction	(1, 19)	211.056	0.000 [a]	0.917
Interaction Effects				
Time*Group	(1, 19)	1.705	0.207	0.082
Limb*Group	(1, 19)	0.042	0.839	0.002
Direction*Group	(1, 19)	1.346	0.260	0.066
Time*Limb	(1, 19)	1.336	0.262	0.066
Time*Limb*Group	(1, 19)	0.034	0.855	0.002
Time*Direction	(1, 19)	18.795	0.000 [a]	0.497
Time*Direction*Group	(1, 19)	0.019	0.891	0.001
Limb*Direction	(1, 19)	0.002	0.969	0.000
Limb*Direction*Group	(1, 19)	0.103	0.752	0.005
Time* Limb*Direction	(1, 19)	4.663	0.044 [a]	0.197
Time* Limb*Direction* Group	(1, 19)	0.246	0.626	0.013
Hamstring Flexibility				
Main Effects				
Time	(1, 24)	0.201	0.658	0.008
Group	(1, 24)	5.088	0.033 [a]	0.175
Limb	(1, 24)	20.702	0.000 [a]	0.463
Interaction Effects				
Time*Group	(1, 24)	0.324	0.574	0.013
Limb*Group	(1, 24)	0.007	0.933	0.000
Time*Limb	(1, 24)	9.701	0.006 [a]	0.274
Time*Limb*Group	(1, 24)	3.544	0.072	0.129

Significance – *alpha level set a priori = 0.05;* Power – *computed using alpha level set a priori = 0.05;* a – *significant effect ($p < 0.05$).*

APPENDIX D
Auburn University Softball Yoga Exit Survey

Please rate how strongly you agree or disagree with each of the following statements using the following scale:

1. Strongly Disagree
2. Disagree
3. Neither Agree nor Disagree
4. Agree
5. Strongly Agree

1.) I felt more flexible in my hips as a direct result of practicing yoga for six weeks.

1 2 3 4 5

2.) Practicing yoga allowed me to physically decompress and relax after softball training.

1 2 3 4 5

3.) Practicing yoga improved my functional performance on the softball field.

1 2 3 4 5

4.) I felt more flexible in my shoulders as a direct result of practicing yoga for six weeks.

1 2 3 4 5

5.) Practicing yoga allowed me to mentally decompress and relax after softball in the mornings.

1 2 3 4 5

6.) I felt stronger in my lower body as a direct result of practicing yoga for six weeks.

1 2 3 4 5

7.) I am more mindful and aware of my body as a result of practicing yoga for six weeks.

1 2 3 4 5

8.) I felt more mobile in my spine as a direct result of practicing yoga for six weeks.

1 2 3 4 5

9.) I enjoyed my time spent practicing yoga for six weeks.

1 2 3 4 5

10.) If given the opportunity, I would continue practicing yoga to supplement my softball training.

1 2 3 4 5

APPENDIX E

AUBURN UNIVERSITY
COLLEGE OF EDUCATION

SCHOOL OF KINESIOLOGY

301 Wire Road
Auburn, AL 36849
(334) 884-4483

BIOMECHANICAL and PERFORMANCE EVALUATION

Part 1. Participant Information

[Please print]

Participant ID: ____________ Date: _____________

Phone: _________________ Email:____

Height: _____ft _____in Weight: ________lbs Age: ____ years ____ months

DOB: _________

Gender: ________ Hand/Arm Dominance: _______ Leg/Foot Dominance: ______

Experiment Group: __________________ Position (circle one): Pitcher Fielder

Date: _____________ **PRE-INTERVENTION** Participant ID: ________

Part 2. Range of Motion Screening

Test		Left	Right	Total Arc	
Shoulder Internal Rotation	1			**Left**	**Right**
	2			1. 2. Avg.	1. 2. Avg.
	Avg.				
Shoulder External Rotation	1				
	2				
	Avg.				
Hip Internal Rotation	1			**Left**	**Right**
	2			1. 2. Avg.	1. 2. Avg.
	Avg.				
Hip External Rotation	1				
	2				
	Avg.				

Part 3. Flexibility Assessment

Test		Left	Right
Passive Knee Extension	1		
	2		
	Avg		

Part 4. Strength Assessment

Test		Peak Torque		Dynamic Control Ratio	
Knee Flexion (Hamstrings)	L	1-a. Concentric		1. H_{con}:Q_{ecc}	
		2-a. Eccentric		a. Left	b. Right
	R	1-b. Concentric			
		2-b. Eccentric			
Knee Extension (Quadriceps)	L	2-a. Concentric		2. H_{ecc}:Q_{con}	
		1-a. Eccentric		a. Left	b. Right
	R	2-b. Concentric			
		1-b. Eccentric			

Date: _____________ **POST-INTERVENTION** Participant ID: ________

Part 2. Range of Motion Screening

Test		Left	Right	Total Arc	
Shoulder Internal Rotation	1			**Left**	**Right**
	2			1. 2. Avg.	1. 2. Avg.
	Avg.				
Shoulder External Rotation	1				
	2				
	Avg.				
Hip Internal Rotation	1			**Left**	**Right**
	2			1. 2. Avg.	1. 2. Avg.
	Avg.				
Hip External Rotation	1				
	2				
	Avg.				

Part 3. Flexibility Assessment

Test		Left	Right
Passive Knee Extension	1		
	2		
	Avg		

Part 4. Strength Assessment

Test		Peak Torque		Dynamic Control Ratio	
Knee Flexion (Hamstrings)	L	1-a. Concentric		1. H_{con}:Q_{ecc}	
		2-a. Eccentric		a. Left	b. Right
	R	1-b. Concentric			
		2-b. Eccentric			
Knee Extension (Quadriceps)	L	2-a. Concentric		2. H_{ecc}:Q_{con}	
		1-a. Eccentric		a. Left	b. Right
	R	2-b. Concentric			
		1-b. Eccentric			

APPENDIX F

AUBURN UNIVERSITY
COLLEGE OF EDUCATION

YOGA PRACTICE LOG SHEET

SCHOOL OF KINESIOLOGY
301 Wire Road
Auburn, AL 36849

Participant ID:__________

Week	Date – Time	Duration (minutes)	Initials
1	Mon		
	Wed		
	Fri		
2	Mon		
	Wed		
	Fri		
3	Mon		
	Wed		
	Fri		
4	Mon		
	Wed		
	Fri		
5	Mon		
	Wed		
	Fri		
6	Mon		
	Wed		
	Fri		