RESEARCH ARTICLE

Influence of posture-cueing compression garment on overhead throwing kinematics

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OBJECTIVE: Throwing is a dynamic and complex task, which requires sequential movement to sufficiently transfer energy from the lower extremity to the upper extremity. Due to the repetitive stress of the overhead throwing motion, sport medicine personnel have developed different methods to assist in alleviating pain an athlete may be experiencing. One method is the use of a posture-cueing compression garment. These garment designs aim to cue the individual in maintaining and improving alignment, specifically targeting the posterior shoulder to improve scapular positioning and therefore restore normal shoulder kinematics. The purpose of this study was to determine the influence of a posture-cueing compression garment on overhead throwing kinematics.
METHODS: A convenience sample of nine National Collegiate Athletic Association [NCAA] Division I Collegiate softball players [20.3 ± 1.5 years; 166.6 ± 6.3 cm; 68.0 ± 7.5 kg] volunteered to participate. Kinematic data were collected at 100 Hz using an electromagnetic tracking system synced with The Motion Monitor®. All kinematic variables of the overhead throw in both garment conditions were analyzed using repeated measures ANOVA.
RESULTS: Results revealed no statistically significant main effect of Garment or Garment by Throwing Event interaction of any kinematic variables for the overhead throw task.
CONCLUSION: Although the current study did not reveal kinematic differences during the overhead throwing task while wearing a posture-cueing compression garment further research should evaluate the use of posture-cueing compression garments, on overhead athletes suffering from upper extremity pathologies.
Key Words: Glenohumeral joint, Kinetic chain, Rehabilitation, Scapular kinematics

INTRODUCTION

In softball, the overhead throwing motion is one of the most complex and dynamic skills performed. Overhead throwing places great demands on the upper extremity due to repetitive stresses to the glenohumeral joint and requires sequential patterns throughout the kinetic chain to efficiently transfer energy and accurately deliver a ball to a specific target (1-3). In addition, stability and strength of the lumbopelvic hip complex [LPHC] coupled with synchronization of the scapulothoracic and glenohumeral joints are required to provide appropriate balance of joint mobility and functional stability in reducing risk of injury (4). However, due to lack of muscular strength, proper mobility, structural complexity of the shoulder, and repetitive overhead movements, overuse injuries among throwing athletes are commonplace (5-7).

Overhead throwing athletes are required to deliver an accurate throw to an intended target, which demands precise mechanical timing, strength, stabilization, and efficient energy transfer along the kinetic chain from the proximal segment [foot] to distal segment [hand] (8,9). The kinetic chain is defined as linked segments of the body maintaining a synergistic relationship and coordination among joints and muscles to efficiently execute specific tasks (10). Lack of precise mechanical timing, strength, and stabilization during the overhead throw results in movement dysfunction and decreases the efficiency of energy transfer, thus potentially inhibiting the appropriate proximal-to-distal sequence necessary to execute an efficient overhead throw (1,2). Previous studies have shown that pathomechanics, with improper proximal-to-distal sequencing in overhead throwing movements, often lead to a decrease in performance and increase potential injury (9,11).

The direct link connecting the lower extremity to the upper extremity is the LPHC. In the overhead throwing motion, the LPHC provides a base of support, postural stability and efficient dispersion of force utilized during the proximal-to-distal sequence (8,9,11). Literature has shown that the lower extremity and LPHC produce approximately 51-55% of the kinetic energy that is transferred to the hand during the overhead throw (1,9,12). Previous studies have also shown that decreased hip range of motion and strength can increase demands placed on the shoulder and upper extremity, where 58% of injuries in baseball and softball were found to occur (13,14). Therefore, the coordination of the lower extremities, LPHC, and upper extremities is vital to enhance performance during an overhead throw.

