ASSOCIATIONS BETWEEN GLENOHUMERAL ROTATION STRENGTH AND SELECT KINETIC PARAMETERS DURING THE BASEBALL PITCH IN ADOLESCENT BASEBALL PITCHERS

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The purpose of this study was to examine the associations between isometric glenohumeral rotation strength and select biomechanical parameters during the pitching motion in adolescent baseball pitchers. Glenohumeral (GH) rotation strength and pitching kinetic data were assessed in 28 (14.2 $\pm$ 0.94 yrs; 66.5 $\pm$ 11.7 kg; 175 $\pm$ 10.8 cm) adolescent baseball pitchers. Spearman's rank correlations were used to assess relationships between GH rotation strength and upper extremity torques during the pitching motion. Peak GH internal rotation torque during the pitch was negatively correlated with the ratio of throwing arm external rotation strength to non-throwing arm external rotation strength (ρ = -0.552, $p < 0.05$). These results provide evidence for a potential mechanism behind the increased injury risk seen in pitchers who exhibit GH external rotation weakness.

KEYWORDS: baseball, pitching, injury, rotational shoulder strength.

INTRODUCTION: The baseball pitch is a dynamic, challenging movement forcing the pitcher's glenohumeral (GH) joint into extreme ranges of motion as well as subjecting it to substantial, multidirectional loads. These mechanical demands place enormous strain on the musculature surrounding the GH joint; potentially leading to decreased stability of the humeral head in the glenoid fossa. This decreased stability has been hypothesized as a risk factor for potential shoulder injury in overhead throwing athletes (Burkhart, 2003).
Sports medicine professionals assess shoulder injury risk using GH rotational strength tests. Previously it has been suggested that weakness or imbalances between GH external rotation (ER) and internal rotation (IR) strength may affect performance as well as increase injury susceptibility (Byram, 2010; Tyler, 2014). However, mechanisms behind this potential increase in injury risk remain unclear.
Weakness or imbalances in GH ER and IR strength may manifest during high intensity dynamic movements such as the baseball pitch. Limited data are available connecting clinically assessed GH rotation strength and pitching mechanics. Therefore, the purpose of this study was to investigate the relationships between clinically assessed GH rotation isometric strength and laboratory-based biomechanical evaluations. Specifically, the relationships between ratio-based measurements of GH rotation strength and pitching mechanics related to injury risk in adolescent pitchers. Improved understanding of how these tools are related will allow sport science professionals and coaches to more effectively evaluate and train overhead throwing athletes. It was hypothesized that imbalances in GH rotation strength ratios would be associated with potential pathomechanics along the kinetic chain during the pitching motion.

METHODS: The purpose of this study was to investigate the relationships between GH rotation strength and peak elbow varus and shoulder rotation torques during the baseball pitch. Kinetic parameters were normalized to each participant's body mass. Glenohumeral rotation strength was measured using three IR and ER strength ratios. Glenohumeral ER strength was defined as the ER force produced by the proximal trunk on the distal humerus to resist IR. Glenohumeral IR strength was defined as the IR force produced by the proximal trunk on the distal humerus to resist ER. These ratios included one within-arm (throwing ER:IR) comparison and two between-arm (throwing and non-throwing IR and ER) comparisons. Comparing within the throwing arm was hypothesized to indicate the extent to which the posterior, externally rotating musculature of the shoulder was able to tolerate the stresses generated by the internal rotating antagonists. Comparing between arms was hypothesized to indicate the extent to which pitching has affected the strength of the GH rotators of the throwing arm compared to non-throwing arm.

Twenty-eight (14.2 ± 0.94 yrs; 66.5 ± 11.7 kg; 175 ± 10.8 cm) right handed, adolescent baseball pitchers participated. Participants were free from injury for the past 6 months and had no history of surgery to the pitching arm. The Institutional Review Board of Auburn University approved all testing protocols.

Bilateral GH rotational strength was assessed using a hand-held dynamometer. Participants were instructed to lay in a supine position with the arm at approximately 90 degrees of shoulder abduction and elbow flexion. Because of higher observed reliability when using a handheld dynamometer, make tests rather than break tests were used for all shoulder strength measurements (Stratford, 1994).

