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Relationship between gluteal muscle activation and upper extremity kinematics and kinetics in softball position players

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Abstract As the biomechanical literature concerning softball pitching is evolving, there are no data to support the mechanics of softball position players. Pitching literature supports the whole kinetic chain approach including the lower extremity in proper throwing mechanics. The purpose of this project was to examine the gluteal muscle group activation patterns and their relationship with shoulder and elbow kinematics and kinetics during the overhead throwing motion of softball position players. Eighteen Division I National Collegiate Athletic Association softball players (19.2 ± 1.0 years; 68.9 ± 8.7 kg; 168.6 ± 6.6 cm) who were listed on the active playing roster volunteered. Electromyographic, kinematic, and kinetic data were collected while players caught a simulated hit or pitched ball and perform their position throw. Pearson correlation revealed a significant negative correlation between non-throwing gluteus maximus during the phase of maximum external rotation to maximum internal rotation (MIR) and elbow moments at ball release ($r = -0.52$). While at ball release, trunk flexion and rotation both had a positive relationship with shoulder moments at MIR ($r = 0.69$, $r = 0.82$, respectively) suggesting that the kinematic actions of the pelvis and trunk are strongly related to the actions of the shoulder during throwing.

Keywords Kinetic chain · Overhead throwing · EMG

1 Introduction

Fast-pitch softball literature is beginning to emerge with primary focus on the pitcher [3, 7, 15, 20–22, 25–27]. In addition to the science evolving, participation rates in fast-pitch softball are on the rise. It has been reported that the Amateur Softball Association annually registers over 1.2 million girls [2]. During 2010–2011, the National Federation of State High School Associations reported 385,028 fast pitch softball participants, resulting in a 4 % increase in participation from 2008 to 2009 [2]. It was also reported that softball ranked as the fourth most popular high school sport for girls [2]. Though there has been an increase in participation, there are limited data regarding the throwing mechanics of softball position players.

Previously, joint motions and movement patterns of the kinetic chain during the windmill softball pitch have been described sequentially from proximal to distal [17]. It is evident in the literature that torso control plays a major role in dynamic human movements [1, 13, 18, 19]. Since the torso is a part of the lumbopelvic-hip complex, it allows for optimal transfer of forces from the lower extremity to the upper extremity. For dynamic movement it is imperative to have proximal stability to accomplish distal mobility. Structurally, the lumbopelvic-hip complex is the area encompassing the pelvis and torso with the gluteal muscle group supplying the foundation of the pelvis. The gluteal muscle group stabilizes the torso over a planted leg and allows for efficient transfer of energy for forward movements.

As a part of the kinetic chain, the gluteal muscle group will affect the more distal segments of the lumbopelvic-hip complex. The true dynamic relationship of gluteal muscle activation and upper extremity kinematics and kinetics has yet to be thoroughly researched. Though data are beginning to evolve on windmill softball pitching, there are no data available on the softball position players. Therefore, the purpose of this project was to examine the gluteal muscle group activation patterns and their relationship with

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shoulder and elbow kinematics and kinetics during the overhead throwing motion of softball position players. It was hypothesized that the observed gluteal muscle activation patterns would be significantly correlated with upper extremity kinematics and kinetics.

2 Methods

A controlled laboratory study design was implemented. Eighteen Division I National Collegiate Athletic Association softball players (19.2 ± 1.0 years; 68.9 ± 8.7 kg; 168.6 ± 6.6 cm) who were listed on the active playing roster volunteered to participate. Participant inclusion criteria included coach recommendation, multiple years of playing experience prior to this study, and freedom from injury. Participants were excluded if they had suffered an injury within the past 6 months, which required medical attention, in attempt to avoid any biomechanical compensation that may have developed affecting the throwing mechanics. Data collection was conducted in the University's Health, Physical Education, Recreation, and Dance building. The University Institutional Review Board approved all testing protocols. Approved testing procedures were explained to each participant and their parent(s)/legal guardian(s) and proper informed consent and participant assent were obtained before data collection began.