Of the coordination of the upper extremity, the scapula is a site of attachment for many muscles and plays a vital role in stabilization. The scapula, humerus, and clavicle work synergistically to control the shoulder girdle during an overhead throw. More specifically, the scapula is a significant feature in the human body and is a critical link utilized in the kinetic chain. It articulates with the head of the humerus and is normally positioned against the posterior-lateral surface of the thorax at rest (15). The scapula is a floating bone which maintains four roles for optimal function in athletic performance and overhead motion: 1) stability of the glenohumeral articulation, 2) retraction and protraction along the thoracic wall, 3) elevation of the acromion, and 4) link in the proximal-to-distal sequencing of velocity, energy, and forces that allow the most appropriate shoulder function (16). As stated previously, movement at the shoulder requires a synergistic relationship from the lower extremities to the upper extremities and specific linking of the glenohumeral and scapulothoracic joints to maximize the range of motion and dissipation of forces during overhead movements (15,16).

To combat the decline in optimal scapular positioning, physical therapists and athletic trainers have used different taping methods, as well as worked with apparel companies to design posture-cueing compression garments and shoulder and trunk braces (17-19). These garment designs aim to cue the individual in maintaining and improving alignment, specifically targeting the posterior shoulder to improve scapular positioning and therefore restore normal shoulder kinematics (20). Posture-cueing compression garment designs have been assessed in some studies focusing

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on alterations in forward shoulder posture (21,22). Of the previous studies, forward shoulder posture was improved when participants wore a scapular-stabilizing compression garment with increased tension on the straps (21). Additionally, it has been reported that when wearing compressive bracing, the position of the shoulder was enhanced as well as sensation of stability was improved (22). Furthermore, other styles of postural-cueing compression garments are specifically designed to signal posture and core musculature to activate and align an individual's shoulders, spine, trunk, and pelvis (23). The posture-cueing technology in combination with the compression material mimics the effects of Kinesiology Tape [KT] to better assist the body in postural control (23).

Due to the increase risk of injury in the overhead throw, sports medicine personnel have designed and developed various methods to combat the prevalence of such injuries (4,24-27). Research has shown benefits of the strategies, however, to the authors' knowledge, no research has shown the influence of a posture-cueing compression garment during a dynamic movement such as the overhead throw. Therefore, the purpose of this study was to determine the influence of a posture-cueing compression garment on overhead throwing kinematics. This study attempted to determine if kinematic changes occurred during an overhead throwing task in the pelvis, trunk, scapula and humerus. The specific aims of this study were to measure the differences of throwing kinematics of the pelvis, trunk, scapula, and humerus with and without a posture-cueing compression garment. It was hypothesized that the pelvis, trunk, scapula, and shoulder kinematics would be significantly different among a team issued performance garment when compared to a posture-cueing compression garment utilized to improve posture during an overhead throwing task.

METHODS

Experimental approach to the problem

The aim of this study was to compare the effects of the IntelliSkin™ posture-cueing compression garment to a team issued performance garment during an overhead throwing task. The independent variable in this study was the type of garment while the dependent variables analyzed were the pelvis, trunk, scapula, and shoulder kinematics.

Participants

A convenience sample of nine female National Collegiate Athletic Association [NCAA] Division I Collegiate softball players [20.3 ± 1.5 years; 166.6 ± 6.3 cm; 68.0 ± 7.5 kg] was taken. Selection criteria included being currently active on the playing roster and medically cleared by sports medicine staff to participate in throwing activities. Participants were excluded if they reported any upper or lower extremity injury within the past six months. The University's Institutional Review Board approved all testing protocols. Prior to data collection, all testing procedures were explained to each participant and informed written consent was obtained. Prior to participation, the female athletes submitted their t-shirt size. Sizes of extra small, small, medium, large, and extra-large were available. The IntelliSkin™ posture-cueing compression garment is controlled by US standard sizing for the female population (28).

