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Article Title: Correlation among Y Balance Test-Lower Quarter Composite Scores, Hip Musculoskeletal Characteristics, and Pitching Kinematics in NCAA Division I Baseball Pitchers

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Correlation among Y Balance Test-Lower Quarter Composite Scores, Hip Musculoskeletal Characteristics, and Pitching Kinematics in NCAA Division I Baseball Pitchers

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Abstract

Context: Numerous studies have reported kinematic data on baseball pitchers using 3D motion analysis, but no studies to date have correlated this data with clinical outcome measures. **Objective:** To examine the relationship among Y Balance Test-Lower Quarter (YBT-LQ) composite scores, musculoskeletal characteristics of the hip and pitching kinematics in NCAA Division I baseball pitchers. **Design:** Cross-sectional. **Setting:** 3D motion analysis laboratory**.** **Participants: 19** healthy male collegiate baseball pitchers. **Main Outcome Measures:** Internal and external hip passive range of motion (PROM); hip abduction strength; YBT-LQ composite scores; kinematic variables of the pitching motion. **Results:** Stride length demonstrated a moderate positive correlation with dominant limb YBT-LQ composite score (r=0.524, p=0.018) and non-dominant limb YBT-LQ composite score (r=0.550, p=0.012), and a weak positive correlation with normalized time to maximal humerus velocity (r=0.458, p=0.043). Stride length had a moderate negative correlation with normalized time to maximal thorax velocity (r= -0.522, p=0.018) and dominant hip TRM (r= -0.660, p=0.002), and had a strong negative correlation with normalized time from SFC to maximal knee flexion (r= -0.722, p<0.001). Dominant limb YBT-LQ composite score had a weak negative correlation with hip abduction strength difference (r= -0.459, p=0.042) and normalized time to maximal thorax velocity (r= -0.468, p=0.037), as well as a moderate negative correlation with dominant hip TRM (r= -0.160, p=0.004). Non-dominant limb YBT-LQ composite score demonstrated a weak negative correlation with normalized time to maximal thorax velocity (r= -0.450, p=0.046) and had a moderate negative correlation with dominant hip TRM (r= -0.668, p=0.001). Hip abduction strength difference demonstrated a weak positive correlation with dominant hip TRM (r=0.482, p=0.032). Dominant hip TRM had a moderate positive correlation with normalized time to maximal thorax velocity (r=0.484, p=0.031). There were no other significant relationships between the remaining variables. **Conclusions:** YBT-LQ is a clinical measure which can be used to correlate with hip musculoskeletal characteristics and pitching kinematics in NCAA Division I pitchers.

Pitching is a series of dynamic movements that require full body coordination and utilization of the entire kinetic chain. The pitching motion consists of 6 phases: windup, stride, arm cocking, arm acceleration, arm deceleration, and follow-through.[1] Pitchers generate energy in the windup, stride, and arm cocking phases, which is transferred to the hand and ball during the arm acceleration phase.[2] Appropriate kinetic chain patterning starts at the proximal hip and trunk, then proceeds distally to the shoulder, arm, elbow and hand.[3] This patterning is necessary for the kinetic chain to function optimally and efficiently transfer energy to distal segments. Inefficient use of activation patterns may alter kinetic chain sequencing and lead to increased stress on the distal segments.[4] Adding further stress to distal structures puts the ulnar collateral ligament (UCL) at risk for injury[28]. Appropriate muscle activation sequencing requires each link of the chain to function optimally. Assessing each component clinically through lower extremity (LE) range of motion (ROM), strength, and neuromuscular control provides insight to potential functional deficits for each pitcher.

