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Effects of Pitching a Simulated Game on Upper Extremity Kinematics in Youth Baseball Pitchers

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Abstract

Overuse injuries in youth baseball players has increased exponentially while clinicians are trying to reduce the risk of injury by identifying potential risk factors. It was the purpose of this study to examine the effects of throwing a simulated game, up to age restricted pitch count, on shoulder (plane of elevation, elevation, and rotation) and scapular (protraction/retraction, tilt, and rotation) kinematics in youth baseball pitchers. Thirty-three youth baseball pitchers [11.1 ± 1.2 yrs; 152.6 ± 9.9cm; 46.7 ± 10.1kg] participated. Participants were instructed to throw based on randomly provided game situations from the windup position. Results revealed significantly lower shoulder elevation the last inning compared to the first [p=0.04] at the pitching event of maximum shoulder external rotation. Additionally, ball velocity was significantly lower [p=0.02] in the last inning [21.7 ± 2.2m/s; 48.5 ± 5.0mph] compared to the first inning [22.0 ± 2.3m/s 49.2 ± 5.1mph]. It was concluded that shoulder and scapular kinematics of youth pitchers are remarkably unchanged from the first to the last inning of pitching a simulated game. Thus implying that as youth pitchers approach their age restricted pitch count, few mechanical changes in the upper extremity occur. Additional biomechanical examinations are needed during consecutive simulated games in effort to mimic the cumulative fatigue youth baseball pitchers experience during their competitive season.

Keywords

Fatigue, Pitch counts, Scapula, Shoulder, Throwing

Introduction

Overuse injuries in youth baseball players have increased exponentially with the insurgence of participation in the sport. It has been estimated that 5 million children (6-17 years) participate in organized youth baseball in the United States [1]. Additionally, it has been documented in a survey of 476 youth pitchers (9-14 years) that roughly half reported either shoulder or elbow pain while pitching [2], thus leading researchers to speculate overuse injury. As overuse injuries are continuing to be apparent in youth baseball, sports medicine professionals are trying to reduce the risk of injury in youth by considering many variables as potential risk factors. Upper extremity risk factors previously identified in professional pitchers have been excessive horizontal shoulder adduction, decreased shoulder elevation and external rotation [3]. In addition, it is believed that mechanisms contributing to degenerative overuse injuries observed in adult baseball pitchers are initiated during the youth playing years [4,5]. Recently youth injury focus has been on pitch volume and fatigue [6]. However, there have yet to be thorough exploration into the mechanics associated with these risk factors.

The pitching motion requires efficiency of the kinetic chain working in a proximal to distal manner. Specifically, the upper extremity relies on the stability of the pelvis and scapula for effective movement. Further, scapular stability and movement plays a vital role in normal shoulder function [7]. It is the efficiency and coordinated movement of not only the lower extremity and pelvis but also the stability of the upper extremity that allows for the functional dynamic movement of the baseball pitch. Without that coordinated movement, the system fails and injury occurs.

In effort to reduce injuries in youth baseball, age restricted pitch counts have been implemented in attempt to control pitch volume. However, there are no data to the author's knowledge examining the effectiveness of the pitch counts in either preventing throwing to fatigue or even injury prevention. It is the volume of pitching over the course of a season that is associated with higher rate of elbow and shoulder pain [2]. Thus resulting in pitch count restrictions in attempt to regulate workload and ultimately limit the susceptibility of pitching with fatigue. It was therefore the purpose of this study to examine how the effects of throwing a simulated game, up to age restricted pitch count, effects upper extremity kinematics in youth baseball pitchers. It was hypothesized that as the youth pitchers approached their age restrict pitch count, upper extremity kinematics would differ from those displayed in the first inning. Specifically a decrease in shoulder elevation and scapular posterior tilt, retraction, and upward rotation while an increase in shoulder plane of elevation [less horizontally abducted], during the event of maximum shoulder external rotation [MER] of the pitching motion.

Materials and Methods

Thirty-three youth baseball pitchers [11.1 ± 1.2 yrs.; 152.6 ± 9.9cm; 46.7 ± 10.1kg] participated. Selection criteria for participation included coach recommendation, years of pitching experience, and freedom from injury within the past six months. Recommendation from the coach was sought to ensure that all participants were competitively active at the pitching position. Freedom from injury within the past six months was one criterion for selection, however none of the participants reported that they had suffered any injury.

