Biomechanical Implications of Performance Garments During the Overhead Throw Among Female Athletes

by

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Abstract

The overhead throw is a dynamic motion that requires sequential movements of segments throughout the kinetic chain to efficiently deliver a ball to a specified target. Alterations throughout the kinetic chain often result in increased injury susceptibility (Atwater, 1979; Bartlett, 2008; Bencke, van den Tillaar, Møller, & Wagner, 2018; Chu, Jayabalan, Kibler, & Press, 2016). A major contributor of kinetic chain breakdown in overhead throwing athletes is the lack of scapula stability and mobility. In the dynamic overhead movement, the scapula must exhibit adequate stability as well as mobility for efficient humeral movement. Due to the repetitive and dynamic nature of overhead throwing, scapular dyskinesis, or inefficient movement of the scapula, is a common issue. It has been suggested that rehabilitative exercises, scapular taping, bracing, and more recently, performance garments assist in targeting scapular repositioning and improvement in mobility during dynamic tasks (Ashcraft, Lyman, Grange, Albrecht, & Hanson, 2017; Brophy-Williams, Driller, Shing, Fell, & Halson, 2015; Cole, 2008; Cole, McGrath, Harrington, Padue, Rucinski, & Prentice, 2013; Gascon, Gilmer, Hanks, Washington, & Oliver 2018a; Vangsness Jr; Zappala, Orrego, Boe, Fechner, Salminen, Cipriani, 2017). Performance garments have become increasingly popular with athletes for training and recovery; yet, the extant literature is not consistent on the overall biomechanical benefits during the overhead throw (Cipriani, Tiffany, & Lyssanova, 2014; Liu, Fu, He, & Xiong, 2011; MacRae, Laing, Niven, & Cotter, 2012). Therefore, the goal of this study was to determine upper extremity kinematic differences during a static stance and while performing an overhead throw among female athletes wearing two different

performance garments. Results revealed a main effect of garment in posterior tilt during static standing during the Design Garment condition ($p < 0.01$). Results also reveal a significant main effect of Garment in scapular lateral/medial rotation ($p = 0.03$) and Garment by Event interaction for protraction/retraction (MER, $p = 0.02$), lateral/medial rotation (BR and MIR, $p < 0.01$), and anterior/posterior tilt (BR, $p = 0.02$ and MIR, $p = 0.04$). The overhead throw places great demands on the upper extremity due to repetitive stresses to the glenohumeral joint, which have shown to lead to ligament and soft tissue injuries. Various non-operative methods exist for the prevention and treatment of these injuries, however, literature is still lacking on the use of specific types of performance garments as an alternative method of upper extremity injury prevention and treatment. Although the current study provided additional insight into the influence of garments during static and dynamic conditions further investigation into electromyography and kinetic differences, as well as physiological, psychophysiological, and sociological adaptations that may impact athletic performance among the female athlete populations should be conducted.

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List of Abbreviations

FC	Foot Contact
MER	Maximum Shoulder External Rotation
BR	Ball Release
MIR	Maximum Shoulder Internal Rotation
LPHC	Lumbopelvic-Hip Complex
NCAA	National Collegiate Athletic Association
SB	Softball

Chapter 1

1. Introduction

The overhead throw is one of the most dynamic and complex athletic movements. The main objective of the throwing motion is to deliver an accurate throw as quickly as possible to a specific target. This is achieved through sequential sequencing of body segments along the kinetic chain. Force and energy are generated and transferred from the most proximal segments (lower extremity) to the most distal segments (upper extremity) (Atwater, 1979; Chu et al., 2016; Kibler, Wilkes, & Sciascia, 2013; Sciascia, Thigpen, Namdari, & Baldwin, 2012). The application of force is a critical component to maximum ball velocity. Proper scapular positioning and mobility is required to efficiently transfer forces and energy throughout the kinetic chain in order to achieve maximum force production during dynamic movements (Chu et al., 2016; Seroyer, Nho, Bach, Bush-Joseph, Nicholson, & Romeo, 2010). Unfortunately, due to activities of daily living and repetitive athletic movements, deviation from proper scapular positioning and mobility can adversely affect athletic performance (Barczyk-Pawelec, Bańkosz, & Derlich, 2012; Gascon, Washington, Gilmer, & Oliver, 2018b; Gilleard, 2007; O'sullivan, 2006; Zappala et al., 2017). To assist an individual in optimal scapular positioning and mobility, performance garments specifically designed to target scapular positioning have become a popular solution (Cipriani et al., 2014; Fu, 2013; MacRae et al., 2012; Michael, Dogramaci, Steel, & Graham, 2014; Wallace, 2006). The most popular performance garments are typically designed to be tight-fitting and marketed to aid in recovery, improve posture, and performance (Cipriani et al., 2014; Fu, 2013; MacRae et al., 2012; Michael et al., 2014; Wallace, 2006). Research in recovery benefits of performance garments include decreases in post-exercise edema and perception of delayed onset of muscle soreness; while performance benefits include increased joint awareness, perfusion, muscle oxygenation, skin temperature, and decreased perception of fatigue (MacRae et al., 2012; Wallace, 2006). Additionally, other research has shown that some performance garments biomechanically cue an individual to maintain and improve posture, scapular positioning, and alignment (Casselman-Dickson & Damhorst, 1993; Dickson, 2000; Gascon et al., 2018a; Hoiness, 2008; Stryker, 1968). However, there are insufficient data supporting performance garments facilitating dynamic movements, such as the overhead throw (Ashwell, 1985; Cole, 2008; Cole et al., 2013; Gascon et al., 2018b).

The kinematics of the overhead throw places great demands on the upper extremity due to repetitive stresses to the glenohumeral joint, and requires efficient segmental sequencing to optimally transfer energy and force to deliver a ball to a specific target (Kibler & Sciascia, 2017; Kibler et al., 2013; Sciascia & Kibler, 2006). The kinetic chain is an integrated system by which movement at one segment affects movement at the next adjacent segment. This integrated system includes motor patterns that are repetitive and task-specific working synergistically through an interdependent linked segment (Chu et al., 2016). During the overhead throw, for the kinetic chain to work efficiently, sequential muscle activity beginning proximally at the feet, is required to create a stable base of support (Chu et al., 2016). The force and energy generated in the lower extremity, is transferred to the lumbopelvic-hip complex (LPHC) and on to the distal end of the upper extremity (Burkhart, Morgan, & Kibler, 2003c; Chu et al., 2016; Kibler et al., 2013; Seroyer et al., 2010). The upper extremity, specifically the shoulder, is designed to transfer energy and force through great ranges of motion through coordinated actions of the shoulder complex. The shoulder complex is comprised of four joint articulations that include the scapulothoracic, sternoclavicular, acromioclavicular, and glenohumeral joints. These joints work concomitantly and are vital to optimal positioning of the elbow and hand during the overhead throw (Chu et al., 2016; Kibler et al., 2013; Sciascia et al., 2012). More specifically, within the shoulder complex, the scapula plays a vital role in facilitating and optimizing shoulder function during the overhead throw. Optimal positioning of the scapula is commonly evaluated at the throwing events of foot contact, maximum shoulder external rotation, ball release, and maximum shoulder internal rotation (Calabrese, 2013; Chu et al., 2016; Erickson, Thorsness, Hamamoto, & Verma, 2016; Gascon et al., 2018b; Oliver & Weimar, 2015; Oliver, Plummer, Henning, Saper, Glimer, Brambeck, & Andrews, 2017). At foot contact, the scapula should be in a position of retraction/external rotation, slight lateral/upward rotation and anterior tilt (Kibler, 1998; Burkhart et al., 2003c; Kibler, 1991; Kibler & Sciascia, 2017; Oliver & Weimar, 2015). During maximum shoulder external rotation, the scapula should be in a position of maximum retraction/external rotation, lateral/upward rotation as well as posterior tilt (Kibler, 1998; Burkhart et al., 2003c; Kibler, 1991; Kibler & Sciascia, 2017; Oliver & Weimar, 2015). To position the shoulder into maximum internal rotation, the scapula should be in a position of protraction/internal rotation and anterior tilt (Kibler, 1998; Burkhart et al., 2003c; Kibler, 1991; Kibler & Sciascia, 2017; Oliver & Weimar, 2015). These scapular positions, during the throwing motion, allow for efficient transfer of force and energy over a greater range of motion and a reduction of glenohumeral joint stress (Kibler, 1998; Burkhart et al., 2003c; Kibler, 1991; Kibler & Sciascia, 2017; Oliver & Weimar, 2015).

Musculoskeletal health and the ability to perform daily living activities and athletic movements is heavily influenced by optimal posture (Christian, Zubrick, Knuiman, Nathan, Foster, Villanueva, & Giles-Corti, 2017; Davies, Vandelanotte, Duncan, & Van Uffelen, 2012; Di Bartolo & Braun, 2017; Wilmot et al., 2012). Optimal posture has previously been defined as the state of muscular and skeletal balance which protects the supporting structures of the body regardless of the position of the body during rest or motion (Peterson-Kendall, Kendall-McCreary, Geise-Provance, McIntyre-Rodgers, & Romani, 2005). Optimal posture allows the body to perform at its best and reduce the possibility of injury during athletic movements (Gascon et al., 2018b; Kritz, 2008; Peterson-Kendall et al., 2005; Zappala et al., 2017). The integrity of the slight S shape of the spine is a characteristic of proper posture and should be maintained during both static and dynamic activities. Conversely, poor posture, often associated with repetitive patterns of activities, causes excessive strain on the supporting structures which leads to alterations in movement patterns (Peterson-Kendall et al., 2005). Postural deviations of the spine typically occur as a result in poor posture sustained during positions and repetitive patterns of daily activities such as excessive sitting and screen time use (Christian et al., 2017; Davies et al., 2012; Di Bartolo & Braun, 2017; O'sullivan, 2006). Poor posture limits range of motion effecting static and dynamic activities (Peterson-Kendall et al., 2005). More specifically, poor posture during athletic performance is the leading cause and main risk factor in many athletic injuries (Barczyk-Pawelec et al., 2012; Cipriani et al., 2014; Gilleard, 2007; Kritz, 2008; Lewis, Wright, & Green, 2005; O'sullivan, 2006; Peterson-Kendall et al., 2005; Zappala et al., 2017). It has been reported that postural deviations may decrease force production, efficient transfer of energy, power output, increase muscular fatigue, and lead to increased risk of injury (Chu et al., 2016; Kritz, 2008).

Postural deviations are often characterized by pelvic anterior tilt, thoracic kyphosis, and a forward head position (Gilleard, 2007; O'sullivan, 2006). Additionally, individuals displaying postural deviations often have altered scapular kinematics, referred to as scapular dyskinesis (Kibler, 1998; Grimsby & Gray, 1997; Kibler, 1991; Kibler & Sciascia, 2017). Scapular dyskinesis is a condition which alters scapular mechanics and motion (Kibler & McMullen, 2003; Kibler & Sciascia, 2016; Postacchini, 2013). Scapular dyskinesis impairs optimal scapular motion and increases the risk of shoulder pathology. Research suggests scapular dyskinesis may contribute to abnormal joint stresses and can be identified through specific patterns. The scapula may present as a prominence of the inferior angle, as well as prominence at the medial boarder. Although individuals may present with specific scapular positioning risk factors, they may not necessarily develop shoulder or elbow pathology (Kibler, 1998; Burkhart, Morgan, & Kibler, 2003a; Kibler & Sciascia, 2017; Kibler et al., 2013). However, research has shown these scapular positions are closely related to restrictions in movement of the humerus, and thus, affecting the scapulohumeral rhythm (Chu et al., 2016; Codman, 1934; Cools, Ellenbecker, & Michener, 2017; Kibler, 1998; Kibler et al., 2013; McLeod & Andrews, 1986). Scapulohumeral rhythm is the coupled and coordinated movement of the scapula and humerus and is a necessary component to optimize efficient transfer of energy and force in the overhead throw (Kibler & Sciascia, 2016; McQuade & Smidt, 1998; Postacchini, 2013).