Kinematic analysis

Kinematic data were collected at 100 Hz using an electromagnetic tracking system [trakSTARTM, Ascension Technologies, Inc., Burlington, VT, USA] synced with The MotionMonitorTM [Innovative Sports Training, Chicago, IL., USA]. A series of eleven electromagnetic sensors were affixed to the skin using PowerFlex cohesive tape [Andover Healthcare, Inc., Salisbury, MA] to ensure the sensors remained secure throughout testing. 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) forehead 4,5) flat, broad portion of the acromion, bilaterally; 6,7) lateral aspect deltoid tuberosity, bilaterally; 8,9) posterior aspect of bilateral distal forearm, centered between the radial and ulnar styloid processes; and 10,11) lateral aspect of each thigh, centered between the greater trochanter and the lateral condyle of the knee. A twelfth, moveable sensor was attached to a plastic stylus used for the digitization of bony landmarks (29-31). To ensure accurate identification and palpation of bony landmarks, the participant stood in anatomical neutral throughout the duration of 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 (29,30,32). The spinal column was defined as the digitized space between C7-T1 and T12-L1 (29,32). A rotation method, validated as capable of providing accurate positional data (33,34) was utilized to estimate the joint centres of the shoulder and hips. The shoulder joint centers were 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 investigator stabilizing the joint then passively moving the limb into six different positions in a small, circular pattern (33). 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 obtained using Euler angle sequences that were consistent with the International Society of Biomechanics standards and joint conventions (30,31). All raw data were independently filtered along each global axis using a 4th order Butterworth filter with a cutoff frequency of 13.4 Hz (29,35,36). All data were time stamped through the MotionMonitor® and passively synchronized using a data acquisition board.

Once all sensors were secured, participants were given an unlimited time to perform their specified pre-competition warm-up [average warm-up time was 10 minutes]. Participants were instructed to execute five maximal effort throws to a teammate 60 feet [18.29 m] away for both garment conditions. Data for each kinematic variable were averaged for each set of throws of both garment conditions during data analysis to limit potential variability between trials. The overhead throw was divided into the four major overhead throwing events: foot contact [FC], maximal shoulder external rotation [MER], ball release [BR], and maximal shoulder internal rotation [MIR]. All variables were analyzed at these events in both garment conditions.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics 22 software [IBM Corp, Armonk, NY] with an alpha level set a priori at $\alpha = 0.05$. Prior to analysis, Shapiro-Wilk Tests of Normality were run. Results showed an approximately normal distribution of the overhead throw in both garment conditions. All kinematic variables and 95% confidence intervals [CIs] of the overhead throw in both garment conditions were analyzed using a 2 [Garment] x 4 [Throwing Events] repeated measure analysis of variance [ANOVA]. This ANOVA was applied to the following kinematic variables: pelvis rotation, lateral tilt, anterior/posterior tilt; trunk rotation, flexion, lateral flexion; 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 when sphericity was violated. Post-hoc paired-samples t-test was conducted in the event of statistical significance in Garment and/or Garment by Throwing Events interaction.

RESULTS

Means and standard deviations [SDs] for each kinematic variable for the overhead throw in both garment conditions are reported in Table 1. Confidence intervals [CIs] for each kinematic variable for the overhead throw in both garment conditions are reported in Table 2a, 2b, 2c, 2d.

Table 1 Data presented as means (standard deviation) of kinematic variables (degrees) for two conditions: Control Garment (CG) and Posture-Cueing Garment (PG).