Adequate hip total rotational ROM, 50.6° for the non-dominant and 50.1° for the dominant, is needed for the kinetic chain to efficiently transfer energy, making these metrics especially important to assess in the collegiate pitcher.[5] Decreased hip total rotational ROM alters the transfer of energy through the kinetic chain leading to increased torque on the shoulder[6], which is a risk factor for elbow injury.[7] In addition to ROM, hip strength and power likely provide more contribution for performance purposes, including stride length. Division III collegiate pitchers with a greater single leg jump distance in the medial to lateral direction threw significantly harder than those with a shorter jump distance[8]. Jumping in this manner is similar to the pitching motion and may correlate with greater stride length; it has been shown greater stride length directly relates to increased power towards home plate.[9] Several studies have found that increasing stride length increases throwing velocities of various overhead athletes.[10,11] Likewise, Post et al.[12] found high throwing velocities can be achieved without further increasing deleterious forces at the shoulder and elbow by simply increasing stride length. Striding further (a greater percentage of normalized body height) aids energy transfer to the upper extremity (UE).[15] For example, pitchers who overstride are better at using the entire kinetic chain with each throw.[15] As such, striding further towards home plate increases forward trunk velocity and may reduce the arm's overall contribution.[15]

Factors needed to utilize hip ROM and strength which may influence stride length are balance and LE neuromuscular control. The YBT-LQ is used to clinically assess an athlete's LE strength, neuromuscular control, and balance.[16,20] Previous data suggest lower YBT-LQ composite scores may be associated with risk of injury in the LE[20] and in the UE may help to distinguish injured versus healthy baseball players.[13] High school and collegiate pitchers with a confirmed ulnar collateral ligament (UCL) tear had significantly lower YBT-LQ composite scores at the time of injury compared to healthy controls.[13] These same pitchers completed balance training as part of their rehabilitation program and had normalized YBT-LQ scores at time of return to throwing.[14]

Decreasing the arm's relative contribution to the pitching motion is of great interest as increased elbow valgus torque and shoulder external rotation torque are risk factors for elbow injury.[7] Appropriate sequencing of the forces needed to increase stride is critical. Pitchers who overthrew and had a subsequent decrease in velocity demonstrated poor movement sequencing as they pushed off "too soon".[9] A consequence of poor sequencing may be a pitcher opening up early on his glove side shoulder, which could impact injury risk and performance.

Evaluation of the pitcher is multifactorial due to the direct effect each link in the kinetic chain has on adjacent body segments. A pitcher's utilization of strength, balance, and ROM influence multi-segmental sequencing and directly impact performance and injury risk. The purpose of this study was to evaluate the relationship between UE and LE kinematics during the pitching motion, YBT-LQ, hip ROM, and hip strength. The primary hypothesis was that performance on YBT-LQ would correlate with stride length during the pitching motion. Additional hypotheses included the following: 1) increased lead knee extension velocity and greater forward trunk flexion at ball release would positively correlate with YBT-LQ scores, 2) increased hip strength would correlate with increased stride length and higher YBT-LQ scores, and 3) increased hip strength would correlate with increased hip ROM.

Methods

Design

This was a cross sectional study design and the variables were UE and LE kinematics during the pitching motion, YBT-LQ, hip ROM, and hip strength.

Participants

Nineteen healthy male collegiate baseball pitchers (mean age 19.30 ± 1.16) volunteered to participate in the study. Participants reported playing baseball for an average of 14.42 ± 1.64 years and pitching for an average of 9.21 ± 2.90 years. Table 1 summarizes the complete demographic characteristics of the participants. Inclusion criteria for study participation included the following: (1) baseball pitcher between the ages of 18 and 22 years, (2) playing or committed to play collegiate baseball, and (3) healthy and actively participating in full baseball activities at the time of testing. Exclusion criteria were (1) unable to throw with maximal effort at the time of testing, and (2) shoulder or elbow surgery in the 6 months prior to testing. If, after a subject was enrolled, it was discovered that he was experiencing one of the previously listed conditions, then he was removed from data collection. Participants were enrolled in the study by an investigator in the outpatient sports medicine facility once they were confirmed to meet the inclusion and exclusion criteria. Participants provided written informed consent prior to collection of objective measurements. The Institutional Review Board of Texas Health Resources approved the research procedures.