Although altered scapular positions have been shown to be advantageous for specific athletes (i.e. throwing shoulder asymmetry displaying increases in scapular upward rotation leading to increases in subacromial space and decreasing subacromial impingement) (Kibler & Sciascia, 2017; Kritz, 2008), these altered scapular positions have also been associated with limited range of motion and pain (Kibler et al., 2013; Kritz, 2008). Altered scapular positions and lack of mobility may predispose individuals to ligament and soft tissue injuries resulting in the disruption of the efficacy of the kinetic chain; and ultimately time lost in their respective sport(s) (Kibler, 1998). To rectify scapular deviations, postural taping, bracing, and performance garments have been suggested in an attempt to reduce injury risk and improve performance (Ashcraft et al., 2017; Cipriani et al., 2014; Cole et al., 2013; Gascon et al., 2018b; Kritz, 2008; Michael et al., 2014; Peterson-Kendall et al., 2005; Ribeiro, 2013; Vangsness Jr; Zappala et al., 2017). However, scapular taping and bracing have been known to limit range of motion causing altered overhead kinematics (Bandyopadhyay & Mahapatra, 2012; Cole et al., 2013; Hsu, Chen, Lin, Wang, & Shih, 2009; Intelangelo, Bordachar, & Barbosa, 2016; Keenan, Akins, Varnell, Lovalekar, Lephart, & Sell, 2017; Kneeshaw, 2002; Leong, Ng, & Fu, 2017; Morrissey, 2000; Rovere, Curl, & Browning, 1989; Shaheen, Villa, Lee, Bull, & Alexander, 2013; Ulkar, Kunduracioglu, Cetin, & Güner, 2004); therefore, it has been suggested that the use of performance garments may be a better alternative treatment as the effectiveness of these garments have been shown to reduce the incidence of athletic injury (Brophy-Williams et al., 2015; Duffield & Portus, 2007; Fu, 2013; Gascon et al., 2018a; Wallace, 2006). Performance garments have often been targeted as scapular-stabilizing and posture-cueing. Within the performance garment literature, it has been found that the application of a scapular-stabilizing garment improved shoulder posture and scapular muscle activity while participants performed rehabilitative exercises (Cole, 2008; Cole et al., 2013). Specifically, the scapular-stabilizing garment showed an increase in lower and middle trapezius activation while there was a decrease in upper trapezius activation (Cole, 2008; Cole et al., 2013). The posture-cueing garments have shown some improvement in posture and performance among overhead athletes in sports such as baseball, tennis, and volleyball (Shepard, 2012; Vangsness Jr; Zappala et al., 2017). However, in a more recent examination of posture-cueing garments, softball athletes showed no benefits to improved scapular positioning (Gascon et al., 2018a). Although research has shown that performance garments (scapular-stabilizing and posture-cueing) provide athletes with scapular positioning and performance benefits, there is a need for improvement of positioning, stability, and mobility of the scapula during dynamic movements such as an overhead throwing task (Gascon et al., 2018a).

1.1. Statement of the Problem

Due to the repetitive nature of overhead throwing, dissipation of force and energy through greater ranges of motion, and scapular asymmetry, many athletes lack the proper scapular positioning and mobility to efficiently execute the overhead task which therefore leads to altered overhead throwing kinematics (Wilk, Meister, & Andrews, 2002; Wilk, Yenchak, Arrigo, & Andrews, 2011). Optimal scapular positioning and mobility has been shown to contribute to coordinated upper extremity movements providing maximum force production and a reduction in the risk of injury (Cipriani et al., 2014; Cole et al., 2013; Gascon et al., 2018a). However, due to specific lifestyle choices and repetitive dynamic overhead movements, common deviations are often seen in positioning and mobility of the scapula among overhead athletes. Altered scapular positioning and mobility has been shown to cause disruption in the kinetic chain and therefore increases the risk of overhead injuries (Chu et al., 2016; Erickson et al., 2016; Kibler, 1998; Wilk et al., 2002). Taping and bracing techniques have previously been used to assist athletes with maintaining proper scapular positioning to provide stability and mobility for the glenohumeral joint; however, they are often cumbersome and ineffective during a dynamic movement such as overhead throw (Cole et al., 2013; Lindley & Kernozek, 1995; Rovere et al., 1989; Ulkar et al., 2004; Vastamäki, Pikkarainen, Vastamäki, & Ristolainen, 2015). One alternative that athletes, sports medicine personnel, and physical therapists have begun implementing during rehabilitation and sports competitions is the use of performance garments.

Performance garments have been evaluated and tested for physiological, psychological, and overall sport performance benefits (Bochmann, Seibel, Haase, Hietschold, Rodel, & Deussen, 2005; Born, Sperlich, & Holmberg, 2013; Cangur, Yaman, Ercan, Yaman, & Tok, 2017; Jakeman, 2010; MacRae et al., 2012; Marques-Jimenez, Calleja-Gonzalez, Arratibel, Delextrat, & Terrados, 2016; Monteath & McCabe, 1997; Singh, 1993); however, little research has provided biomechanical implications for performance garments during overhead tasks among athletes, more specifically female overhead throwing athletes (Ashwell, 1985; Cole, 2008; Cole et al., 2013; Gascon et al., 2018b). Therefore, the purpose of this study was to examine upper extremity kinematic differences among female athletes wearing two different types of performance garments during static standing and a dynamic overhead throw. One garment is a performance garment with a built-in sports bra designed specifically for female athletes. This garment is referred to as the Design Garment. The second garment was a generic performance garment worn over the participants individual sports bra. This garment is referred to as the Generic Garment.

1.2. Statement of the Purpose

The purpose of this research was to determine upper extremity kinematic differences during a static stance and overhead throwing events among female throwing athletes during two different garment conditions. A comparative analysis of the Design Garment versus Generic Garment was assessed. Analysis of upper extremity kinematic variables included scapular protraction/retraction, lateral/medial rotation, and anterior/posterior tilt; and shoulder horizontal abduction, elevation, and rotation.

1.3. Research Questions

RQ1: Is there a difference in the scapular position (protraction/retraction, lateral/medial rotation, anterior/posterior tilt) during a static stance while wearing two different performance garments?

RQ2: Are there kinematic differences of horizontal abduction, elevation, and rotation during the overhead throw at the four throwing events of foot contact, maximal shoulder external rotation, ball release and maximal shoulder internal rotation between two different performance garments?

RQ3: Are there kinematic differences of scapular protraction/retraction rotation, lateral/medial rotation, and anterior/posterior tilt during the overhead throw at the four throwing events of foot contact, maximal shoulder external rotation, ball release and maximal shoulder internal rotation between two different performance garments?

1.4. Hypotheses

H01: The scapula will be in a position of decreased protraction, lateral rotation, and anterior tilt among female athletes during static standing during the Design Garment condition compared to the Generic Garment condition.

H02: There will be increased horizontal abduction, elevation, and rotation during the Design Garment condition compared to the Generic Garment condition during the overhead throwing events of foot contact, maximum shoulder external rotation, ball release, and maximum shoulder internal rotation.

H03: There will be increased scapular retraction, lateral rotation and posterior tilt during the Design Garment condition compared to the Generic Garment condition during the overhead throwing events of foot contact, maximum shoulder external rotation, ball release, and maximum shoulder internal rotation.

1.5. Limitations

Limitations of this study included:

1. All female athletes wore their own workout garments over each undergarment condition.
2. Gradient compression of each garment varied depending on the size of each athlete.
3. Design Garment cup size remained the same despite potential differences for each female athlete.

1.6. Delimitations

Delimitations of this study included:

1. All data collections were executed in a controlled laboratory setting in the Auburn University, School of Kinesiology Sports Medicine and Movement Laboratory.
2. All participants were female softball athletes aged 19-30 years, with a minimum of 2 years playing experience at the high school or travelball level.
3. All throws utilized a National Collegate Athletic Association (NCAA) regulation size softball (30 cm).
4. All of the Generic Garments were purchased from the same company at the same store.
5. All of the Design Garments were made specifically for female athletes based on data collected from the $[TC]^2$ NX-16 Model three-dimensional whole-body scanner ($[TC]^2$, Cary, NC) in the Department of Consumer and Design Sciences (CADS) at Auburn University.

Chapter 2

2. Review of Literature

The purpose of this study examined upper extremity kinematic differences among female athletes wearing two different types of performance garments during a static stance and while performing an overhead throw. A comparative analysis of a Design Garment versus a Generic Garment was assessed. The main objectives of this chapter were to articulate the biomechanics of the overhead throw, and the biomechanical influence of performance garments on scapular positioning and sport performance.

2.1. Biomechanics of the Overhead Throw

The overhead throwing motion is one of the most explosive, unilateral athletic movements the body can perform. At the elite level, athletes are able to produce angular velocities over 7000º per second at the glenohumeral joint when performing overhead throws (Edelson, 2000; Kibler & Sciascia, 2017; van den Tillaar & Ettema, 2007). In order to achieve such high velocities, athletes maximize the transfer of momentum from larger proximal segments to smaller distal segments (Chu et al., 2016; Fradet, 2004; Seroyer et al., 2010; Van Den Tillaar, 2009; Wagner et al., 2014). During the overhead throw, two main principles apply; conservation of momentum and force summation. These two principles allow an athlete to optimally perform an overhead throwing task with the desired velocities and performance outcome(s). The Law of Conservation of Momentum states that the total linear or angular momentum in any system is constant as long as no external force is applied (Hamilton, 2011). The ability to utilize and transfer momentum from the body to a ball can be achieved through force summation. The combination of force produced by different segments of the body over a period of time produce maximal or submaximal force depending on the required demand of the overhead throwing task.

The linked segmental system of the body is commonly referred to as the kinetic chain. Segmental interactions throughout the kinetic chain are critical to optimizing efficient movement to execute specific tasks (Chu et al., 2016; Putnam, 1993). An efficient kinetic chain requires proximal stability of the lower extremity for distal mobility at the upper extremity (Chu et al., 2016; Erickson et al., 2016). The greatest force production is generated in the lower extremity and transferred through the lumbopelvic-hip complex and on to the upper extremity. The key contributor to efficiently transferring energy and force through the upper extremity and on to the hand for ball release is the scapula (Kibler & Sciascia, 2017; Seroyer et al., 2010). Any disruption within the kinetic chain, from force generation in the lower extremity to the energy transfer via scapular stability and mobility to the upper extremity, increases injury susceptibility (Burkhart et al., 2003c; Chu et al., 2016; Sciascia et al., 2012; Seroyer et al., 2010).

2.2. Contribution of Lumbopelvic-Hip Complex

The direct link connecting the lower extremity to the upper extremity is the lumbopelvic-hip complex (LPHC). The LPHC is considered the core of the body where muscles either attach or insert on the lumbar spine, pelvis, and femur. LPHC stability has previously been defined as the ability to control the location of the trunk over the pelvis, which allows for uninterrupted transfer of energy during the overhead throw (Kibler, 2006). The LPHC provides a base of support, for postural stability and efficient dispersion of force utilized during the proximal to distal sequence of the overhead throw (Chu et al., 2016; Kibler, Press, & Sciascia, 2006; Putnam, 1993). However, any deviation of timing (i.e., pelvis and trunk rotation) or lack of strength and stabilization of the LPHC during dynamic movements, such as the overhead throw, will result in movement dysfunction. Lack of stability in the LPHC often leads to decreased efficiency of energy transfer, decreased optimal force output, and furthermore inhibits the appropriate proximal to distal sequence. Lumbopelvic-Hip Complex stability is vital to the transfer of energy from the lower extremity to upper extremity as 51-55% of the kinetic energy that is transferred to the hand during the overhead throw is generated in the lower extremity (Chu et al., 2016; Kibler et al., 2013; Lintner, Noonan, & Kibler, 2008). It has been shown that decreased hip range of motion and strength can increase demands placed on the shoulder and upper extremity; 58% of injuries in baseball and softball were found to occur in the upper extremity (Dick, Hertel, Agel, Grossman, & Marshall, 2007; Krajnik, Fogarty, Yard, & Comstock, 2010). Additionally, pathomechanics of the throwing motion often leads to a decrease in performance and increase in injury susceptibility (Chu et al., 2016). Due to the high demand placed on the upper extremity from repetitive stresses to the shoulder, strength and stability of the LPHC coupled with the synchronization of the scapulothoracic and glenohumeral joints, are required to provide appropriate balance of joint mobility and functional stability in reducing the risk of injury (Kibler, 1998; Wilk et al., 2002; Wilk, Obma, Simpson, Cain, Dugas, & Andrews, 2009). Unfortunately, due to repetitive overhead movements, lack of muscular strength, inadequate mobility, and structural complexity of the shoulder and LPHC, overuse injuries among throwing athletes are commonplace (Henning, Plummer, & Oliver, 2016; Prentice & Arnheim, 2013; McLeod et al., 2011). Therefore, the coordination of the lower extremity, LPHC, and upper extremity is vital to enhance performance during an overhead throw.

2.3. Contribution of the Shoulder Complex

Due to the dynamic and forceful nature of the overhead throw, one of the most commonly injured joints is the shoulder complex (Kibler, 1998; Burkhart, Morgan, & Kibler, 2000; Burkhart et al., 2003a; Burkhart, Morgan, & Kibler, 2003b; Carling, Francis, & Lorish, 1995; Clarsen, Bahr, Andersson, Munk, & Myklebust, 2014; Kibler & McMullen, 2003; Kibler & Sciascia, 2017; K.