Adhesive 3 M red-dot (3 M, St. Paul, MN) bipolar (Al/AgCl) disk surface electrodes (6 cm in diameter) were attached bilaterally over the muscle bellies of the gluteus maximus and medius. The electrodes were positioned parallel to muscle fibers using techniques described by Basmajian and Deluca [4]. Prior to electrode placement the identified locations for surface electrode placement were shaved, abraded and cleaned using standard medical alcohol swabs. The selected inter-electrode distance was 25 mm [8, 17, 21, 22]. An additional electrode was placed on the anterior superior iliac spine (ASIS) to serve as a ground lead. Electromyographic data were collected via a Noraxon Myopac 1400L 8-channel amplifier (Noraxon USA, INC, Scottsdale, AZ). The signal was full wave rectified and root mean squared at 100 ms. Surface EMG data were sampled at a rate of 1,000 Hz. The surface EMG data were notch filtered at frequencies of 59.5 and 60.5 Hz [5, 17, 21, 22].

Following the application of surface electrodes, manual muscle testing (MMT) techniques by Kendal et al. [8] were used to determine steady state contraction. A certified athletic trainer, familiar with the techniques, performed all MMT to ensure consistency throughout testing. Three MMT, lasting 5 s, were performed for each muscle and the first and last second of each contraction was removed [21, 22]. The MMT provided baseline data in which all surface EMG data could be compared.

The MotionMonitor^{TM} (Innovative Sports Training, Chicago IL) synched with electromagnetic tracking system (Flock of Birds Ascension Technologies Inc., Burlington, VT) was used to collect data. The electromagnetic tracking system has been validated for tracking humeral movements, producing trial-by-trial interclass correlation coefficients for axial humerus rotation in both loaded and non-loaded condition in excess of 0.96 [12]. With electromagnetic tracking systems, field distortion has been shown to be the cause of error in excess of 5° at a distance of 2 m from an extended range transmitter [6], but increases in instrumental sensitivity have reduced this error to near 10° prior to system calibration and 2° following system calibration [14, 24]. Thus, prior to data collection, the current system was calibrated using previously established techniques [6, 14, 24]. Following calibration, pilot data collected prior to testing participants indicated that the magnitude of error in determining the position and orientation of the electromagnetic sensors within the calibrated world axes system was less than 0.01 m and 3°, respectively.

Participants had 10 electromagnetic sensors attached at the following locations: (1) the medial aspect of the torso at C7; (2) medial aspect of the pelvis at S1; (3–4) bilateral distal/posterior aspect of the upper arm; (5–6) bilateral distal/posterior aspect of the forearm; (7–8) bilateral distal/posterior aspect of lower leg; and (9–10) bilateral distal/posterior aspect upper leg [15, 18, 19, 21]. Sensors were affixed to the skin using double-sided tape and then wrapped using flexible hypoallergenic athletic tape to reduce movement artifact. In addition, sensors were placed over areas with the least muscle mass in an attempt to minimize sensor movement. Following sensor placement, an 11th sensor was attached to a wooden stylus and used to digitize the palpated positions of the body landmarks described in Table 1 [15, 21, 28]. Participants were instructed to stand in anatomical neutral while selected body landmarks were accurately digitized.

The coordinate systems used were calculated in accordance with the standards and conventions for reporting joint motion recommended by the International Shoulder Group of the International Society of Biomechanics Recommendations [28]. Raw data describing sensor orientation and position were transformed to local coordinate systems for each of the respective body segments. Euler angle decomposition sequences were used to describe both the position and orientation. Shoulder movement was defined as the movement about the center of mass of the humerus relative to the center of mass of the thorax, while the trunk was defined as the center of mass of the thorax relative to the world axis. Rotational sequences allowed the data to be

Table 1 Description of bony landmarks palpated and digitized

Bony landmark	Bony process palpated and digitized
Thorax	
Seventh cervical vertebra [C7]	Most dorsal aspect of the spinous process
Eighth thoracic vertebra [T8]	Most dorsal aspect of the spinous process
Suprasternal notch	Most cranial aspect of sternum
Humerus	
Medial epicondyle	Medial/distal aspect of condyle
Lateral epicondyle	Lateral/distal aspect of condyle
Glenohumeral joint center of rotation	Rotation method[a]
Forearm	
Radial styloid process	Lateral/distal aspect of radial styloid
Ulnar styloid process	Medial/distal aspect of ulnar styloid

[a] Center of glenohumeral rotation was not digitized. The rotation method estimated joint center using lest of squares algorithm for the point moving the least during a series of short rotational movements [15]