Variables	Foot Contact	Maximum External Rotation	Ball Release	Maximum Internal Rotation
Pelvis Rotation CG	-73.7 (18.5)	-0.4 (20.7)	11.8 (11.4)	8.2 (9.6)
Pelvis Rotation PG	-72.4 (16.9)	1.3 (18.6)	12.6 (12.5)	8.7 (11.3)
Pelvis Lateral Tilt CG	1.5 (5.6)	-5.2 (5.0)	-5.8 (7.6)	-6.9 (4.4)
Pelvis Lateral Tilt CG	1.3 (5.2)	-4.7 (5.5)	-5.0 (7.6)	-5.7 (5.4)
Pelvis Anterior/Posterior Tilt CG	4.0 (5.8)	-15.3 (7.2)	-14.8 (7.0)	-16.5 (6.5)
Pelvis Anterior/Posterior Tilt PG	3.0 (5.0)	-14.9 (7.1)	-14.5 (7.0)	-16.2 (6.7)
Trunk Rotation CG	-84.0 (15.7)	-7.2 (20.7)	25.7 (13.9)	30.5 (14.1)
Trunk Rotation PG	-82.2 (13.1)	-7.3 (17.6)	26.2 (13.9)	29.8 (15.1)
Trunk Flexion CG	13.3 (8.3)	15.0 (8.6)	0.8 (11.8)	-9.4 (14.8)
Trunk Flexion PG	15.8 (9.3)	15.2 (8.5)	0.9 (11.5)	-9.0 (15.1)
Trunk Lateral Flexion CG	-5.3 (12.6)	-11.3 (4.9)	-18.8 (7.9)	-24.8 (9.4)
Trunk Lateral Flexion PG	-4.8 (12.8)	-12.1 (5.0)	-20.3 (6.8)	-26.6 (7.8)
Scapula Protraction/Retraction CG	-7.2 (11.4)	6.3 (10.6)	14.2 (9.4)	24.2 (8.8)
Scapula Protraction/Retraction PG	-7.1 (13.3)	2.3 (10.4)	11.1 (7.7)	24.6 (8.0)
Scapula Lateral/Medial Rotation CG	-24.1 (7.5)	-30.4 (8.1)	-17.3 (10.8)	-10.1 (8.8)
Scapula Lateral/Medial Rotation PG	-25.7 (8.2)	-29.7 (6.9)	-17.7 (5.6)	-9.3 (7.8)
Scapula Anterior/Posterior Tilt CG	0.3 (7.1)	12.3 (11.0)	2.7 (10.9)	0.3 (7.0)
Scapula Anterior/Posterior Tilt PG	2.0 (4.3)	14.6 (9.9)	7.2 (9.4)	-0.2 (7.1)
Shoulder Horizontal Abduction CG	-96.3 (29.6)	5.5 (45.4)	49.7 (23.6)	62.92 (19.9)
Shoulder Horizontal Abduction PG	-79.5 (50.1)	-19.1 (37.2)	33.1 (39.1)	44.92 (41.9)
Shoulder Elevation CG	-85.2 (27.5)	-107.1 (30.7)	-91.7 (24.1)	-68.96 (16.2)
Shoulder Elevation PG	-79.5 (32.8)	-102.2 (38.9)	-87.7 (33.7)	-65.80 (26.0)
Shoulder Rotation CG	-28.4 (16.3)	-75.3 (24.0)	-27.1 (16.8)	30.55 (11.1)
Shoulder Rotation PG	-20.4 (20.3)	-60.9 (20.4)	-13.1 (25.2)	28.94 (16.7)

Table 2a 95% Confidence Intervals of shirt, events and shirt*events interaction of the pelvis.

	Pelvis Anterior/Posterior Tilt	Pelvis Lateral Tilt	Pelvis Rotation
Control Garment	-14.3, -6.9	-7.3, -0.9	-22.0, -5.1
Posture-Cueing Garment	-14.3, -6.9	-6.7, -0.3	-20.9, -4.0
Foot Contact	0.7, 6.2	-1.3, 4.1	-81.9, -64.2
Maximum External Rotation	-18.6, -11.5	-7.6, -2.3	-9.4, -10.3
Ball Release	-18.1, -11.1	-8.9, -1.9	6.3, 18.2
Maximum Internal Rotation	-19.6, -13.0	-8.8, -3.9	3.2, 13.7
Control Garment * Foot Contact	0.2, 7.8	-2.4, 5.3	-86.3, -61.2
Control Garment * Maximum External Rotation	-20.4, -10.3	-8.9, -1.5	-14.4, 13.5
Control Garment * Ball Release	-19.7, -9.8	10.8, -0.9	3.4, 20.3
Control Garment * Maximum Internal Rotation	-21.1, -11.8	-10.4, -3.4	0.8, 15.6
Postural-Cueing Garment * Foot Contact	-0.8, 6.8	-2.5, 5.1	-85.0, -59.9
Postural-Cueing Garment * Maximum External Rotation	-19.9, -9.8	-8.4, -0.9	-12.6, 15.3
Postural-Cueing Garment * Ball Release	-19.4, -9.5	-9.9, -0.1	4.2, 21.1
Postural-Cueing Garment * Maximum Internal Rotation	-20.8, -11.6	-9.2, -2.3	1.3, 16.1

Table 2b 95% Confidence Intervals of shirt, events and shirt*events interaction of the torso.