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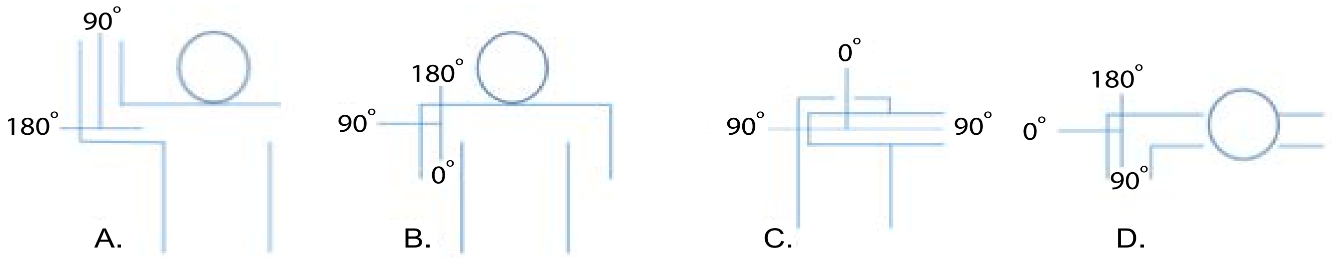

Figure 1: Definitions of kinematic variables: [A] elbow flexion/extension; [B] shoulder elevation; [C] shoulder internal/external rotation; [D] shoulder horizontal abduction.

Table 1: Description of bony landmarks palpated and digitized

Bony Landmark	Bony Process Palpated & 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
Scapula	
AngulusAcromialis	Most lateral-dorsal point of the scapula
Trigonum Spine	Midpoint of triangular surface on medial boarder of scapula in line with scapular spine
Angulus Inferior	Most caudal point of scapula
Humerus	
Medial Epicondyle	Medial/distal aspect of condyle
Lateral Epicondyle	Lateral/distal aspect of condyle
Glenohumeral Joint Center	Rotation method*

*Glenohumeral joint center was not digitized.

Table 2: Angle orientation decomposition sequences

Segment	Axis of Rotation	Angle
Scapula		
Rotation 1	Y	Internal (Protraction) [+]/External Rotation (Retraction) [-]*
Rotation 2	X'	Upward [+]/Downward Rotation [-]
Rotation 3	Z"	Anterior [-]/Posterior Tilt [+]
Shoulder		
Rotation 1	Y	Plane of Elevation [0=Abduction; 90=Flexion]
Rotation 2	X'	Elevation
Rotation 3	Y"	Internal Rotation [+]/External Rotation [-]

*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.

Nor did any participants report any pain or stiffness in their upper or lower extremity following extensive throwing sessions within the past year. The Institutional Review Board of Auburn University approved all testing protocols. Prior to data collection all testing procedures were explained to each participant as well as parent[s]/legal guardian[s] and informed consent and participant assent was obtained. All participants were tested during the fall baseball season and had not thrown that day prior to arrival for testing.

Data were collected with The MotionMonitor™ [Innovative Sports Training, Chicago IL] synchronized with electromagnetic tracking system [Flock of Birds Ascension Technologies Inc., Burlington, VT]. The Flock of Birds Ascension 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 conditions in excess of 0.96 [8]. Participants had a series of 11 electromagnetic sensors affixed to the skin using PowerFlex cohesive tape [Andover Healthcare, Inc., Salisbury, MA]. Sensors were attached to the following locations: [1] the posterior/medial aspect of the torso at C7 [2], posterior/medial aspect of the pelvis at S1 [3,4], bilateral distal/posterior aspect of the upper arm [5], the flat, broad portion of the acromion of the scapula, [6,7] bilateral distal/posterior aspect of the forearm, [8,9] bilateral distal/posterior aspect of the lower leg, and [10,11] bilateral distal/posterior aspect of the upper leg [9-13]. A twelfth sensor was attached to a stylus that was used to digitize bony landmarks [14]. The digitization of the bony landmarks allowed transformation of the sensor data from the global coordinate system to the anatomically based local coordinate system (Table 1).

Data describing the position and orientation of electromagnetic sensors were collected at 100Hz [15-18]. 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 [13]. Euler angle decompositions were used to determine shoulder (Y,X',Y") and scapular (Y,X',Z") orientation with respect to the thorax (Figure 1, Table 2). All rotations were based on the recommendations of the International Shoulder Group [14].

Once all sensors were secured, participants were given an unlimited time to perform their own specified pre-competition warm-up. Average warm-up time was ten minutes. Following warm-up, participants were instructed to throw based on randomly provided game situations from the windup position. To provide these situations, an expert with seven years of youth, high school, and collegiate coaching experience developed the protocol. Verbal feedback based on batter count [balls and strikes], simulated runners, and a simulated fielder was provided to participants throughout the simulated game protocol. Based on the simulation, the participant was allowed to throw the pitch that would normally be thrown in the proposed situation during competition. All testing was completed indoors in a controlled environment.