Procedures

All participants completed testing during one session and all data were collected within a 3 week span prior the 2016 NCAA baseball season. Testing procedures consisted of hip passive range of motion (PROM), isometric hip strength, Y-Balance Test Lower Quarter (YBT-LQ) and 3D motion capture analysis of pitching mechanics. Participants completed all clinical measurements in random order prior to completing motion capture analysis. Hip external rotation (ER) and internal rotation (IR) PROM were measured with the subject lying prone while the limb being measured was bent in 90º of knee flexion; one physical therapist stabilized and passively rotated the hip for all participants. All PROM measurements were recorded in one trial using a bubble goniometer. Participants were secured to the table by a mobilization belt fastened proximal to the iliac crest while the physical therapist stabilized the ipsilateral posterior superior iliac spine (PSIS). The participant's hip was passively rotated and measurements were recorded when movement was felt at the PSIS[27]. Hip IR and ER PROM measurements were analyzed individually and combined to calculate a number for hip total rotational motion (TRM) to be used for data analysis.

All isometric strength measurements were recorded with a handheld dynamometer (microFET2, Hoggan Health Industries, West Jordan, UT) using a break test while participants were secured with a mobilization belt in the same fashion as previously described. Hip extension strength was recorded with the participant prone and the ipsilateral knee flexed to 90º with manual stabilization on the PSIS. The dynamometer was placed approximately 5cm proximal to the popliteal fossa and the subject was instructed to lift their heel towards the ceiling while extending at the hip and maintaining 90º of knee flexion. Hip ER strength was measured with the participant in the same position. The dynamometer was placed proximal to the medial malleolus while the physical therapist stood on the contralateral side of the limb being tested. Participants were instructed to rotate their foot toward the midline of the body while maintaining 90º of knee flexion and minimizing hip flexion on the testing side. Hip abduction strength was measured with the participant in sidelying and the hip being tested placed in neutral hip extension, neutral rotation and slight abduction while the knee was fully extended. The dynamometer was placed laterally just distal to the knee joint line while the physical therapist stabilized at the iliac crest. Participants were instructed to lift their limb toward the ceiling. Participants were instructed to exert maximal effort during all strength testing for 3 to 5 seconds and were given approximately 30 seconds of rest between trials. The average of 2 trials was recorded for data analysis. All measurements were recorded in pounds and were normalized to body mass. All isometric strength measurements using the handheld dynamometer were recorded by one physical therapist to increase reliability and decrease the risk of error. Prior to the study, intra-rater reliability was calculated and found to be good for hip abduction (Intraclass Correlation Coefficient (ICC)=.96, 95% CI [.85-.98]), hip extension (ICC=.98, 95% CI [.93-.99]), and hip external rotation (ICC=.87, 95% CI [.59-.97]). Hip strength asymmetry was calculated for each hip strength measure as the absolute difference between the stance and lead limb.

Participants completed the YBT-LQ reaching in the anterior (ANT), posteromedial (PM) and posterolateral (PL) directions bilaterally[20]. The dominant limb was identified as the pitcher's stance limb and non-dominant limb as the stride limb. Participants were instructed on YBT-LQ testing procedures by verbal instruction and demonstration.[19] Participants wore shoes during testing and were given up to 3 practice attempts in each direction prior to data collection. The ANT reach was recorded bilaterally, followed by the PM and PL in the same fashion; the furthest valid reach in each direction was recorded for analysis.[20]

Composite scores were normalized to leg length by adding the values from all 3 directions, dividing by 3 times the participant's leg length, and multiplying this dividend by 100 to give a percentage.[19,20] The leg length was determined using the distance between the most prominent portion of the greater trochanter and the floor while the individual was in a standing position.[13] Inter-rater reliability was determined prior to the initiation of this study using an Intraclass correlation coefficient (ICC). Reliability of the measurements for the anterior ($ICC_{3,1}$ = 0.86; SEM, 3.3 cm), posteromedial ($ICC_{3,1}$ = 0.99; SEM, 1.7 cm), and posterolateral ($ICC_{3,1}$ = 0.95; SEM, 2.7 cm) directions for the testers participating in the study was considered to be acceptable. These are similar values to previously published data on intrarater ($ICC_{3,1}$ = 0.91) and interrater ($ICC_{2,1}$ = 0.99) reliability of composite scores.[19, 20,21]