	Torso Rotation	Torso Flexion	Torso Lateral Flexion
Control Garment	-18.7, 1.1	-1.8, 11.7	-19.3, -10.8
Posture-Cueing Garment	-18.2, 1.5	-1.0, 12.5	-20.2, -11.7
Foot Contact	-90.3, -75.9	10.1, 18.9	-11.4, 1.3
Maximum External Rotation	-16.9, 2.4	10.9, 19.4	-14.2, -9.2
Ball Release	19.0, 32.9	-5.0, 6.7	-23.2, -15.8
Maximum Internal Rotation	22.8, 37.4	-16.6, -1.7	-30.0, -21.4
Control Garment * Foot Contact	-94.3, -73.8	7.1, 19.5	-14.3, 3.7
Control Garment * Maximum External Rotation	-20.8, 6.4	9.0, 21.1	-14.8, -7.8
Control Garment * Ball Release	15.8, 35.5	-7.5, 9.0	-24.0, -13.5
Control Garment * Maximum Internal Rotation	20.1, 40.8	-19.9, 1.2	-30.9, -18.7
Postural-Cueing Garment * Foot Contact	-92.4, -72.0	9.6, 22.0	-13.8, 4.2
Postural-Cueing Garment * Maximum External Rotation	-20.9, 6.3	9.2, 21.3	-15.6, -8.5
Postural-Cueing Garment * Ball Release	16.4, 36.1	-7.3, 9.2	-25.5, -15.0
Postural-Cueing Garment * Maximum Internal Rotation	19.5, 40.1	-19.5, 1.6	-32.7, -20.5

Table 2c 95% Confidence Intervals of shirt, events and shirt*events interaction of the scapula.

	Scapula Protraction/Retraction	Scapula Lateral/Medial Tilt	Scapula Anterior/Posterior Tilt
Control Garment	3.2, 15.6	-25.1, -15.8	-1.2, 8.7
Posture-Cueing Garment	1.5, 13.9	-25.3, -16.0	0.9, 10.9
Foot Contact	-13.3, -1.0	-28.8, -21.0	-1.8, 4.1
Maximum External Rotation	-1.0, 9.5	-33.8, -26.3	8.2, 18.7
Ball Release	8.3, 16.9	-21.8, -13.2	-0.2, 10.0
Maximum Internal Rotation	20.2, 28.6	-13.8, -5.5	-3.8, 3.3
Control Garment * Foot Contact	-16.0, 1.5	-29.7, -18.6	-3.8, 4.5
Control Garment * Maximum External Rotation	-1.1, 13.7	-35.7, -25.1	4.8, 19.7
Control Garment * Ball Release	8.1, 20.2	-23.4, -11.2	-4.6, 9.9
Control Garment * Maximum Internal Rotation	18.3, 30.2	-15.9, -4.2	-5.3, 4.8
Postural-Cueing Garment * Foot Contact	-15.8, 1.7	-31.3, -20.2	-2.2, 6.1
Postural-Cueing Garment * Maximum External Rotation	-5.1, 9.7	-35.0, -24.4	7.2, 22.0
Postural-Cueing Garment * Ball Release	5.0, 17.1	-23.8, -11.6	-0.02, 14.4
Postural-Cueing Garment * Maximum Internal Rotation	18.6, 30.5	-15.2, -3.4	-5.2, 4.8

Table 2d 95% Confidence Intervals of shirt, events and shirt*events interaction of the shoulder.