Participants were required to produce three outs an inning as per the standard rules of baseball. After three outs were produced, a rest period was provided to simulate the second half of the inning. Rest periods were randomly altered in length to mimic typical offensive innings in little league baseball. Participants were limited to their age restricted pitch count for 10 year olds, 75 pitches [19]. Participants were instructed to throw maximal effort for strikes over a regulation distance [46 feet; 14.02 meters] to a catcher. A JUGS radar gun [OpticsPlanet, Inc., Northbrook, IL] positioned in the direction of the throw determined ball speed. As the protocol was a simulated game, participants threw a variety of pitches. However, for the purpose of this study, only four seam fastball strikes thrown in the first and last innings of the simulated game were selected for all analysis.

Results

Statistical analyses were performed using IBM SPSS Statistics 20 [IBM corp., Armonk, NY]. Descriptive statistics were expressed

Table 3: Means and standard error of the mean of shoulder and scapular kinematics

Foot Contact						
Inning Analyzed	Humeral Plane of Elevation	Humeral Elevation	Humeral External Rotation	Protraction/Retraction	Upward Rotation	Anterior/ Posterior Tilt
FIRST	19.0 ± 4.6	87.0 ± 2.4	32.7 ± 3.6	-17.1 ± 4.1	22.7 ± 4.5	3.2 ± 2.5
LAST	30.5 ± 3.9	83.9 ± 5.6	46.6 ± 5.2	-16.1 ± 4.5	23.6 ± 5.2	1.1 ± 2.7
Maximum External Rotaiton						
Inning Analyzed	Humeral Plane of Elevation	Humeral Elevation	Humeral External Rotation	Protraction/Retraction	Upward Rotation	Anterior/ Posterior Tilt
FIRST	17.5 ± 2.0	77.5 ± 6.9	86.0 ± 2.6	-17.4 ± 3.0	25.9 ± 3.7	12.7 ± 2.0
LAST	19.2 ± 2.2	43.6 ± 14.7*	85.1 ± 6.6	-14.2 ± 3.9	22.3 ± 5.5	13.7 ± 2.4
Ball Release						
Inning Analyzed	Humeral Plane of Elevation	Humeral Elevation	Humeral External Rotation	Protraction/Retraction	Upward Rotation	Anterior/ Posterior Tilt
FIRST	5.7 ± 3.2	80.9 ± 1.8	52.0 ± 2.8	-6.1 ± 1.8	18.3 ±3.5	1.1 ± 1.8
LAST	16.1 ± 2.6	79.6 ± 6.0	57.4 ± 4.0	-3.2 ± 2.0	17.4 ± 4.4	1.4 ± 1.7
Maximum Internal Rotation						
Inning Analyzed	Humeral Plane of Elevation	Humeral Elevation	Humeral External Rotation	Protraction/Retraction	Upward Rotation	Anterior/ Posterior Tilt
FIRST	30.3 ± 3.1	85.7 ± 1.6	11.6 ± 3.3	12.5 ± 2.5	15.8 ± 3.8	-5.5
LAST	30.6 ± 2.7	89.0 ± 2.0	13.7 ± 3.3	14.4 ± 3.4	15.6 ± 3.8	-6.8

* = Significant at p<0.05

Protraction (+); Retraction (-); Anterior Tilt (-); Posterior Tilt (+)

by means and standard error of the mean at the throwing events of foot contact [FC], maximum shoulder external rotation [MER], ball release [BR], and maximum shoulder internal rotation [MIR]. Shoulder and scapular kinematics recorded during the first and last inning (last inning was considered the inning the participant reached their limit of 75 pitches) are presented in table 3. A 2-tailed *t* test was conducted with significance set *a priori* at $p \leq 0.05$ to examine shoulder and scapular kinematics during the first and last inning of the simulated game. Shoulder elevation at MER was significantly lower [p=0.04] in the last inning compared to the first inning. Though no other shoulder or scapular kinematic variables were significantly different, ball velocity was significantly lower in the last inning [21.7 ± 2.2m/s; 48.5 ± 5.0mph] compared to the first inning [22.0 ± 2.3m/s 49.2 ± 5.1mph], t(44)=2.39, p=0.02.