Following the strength measurements, kinematic data were collected at 100 Hz using an electromagnetic tracking system (trakSTAR™, Ascension Technologies, Inc., Burlington, VT, USA) synced with The MotionMonitor® (Innovative Sports Training, Chicago, IL., USA). Five electromagnetic sensors were attached to the relevant body segments: (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) flat, broad portion of the acromion on the throwing arm scapula; (4) lateral aspect of throwing-side upper arm at the deltoid tuberosity; (5) posterior aspect of distal throwing-side forearm, centered between the radial and ulnar styloid processes. A sixth sensor was attached to a plastic stylus used for the digitization of bony landmarks.

Using the stylus, a link segment model was developed. Joint centers for the wrist and elbow were determined by digitizing the medial and lateral aspect of a joint then calculating the midpoint between those two points (Wu, 2005). The shoulder joint center was calculated from the rotation of the humerus relative to the scapula (Veeger, 2000). The spinal column was defined as the digitized space between C7-T1 and T12-L1.

Following development of the link segment model, participants were allotted unlimited time to warm-up to prepare for full effort pitching. Participants were instructed to throw 3 game-effort fastballs to a catcher at an age specific regulation distance (14.0–18.4m). Prior to analysis, the pitching motion was event marked at foot contact (FC) and peak GH IR angle. The pitching motion was defined as the phase between FC and peak GH IR angle FC was identified using in-ground force plates (Bertec Corporation; Worthington, OH) and was defined as the first frame in which a non-zero ground reaction force was observed.

Position and orientation of the humerus and thorax used to denote phases of the pitching motion were obtained using Euler angle sequences consistent with the International Society of Biomechanics standards (Wu, 2005). Upper extremity kinetics were calculated using top-down inverse dynamic equations provided in The MotionMonitor®. Elbow kinetics were defined as the torque imposed by the proximal humerus on the distal forearm. Elbow varus torque was defined as the torque needed to counteract the valgus load imposed on the humerus by the inertia of the forearm during the arm cocking and acceleration phases of the pitch. Shoulder kinetics were defined as the torque imposed by the proximal thorax on the distal humerus. Shoulder IR torque represented the torque needed to slow down and reverse humeral ER during the arm cocking and acceleration phases. Shoulder ER torque represented the torque needed to negatively accelerate the humerus during the follow through phase after ball release. Kinetic parameters were averaged from all 3 trials before statistical analysis. Sensor data were independently filtered along each global axis using a 4th order Butterworth filter with a cutoff frequency of 13.4 Hz. All data were time stamped through The MotionMonitor® and passively synchronized using a data acquisition board.

RESULTS: All data were processed using a customized MATLAB script (MATLAB R2018a, MathWorks, Natick, MA, USA). Statistical analyses were performed using IBM SPSS Statistics 25 software (IBM Corp., Armonk, NY) with an alpha level set *a priori* at $\alpha = 0.05$. Prior to analysis, Sharpio-Wilk tests of normality were run, and showed the data were non-normally

distributed. Spearman's rank correlations were used to examine relationships between isometric shoulder strength measurements and peak upper extremity torques during the pitching motion.
Peak GH IR torque during the pitch was negatively correlated with the ratio of dominant ER strength to non-dominant ER strength (ρ = -0.552; p = 0.002; Figure 1). No significant correlations were found for peak ER torque or peak elbow varus torque. Results are shown in Table 1.

Table 1: Spearman's Rank Correlations between Isometric GH Strength and Peak Upper Extremity Torques during the Baseball Pitch[a]

Variable1*Variable2	Spearman's Rho	Significance
IRTorque*ER_t:IR_t	-.231	.229
IRTorque*ER_t:ER_{nt}	-.552	.002*
IRTorque*IR_t:IR_{nt}	.001	.994
ERTorque*ER_t:IR_t	.001	.996
ERTorque*ER_t:ER_{nt}	.135	.484
ERTorque*IR_t:IR_{nt}	-.007	.970
VarusTorque*ER_t:IR_t	-.171	.374
VarusTorque*ER_t:ER_{nt}	-.122	.530
VarusTorque*IR_t:IR_{nt}	-.057	.768