Table 2 Angle orientation decomposition sequences

Segment	Axis of rotation	Angle
Torso		
Rotation 1	Z	Flexion (−)/extension (+)
Rotation 2	X'	Left lateral tilt (−)/right lateral tilt (+)
Rotation 3	Y''	Right rotation (+)/left rotation (−)
Shoulder		
Rotation 1	Y	Plane of elevation (0 = abduction; 90 = flexion)
Rotation 2	X'	Elevation
Rotation 3	Y''	Internal rotation (+)/external rotation (−)
Elbow		
Rotation 1	Z	Flexion (+)/hyperextension (−)
Rotation 2	X'	Carrying angle
Rotation 3	Y''	Pronation (+)/supination (−)

[a] Prime ($'$) and double prime ($''$) notations represent previously rotated axes due to the rotation of the local coordinate system resulting in all axes within that system being rotated (rotation about X axis also results in rotation of both Y and Z axes resulting in a new system of X', Y', Z'. Subsequent rotation are then about those axes

described in a manner that most closely represented the clinical definitions for the movements [15]. Angle decomposition sequencing for the torso, shoulder, and elbow, as well as definitions of the movements they describe are shown in Table 2. Throwing kinematics for left handed participants were calculated using the same conventions; however, the world z-axis was mirrored so that all movements could be calculated, analyzed, and described from a right hand point of view [28]. Data describing the position and orientation of electromagnetic sensors were collected at 100 Hz. Raw data were independently filtered along each global axis using a 4th order Butterworth filter with a cutoff frequency of 13.4 Hz [18, 19]. Two points described the longitudinal axis of each segment and the third point defined the plane of the segment. A second axis was defined perpendicular to the plane and the third axis was defined as perpendicular to the first and second axes. Neutral stance was the y-axis in the vertical direction, horizontal and to the right of y was the x-axis, and posterior was the z-axis [21].

Following set-up, participants were allotted an unlimited time to perform their own specified pre-competition warm-up routine. Participants spent an average of 10–12 min for their warm-up. Once the participants deemed themselves warm, they were instructed on the protocol. The participant had to catch a simulated hit or pitched ball and perform their position throw to a designated position player standing on base to prevent a runner from advancing to that base. Infielders caught a simulated line drive and threw to a position player at second base. Outfielders caught a simulated fly ball; crow hoped and threw to a position player at second base, while catchers caught a simulated pitched ball and threw down to second base where a position player received the ball. All position players (infielder, outfielder, and catcher) threw the same average distance of 25.6 m. For each throw, a position player was on the designated base to catch the ball. Only those throws where the position player on base was able to catch the ball without stepping off the base were recorded. Those data from the fastest throw were selected for detailed analysis [18, 19, 25]. The throwing surface was constructed so that the participant's stride foot would land on top of the 40 × 60 cm Bertec force plate [Bertec Corp, Columbus, Ohio] that was anchored into the floor. A JUGS radar gun (OpticsPlanet, Inc., Northbrook, IL) positioned in the direction of the throw determined ball speed.

2.1 Data analysis

Data were analysed using PASW 19 for Windows (SPSS, Chicago, IL). Pearson product moment correlation coefficients were calculated to identify the possible relationships between gluteal activity and upper extremity kinematics and kinetics. The throwing motion traditionally is broken down into four major events of foot contact (FC), shoulder maximum external rotation (MER), ball release (BR), and shoulder maximum internal rotation (MIR) (Fig. 1). The time interval between the events is referred to as a movement phase. For the current study, the throwing motion was broken down into three phases: (1) start of throwing (at the point of removing ball from the glove) motion to FC, (2)