	Shoulder Horizontal Abduction	Shoulder Elevation	Shoulder Rotation
Control Garment	2.0, 18.3	-103.0, -73.8	-27.5, -17.6
Posture-Cueing Garment	-1.5, 14.8	-108.0, -79.4	-24.2, -14.3
Foot Contact	-29.2, -14.4	-100.0, -74.5	-33.6, -15.2
Maximum External Rotation	66.5, -40.2	-123.0, -95.9	-73.2, -53.0
Ball Release	38.4, 58.5	-106.0, -83.4	-34.7, -16.9
Maximum Internal Rotation	51.3, 69.5	-81.7, -63.1	22.6, 36.8
Control Garment * Foot Contact	-30.9, -9.9	-103.0, -67.1	-41.4, -15.4
Control Garment * Maximum External Rotation	-70.3, -33.0	-126.0, -87.7	-79.5, -51.0
Control Garment * Ball Release	35.5, 64.0	-108.0, '-75.8	-39.7, -14.5
Control Garment * Maximum Internal Rotation	50.1, 75.8	-82.1, -55.8	20.5, 40.6
Postural-Cueing Garment * Foot Contact	-33.7, -12.8	-108.0, -71.4	-33.4, -7.4
Postural-Cueing Garment * Maximum External Rotation	-73.7, -36.4	-132.0, -92.8	-75.2, -46.6
Postural-Cueing Garment * Ball Release	32.9, 61.4	-114.0, -81.8	-37.2, -12.0
Postural-Cueing Garment * Maximum Internal Rotation	44.9, 70.7	-88.9, -62.7	18.9, 39.0

Table 3 Results for repeated measures ANOVAs of Shirt * Events Interaction for all kinematic variables.

Kinematic Variables	Shirt * Events Interaction
Pelvis Rotation	F(1.83,29.2) = 0.10, *p* = 0.99
Pelvis Lateral Tilt	F(1.39, 22.2) = 0.10, *p* = 0.84
Pelvis Anterior/Posterior Tilt	F(1.14,18.4) = 0.09, *p* = 0.80
Trunk Rotation	F(2.06,32.9) = 0.08, *p* = 0.93
Trunk Flexion	F(1.29, 20.6) = 0.12, *p* = 0.80
Trunk Lateral Flexion	F(1.17,18.6) = 0.08, *p* = 0.82
Scapula Protraction/Retraction	F(3,48) = 0.65, *p* = 0.59
Scapula Lateral/Medial Rotation	F(3, 48) = 0.19, *p* = 0.85
Scapula Anterior/Posterior Tilt	F(3,48) = 0.44, *p* = 0.66
Shoulder Horizontal Abduction	F(1.31,20.9) = 0.02, *p* = 0.95
Shoulder Elevation	F(1.48, 23.7) = 0.03, *p* = 0.94
Shoulder Rotation	F(3,48) = 0.66, *p* = 0.56

The repeated measures ANOVA statistics of Garment by Throwing Events interaction of all kinematic variables are shown in Table 3. Results revealed no statistically significant main effect of Garment or Garment by Throwing Event interaction of any kinematic variables for the overhead throw task.

DISCUSSION

The purpose of this study was to compare the effects of an IntelliSkin™ posture-cueing compression garment to a team issued performance garment on throwing kinematics during an overhead throwing task. It was hypothesized that pelvis, trunk, scapula, and shoulder kinematics would be significantly different amongst a team issued performance garment when compared to a posture-cueing compression garment. While no significant differences were found during the overhead throwing task, it should be noted that these individual athletes are healthy and regularly participate in scheduled resistance training regimen, and therefore, may not reflect the influence of the IntelliSkin™ posture-cueing compression garment on the general population. In addition, the authors believe it is imperative to highlight some differences.

The IntelliSkin™ posture-cueing compression garment is specifically designed to signal posture and LPHC musculature to activate and align an individual's shoulders, spine, trunk, and pelvis (23). Proper posture is defined as the muscular balance which protects the supporting structures of the body against injury or progressive deformity, while poor posture is 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 (37). The base of support is defined as the position required maintaining the center of mass and is a critical component utilized by the overhead throwing athlete. It allows the efficient transfer of forces from the proximal segment to the distal segment (9,38,39). The neuromuscular system adapts to the demands and sequencing required of the movement, however, with continued stress and force placed on the body, there is an increased likelihood for overuse injuries to occur (4,24,40). Results in the current study reveal the consistency in the pelvis and trunk of each athlete throughout the throwing events regardless of the garment. The consistency of both the pelvis and trunk allows gravitational forces to be evenly distributed through the bones, ligaments, and muscles of the body and potentially helps to create an efficient sequencing of the throwing motion to decrease the likelihood for upper extremity injury regardless of the garment (37).