Participants completed a self-selected warm-up of stretching and baseball specific drills after clinical measurements but prior to 3D motion capture data collection. Kinematic variables used for analysis in the current study included stride length, time to maximal humerus velocity, time to maximal thorax velocity, and time from stride foot contact (SFC) to maximal knee flexion. All kinematic data were analyzed using a 9 camera Qualisys (Göteborg, Sweden) camera system sampling at 200Hz. Each participant then self-selected the amount of throwing to occur prior to marker placement. For marker placement, participants changed into compression style shorts, socks, and shoes. A total of 46 reflective markers were placed on the participant with an additional

4 on the pitching rubber, and 1 on the baseball (reflective tape). Each participant donned a hat with 4 markers affixed at the front right, front left, back left, and back right. Marker placement was as follows; 7th cervical vertebrae (C7) spinous process; bilaterally over the most distal portion of the acromion, biceps, upper triceps, lower triceps, medial and lateral epicondyle of the humerus, lateral forearm (halfway between the ulnar styloid and lateral epicondyle of the humerus), and radial and ulnar styloid processes (applied via wrist bands). The dominant arm wrist band was taped to the wrist to reduce marker displacement during throwing. Additional markers were placed between the 4th and 5th metacarpal-phalange joints on the throwing hand (taped to reduce displacement), and on the non-throwing hand 4cm proximal to the most distal point of the 5th digit projection of the baseball glove. A flexible board was attached to each participant's back containing 4 markers to approximate the disc space between lumbar vertebral levels 2 and 3, the disc space between lumbar vertebrae 5 and sacral vertebrae 1, left kidney and left PSIS. Markers were then placed bilaterally over anterior superior iliac spine (ASIS), lateral thigh (halfway between the greater trochanter and lateral femoral condyle), medial and lateral femoral condyles, lateral calf (halfway between the fibular head and lateral malleolus), lateral malleoli, medial malleoli, heel and 5th metatarsal-phalange joint. Markers over the medial femoral condyles and medial malleoli were removed after the static calibration as they were unnecessary for dynamic biomechanical data collection. Participants were then allowed to throw again for a self-selected period of time. Any markers that fell off were reattached prior to calibration.

Each participant performed a static and dynamic calibration process. The static trial consisted of the participant facing home plate with both heels centered on the front of the pitching rubber, hips width apart. Participants flexed both knees to approximately 30º, flexed shoulders to 90º, and bent elbows to 45º flexion and 45º pronation, holding that position for 1 second. The dynamic calibration utilized the same starting position followed by participants moving their hips in a circular motion like performing a hula hoop for 8 seconds. Markers only used for calibration purposes were removed and participants threw 3-6 fastball trials, 3-6 breaking ball trials, and 3-6 off-speed trials. Trial ranges differed for each participant based on quality of data collection. Participants threw the breaking ball and off-speed pitches of their choice. In the situation that participants threw 2 different pitches in the same category (i.e. slider and curveball, changeup and splitter), they were instructed to throw their preferred pitch. Percent time of the throwing motion was normalized for all participants based on methods previously established where 0% represents SFC and 100% represents ball release.[15]

Statistical Analyses

Pearson product moment correlations were calculated to determine relationships between throwing kinematic data and clinical measures. Statistical significance was set at $p < 0.05$. All analysis was conducted using SPSS Version 24.