**p<.05*
[a]*ER_t = external rotation strength on throwing side; ER_{nt} = external rotation strength on non-throwing side; IR_t = internal rotation strength on throwing side; IR_{nt} = internal rotation strength on non-throwing side. IRTorque = internal rotation torque; ERTorque = external rotation torque. VarusTorque = elbow varus torque*

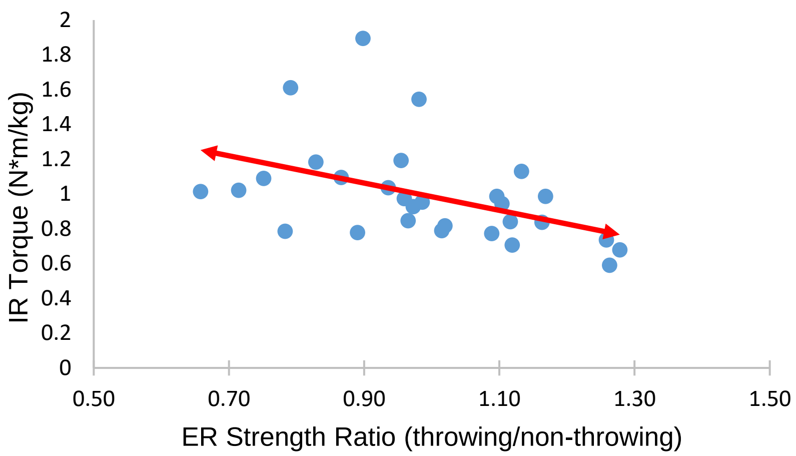

Figure 1: Glenohumeral internal rotation torque vs. external rotation strength ratio. Torques are normalized to body mass. ER_t:ER_{nt} is the strength of the throwing arm divided by the strength of the non-throwing arm.

DISCUSSION: Throwing arm ER weakness and higher throwing arm IR torques during the pitching motion are associated with increased risk of injury (Byram, 2010; Chalmers, 2017; Fleisig, 1995; Tyler, 2014;). Based on the results of this study, pitchers who present with reduced ER strength ratios have a greater likelihood of increased GH IR torque during the pitch. This relationship may be due to reduced stability of the humeral head in the glenoid fossa brought about by either weakness of the GH external rotators or unequalled increases in

strength of the GH internal rotators (Magnusson, 1994). Instability may result in altered pitching kinematics which can decrease mechanical effectiveness and potentially require greater IR torque to produce satisfactory ball velocities.
Previous research has shown that adolescent pitchers with throwing-related pain exhibited significantly less throwing arm ER strength compared to the non-throwing arm (Trakis, 2008). Based on the trend observed in this study, it is plausible that adolescent pitchers with concurrent throwing arm ER weakness and throwing-related pain experience such pain because of greater IR torques placed on the shoulder. However, healthy professional pitchers have demonstrated less ER strength in the throwing arm than the general population (Magnusson, 1994). Therefore, given that some degree of ER weakness is seen in elite pitchers (Magnusson, 1994; Byram, 2010), it is possible that certain amounts of GH strength adaptations may be inevitable while achieving high performance.
The present study has several limitations that must be addressed. The use of only healthy, adolescent pitchers limits the generalizability of these findings. Future investigation into older pitchers and pitchers experiencing pain would provide increased insight into the relationships between strength ratios and pitching mechanics. Additionally, while it is established that increased GH IR torque during the pitch is related to risk of injury, it is also known that high GH IR torques are needed to produce elite ball velocities (Fleisig, 1999). Because the present study did not include ball speed as a performance measure, it is beyond the current scope to correlate GH rotation strength ratios and GH IR torque with pitching performance in this population. Future work should include ball velocity to elucidate the relationships between performance and the observed trends in this study.

CONCLUSION: The results of this study provide initial evidence for a potential mechanism behind throwing-related pain in adolescent pitchers with throwing arm reduced ER strength ratios. Clinicians should focus on strengthening the ER musculature of pitchers as a means of correcting strength imbalances between the glenohumeral rotators.

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