Although the results of this study indicate similarities of the pelvis and trunk during each throwing event, the slight differences in the scapula and shoulder variables during the throwing events between the garments should be assessed. Upon further evaluation, results revealed an increase in scapular lateral rotation during FC, MER, and BR events for both garment types (Table 1). Research has shown that increased scapular lateral rotation of the dominate arm increases the subacromial space reducing the likelihood of impingement (3,41-44). Similarly, posterior tilting of the scapula is shown to elevate the anterior acromion, thereby decreasing compression of subacromial soft tissues during humeral elevation and abduction (45,46). Results reveal the athletes were more posteriorly tilted during FC, MER, and BR in the posture-cueing compression garment. For efficient arm elevation in dynamic upper extremity movements, the scapula must posteriorly tilt to allow for acromial elevation (15,16,47). Since elevation allows for increased subacromial space for full arm elevation, if one is performing dynamic overhead movement without acromioclavicular elevation, then there is a decrease in subacromial space and a greater susceptibility for impingement of the supraspinatus or biceps tendon. By eliciting greater scapular posterior tilt, the posture-cueing compression garment appears to place bony landmarks of the shoulder in a more optimal position to increase range of motion and decrease instances of subacromial impingement.

Our results reveal the participant is in a scapular retracted position during FC and MER while wearing the posture-cueing compression garment. The scapula should be in a retracted position to facilitate the position of maximum external rotation to efficiently execute overhead tasks (15,45,48,49). Positioning the glenohumeral joint in retraction allows for an efficient transfer of energy from eccentric to concentric for explosive acceleration in dynamic overhead movements (12,24,45,48,50,51). Kibler et al. and Myers et al. described the necessity of the scapular retraction position during the cocking phase among overhead athletes (47,48). Myers et al. suggests increased retraction may facilitate a maximum cocking position and increase acceleration during the throwing motion (47). Therefore, it is proposed that by wearing the posture-cueing compression garment, the overhead athletes may increase the efficiency of the throwing motion.

As stated previously, the glenohumeral joint must work synergistically with the scapula to maximize the efficiency of the overhead throwing task. It has been established that the scapula must move in a coordinated manner with the humerus for the most effective movement of the glenohumeral joint (15,47,48). Our results reveal >60° of shoulder horizontal abduction during FC, MER, and BR events for both garment types. This may predispose the athlete to upper extremity injury as research has also shown that subacromial impingement occurs at >60° in shoulder horizontal abduction (3,27,52,53). However, our results also revealed greater shoulder elevation during the throwing events in the posture-cueing compression garment when compared to the team issued garment. Although these results were not significant, they do support previous findings describing the synergistic relationship of the scapula and shoulder elevation of the arm in healthy participants. As the shoulder elevates, the scapula should laterally rotate and posteriorly tilt (54-56). Our results support this movement in both garment types during all throwing events. The authors believe this movement and positioning may allow for appropriate subacromial spacing and prevention of impingement.

Literature has documented the importance of careful monitoring and appropriate recovery of athletes performing multiple overhead tasks (24,47,57,58). The posture-cueing compression garment may assist with recovery and properly align the athlete after excessive bouts of training and although the influence of compression was not the focus of this study it is important to note the benefits of compression on recovery. Research has shown compression garments are effective in enhancing recovery from muscle damage and perceived muscle soreness (59-63). Further research must be conducted to determine the influence this posture-cueing garment exhibits during recovery after strenuous bouts of exercise on the overhead athletes.

CONCLUSION

Throwing is a dynamic and complex task, which requires sequential movement to sufficiently transfer energy from the lower extremity to the upper extremity. Although the current study did not reveal kinematic differences during the overhead throwing task while wearing a posture-cueing compression garment, further research should evaluate the use of posture-cueing compression garments on overhead athletes suffering from upper extremity pathologies.

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