Results

Stride length demonstrated a moderate positive correlation with dominant limb YBT-LQ composite score ($r = .524$, $p = .018$) and non-dominant limb YBT-LQ composite score ($r = .550$, $p = .012$), and a weak positive correlation with normalized time to maximal humerus velocity ($r = .458$, $p = .043$). Stride length had a moderate negative correlation with normalized time to maximal thorax velocity ($r = -.522$, $p = .018$) and dominant hip TRM ($r = -.660$, $p = .002$), and had a strong negative correlation with normalized time from SFC to maximal knee flexion ($r = -.722$, $p = <.001$). Dominant limb YBT-LQ composite score had a weak negative correlation with hip abduction strength difference ($r = -.459$, $p = .042$) and normalized time to maximal thorax velocity

($r = -.468$, $p = .037$), as well as a moderate negative correlation with dominant hip TRM ($r = -.160$, $p = .004$). Non-dominant limb YBT-LQ composite score demonstrated a weak negative correlation with normalized time to maximal thorax velocity ($r = -.450$, $p = .046$) and had a moderate negative correlation with dominant hip TRM ($r = -.668$, $p = .001$). Hip abduction strength difference demonstrated a weak positive correlation with dominant hip TRM ($r = .482$, $p = .032$). Dominant hip TRM had a moderate positive correlation with normalized time to maximal thorax velocity ($r = 0.484$, $p = .031$). There were no other significant relationships between the remaining variables.

Discussion

The findings of the current study prove that collegiate baseball players who have better lower extremity balance as measured by the YBT-LQ demonstrate increased stride length during the pitching motion. In addition, the finding of increased stride length was found to have an effect on upper extremity kinematics in regards to timing of humeral and thoracic velocity, and with knee position of the stride foot limb during the pitching motion. These results in combination with those clinical measures of YBT-LQ and hip strength point to the fact that pitching is a full body activity that requires an assessment and treatment approach that is multifaceted and involves the entire kinetic chain. To the authors' knowledge, this is the first known study to correlate YBT-LQ composite scores to a pitcher's stride length during 3D biomechanical pitching analysis. In the current study there was a moderate positive correlation between stride length and YBT-LQ composite score in both the dominant or non-dominant limb. This suggests the YBT-LQ may provide insight in assessing stride length during the pitching motion in the absence of 3D motion capture. As stride length is indicative of how well a pitcher uses the entire kinetic chain, pitchers who overstride use relatively less arm contribution to the entire momentum generated during a throw compared to pitchers who understride, which may reduce stress to the shoulder and elbow.[15] The ability to reduce the load across the elbow during the throwing motion may be important secondary to the high failure loads of the UCL with every pitch.[1,22,23] The YBT-LQ is a less dynamic task than the pitching motion; power and explosiveness are not measured with the YBT-LQ which may explain the moderate and not significant correlation with stride length.

Similarly, stride length influences the ability to transfer forces from the LE to the trunk and UE. In the current study, stride length and time to maximal thorax velocity were negatively correlated, indicating pitchers achieved peak thorax velocity (forward trunk flexion velocity) earlier in the throwing cycle when striding further. Striding further towards home plate decreases the amount of time between SFC and ball release.[24] Decreased time between SFC and ball release increases the time spent in single limb stance of the stance limb.[15] Increasing single limb stance time increases the body's momentum transfer towards home plate;[15] therefore, earlier initiation of forward trunk flexion may facilitate kinetic chain energy transfer towards home plate.

In the UE, stride length was positively correlated with time to maximal humerus velocity. This finding may suggest better overall timing and sequencing during the throwing motion. If a pitcher achieves peak humeral velocity later in the throwing cycle, it is possible potential energy is more efficiently transferred into kinetic energy. Likewise, achieving peak humeral velocity later may lead to greater energy transfer from the arm to ball at release, potentially increasing the pitcher's efficiency. Pitchers who throw with less kinetic chain involvement may need to achieve maximal humerus velocity earlier to compensate for decreased lower extremity contribution. Although the current study found no correlation between stride length and throwing velocity, previous studies have found greater stride length is correlated to increased throwing velocity.[9-11] Pitchers with shorter strides can achieve high throwing velocities by increasing trunk transverse plane momentum after SFC.[25] Pitchers in the current study may have demonstrated compensatory kinetic chain patterns to achieve higher throwing velocities without increasing stride length. The examination of this through kinetic data was outside of the scope of this paper.