Laudner & Sipes, 2009; Wilk et al., 2009). The shoulder complex is a highly mobile joint with the primary purpose of accurately positioning the elbow and hand for ball release during overhead throwing tasks. The shoulder complex consists of four individual joints which allow for multiplanar movements of the upper extremity. These joints include the glenohumeral joint, acromioclavicular joint, sternoclavicular joint, and scapulothoracic joint. The glenohumeral joint, commonly referred to as the shoulder, is a synovial ball-and-socket where the head of the humerus articulates with the glenoid fossa of the scapula. The glenohumeral joint offers the greatest range of motion of any joint in the body. The acromioclavicular joint includes the clavicle connected to the scapula. It lies over the top of the head of the humerus and serves as a bony restriction to overhead arm movement (Wilk et al., 2009; Neumann, 2002). The scapulothoracic joint consists of the clavicle articulating with the manubrium of the sternum. The sternoclavicular joint is the only direct connection between the upper extremity and the trunk (Prentice & Arnheim, 2013). The scapulothoracic joint is not a typical articulation but it is described as the convex surface of the posterior thoracic cage and the concave surface of the anterior scapula. The movement of the scapulothoracic joint occurs as the scapula moves along the thorax. The scapulothoracic joint serves two major functions: (1) to increase range of motion about the glanohumeral joint and, (2) to facilitate a large lever for the muscles attaching to the scapula (Wilk et al., 2009; Neumann, 2002). The coordinated effort between these joints about the shoulder is vital during the overhead throw. For the shoulder to perform efficiently during the ballistic movement of overhead throwing, there has to be a stable base of support for the facilitation of energy transfer. It is the stability of the scapula that allows for the stable base of support for the shoulder to function optimally.

The ability of the shoulder to provide great range of motion during ballistic upper extremity movements is dependent on the stability and mobility of the scapula. As stated previously, the glenoid fossa of the scapula articulates with the head of the humerus to form the shoulder joint (D., 2002). In addition to the articulation between the scapula and humerus, there are eighteen muscles that originate or insert on the scapula (Neumann, 2002). These muscles can be categorized into three groups: axioscapular, scapulohumeral, and muscles of the upper arm (Kibler & Sciascia, 2017). The axioscapular muscles include serratus anterior, levator scapulae, pectoralis minor, rhomboids, and trapezius. These muscles anchor the scapula and assist in guiding the scapula through the necessary degrees of freedom to help stabilize the humerus. The serratus anterior assists with protraction, lateral rotation, and posterior tilting of the scapula with arm elevation as well as stabilizes and protects against excessive internal rotation and protraction in varying arm positions. The levator scapula works closely with the serratus anterior to elevate and upwardly rotate the scapula. The pectoralis minor is often associated with malpositioning of the scapula as it is often affiliated with chronic tightness causing protraction and anterior tilting. The rhomboids are divided into major and minor portions and assists with scapular retraction. Lastly, the trapezius muscles are the largest and most superficial muscles. These muscles consist of the upper, middle, and lower trapezius muscles. They retract, elevate, and posteriorly tilt the scapula depending on the recruitment pattern. The scapulohumeral muscles include the deltoid, supraspinatus, infraspinatus, subscapularis, teres minor, and teres major (Kibler, 1998; Cools et al., 2017; Kibler & Sciascia, 2017; Leong et al., 2017). The purpose of these muscles is to act as dynamic stabilizers to hold the humeral head tightly within the glenoid cavity and produce glenohumeral motion. The deltoid muscles are divided into three sections: anterior, middle, and posterior deltoids. The anterior deltoid flexes and medially rotates the humerus, the middle is responsible for abduction of the humerus, and the posterior deltoid extends and laterally rotates the humerus. The scapulohumeral muscles of supraspinatus, infraspinatus, subscapularis, and teres minor are also often referred to as the rotator cuff muscles. The supraspinatus is responsible for abduction, infraspinatus is responsible for the external rotation of the humerus, subscapularis is responsible for internal rotation of the humerus, and teres minor is responsible for external rotation of the humerus. The last of the scapulohumeral muscles is the teres major. The teres major includes the following functions; adduction, internal rotation, and extension and retroversion of the humerus. Lastly, the upper arm muscles include coracobrachialis, biceps brachii, and triceps brachii. These muscles assist in supporting the shoulder girdle and provide flexion and extension of the elbow during dynamic overhead tasks (Kibler & Sciascia, 2017). The coracobrachialis flexes and adducts the humerus. The biceps brachii depresses the head of the humerus, flexes the elbow, and supinates the forearm. The triceps brachii is responsible for the extension of the elbow. The function of these muscles further illustrates the importance of the role of the scapula for stability and mobility during any type of overhead movement.

The scapula serves five major roles for shoulder function which include: (1) a stable base for glenohumeral joint articulation, (2) retraction and protraction movement along the thoracic wall, (3) acromion elevation, (4) provide a stable base for muscle attachments, and (5) being the link in the proximal to distal segmental sequencing of velocity, energy, and forces that allows the most appropriate shoulder function (Kibler, 1998). These functions are crucial, dynamic components of the upper extremity, as the scapula acts to perform specific tasks for efficient and optimal movement. These actions include protraction and retraction, lateral and medial rotation, anterior and posterior tilt, and elevation and depression (Kibler, 1998; Peterson-Kendall et al., 2005). For the most effective movement of the glenohumeral joint, the scapula must move in a coordinated manner with the humerus (Kibler, 1998; Kibler & Sciascia, 2016). Additionally, movement at the scapula is not possible without motion at the AC and/or SC joints (Kibler, 1998;

Kibler & Sciascia, 2017). The scapula must posteriorly tilt to allow for acromial elevation in order to achieve efficient arm elevation in dynamic upper extremity movements (Kibler, 1991; Myers, Laudner, Pasquale, Bradley, & Lephart, 2005). Furthermore, posterior tilting of the scapula and elevation of the acromion results in decreasing compression of subacromial soft tissues during humeral elevation and abduction (Kibler & Sciascia, 2016; Ludewig & Cook, 2000; Sciascia et al., 2012). Decrease subacromial space due to lack of acromion elevation, often results in supraspinatus or biceps tendon impingement (Kibler & Sciascia, 2017; Oliver & Weimar, 2015). Thus, due to the ballistic nature of overhead throwing as well as the high prevalence of shoulder injury, adequate positioning, stability, and mobility of the scapula is essential (Cools et al., 2017; Kibler, 1998; Kibler & Sciascia, 2017; Oliver & Weimar, 2015).

2.4. Overhead Throwing Events

The overhead throw is often divided and assessed into the events of foot contact, maximum shoulder external rotation, ball release, and maximum shoulder internal rotation (Atwater, 1979; Erickson et al., 2016; Fleisig, 2001; Gascon et al., 2018b; Oliver & Weimar, 2015). Foot contact is characterized by the lead leg (contralateral to the throwing arm) in contact with the ground. Foot contact provides the body with a stable base of support to allow for efficient pelvic and trunk rotation. At foot contact, the throwing arm is in a semi-cocked and abducted position (Kibler & Sciascia, 2017; Weber, 2014). The scapula should be in a slightly retracted, laterally rotated, and anteriorly tilted position. This scapular positioning prepares the overhead athlete for an optimal position of maximum shoulder external rotation.

The throwing event of maximum shoulder external rotation occurs as the pelvis and trunk rotate toward the target while the scapula is further retracted, laterally rotated, and posteriorly tilted (Kibler & Sciascia, 2017; Weber, 2014). This position of scapular retraction, lateral rotation and posterior tilt will allow for the most effective movement of the glenohumeral joint, increasing the range of motion and permitting the scapula to move in a coordinated manner with the humerus (Kibler, 1998; Kibler & Sciascia, 2016). However, malposition of the scapula during maximum shoulder external rotation, such as anterior tilt and protraction, has shown to contribute to a decrease in glenohumeral external rotation (Kibler & McMullen, 2003) and therefore resulted in decrease range of motion and force and may result in a compromised position for the throwing shoulder during ball release (Kibler, 1998; Burkhart et al., 2003c; Chu et al., 2016).

Following the event of maximum shoulder external rotation is ball release. During the progression from maximal shoulder external rotation to ball release, the trunk moves from hyperextension to forward flexion, the shoulder begins to internally rotate and increase horizontal adduction; the scapula begins to protract, and anterior tilt; the elbow begins to move into extension; and the hand moves forward to release the ball (Erickson et al., 2016; Fleisig, 2001; Weber, 2014). The event of ball release is a crucial position to optimize ball velocity and decrease the risk of injury (Chu et al., 2016; Oliver & Keeley, 2010). It is imperative for the scapula to provide dynamic stability to the humerus, during the ball release event, in order to minimize shear forces, tension of the ligaments, and muscle activation which would create the most efficient positioning to transfer energy and force from the lower extremity.

Immediately following ball release is the event of maximum shoulder internal rotation. At maximum shoulder internal rotation, the trunk is in full forward flexion, the throwing arm continues to horizontally adduct across the trunk as the shoulder internally rotates, the elbow is fully extended, and the scapula is protracted, and anteriorly tilted (Erickson et al., 2016; Fleisig, 2001; Weber, 2014). Acceleration in the negative direction is needed to slow the arm movement in the positive direction (or towards the intended target). The scapula is at the other end of the range of motion in comparison to the maximum shoulder external range of motion. This scapular positioning is critical to the appropriate dissipation of energy and force during the final event of the throw.

As previously stated, the overhead throw is a dynamic movement utilizing the entire kinetic chain to produce the greatest ball speed. This linked segmented system is an integrated system which requires the body to maintain proximal stability for distal mobility to transfer energy and force efficiently. Deviation of the proximal to distal sequencing due to improper positioning or motion of the scapula disrupts the integrated system of the kinetic chain increasing the stress and force on the shoulder and increasing the likelihood of soft tissue injury (Chu et al., 2016; Kibler & Sciascia, 2017; Kibler et al., 2013; Seroyer et al., 2010).

2.5. Performance Garments Influence on Biomechanics

Biomechanical benefits have been observed with performance garments (Vangsness Jr; Zappala et al., 2017) and these garments are becoming more commonly used among the athletic population for both performance and recovery (Born et al., 2013; Brophy-Williams et al., 2015; Liu et al., 2011; Marques-Jimenez et al., 2016). Performance garments come in a variety of styles: upper body, long sleeve and short sleeve; lower body, full-body, partial length, and short length (MacRae et al., 2012). Some performance garments, also known as compression performance garments, are made of an elastic textile fabric that exerts pressure onto the body (Liu et al., 2011; Marques-Jimenez et al., 2016). These types of garments have recently evolved and have been redesigned to provide postural improvement. Postural control and overhead throwing performance are heavily influenced by the positioning of the pelvis, trunk, scapula, and shoulder (Gilleard, 2007; Lewis et al., 2005; O'sullivan, 2006; Peterson-Kendall et al., 2005). However, among the overhead throwing athlete population, scapular positioning has been one of the greatest factors to consider when evaluating posture and optimal performance during the overhead throw (Cools et al., 2017; Kibler, 1998; Kibler & Sciascia, 2017). Research has shown the glenohumeral internal rotation deficit as well as scapular protraction, anterior tilt, and internal rotation during a resting condition predisposes the shoulder to pathomechanics during the overhead throw (Kibler, 1998; Burkhart et al., 2003c; Cools et al., 2017; Kibler & McMullen, 2003; Kibler, 1991; Kibler, 1998). In an attempt to address shoulder pathomechanics due to scapular positioning, sports medicine personnel have utilized other methods such as rehabilitative protocols, taping, bracing, and more recently posture-cueing garments (Cipriani et al., 2014; Gascon et al., 2018a; Gascon et al., 2018b; Shepard, 2012).