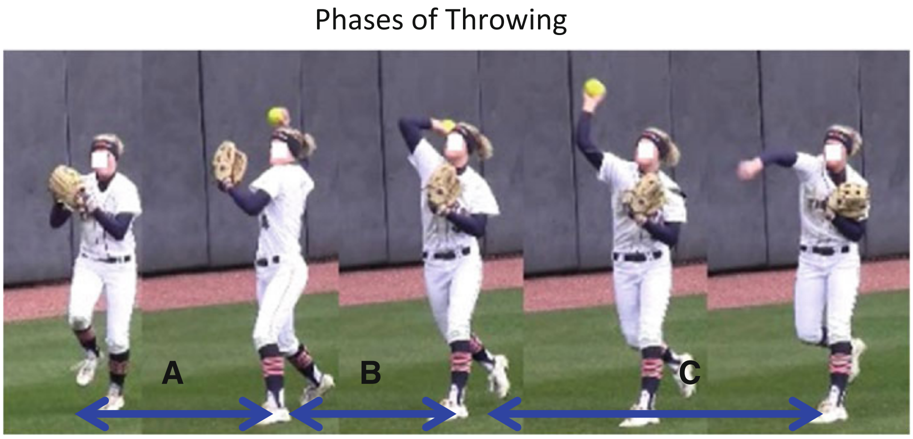

Fig. 1 **a** Start of movement to foot contact. **b** Foot contact to maximum external rotation. **c** Maximum external rotation to maximum internal rotation

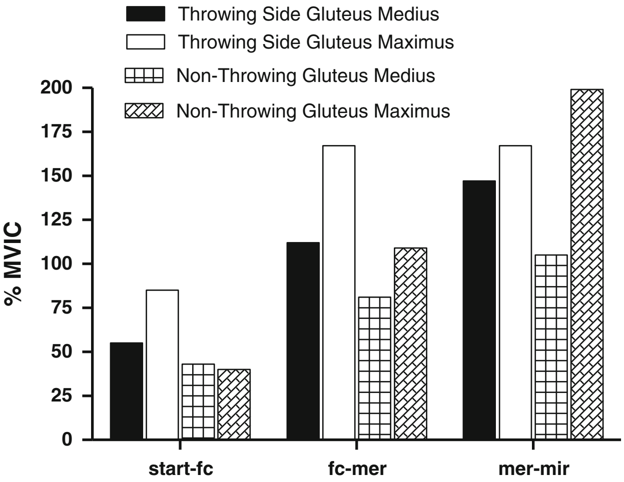

Fig. 2 Gluteal muscle pattern activity expressed as a %MVIC during three phases of throwing. *FC* foot contact, *MER* maximum shoulder external rotation, *MIR* maximum internal shoulder rotation

FC to MER, and (3) MER to MIR for all sEMG data, while kinematics and kinetics were analyzed at the events of FC, MER, BR, and MIR (Fig. 1).

Descriptive statistics were calculated for all sEMG (Fig. 2), kinematic, and kinetic parameters (Table 3) for the fastest throw made by each participant. All sEMG data were reported as a percentage of each individual's maximum voluntary isometric contraction (%MVIC), kinematic data by degrees, and kinetic data in Newtons.

3 Results and discussion

Pearson correlation revealed a significant negative correlation between non-throwing gluteus maximus during the phase of MER–MIR and elbow moments at ball release ($r = -0.52$). To position for FC, the throwing side gluteus maximus was most active as it was temporarily in a position of single leg support while propelling the body forward. From FC to MER, the throwing side gluteus maximus and medius and non-throwing gluteus maximus displayed over 100 % MVIC indicating activation while maintaining pelvic support. Often in dynamic movements muscle activations will display over 100 % MVIC indicating that the muscles are performing outside of the norms of an isometric contraction [18, 19, 22]. From MER, beginning of the acceleration phase of throwing, all gluteal musculature exhibited more than 100 % MVIC in providing pelvic support as well as transfer of energy up the kinetic chain from the proximal lower extremity to the more distal upper extremity and on to ball release.

The negative relationship between non-throwing gluteus maximus and elbow moments reveal the possibility of adequate lower extremity muscle activation of gluteals to stabilize the pelvis and transfer energy up the kinetic chain to the upper extremity. A more stable pelvis allows for greater energy transferred and less energy that needs to be generated by the upper extremity. The contralateral relationship of non-throwing pelvic stabilizer and throwing elbow are indicative of the neuromuscular loop and the activation of the contralateral hip in attempt to get full humeral elevation [13].