Discussion

Efficient baseball pitching in youth requires the coordination of both the lower and upper extremity to propel the ball 14.02m at speeds of up to 25m/s [56mph], as displayed by our participants. This repeated motion over the course of several innings eventually could result in fatigue. It has been reported that there is increased risk of elbow and shoulder pain in youth with self-reported fatigue [2]. The current study aimed to examine how the effects of throwing a simulated game, up to age restricted pitch count, effects shoulder and scapular kinematics in youth baseball pitchers. It was hypothesized that indicators of fatigue, through altered upper extremity kinematics, would begin to emerge, as the participant got closer to the age predicted pitch count maximum. Specifically, it was anticipated that shoulder elevation, plane of elevation, scapular rotation and tilt would be different between the first and last innings pitched. These variables were chosen as they have been shown to either affect performance and or contribute to injury prevalence [2,8-10,20,21].

At the instance of foot contact, for proper pitching mechanics, the foot should be positioned slightly toward third-base [for a right handed pitcher], humerus abducted to 90° with approximately 60° of humeral external rotation [22]. We were unable to find any significant decreases in humeral horizontal abduction [shoulder plane of elevation], humeral elevation, or scapular retraction at the event of FC following the simulated game. Foot contact marks the end of the stride phase of the pitching motion and the lack of significant differences following the simulated game indicates that the initiation of the motion and the stride remained consistent. This is important because if the stride is altered then the timing and the kinematics of the entire pitch can subsequently be hindered as well.

Continuing on in the pitching cycle is the event of MER. When examining proper pitching mechanics at MER, the humerus could approach as much as 180° of shoulder external rotation and 90° of abduction. In an attempt to get maximum shoulder external rotation the scapula must retract, posteriorly tilt, and laterally/upwardly rotate. The current study revealed that the youth pitchers were in the position of shoulder elevation, external rotation and scapular retraction during both the first and last inning of the simulated game. A decrease in scapular lateral/upward rotation is often thought to contribute to decreased subacromial space during humeral abduction [8,23]. Though the current study was unable to find any significant differences in scapular kinematics, the significant decrease in shoulder elevation could be indicative of the pitchers approaching fatigue. However, due to the pitch count restriction, they did not continue to throw through their fatigue, though it should be noted that the significant decrease in shoulder elevation in the last inning as compared to the first inning, is of concern. Decreased shoulder elevation is not an efficient arm position in such dynamic movements as baseball pitching, as it has been reported that lack of shoulder elevation results in increased valgus loads at the elbow [21].

The pitching events of BR and MIR, in the current study, revealed no significant differences in shoulder or scapular kinematics in the last inning as compared to the first inning. Though the youth did not display a significant difference in shoulder horizontal abduction there was a significant decrease in ball velocity and it has been reported that decreases in horizontal abduction at ball release are associated with decreases in ball velocity [22]. As ball velocity did decrease in this sample of youth pitchers it can be speculated that there are altered mechanics in other segments of the kinetic chain that were not examined in this study. Examining the more proximal segments of the kinetic chain may yield significantly different results following the simulated game. The period of BR to MIR is indicative of the follow-through phase of the pitching motion in which the body must act to rapidly decelerate the body once the ball has left the pitchers hand. The fact that the upper extremity kinematics remained consistent at the end of the simulated game is valuable as it likely means that the upper extremity is not compensating during deceleration.

Previously, it has been reported that when collegiate baseball pitchers approach fatigue from a simulated game, the only significant differences were ball velocity and trunk flexion [24]. Yet the current study, revealed a significant difference in shoulder elevation at the position of MER. This finding could prove interesting with further examination as it has been documented that the mechanisms contributing to overuse injuries at the more mature levels of baseball are initiated during the younger playing years [5].

In conclusion, our findings from the current study reveal that the pitching mechanics of youth in the first and last inning of a simulated game are remarkably unchanged. Data from the current study implies that as youth pitchers approach their age restricted pitch count, few mechanical changes occur. Those of which are shoulder elevation and ball velocity. Additional biomechanical examinations are needed during consecutive simulated games in effort to mimic the cumulative effects youth baseball pitchers experience during their competitive season. Likewise, it should be understood that fatigue is a very individualized variable. As the current study only examined pitching kinematics up to age restricted pitch count, no fatigue indices were reported. Thus more research is needed to identify the causes of fatigue as well as efficient and effective throwing patterns to avoid the cascade effect of compensatory injuries as throwing athletes age. As from the current data, age restricted pitch counts may be serving their purpose of preventing pitching to fatigue. However, consecutive days of throwing to age restricted pitch counts still needs to be examined.

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Ethical Statement

The University Institutional Review Board approved all procedures for this study. Informed consent was obtained from each participant prior to data collection.

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