Performance garment designs have been heavily influenced by the reported success of taping and bracing methods (Gascon et al., 2018a; Gascon et al., 2018b; Rovere et al., 1989). Performance garments have been used by athletes to improve posture, scapular positioning and mobility, and athletic performance (Cipriani et al., 2014; Gascon et al., 2018a; Vangsness Jr). Upper extremity performance garments come in a variety of designs, some with and without shoulder straps. The biomechanical influence of performance garments with shoulder straps cue the individual to maintain and improve alignment. Specifically, the shoulder straps target the posterior shoulder to improve scapular positioning and therefore restore normal shoulder kinematics (Smith). These designs have been used on individuals with forward head and rounded shoulder postures (Cole et al., 2013; Ulkar et al., 2004) and have been shown to improve posture when participants wore a scapular-stabilizing compression garment with straps (Cole et al., 2013). Performance garments without shoulder straps are constructed in an attempt to signal, or promote, activation of the LPHC and scapular muscles for better postural alignment of an individual's shoulders, spine, and trunk (Gascon et al., 2018a). This is achieved through a proprioceptive feedback mechanism (Bragg et al., 2002; Feuerbach, Grabiner, Koh, & Weiker, 1994; Robbins, Waked, & Rappel, 1995; Simoneau, Degner, Kramper, & Kittleson, 1997). Proprioceptive feedback is muscle-joint input that provides information regarding position in space and/or in relation to objects. Pressure of the posture-cueing garment provides cutaneous sensory cues providing input to the central nervous system. These sensory cues will allow specific musculature to signal the body to maintain a more upright and proper posture (Gascon et al., 2018a). Proper posture has been defined as the muscular balance which protects the supporting structures of the body against injury or progressive deformity (Peterson-Kendall et al., 2005). Poor posture has been defined as a faulty relationship of the various parts of the body which produce increased strain on the supporting structures causing decreased efficiency of balance of the body over its base of support (Peterson-Kendall et al., 2005). Gascon et al. (2018) reported an increase in scapular retraction and posterior tilt when wearing a posture-cueing garment, thus concluding that the posture-cueing garment allowed for an optimal scapula position potentially decreasing the susceptibility of shoulder impingement (Gascon et al., 2018a). These types of posture-cueing garments are directly linked to improved performance and have been shown to assist baseball pitchers and tennis athletes during execution of sport specific tasks (Vangsness Jr; Zappala et al., 2017). When wearing the posture-cueing garment, baseball pitchers displayed an increase in pitch velocity as well as increased blood flow to the pitching arm (Vangsness Jr). Tennis athletes exhibited significant increases in peak shoulder internal rotation velocity and shoulder internal rotation velocity at the time of impact (Zappala et al., 2017), which has shown to result in an increase in racket and ball velocity (Zappala et al., 2017). However, it has been reported that posture-cueing garments during the overhead throw among softball athletes resulted in neither performance nor postural benefits (Gascon et al., 2018b). Posture-cueing garments have been shown to assist athletes during athletic performance. However, there are limited data supporting the kinematic influence of posture-cueing garments among athletes during the overhead throw. Based on the author's extensive literature reviews, limited research has been conducted to determine the kinematic influence on performance garments designed specifically for the female athlete.

2.6. Summary

The overhead throw is a dynamic, synergistic movement requiring a coordinated sequence of segmental movements throughout the kinetic chain. The LPHC is critical to the efficient transfer of energy from the proximal segments to the distal and the reduction of injury to the upper extremity, particularly to the shoulder complex. The shoulder complex, during overhead throwing activity, is a highly mobile joint with the primary purpose of accurately positioning the elbow and hand for ball release. Unfortunately, due to the complexity of and demand on the shoulder complex, there is increased susceptibility of injury during overhead tasks. Reducing the likelihood of injury to the shoulder complex requires both stability and mobility of not only the LPHC but also the scapula. The scapula is an attachment site for numerous muscles, acts as a stable base of support, and links lower and upper extremities in the kinetic chain, allowing for optimal energy and force transfer. Any deviation from optimal scapular stability, mobility, or positioning will increase upper extremity injury susceptibility during the overhead throw.

One popular option for performance enhancement and injury prevention is the use of a performance garment. Performance garments have been shown to improve scapular function and shoulder joint mechanics and provide efficient execution of overhead tasks (Davies, Thompson, & Cooper, 2009; Duffield & Portus, 2007; Fu, 2013; MacRae et al., 2012; Marques-Jimenez et al., 2016; Michael et al., 2014; Trenell, Rooney, Sue, & Thomspon, 2006). However, research is limited on the influence of performance garments specifically designed to support the multiplanar movements of female athletes. Therefore, the purpose of this study is to determine differences in upper extremity kinematic differences during static standing and while performing an overhead throw among female throwing athletes during two different performance garment conditions.

Chapter 3

3. Methods

The purpose of this research was to determine differences in upper extremity kinematics during static standing and while performing an overhead throw among female throwing athletes during two different performance garment conditions. A comparative analysis of the Design Garment condition versus the Generic Garment condition was assessed during static standing posture and a 60 ft overhead throw. The objectives were to: 1) determine the kinematic differences of the scapula during static stance; and 2) determine shoulder and scapula kinematic differences during the four throwing events of foot contact, maximum shoulder external rotation, ball release, and maximum shoulder internal rotation. The role of this chapter is to outline and describe the methodology that was used for this study. This chapter will include participants, setting, instrumentation, design and procedures, and data analysis.

3.1. Participants

An *a-priori* power analysis determined that a minimum of 20 participants for the static standing condition and the overhead throwing task were necessary to achieve a power of 0.80 at $\alpha = 0.05$. The sample population was conveniently recruited by email from a variety of departments directly associated with Auburn University, Auburn, AL. Selection criteria included: female athletes (19-30 years) participating in the minimum recommendation of physically active (Piercy & Troiano, 2018) with a minimum of 2 years playing experience in softball at the varsity high school or travel ball levels, being medically cleared to participate in overhead throwing activities, and no having injuries to the upper or lower extremities within the last six months. Participants completed a health history questionnaire to determine eligibility for participation in the study (Appendix A). The questionnaire was immediately evaluated by the primary investigator to eliminate any participants that may not have been eligible to participate in the current study. The Auburn University's Institutional Review Board approved all testing protocols. All participants read and signed the informed consent document approved by the Auburn University's Institutional Review Board prior to participation (Appendix B). In addition, participants specified their garment size (extra-small, small, medium, large, or extra-large), which was available for all garments, to wear during testing. The Generic Garment and sports bra were controlled by US standard sizing for the female population (Ashdown, 2007). The Generic Garments were purchased at a local store. The Design Garment with built-in sports bra designed specifically for female athletes are controlled by measurements previously determined by the $[TC]^2$ NX-16 Model Three-Dimensional Whole Body Scanner ($[TC]^2$, Cary, NC). The $[TC]^2$ NX-16 Model is designed for accurate results of the measurement of the human body. The accuracy level is higher than traditional circumference measurements and yields a circumference of <3 mm and a point accuracy of <1 mm (Gropper, Simmons, Gaines, Drawdy, Saunders, Ulrich, & Connell, 2009; Simenko & Cuk, 2016).

3.2. Setting

All data collections were conducted in a controlled laboratory setting in the Sports Medicine and Movement Laboratory within the School of Kinesiology at Auburn University. This location had the space and necessary equipment to successfully execute the objectives of the study.

3.3. Instrumentation

All kinematic data were collected with an electromagnetic tracking system (trackSTAR™, Ascension Technologies Inc., Burlington, VT) synchronized with The MotionMonitor (Innovative Sports Training, Chicago, IL). Prior to data collection, the system was calibrated for the day using previously established techniques (Gascon et al., 2018b; Oliver & Weimar, 2015; Oliver, &

Keeley, 2010; Oliver & Keeley, 2010; Oliver & Keeley, 2010; Oliver & Plummer, 2011; Plummer, 2013). All kinematic data were sampled at a frequency of 240 Hz (Sachlikidis, 2007; Wagner, Pfusterschmied, von Duvillard, & Müller, 2011). Raw data regarding sensor orientation and position were transformed to a locally-based coordinate system for each respective body segment and independently filtered using a fourth-order Butterworth filter with a cutoff frequency of 13.4 Hz (Henning, 2016; Plummer, 2015; Plummer, & Oliver, 2017).

A 40 cm x 60 cm Bertec force plate (Bertec Corp., Columbus OH) was built into the surface from which all throws were made such that the participant's stride foot landed on the force plate during the throwing motion. Force plate data were used to event mark the instance of stride foot contact during the throwing motion and were sampled at a rate of 1200 Hz.

3.4. Design and Procedures

Participants were asked to arrive in athletic clothing and shoes; however, testing garments were supplied to each participant. Prior to data collection, all testing procedures were explained to each participant and informed written consent was obtained. Testing was conducted on two separate days and was composed of two different performance garment conditions. Testing conditions were counterbalanced in the following manner: (1) a Generic Garment, which was a generic performance garment and sports bra *(*see *figure 4)* and participant's personal training apparel and (2) a Design Garment, which was a performance garment with a built-in sports bra designed specifically for female athletes *(*see *figure 5)* and participant's personal training apparel.

Figure 1. Generic Garment

Figure 2. Design Garmen

Following signed informed consent and issued garments, a series of ten electromagnetic sensors *(*see *figure 3)*, approximately the size of a pencil eraser, were affixed to the skin using double-sided tape, Cover Roll® adhesive fixation dressing (BSN Medical, Inc., Charlotte, NC), and PowerFlex cohesive tape (Andover Healthcare, Inc., Salisbury, MA) to ensure the sensors remained secure throughout testing. An eleventh, moveable sensor attached to a plastic stylus was used for the digitization of bony landmarks (Oliver, & Keeley, 2010; Oliver & Plummer, 2011; Plummer, & Oliver, 2017; Wu, Siegler, Allard, Kirtley, Leardini, Rosenbaum, Whittle, D'Lima, Cristofolini, Witte, Schimid, & Stokes, 2002; Wu, Van der Helm, Veeger, Makhsous, Van Roy, Anglin, Nagels, Karduna, McQuade, Wang, Werner, & Buchholz, 2005). Sensors were attached to the following locations: (1) posterior aspect of the torso at the first thoracic vertebrae (T1) spinous process; (2) posterior aspect of the pelvis at the first sacral vertebrae (S1); (3-4) flat, broad portion of the acromion, bilaterally; (5-6) lateral aspect deltoid tuberosity, bilaterally; (7-8) posterior aspect of bilateral distal forearm, centered between the radial and ulnar styloid processes; and (9-10) lateral aspect of each thigh, centered between the greater trochanter and the lateral condyle of the knee *(*see *figures 3 and 4)*. To ensure accurate identification and palpation of bony landmarks, the primary investigator performed all digitizing. After sensor set-up, the participant stood in anatomical neutral position throughout the digitization process. Using the digitized joint centers for T12-L1, and C7-T1, a link segment model was developed. Joint centers were determined by digitizing the medial and lateral aspect of a joint then calculating the midpoint between those two points (Oliver, & Keeley, 2010; Oliver, 2011; Wu, Siegler, Allard, Kirtley, Leardini, Rosenbaum, Whittle, D'Lima, Cristofolini, Witte, Schimid, & Stokes, 2002). The spinal column was defined as the digitized space between C7-T1 and T12-L1 (Oliver, & Keeley 2010; Oliver, 2011).

Figure 3. A series of ten electromagnetic sensors affixed to the skin using double-sided tape and PowerFlex cohesive tape.

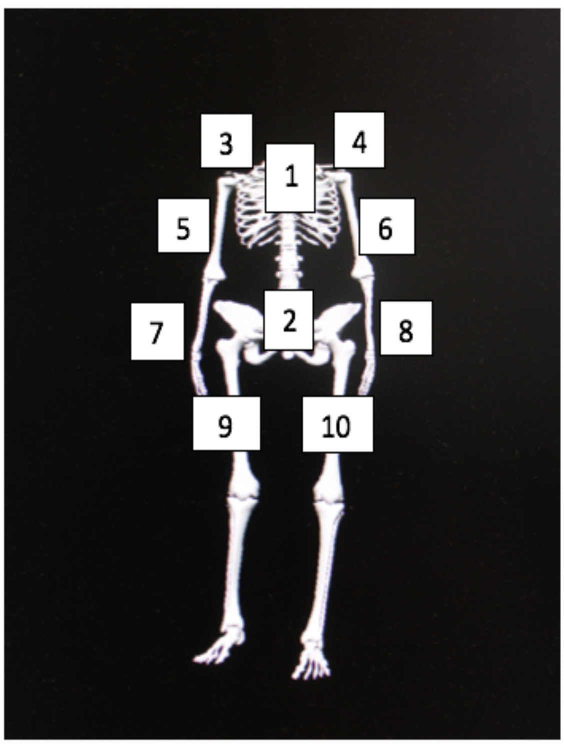

Figure 4. Pictorial representation of electromagnetic sensor placement.

The hip and shoulder joint centers were calculated using the rotation method. The shoulder joint center was calculated from 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 primary investigator stabilizing the joint then passively moving the limb into six different positions in a small, circular pattern (Huang, 2010). Raw data regarding sensor position and orientation were transformed to locally based coordinate systems for each of the representative body segments. 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. Position and orientation of the body segments were obtained using Euler angle decomposition sequences. Kinematic data were obtained using Euler angle sequences that are consistent with the International Society of Biomechanics standards and joint conventions (Wu, Siegler, Allard, Kirtley, Leardini, Rosenbaum, Whittle, D'Lima, Cristofolini, Witte, Schimid, & Stokes, 2002; Wu, Van der Helm, Veeger, Makhsous, Van Roy, Anglin, Nagels, Karduna, McQuade, Wang, Werner, & Buchholz, 2005) *(*see *table 1).* All raw data were independently filtered along each global axis using a 4^{th} order Butterworth filter with a cutoff frequency of 13.4 Hz (G. D. Oliver, & Keeley, D.W., 2010; H. A. Plummer & Oliver, 2013; Wicke, 2013). All data were time stamped through The MotionMonitor and passively synchronized using a data acquisition board.

Table 1. Angle Orientation Decomposition Sequences (Wu et al., 2002; Wu et al., 2005).