At BR, trunk flexion and rotation both had a positive relationship with shoulder moments at MIR ($r = 0.69$, $r = 0.82$, respectively) supporting previous literature, which has suggested that the kinematic actions of the pelvis and trunk are strongly related to the actions of the shoulder during pitching [19]. At the event of BR, the greater the

Table 3 Means and standard deviations of kinematic and kinetic parameters per throwing event

Ground reaction force	332.4 ± 146.3 N	1,000.8 ± 146.6 N	731.2 ± 207.6 N	561.1 ± 163.3 N
Trunk flexion	18.9 ± 9.1°	7.3 ± 9.5°	−2.2 ± 15.0°	−10.6 ± 16.1°
Trunk lateral flexion	−3.2 ± 10.4°	−10.6 ± 9.7°	−21.6 ± 12.8°	−25.5 ± 9.1°
Trunk rotation	−103.0 ± 14.4°	−16.9 ± 9.4°	5.7 ± 10.7°	−16.1 ± 49.1°

trunk was rotated and flexed, the great the shoulder moments produced during MIR. Throughout the throwing motion the trunk tilted laterally toward the glove hand and rotated forward toward the direction of the throw.

4 Conclusions

Dynamic movement of the upper extremity is dependent upon the interaction of structural and functional components of the neuromuscular system. Normal shoulder movement is achieved through a stable lumbopelvic-hip complex and scapula [10]. Thus, the pelvis must provide a stable platform for the scapula and the scapula provide a stable platform for the shoulder. Essentially, allowing the musculature of the lumbopelvic-hip complex to initiate shoulder movement [23].

These results supported the hypothesis that there was a relationship between gluteal muscle activation and elbow kinetics. The non-throwing gluteus maximus acted to stabilize the pelvis with the help of the throwing side gluteal group at the position of MER and then became the primary pelvic support as the throwing motion proceeded to ball release and MIR. If the pelvis is unable to maintain stability then the energy transfer is interrupted and the shoulder and elbow have to generate more energy rather than provide for its transfer. Previously, it has been reported that the pelvis positions the torso in overhand throwing motions [18, 19, 21]. The current study accounted for a large portion of the relationship between the gluteal muscle group and the elbow. It indicated that there could be additional kinetic chain segments such as the pelvis and/or shoulder that preclude the elbow relationship with the gluteal muscle group. This premise is based on the kinetic chain theory and the effect of the neuromuscular loop [10, 13].

In addition, the kinematic and kinetic relationship reiterated the importance of the role of the trunk in the forces ensued at the shoulder and elbow during the overhead throwing motion. It has previously been suggested that actions of the proximal segments [pelvis, trunk/torso] may result in alterations of the more distal segments [shoulder, elbow, wrist] in baseball pitching [1, 18, 19, 21]. Thus, further supporting the need for proximal stability for distal mobility or more specifically trunk and pelvis control as initiated by the gluteal muscle group in attempt to allow for efficient mobility at the shoulder and elbow. The lumbopelvic-hip complex has major functions of lumbopelvic stability as well as the creation and transfer of energy and forces to the upper extremity [11]. The findings of this study indicate that there is a need for greater lumbopelvic control through gluteal activation throughout the throwing motion. These finding have injury prevention implications in that it can be inferred that greater gluteal activation in attempt to stabilize the pelvis will allow more efficient energy transfer to the upper extremity. It has been estimated that the lower extremity contributes 50–55 % of the total energy generated by the body during performance of an upper extremity task [9].

In attempt to increase gluteal activation, overhead throwers should focus on specific training techniques that target the musculature of the lumbopelvic-hip complex [16]. As previously stated the gluteal muscle group is a major contributor to lumbopelvic stability. Injury prevention as well as performance enhancement should concentrate on exercises that not only engage the gluteals to stabilize the pelvis but also more total body exercises proven to target the pelvic stabilizers as well as the scapula stabilizers during functional movement patterns in attempt to allow for effective humeral elevation [23]. Efficient gluteal activation through a stable pelvis allows for fluid transfer of energy throughout the kinetic chain to the more distal segments of shoulder and elbow. A thorough foundation of gluteal training, through utilization of the lumbopelvic-hip complex as a vital link in functional movement, will enhance the efficiency of gluteal activation and ultimately may decrease the incidence of upper extremity pathomechanics resulting in injury [9–11, 16, 23].

Further research is needed to quantify the kinematics and associated kinetics about the shoulder and elbow between the different position players. By understanding the kinematics and kinetics associated with the throwing motion of position players future studies may identify potential pathomechanics that could lead to injury. Furthermore, the inclusion of scapula kinematic data may help to improve the understanding of the transfer of forces proximal–distal and validate the scapula's importance in normal shoulder function during throwing.

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