Segment	**Axis of Rotation**	**Angle**	**Reference**	**Data Type**
Shoulder Rotation 1 Rotation 2 Rotation 3	 Y X’ Y”	 Horizontal Abduction Elevation Rotation	Scapula	Euler Y, X’, Y”
Scapular Rotation 1 Rotation 2 Rotation 3	 Y X’ Z”	 Protraction/Retraction Lateral/Medial Rotation Anterior /Posterior Tilt	Thorax	Euler Y, X’, Z”

Once all sensors were secured and digitization completed, participants were given verbal instructions to position themselves in a natural standing position as if they were standing in line with hands by their side looking forward (Gascon et al., 2018). Following the static stance, participants were given verbal instructions to perform their own throwing warm-up. Warm-up was not standardized because some participants needed more time than others to feel sufficiently warm and capable of executing maximum effort overhead throws without the risk of injury. Participants were instructed to execute five maximal game effort throws to a catcher 60ft away for both garment conditions on separate days, 24-72 hours apart (Milligan, Mills, Corbett, & Scurr, 2015). The catcher was consistent throughout the study. Participants were instructed to throw a NCAA regulation size softball (30 cm) as fast as possible. Ball speeds were recorded using a Stalker Pro II Baseball Radar Speed Gun (Stalker Radar©, Applied Concepts Inc., Richardson, TX, USA). A trial was deemed successful when the ball was caught without significant deviation from its intended trajectory to the catcher, such as the catcher taking a step to catch the ball. Data for each kinematic variable was averaged for all throws in both garment conditions during analysis to limit potential variability between trials. For kinematic assessments, the overhead throw was divided into the four major overhead throwing events: foot contact, maximal shoulder external rotation, ball release, and maximal shoulder internal rotation *(*see *figure 5),* in which all kinematic variables were analyzed in both garment conditions.

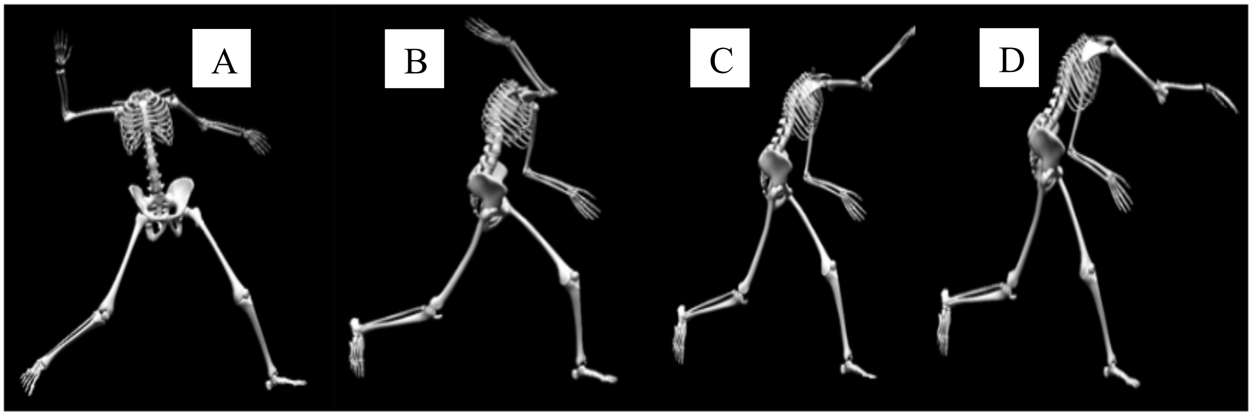

Figure 5. Overhead throwing events. A-Foot Contact, B-Maximum Shoulder External Rotation, C-Ball Release, and D-Maximum Shoulder Internal Rotation.

3.5. Data Analysis

The static standing condition and a total of five overhead throws was collected in both the Generic Garment and Design Garment conditions. All data were reduced and organized per event using a custom MATLAB R2018a (The MathWorks, Inc., Natick, MA) code and analyzed using IBM SPSS Statistics 25 software (IBM Corp., Armonk, NY) with an alpha level set *a priori* at $\alpha = 0.05$. Prior to analysis, a Shapiro-Wilk Test of Normality was employed. The study was a counterbalanced repeated measures design. All kinematic variables and 95% confidence intervals (Carling et al.) of the static stance were analyzed using a 2 (Garment) x 2 (Side) and the overhead throw variables were analyzed using a 2 (Garment) x 4 (Throwing Events) repeated measures analysis of variance (ANOVA) in both garment conditions. These repeated measures ANOVAs were applied to the following variables: scapular protraction/retraction, lateral/medial rotation, anterior/posterior tilt; shoulder horizontal abduction, elevation, and external rotation. For all variables, Mauchly's Test of Sphericity was conducted prior to all analyses, and a Greenhouse-Geisser correction was imposed due to a violation of sphericity. Post-hoc paired-samples t-test was conducted due to statistical significance in Garment during static stance and Garment by Throwing Events interaction during the overhead throw. Post-hoc tests were not conducted for main-effects of Event in order to reduce the total number of statistical tests in the experiment and because the main-effect of Event merely reflects changes in a kinematic variable over time.

Chapter 4

4. Results

The purpose of this project was to determine differences in upper extremity kinematics during static stance and while performing an overhead throw among female throwing athletes during two different performance garment conditions. Twenty female softball athletes volunteered to participate (21.85 ± 2.43 years; 167.12 ± 6.86 cm; 69.03 ± 7.61 kg). A comparative analysis of the Design Garment condition versus the Generic Garment condition was assessed. This chapter describes and outlines the results from each research question and is sectioned accordingly:

RQ1: Is there a difference in the scapular position (protraction/retraction, lateral/medial rotation, anterior/posterior tilt) during a static stance while wearing two different performance garments?

RQ2: Are there kinematic differences of shoulder horizontal abduction, elevation, and rotation during the overhead throw at the four throwing events of foot contact, maximal shoulder external rotation, ball release and maximal shoulder internal rotation between two different performance garments?

RQ3: Are there kinematic differences of scapular protraction/retraction rotation, lateral/medial rotation, and anterior/posterior tilt during the overhead throw at the four throwing events of foot contact, maximal shoulder external rotation, ball release and maximal shoulder internal rotation between two different performance garments?

Research Question 1: Is there a difference in the scapular position (protraction/retraction, lateral/medial rotation, anterior/posterior tilt) during a static stance while wearing two different performance garments?

The static stance was analyzed using a 2 (Garment) x 2 (Side) repeated measures ANOVAs to determine the scapular kinematic differences between both performance garments. Descriptive statistics and statistical results are presented below (see tables 2 and 3). Results indicate a significant main-effect of Garment for scapular anterior/posterior tilt. There were no statistically significant Garment by Side interactions. Post-hoc results are shown in Table 4. Results reveal greater posterior tilt for participants wearing the Design Garment. A summary table of these results are presented in Appendix C.

Table 2. Descriptive data for scapular kinematics (degrees) for each garment condition by side. Mean (M) and Standard Deviation (SD). All means and standard deviations are displayed in degrees. Bold denotes significance.

Garment and Side	Protraction/Retraction M (SD)	Lateral/Medial Rotation M (SD)	Anterior/Posterior Tilt M (SD)
Design Garment Dominate Arm	7.76 (4.61)	2.1 (3.12)	**5.43 (4.28)**
Design Garment Non-Dominate Arm	-7.37 (5.23)	-0.8 (4.57)	4.86 (4.12)
Generic Garment Dominate Arm	8.89 (4.61)	2.67 (2.89)	**2.59 (4.24)**
Generic Garment Non-Dominate Arm	-8.26 (5.19)	-0.17 (3.10)	2.54 (3.17)

Scapular protraction and medial rotation right (+) and scapular retraction and lateral rotation right (-), scapular protraction and medial rotation left (-) and scapular retraction and lateral rotation left (+), anterior tilt right and left (-), and posterior tilt right and left (+).

Table 3. Repeated measures ANOVA for scapular anterior/posterior tilt. Bold denotes significance.

	df	MS	F	Sig.
Garment	**1.00**	**133**	**7.34**	**0.01**
Side	1.00	1.95	0.19	0.67
Garment*Side	1.00	1.34	0.13	0.73

Table 4. Post-hoc results for scapular anterior/posterior tilt by garment and side. Bold denotes significance.

	M	SD	95% CI	t	df	Sig.
Design Garment vs Generic Garment Dominate Arm	**2.84**	**1.32**	**0.08 – 5.60**	**2.15**	**19**	**0.05**
Design Garment vs Generic Garment Non-Dominate Arm	**2.32**	**4.74**	**0.10 – 4.54**	**2.19**	**19**	**0.04**

Research Question 2: Are there kinematic differences of shoulder horizontal abduction, elevation, and rotation during the overhead throw at the four throwing events of foot contact, maximal shoulder external rotation, ball release and maximal shoulder internal rotation between two different performance garments?

The overhead throw was analyzed using a 2 (Garment) x 4 (Throwing Events) repeated measures ANOVA to determine the shoulder kinematic differences between both performance garments. Descriptive statistics and statistical results are presented below (Tables 5-10). Results indicate no statistical significance. A summary table of these results are presented in Appendix C.

Table 5. Descriptive data for shoulder horizontal abduction (degrees) for each garment condition by event. Mean (M) and Standard Deviation (SD). All means and standard deviations are displayed in degrees.

Garment	Foot Contact M (SD)	Max. External Rotation M (SD)	Ball Release M (SD)	Max. Internal Rotation M (SD)
Design Garment	-21.5 (16.4)	-6.41 (20.8)	-3.27 (20.9)	0.85 (18.5)
Generic Garment	-19.72 (18.5)	-2.77 (21.0)	-9.58 (15.4)	-1.84 (15.5)

Shoulder abduction = 0°; shoulder forward flexion = 90°

Table 6. Repeated measures ANOVA results for shoulder horizontal abduction for each garment condition by event. The main-effect of Event merely reflects changes in a kinematic variable over time and therefore no post-hoc test was run for additional evaluation.

	df	MS	F	Sig.
Garment	1.00	671	0.64	0.44
Event	2.17	5628	35.9	0.01
Garment*Event	1.50	450	1.95	0.17

Table 7. Descriptive data for shoulder elevation (degrees) for each garment condition by event. Mean (M) and Standard Deviation (SD). All means and standard deviations are displayed in degrees.

Garment	Foot Contact M (SD)	Max. External Rotation M (SD)	Ball Release M (SD)	Max. Internal Rotation M (SD)
Design Garment	-59.8 (28.0)	-61.1 (15.5)	-60.9 (15.0)	-59.4 (14.4)
Generic Garment	-64.6 (27.5)	-62.8 (15.5)	-64.9 (15.9)	-66.1 (15.5)

Shoulder elevation is negative throughout the throwing motion. Shoulder abduction = -90°

Table 8. Repeated measures ANOVA results for shoulder elevation for each garment condition by event. The main-effect of Event merely reflects changes in a kinematic variable over time and therefore no post-hoc test was run for additional evaluation.

	df	MS	F	Sig.
Garment	1.00	725	1.01	0.33
Event	1.42	16.5	0.05	0.90
Garment*Event	1.41	90.5	0.41	0.60

Table 9. Descriptive data for shoulder rotation (degrees) for each garment condition by event. Mean (M) and Standard Deviation (SD). All means and standard deviations are displayed in degrees.

Garment	Foot Contact M (SD)	Max. External Rotation M (SD)	Ball Release M (SD)	Max. Internal Rotation M (SD)
Design Garment	-58.1 (28.4)	-102 (27.6)	-80.2 (27.9)	-44.4 (26.0)
Generic Garment	-64.6 (22.9)	-104 (20.5)	-82.6 (17.8)	-39.5 (39.4)

Shoulder rotation is negative throughout the throwing motion. -180° = maximum shoulder external rotation. 0° = maximum shoulder internal rotation

Table 10. Repeated measures ANOVA results for shoulder rotation for each garment condition by event. The main-effect of Event merely reflects changes in a kinematic variable over time and therefore no post-hoc test was run for additional evaluation.

	df	MS	F	Sig.
Garment	1.00	96.8	0.05	0.83
Event	2.06	40192	75.6	0.01
Garment*Event	1.73	388	1.15	0.32

Research Question 3: Are there kinematic differences of scapular protraction/retraction rotation, lateral/medial rotation, and anterior/posterior tilt during the overhead throw at the four throwing events of foot contact, maximal shoulder external rotation, ball release and maximal shoulder internal rotation between two different performance garments?

The overhead throw was analyzed using a 2 (Garment) x 4 (Throwing Events) to determine the scapular kinematic differences between both performance garments. Descriptive statistics and statistical results are presented below for each scapular kinematic variable (Tables 11-16). Results indicate a significant main-effect of Garment for scapular medial/lateral rotation. Results indicate a significant Garment by Throwing Event interactions for protraction/retraction, lateral/medial rotation, and anterior/posterior tilt. Post-hoc results revealed significance in protraction/retraction at maximum shoulder external rotation, significance in lateral/medial rotation and anterior/posterior tilt at ball release and maximum shoulder internal rotation. Post-hoc results are shown in Tables 17-19. A summary table of these results are presented in Appendix C.

Table 11. Descriptive data for scapular protraction/retraction (degrees) for each garment condition by event. Mean (M) and Standard Deviation (SD). All means and standard deviations are displayed in degrees. Bold denotes significance.

Garment	Foot Contact M (SD)	Max. External Rotation M (SD)	Ball Release M (SD)	Max. Internal Rotation M (SD)
Design Garment	0.51 (21.0)	**-0.92 (15.9)**	11.2 (14.4)	23.5 (16.1)
Generic Garment	0.12 (15.5)	**7.40 (10.4)**	16.0 (10.7)	27.2 (13.7)

Scapular protraction (+) and scapular retraction (-)

Table 12. Repeated measures ANOVA results for scapular protraction/retraction for each garment condition by event. The main-effect of Event merely reflects changes in a kinematic variable over time and therefore no post-hoc test was run for additional evaluation. Bold denotes significance.

	df	MS	F	Sig.
Garment	1.00	657	2.17	0.16
Event	1.51	10324	38.7	0.01
Garment*Event	**1.68**	**242**	**5.23**	**0.02**

Table 13. Descriptive data for scapular medial/lateral rotation (degrees) for each garment condition by event. Mean (M) and Standard Deviation (SD). All means and standard deviations are displayed in degrees. Bold denotes significance.

Garment	Foot Contact M (SD)	Max. External Rotation M (SD)	Ball Release M (SD)	Max. Internal Rotation M (SD)
Design Garment	-29.6 (19.3)	-27.1 (16.7)	**-19.1 (15.3)**	**-15.9 (14.1)**
Generic Garment	-28.4 (14.9)	-23.0 (13.7)	**-10.5 (11.0)**	**-6.73 (8.80)**

Scapular lateral rotation (-) and scapular medial rotation (+)

Table 14. Repeated measures ANOVA results for scapular lateral/medial rotation for each garment condition by event. The main-effect of Event merely reflects changes in a kinematic variable over time and therefore no post-hoc test was run for additional evaluation. Bold denotes significance.

	df	MS	F	Sig.
Garment	**1.00**	**1330**	**5.34**	**0.03**
Event	1.69	4915	26.9	0.01
Garment*Event	**38.4**	**35.4**	**12.2**	**0.01**

Table 15. Descriptive data for scapular anterior/posterior tilt (degrees) for each garment condition by event. Mean (M) and Standard Deviation (SD). All means and standard deviations are displayed in degrees. Bold denotes significance.

Garment	Foot Contact M (SD)	Max. External Rotation M (SD)	Ball Release M (SD)	Max. Internal Rotation M (SD)
Design Garment	-2.79 (14.2)	12.5 (10.0)	**5.44 (9.25)**	**3.43 (11.1)**
Generic Garment	-0.31 (10.4)	7.81 (11.6)	**0.06 (9.01)**	**-2.36 (8.60)**

Scapular anterior tilt (-) and posterior tilt (+)

Table 16. Repeated measures ANOVA results for scapular anterior/posterior tilt for each garment condition by event. The main-effect of Event merely reflects changes in a kinematic variable over time and therefore no post-hoc test was run for additional evaluation. Bold denotes significance.

	df	MS	F	Sig.
Garment	1.00	448	2.94	0.10
Event	1.92	1629	14.2	0.01
Garment*Event	**1.93**	**237**	**3.95**	**0.03**

Table 17. Post-hoc results for scapular protraction/retraction by event. Bold denotes significance.

Design Garment vs Generic Garment Overhead Throwing Events	M	SD	95% CI	t	df	Sig.
Foot Contact	0.61	17.5	-7.59 – 8.81	0.16	19	0.88
Maximum Shoulder External Rotation	**-8.31**	**14.1**	**-14.9 – -1.71**	**-2.64**	**19**	**0.02**
Ball Release	-4.82	11.3	-10.1 – 0.45	-1.91	19	0.07
Maximum Shoulder Internal Rotation	-3.69	11.3	-9.00 – 1.61	-1.46	19	0.16

Table 18. Post-hoc results for scapular medial/lateral tilt by event. Bold denotes significance.

Design Garment vs Generic Garment Overhead Throwing Events	M	SD	95% CI	t	df	Sig.
Foot Contact	-1.19	13.8	-7.64 – 5.25	0.39	19	0.70
Maximum Shoulder External Rotation	-4.11	11.4	-9.47 – 1.25	-1.61	19	0.13
Ball Release	**-8.63**	**10.9**	**-13.7 – -3.53**	**-3.54**	**19**	**0.01**
Maximum Shoulder Internal Rotation	**-9.14**	**11.4**	**-14.5 – -3.81**	**-3.59**	**19**	**0.01**

Table 19. Post-hoc results for scapular anterior/posterior tilt by event. Bold denotes significance.

Design Garment vs Generic Garment Overhead Throwing Events	M	SD	95% CI	t	df	Sig.
Foot Contact	-2.47	14.2	-9.14 – 4.20	-0.78	19	0.44
Maximum External Rotation	4.69	10.7	-0.33 – 9.71	1.96	19	0.07
Ball Release	**5.38**	**9.40**	**0.98 – 9.78**	**2.56**	**19**	**0.02**
Maximum Internal Rotation	**5.79**	**11.4**	**0.46 – 11.1**	**2.27**	**19**	**0.04**

Chapter 5

5. Discussion

Optimal positioning of the scapula influences the coordinated movement with the humerus. This synergistic and dynamic relationship between the glenohumeral and scapulothoracic joints have shown to significantly influence efficient overhead movement. More specifically, research has revealed scapular positioning directly influences glenohumeral range of motion as well as the ability for energy to be transferred and force to dissipate throughout the kinetic chain (Bartlett, 2008; Bencke et al., 2018). The scapula is utilized as the link between the lower extremity and upper extremity to provide the proper base of support for both stability and mobility for the upper extremity to move in a functional and efficient manner (Kibler, 1998; Kibler & Sciascia, 2017). There are five muscles primarily responsible for the scapulothoracic movement, while the rotator cuff and deltoid muscles are responsible for the glenohumeral joint movements. Scapulothoracic muscles include the trapezius (upper, middle, and lower), levator scapulae, rhomboids, serratus anterior, and pectoralis minor. Glenohumeral muscles include the rotator cuff (supraspinatus, infraspinatus, subscapularis, teres minor) and the deltoid (anterior, middle, and posterior). Movement of the scapula has been described by the following: transverse plane, protraction or internal rotation and retraction or external rotation; sagittal plane, lateral or upward rotation and medial or downward rotation; and anterior tilt and posterior tilt. Understanding of the primary muscles, muscle force couples, positioning, and movement involved with scapulothoracic and glenohumeral joints provides clinicians with greater insight to injury susceptibility among overhead athletes.

Optimal positioning and synchronous movement of the scapula and humerus during the overhead throw is critical to the stability and mobility of the glenohumeral joint during the overhead throw, and therefore makes the shoulder complex one of the most difficult areas of articulation to study. Scapular and humeral positioning, stability, and mobility during the overhead throwing events of foot contact, maximum shoulder external rotation, ball release, and maximum shoulder internal rotation have been comprehensively evaluated (Calabrese, 2013; Chu et al., 2016; Erickson et al., 2016; Gascon et al., 2018b; Oliver & Weimar, 2015; Oliver, Plummer, Henning, Saper, Glimer, Brambeck, & Andrews, 2017). However, as previously stated, minimal biomechanical research has been conducted to determine the benefits of performance apparel on female overhead throwing athletes. The Design Garment, which was created for the current study, is a novel design conceived with the intention to improve overhead throwing mechanics and performance outcomes, as well as reduce the risk of injury among the female athlete populations. Research has revealed the position and lack of optimal stability and mobility of the scapula to be a cause of shoulder pathologies (Burkhart et al., 2003a; Myers et al., 2005; Weber, 2014; Wilk et al., 2002). Malposition of the scapula has shown to cause internal impingement, subacromial impingement, and rotator cuff tendinitis (Kibler & Sciascia, 2017). However, research has shown proper assessment of scapular positioning and motion is often difficult to evaluate (Kibler & Sciascia, 2017). As stated previously, some alternatives to improving scapular positioning and motion include shoulder taping, shoulder bracing, posture-cueing garments, and shoulder rehabilitative protocols. The current study illustrates the kinematic differences and impact performance garments, which were designed specifically for female athletes, has on scapular positioning during static stance and scapular and humeral positioning during an overhead throw. Furthermore, although the current study did not analyze muscle activity of the scapular or humeral musculature, the authors believe a detailed description of the origins, insertions, and muscle actions of the shoulder would provide a better understanding of scapula and humeral positioning during the static stance and overhead throw (Appendix D).

5.1. Static Stance

RQ1: Is there a difference in the scapular position (protraction/retraction, lateral/medial rotation, anterior/posterior tilt) during a static stance while wearing two different performance garments?

H01: The scapula will be in a position of decreased protraction, lateral rotation, and anterior tilt among female athletes during static standing while wearing the Design Garment compared to the Generic Garment.

Results of the current study revealed an increase in scapular posterior tilt in the Design Garment condition compared to the Generic Garment condition in the dominate arm ($p < 0.05$) and non-dominate arm ($p < 0.04$), however, no statistically significant differences were found in scapular protraction ($p > 0.05$) and lateral rotation ($p > 0.05$) between conditions. Therefore, the authors fail to reject the null hypothesis. Although a variety of scapular resting positions have been reported (Gascon et al., 2018a; Kibler & Sciascia, 2016; Kibler & Sciascia, 2017), variability in research has made it difficult to determine disadvantageous scapular positioning during static conditions. Laudner et al. (2006) and McClure et al. found individuals experiencing subacromial impingement displayed increased posterior tilting and increased lateral rotation (Laudner, Myers, Pasquale, Bradley, & Lephart, 2006; McClure, Michener, & Karduna, 2006). Contrary to those findings, Endo et al., Ludwig et al. (2000), and Lukasiewicz et al. found decreased posterior tilt and lateral rotation to cause subacromial impingement (Endo, Ikata, Katoh, & Takeda, 2001; Ludewig & Cook, 2000; Lukasiewicz, McClure, Michener, Pratt, Sennett, & Ludwig, 1999). Due to the inconsistent findings, it is difficult to determine the possible mechanisms of an injury that may occur with overhead athletes. Overhead athletes typically present with scapular protraction, lateral rotation, and anterior tilt of the dominate arm (Kibler, 1998; Burkhart et al., 2003c; Cools et al., 2017; Kibler, 1991; Kibler & Sciascia, 2017). However, the female overhead athletes participating in the current study presented with scapular protraction, medial rotation, and posterior tilting in both garment conditions during the static stance. Although this static scapular position may not result in dysfunction or align with current scientific findings it does give insight into the influence performance garments have on female athletes. Scapular protraction and medial rotation during static standing positions are often affiliated with individuals suffering from a number of shoulder pathologies (Cools et al., 2017; Ellenbecker & Mattalino, 1999; Ludewig & Cook, 2000; Lukasiewicz et al., 1999). As stated previously, although there were no statistically significant differences between garments in protraction/retraction and lateral/medial rotations, results showed the Design Garment condition to present with a decrease in protraction (dominate arm $M = 7.76°$) and medial rotation (dominate arm $M = 2.10°$) compared to the Generic Garment condition (protraction dominate arm $M = 8.89°$; medial rotation dominate arm $M = 2.67°$). These results may have clinical significance; however, further research should be conducted to determine the long-term impact the Design Garment may have on scapular protraction/retraction and lateral/medial rotations among overhead throwing athletes. Results did reveal differences between garments in anterior/posterior tilt. The Design Garment condition showed an increase in posterior tilt (dominate arm $M = 5.43°$) compared to the Generic Garment condition (dominate arm $M = 2.59°$). Research has shown that activities of daily living, repetitive movements, and overuse injuries have all negatively influenced the position, stability, and mobility of the scapula (Christian et al., 2017; Cole, 2008; Davies et al., 2012; Di Bartolo & Braun, 2017; Kibler, 1998; Kibler & Sciascia, 2017). Lifestyle choices and repetitive athletic movement have shown an increase in shoulder pain and injuries (Oyama, 2008). Standing posture among overhead athletes has also revealed scapular asymmetry, however, most research has been conducted on male overhead athletes (Calabrese, 2013; Erickson et al., 2016; Huang, 2010; Krajnik et al., 2010; Oliver & Weimar, 2015; Wicke, 2013; Wilk et al., 2011). Additionally, static standing posture may not be a true representation of optimal scapular positioning and mobility (Seitz, Reinold, Schneider, Gill, & Thigpen, 2012). An increase in scapular posterior tilting is a crucial position for an overhead athlete. An increase in posterior tilting leads to an increase in subacromial space, reduces stress and strain placed on the glenohumeral joint, and therefore reduces the risk of upper extremity injury (Cools et al., 2017; Kibler, 1998; Kibler et al., 2013). For overhead athletes, increase in subacromial space allows the head of the humerus to move through an optimal range of motion to efficiently transfer forces and energy from the lower extremity to upper extremity during overhead tasks.

The position of posterior tilt of the scapula requires efficient muscular control of the scapular stabilizing muscles, specifically the lower trapezius and serratus anterior. In addition, the musculature of the upper trapezius and pectoralis minor also influence the position of scapular posterior tilt. The lower trapezius muscle originates on the spinous processes of the 6^{th} through 12^{th} thoracic vertebrae and inserts on the spine of the scapula (Peterson-Kendall et al., 2005). The serratus anterior (SA) is a fan-shaped muscle, originating on the superolateral surface of the upper 8^{th} or 9^{th} rib and inserts into the medial border on the anterior side of the scapula (Peterson-Kendall et al., 2005). The SA is divided into three parts: superior, intermediate, and inferior. The SA superior originates on the 1^{st} to 2^{nd} rib and inserts on the superior angle of the scapula. The SA intermediate originates on the 2^{nd} to 3^{rd} rib and inserts on the medial border of the scapula. Lastly, the SA inferior originates on the 4^{th} to 9^{th} rib and inserts on the medial and inferior angle of the scapula. Scapula malpositioning is often affiliated with a decrease in serratus anterior and lower trapezius muscle activity and over active upper trapezius and pectoralis minor musculature (Leong et al., 2017; Peterson-Kendall et al., 2005). The upper trapezius muscle originates on the external occipital protuberance, medial 1/3 of the superior nuchal line, ligamentum nuchae and spinous process of the 7th cervical vertebra and inserts on the lateral 1/3 of the clavicle and acromion process of the scapula (Peterson-Kendall et al., 2005). The upper trapezius elevates and laterally rotates the scapula, lateral flexion and rotation of the neck. The pectoralis minor originates on the outer surface of the 3rd, 4th, and 5th ribs near the cartilages and fascia over corresponding intercostal muscles and inserts at the medial border, superior of the coracoid process of the scapula (Peterson-Kendall et al., 2005). The pectoralis minor stabilizes the scapula by pulling the scapula anteriorly against the thoracic wall. The overactivity of the upper trapezius and pectoralis minor muscles, as well as underactivity of the lower trapezius and serratus anterior muscles cause overhead athletes to experience pain and discomfort in both static and dynamic positions and often produce excess stress to musculature and joint structures such as: rotator cuff, labrum, long head of the biceps, acromioclavicular and glenohumeral capsule and ligaments, coracoacromial ligaments, and acromial undersurface (Kibler & Sciascia, 2017).

Future research should be conducted to determine the electromyography of the shoulder, particularly to the serratus anterior, trapezius musculature, and pectoralis minor. Although the current research did not analyze muscle activity of the scapular musculature, the authors suggest possible proprioceptive assistance to the lower trapezius and serratus anterior muscles due to the construction of the Design Garment during the static stance condition.

5.2. Shoulder Kinematics During Overhead Throwing

RQ2: Are there kinematic differences of shoulder horizontal abduction, elevation, and rotation during the overhead throw at the four throwing events of foot contact, maximal shoulder

external rotation, ball release and maximal shoulder internal rotation between two different performance garments?

H02: There will be increased shoulder horizontal abduction, elevation, and rotation while wearing the Design Garment compared to the Generic Garment during the overhead throwing events of foot contact, maximum shoulder external rotation, ball release, and maximum shoulder internal rotation.

Results of the current study revealed no statistically significant results of shoulder horizontal abduction, elevation, and rotation in the Design Garment condition compared to the Generic Garment condition in the dominate arm ($p > 0.05$). Therefore, the author reject the null hypothesis. It is important to note the movement of the glenohumeral joint is heavily influenced by the positioning of the scapulothoracic joint. The glenohumeral joint requires the head of the humerus to maintain a close proximity with the glenoid fossa. Humeral positioning, throughout each event during the overhead throw, is influenced by scapular positioning. The glenohumeral and scapulothoracic musculature work to position the scapula along the thoracic wall creating a stable base, which then allows the humerus to prepare for optimal positioning of the elbow and hand to maximize the force and energy transferred from the lower extremity and core. Although no statistically significant results were shown between garments, these results may have clinical significance and further research should be conducted to determine the long-term influence the Design Garment may have on humeral positioning during longer bouts of throwing. Additionally, further research should include the influence of garments on kinetic and electromyography of the glenohumeral joint. Understanding the kinematics, kinetic, and electromyography of the humerus and the influence of performance garments on the female overhead throwing athlete is helpful to assist in optimal training and rehabilitation protocols.

5.3. Scapular Kinematics During Overhead Throwing

RQ3: Are there kinematic differences of scapular protraction/retraction rotation, lateral/medial rotation, and anterior/posterior tilt during the overhead throw at the four throwing events of foot contact, maximal shoulder external rotation, ball release and maximal shoulder internal rotation between two different performance garments?

H03: There will be increased scapular retraction, lateral rotation and posterior tilt while wearing the Design Garment compared to the Generic Garment during the overhead throwing events of foot contact, maximum shoulder external rotation, ball release, and maximum shoulder internal rotation.

Results of the current study revealed the Design Garment condition showed an increase in scapular retraction during maximum shoulder external rotation ($p < 0.02$), an increase in lateral rotation at ball release ($p < 0.01$) and maximum shoulder internal rotation ($p < 0.01$), and an increase in posterior tilt at ball release ($p < 0.02$) and maximum shoulder internal rotation ($p < 0.04$) compared to the Generic Garment condition. Therefore, the authors fail to reject null hypothesis.

During maximum shoulder external rotation, the scapula should be in a position of maximum retraction, lateral rotation, and posterior tilt (Kibler, 1998; Burkhart et al., 2003c; Kibler, 1991; Kibler & Sciascia, 2017; Oliver & Weimar, 2015). Retraction, lateral rotation, and posterior tilting of the scapula is caused by actions of the upper and lower trapezius, serratus anterior, rhomboids, and levator scapulae. The Design Garment condition showed an increase in scapular retraction (M = -0.92°) compared to the Generic Garment condition (M = 7.40°) during maximum shoulder external rotation. According to previous research (Kibler, 1998; Burkhart et al., 2003c; Cools et al., 2017; Kibler, 1991; Kibler & Sciascia, 2017), full scapular retraction creates a funnel like design to transfer forces and energy from the lower extremity and torso to the upper extremity. Additionally, scapular retraction combined with lateral rotation and posterior tilting increases subacromial space allowing clearance of the supraspinatus tendon (Kibler, 1998; Burkhart et al., 2003c; Cools et al., 2017; Kibler & Sciascia, 2017). Subacromial impingement is caused by malpositioning of the scapula and humerus in the maximum shoulder external rotation and ball release events. This malposition of the scapular entraps the rotator cuff between the glenoid and the head of the humerus causing pain and discomfort for the athlete during the overhead throw. Although there were no statistically significant differences of humeral positions between garments, results revealed the Design Garment condition may provide the overhead athlete with optimal positioning, increase in subacromial space leading to maximum transfer of force and energy, and reducing the risk of injury.

During the event of ball release, the scapula begins to protract, and anterior tilt (Erickson et al., 2016; Fleisig, 2001; Weber, 2014). It is imperative for the scapula to provide dynamic stability to the humerus, during the ball release event, in order to minimize shear forces, tension of the ligaments, and muscle activation which would create the most efficient positioning to transfer energy and force from the lower extremity. The Design Garment condition showed an increase lateral rotation (M = -19.1°) and posterior tilt (M = 5.44°) compared to the Generic Garment condition (lateral rotation M = -10.5°, posterior tilt M = 0.06°). Similar to maximum shoulder external rotation, an increase in lateral rotation and posterior tilting increases subacromial space. Research has revealed individuals suffering from subacromial impingement generally display decreased lateral rotation and posterior tilting (Burkhart et al., 2003c; Cools et al., 2017; Kibler & Sciascia, 2017). Malpositioning of the scapula results in inadequate space for clearance of the rotator cuff tendons during the event of ball release. Additionally, fatigue and weakness of the rotator cuff musculature increases the risk of injury (Bartlett, 2008; Bencke et al., 2018; Chu et al., 2016; Cools et al., 2017; Erickson et al., 2016; Kibler & Sciascia, 2017; Kibler et al., 2013). During the event of ball release, the rotator cuff must produce compressive forces to maintain the optimal positioning, stabilization, and contact between the humeral head and glenoid fossa. Failure of optimal glenohumeral and scapulothoracic joint positioning, decreases subacromial space and therefore leads to impingement, which may result in rotator cuff and/or labral tears.

To position the shoulder into maximum shoulder internal rotation, the scapula should be in a position of protraction, lateral rotation, and anterior tilt (Kibler, 1998; Burkhart et al., 2003c; Kibler, 1991; Kibler & Sciascia, 2017; Oliver & Weimar, 2015). The key component at the maximum shoulder internal rotation event is the ability to optimally dissipate force and energy utilizing the posterior musculature. Research has shown the maximum shoulder internal rotation event to be the most active of the glenohumeral and scapulothoracic joint musculature (Calabrese, 2013; Erickson et al., 2016; Escamilla & Andrews, 2009). During maximum shoulder internal rotation, the trapezius, deltoids, serratus anterior, rhomboids, teres minor, infraspinatus, and supraspinatus have shown to produce high activity as these muscles assist in negatively accelerating the humerus (Calabrese, 2013; Erickson et al., 2016; Escamilla & Andrews, 2009). The rotator cuff, posterior deltoid, trapezius, rhomboids, and serratus anterior musculature work synergistically to negatively accelerate and assist with limiting excessive anterior translation of the humerus. Similar to ball release, the results during the Design Garment condition revealed statistical significance of lateral rotation (M = -15.9°) and posterior tilting (M = 3.43°) compared to the Generic Garment condition (lateral rotation M = -6.73° and anterior tilting M = -2.36°). As the humerus is rotated into maximum shoulder internal rotation, the Design Garment condition showed a greater value in lateral rotation and maintaining posterior tilt during the final event, while the Generic Garment condition reveals a lesser value in lateral rotation and moves into anterior tilt during the final event. Although it is imperative for overhead athletes to move through a full range of motion, it is crucial for the athlete to perform in an optimal and pain-free range of motion. Research has shown the maximum shoulder internal rotation event to be considered the most violent of the events (Burkhart et al., 2003c; Chu et al., 2016; Kibler et al., 2013; Seroyer et al., 2010). As stated previously, the trapezius, rhomboids, serratus anterior, and rotator cuff musculature, particularly the teres minor, are highly active to decelerate the humerus and stabilize the scapula (Seroyer et al., 2010). Although the Design Garment condition does not indicate a position of anterior tilt in the event of maximum shoulder internal rotation, authors believe the posterior tilt, among these participants, may reduce excessive distraction, posterior/inferior shear forces on the glenohumeral joint, which has been shown to cause injury among overhead athletes (Bartlett, 2008; Bencke et al., 2018; Chu et al., 2016; Erickson et al., 2016; Kibler et al., 2013; Sciascia et al., 2012; Seroyer et al., 2010). Further research of the Design Garment should be conducted to determine if the scapular positioning during maximum shoulder internal rotation provides the female overhead athlete with the optimal positioning to properly dissipate the large forces and transfer of energy throughout the deceleration phase of the overhead throw.

5.4. Conclusion

Scapulothoracic and glenohumeral positions, during each overhead throwing event, are crucial to understand as these positions provide insight for coaches, clinicians, and athletes to perform optimally. Efficient transfer of force and energy from the lower extremity to upper extremity over a greater range of motion, optimal force couple sequencing, and stability of glenohumeral joint, all contribute to a reduction of injury among overhead athletes (Kibler, 1998; Burkhart et al., 2003c; Kibler, 1991; Kibler & Sciascia, 2017; Oliver & Weimar, 2015).

Unfortunately, due to the repetitive nature of the sport, overhead throwing athletes are susceptible to overuse injuries. Research has shown causes of overuse injuries to include poor mechanics and muscular fatigue, which leads to excessive stress placed on the soft tissue of the shoulder complex. Performance garments have increased in popularity over the last few years, and have become a tool utilized among coaches, clinicians, and athletes to improve performance and reduce injury. However, more specifically among female athletes, minimal research has been conducted to determine the biomechanical benefits of performance garments. Additionally, research has shown performance garments designed and constructed for female athletes are not fulfilling the need of the female athletes as female athletes have expressed dissatisfaction with fit, comfort, and performance (Dickson, 2000; Feather, Ford, & Herr, 1996; Wheat & Dickson, 1999). The current study, which included a garment constructed specifically for female athletes, allowed for a more optimal positioning of scapular posterior tilt during static standing as well as a decreased anterior tilt and increased lateral rotation during the overhead throw. However, the Design Garment also illustrates the need for further biomechanical research between performance garments during static stance and dynamic movements. Future research should include investigations into electromyography and kinetic differences, as well as physiological, psychophysiological, and sociological adaptations that may impact athletic performance among the female athlete populations.

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Appendix A: HEALTH and SPORT HISTORY QUESTIONNAIRE

Part 1. Participant Information

(Please print)

ID Number: ________________

Age: _______ State: ___________________ Phone: __________________

Email: _____________________

Height: _____ft _____in Weight: ________lbs

Part 2. Athletic Participation

(Circle or fill in your responses)

1. Are you currently cleared to participate in baseball? **YES** **NO**

2. What is your dominant throwing arm? **RIGHT** **LEFT**

3. What position is your primary position? **Infield** **Outfield** **Catcher** **Pitcher**

4. At what age did you begin playing competitive baseball? __________

5. At what competition level are you currently playing? [Please circle]

Professional	**NCAA Div. I**	**NCAA Div. II**	**NCAA Div. III**
Junior College	**High School**	**Junior High**	**Youth League,**
Other________________			

6. For how many years have you been participating at this level? ________

7. Is baseball your primary sport? **YES** **NO**

List all sports you play competitively

____

8. During the season, how many hours per week do you spend performing the following?

   a. Playing baseball: _____**hrs./week**

   b. Sport Specific training/conditioning: _____**hrs./week**

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

   d. What is the average number of days between games? ______

9. During the off-season, how many hours per week do you spend performing the following?

a. Playing baseball: _____**hrs./week**

b. Sport Specific training/conditioning: _____**hrs./week**

10. Estimate the typical number of throws you perform at or greater than 90% of maximal effort during the following:

a. Practice: _______**throws**

b. Competition/Game: _______**throws**

Part 3. Medical History

11. Are you allergic to adhesive tape or other adhesive products? **YES** **NO**
If **YES, explain:**

____

12. Have you ever had surgery before? **YES** **NO** If **YES, explain:**

____

____

If YES, how long ago? ______ **Years** ______ **Months**

13. In the past year, have you had any injury to your upper or lower extremities that has caused you to miss a practice or game? **YES** **NO** If **YES, explain:**

____

____

If YES, on what part(s)?

FOOT/ANKLE **KNEE** **HIP** **BACK** **SHOULDER**
ELBOW **WRIST** **HAND/FINGER**

14. Do you currently experience pain/stiffness before, during or after throwing or pitching?
YES **NO**

If **YES, please explain** and continue onto question 15:

____

____

If **NO, please sign on page 3.**

15. For how long have you been experiencing pain? (Indicate a number next to one category)
_____Years _____Months _____ Days

16. When you do experience pain, how would you describe the onset of pain? (Circle one)

SUDDEN **GRADUAL**

17. When you do experience pain, how is it related to activity? (Circle one)

ASSOCIATED WITH USE **INTERMITTENT** **ALL THE TIME**

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

____

____

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

____

____

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

____

____

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

____

____

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

____

____

23. When you do experience pain, what is the intensity of the pain (1 = NO pain; 10 = unbearable pain)?

NO PAIN **UNBEARABLE PAIN**

1 2 3 4 5 6 7 8 9 10

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

Signature of Participant (or parent/guardian):

____

Appendix B: Informed Consent

DEPARTMENT OF KINESIOLOGY
2050 Beard-Eaves Memorial Coliseum
Auburn, AL 36849
(334) 884-4483

AUBURN UNIVERSITY
COLLEGE OF EDUCATION

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

Participant INFORMED CONSENT for a Research Study (Stage 3) entitled
"Investigating Biomechanical and Functional Design of a Compression Garment in Collegiate Women" while performing functional and sport-specific tasks.

Explanation and Purpose of the Research

As a participant from Stage 2, you are being asked to participate in Stage 3 of this research study for the Sports Medicine & Movement Lab in the Department 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 postural and sport performance changes that occur before and after you wear a compression garment. The relationships between kinematic data and muscle activation patterns will be examined. To investigate this, range of motion data will be collected before and after you wear the compression garment, and joint position and muscle activity data will be collected as you perform a series of single-leg squats, overhead squats, and sports specific tasks.

Research Procedures

To be considered for this study, you must participate in a women collegiate or professional sport and have played your position at a competitive level a minimum of two years. You must also be deemed free of injury, pain, or surgery for the last 6 months.

Testing will require the evaluation of height, body mass/weight, age, range of motion, and sport specific tasks. Age will be determined from this consent form and will be recorded to the nearest month. Range of motion will be measured with a goniometer and will be recorded to the nearest degree.

Once all preliminary paperwork has been completed, you will need to be dressed in your practice gear and tennis shoes for testing. After dressing, range of motion of the shoulder and hip will be first be measured and recorded. Next, electromagnetic sensors will be placed on your legs, arms, torso, and neck. Placement of the markers at these locations will allow the movement of the joint centers to be properly monitored during testing. Eight surface electrodes will be placed on the following bilateral muscles: serratus anterior, latissimus dorsi, and upper and lower trapezius. Manual muscle testing will be performed to establish baseline muscle activity in which all data will be compared.

Once these measurements have been collected and following the placement of the markers, you will perform your own specified pre-competition warm-up routine.

After completing the warm-up testing will begin. You will be asked to first perform functional exercises. These include overhead squats, single-leg squats, vertical jumps and standing in anatomical neutral. Next, you will be asked to perform your sport-specific task. Softball players will complete ten accurate 60-foot maximal effort throws. Basketball players will complete ten jump shots. Volleyball and tennis players will complete ten overhand serves. Soccer players will complete ten double arm overhand throw. Handball players will complete ten set and jump shot throws. These steps will then be repeated while wearing the prototype compression garment. At the completion of the testing, you will be asked to perform your own specified post competition cool down.

<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 sport you currently participate in and may include: muscle strain, muscle soreness, ligament, labral, and tendon damage. Every effort will be made to minimize these risks and discomforts by selecting participants who are currently playing at the collegiate level. 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.

To reduce the risk of injury, certain precautions will be taken. During the sport-specific task protocol, one board certified athletic trainers will be present to monitor participants as they complete each exercise and task. Ample warm-up and cool-down periods will be required of you, water will be provided to you as needed, and ice will be made available after testing.

<u>Confidentiality</u>

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 may be published 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 happen 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.

<u>Participation and Benefits</u>

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 Department of Kinesiology or the Sports Medicine and Movement 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)-844-5966 or email at irbadmin@auburn.edu or IRBChair@auburn.edu or the primary investigator at ssg0012@auburn.edu or (334)-844-1497.

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.

____	______yr.______mo.
Printed Name of Participant	Age of Participant
____	_________________
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.

Investigator obtaining consent	Printed Name	Date
_______________________________	Sarah Gascon________________	____________
Co-Investigator	Printed Name	Date
________________________________	Dawn Michaelson____________	____________

Appendix C: Summary of hypotheses and results.

HO1: Kinematic differences of the scapula during the static stance.

	Retraction	Lateral Rotation	Posterior Tilt
Design Garment	Increase	Decrease	Increase
Generic Garment	Decrease	Increase	Decrease

Results of HO1. Kinematic differences of the scapula during static stance. Statistical significance between garments in posterior tilt.

	Retraction	Lateral Rotation	Posterior Tilt
Design Garment	Decrease	Decrease	**Increase**
Generic Garment	Decrease	Decrease	Decrease

HO2. Kinematic differences of the shoulder during each overhead throwing event.

Design Garment	Foot Contact	MER	Ball release	MIR
Horizontal Abduction	Increase	Increase	Increase	Decrease
Elevation	Increase	Increase	Increase	Decrease
Rotation	Increase	Increase	Increase	Decrease

Results of HO2. Kinematic differences of the shoulder during each overhead throwing event. No statistically significant differences between garments.

Design Garment	Foot Contact	MER	Ball release	MIR
Horizontal Abduction	Increase	Increase	Decrease	Decrease
Elevation	Decrease	Decrease	Decrease	Decrease
Rotation	Decrease	Decrease	Decrease	Increase

HO3. Kinematic differences of the scapula during the overhead throw.

Design Garment	**FC**	**MER**	**BR**	**MIR**
Retaction	Increase	Increase	Increase	Decrease
Lateral Rotation	Increase	Increase	Increase	Decrease
Posterior Tilt	Increase	Increase	Increase	Decrease

Results of HO3. Kinematic differences of the scapula during the overhead throw. Statistical significance between garments in retraction at MER, in lateral rotation at BR and MIR, and in posterior tilt at BR and MIR.

Design Garment	**FC**	**MER**	**BR**	**MIR**
Retaction	Increase	**Increase**	Decrease	Decrease
Lateral Rotation	Increase	Increase	**Increase**	**Increase**
Posterior Tilt	Increase	Increase	**Increase**	**Increase**

Appendix D: Muscles, origins, insertions, and actions of the shoulder complex [45].

MUSCLES	ORIGIN	INSERTION	ACTION
Anterior Deltoid	Anterior border, superior surface, and lateral 1/3 of the clavicle	Deltoid tuberosity of humerus	Flexion and medial rotation of humerus at the shoulder
Middle Deltoid	Lateral margin and superior surface of the acromion	Deltoid tuberosity of humerus	Abduction of humerus
Posterior Deltoid	Inferior lip of the posterior border of the spine of the scapula	Deltoid tuberosity of humerus	Extension and lateral rotation of humerus
Pectoralis Major (Upper and Lower)	Upper – Anterior surface of the sternal ½ of the clavicle Lower – Anterior surface of the sternum, cartilages of first six or seven ribs, and aponeurosis of the external oblique	Upper – Crest of greater tubercle of humerus; fibers are more anterior Lower – Crest of the greater tubercle of humerus; fibers are more posterior	Upper – Flex and medially rotate the shoulder joint, and horizontally adduct the humerus toward the opposite shoulder Lower – Depress shoulder girdle; obliquely abduct the humerus toward the opposite iliac crest
Pectoralis Minor	Outer surfaces of the 3rd, 4th, and 5th ribs near the cartilages	Medial border, superior of the coracoid process of the scapula	Anterior tilt, protraction, and medial rotation of scapula
Latissimus Dorsi	Spinous processes of last six thoracic vertebrae, last three/four ribs, through the thoracolumbar fascia from the lumbar and sacral vertebrae and posterior 1/3 of external lip of iliac crest, and a slip from the inferior angle of the scapula	Intertubercular groove of humerus	Medial rotation, adduction, and extension of shoulder joint; depresses the shoulder girdle
Levator Scapulae	Transverse processes of the 1st four cervical vertebrae	Medial border of scapula, between	Elevates the scapula, and assists in rotation

		superior angle and root of spine	
Rhomboids (Major and Minor)	Major – Spinous processes of 2nd through 5th thoracic vertebrae Minor – Ligamentum nuchae, spinous processes of 7th cervical and 1st thoracic vertebrae	Major – By fibrous attachment to medial border of the scapula between spine and inferior angle Minor – Medial border at root of spine of the scapula	Retraction, elevate, and downward rotation the scapula
Serratus Anterior	Outer surfaces and superior borders of the upper 8/9 ribs	Costal surface of the medial border of the scapula	Lateral rotation and posterior tilt; depression and elevation of scapula
Trapezius (Upper, Middle, and Lower)	Upper – External occipital protuberance, medial 1/3 of superior nuchal line, ligamentum nuchae and spinous process of the 7th cervical vertebra Middle – Spinous processes of the 1st through 5th thoracic vertebrae Lower – Spinous processes of the 6th through 12th thoracic vertebrae	Upper – Lateral 1/3 of the clavicle and acromion process of the scapula Middle – Medial margin of the acromion and superior lip of the spine of the scapula Lower – Tubercle at the apex of the spine of the scapula	Upper – Elevation and lateral rotation of the scapula Middle – Retraction of the scapula Lower – Depression, lateral and medial rotation of the scapula
Subscapularis	Subscapular fossa	Lesser tuberosity of humerus	Internal rotation and horizontal adduction; stabilizes the head of the humerus in the glenoid cavity
Supraspinatus	Medial 2/3 of supraspinatus fossa of the scapula	Superior and middle impression of the greater tuberosity of the humerus	Abduction and external rotation; stabilizes the head of the humerus in the glenoid cavity

Infraspinatus	Medial 2/3 of the infraspinous fossa of the scapula	Middle facet of the greater tubercle of the humerus and shoulder joint capsule	Horizontal abduction, lateral rotation; stabilizes the head of the humerus in the glenoid cavity
Teres Minor	Upper 2/3, dorsal surfaces of the lateral border of the scapula	Lowest facet of the greater tubercle of the humerus and shoulder capsule	Assists infraspinatus in external rotation, lateral rotation of the scapula; stabilizes the head of the humerus in the glenoid cavity