On the lead limb, stride length was negatively correlated with time from SFC to maximal knee flexion. This time point signifies a transition to knee extension, when the pitcher transitions from eccentric to concentric loading of the knee. It is possible transitioning to knee extension more quickly leads to improved energy transfer up the kinetic chain. Pitchers who stride further may initiate knee extension of their lead limb earlier than pitchers with a shorter stride. As stride length increases deeper knee and hip flexion angles occur. In an effort to minimize front side collapse (excessive knee flexion on the lead limb), knee extension must be initiated earlier. The ability to transition into earlier knee extension increases the strength and neuromuscular demands placed upon the pitcher's lower extremity.

In the current study, dominant limb YBT-LQ composite scores were negatively correlated with hip abduction strength difference; the greater the hip abduction strength difference the greater the asymmetry. Hip abductors provide hip and knee stability in the frontal and transverse planes while in a closed kinetic chain (CKC) posture. An asymmetry in hip ABD strength can be thought of as a deficit on one side, making the weaker side less stable. The authors believe this decrease in stability may provide rationale for the decreased YBT-LQ scores. Although the current study did not evaluate injury risk, abduction strength asymmetry may be associated with LE injury. Previous literature in the lower extremity demonstrates that patients with a diagnosis of patellofemoral pain syndrome exhibit greater hip abduction strength asymmetry as compared to healthy controls.[26] Movements performed at the limits of ROM, such as the YBT-LQ, require greater muscular demand and may challenge the neuromuscular system to a higher degree. Thus, use of the YBT-LQ may provide a clinical measure of LE performance in overhead athletes.

Greater hip abduction strength asymmetry was also associated with dominant hip TRM, which suggests that pitchers not only had greater mobility on the lower extremity limb of their dominant side, but also imbalances in hip abduction strength. Previous research has shown discrepancies in hip TRM between the dominant and non-dominant limb in professional pitchers, but strength was not evaluated.[5] It has been shown there is some utility biomechanically to specific hip TRMs[5] and therefore this asymmetry could be a natural adaptation. However, imbalances in hip musculoskeletal characteristics could be detrimental during conditioning drills which collegiate pitchers participate in (e.g. weight lifting, running, plyometrics). The authors believe a larger hip abduction strength asymmetry could potentially be a risk factor for injury and may affect a pitcher's ability to generate and transfer force during the throwing motion.

The study had a small sample size of only 19 pitchers limiting the power of the study. Additionally, the findings of the current study are correlational and do not provide any cause and effect relationship. All pitchers in the study were analyzed in a 3 week timespan during their pre-season training, which may have altered their mechanics compared to in-season throwing.

Conclusions

The YBT-LQ may be used as a screening tool to help identify decreased stride length in pitchers which is known to be associated with increased stress to the shoulder and arm[15], suboptimal pitching mechanics, and possible injury risk. Additional research is needed to confirm the YBT-LQ's association with decreased stride length due to the low to moderate correlation found in the current study. The YBT-LQ may be a useful clinical measure to screen for hip ABD strength asymmetries, which are associated with LE injury in other populations; however, the relationship between hip ABD strength asymmetry and injury risk has not been established in the current study's population.

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Table 1: Demographics

Subjects n=19	Mean±SD
Age (years)	19.30±1.16
Height (cm)	187.96±4.99
Weight (kg)	90.44±9.05
Baseball Experience (years)	14.42±1.64
Pitching Experience (years)	9.21±2.90

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Journal of Sport Rehabilitation

Table 2: Pearson correlational coefficients (r-value) for all variables

	Stride Length	Time to Maximal Humerus Velocity	Time to Maximal Thorax Velocity	Time from Foot Strike to Maximal Knee Flexion	Dominant YBT-LQ Composite Score	Non-Dominant YBT-LQ Composite Score	Hip Abduction Strength Difference
Time to Maximal Humerus Velocity	0.458*						
Time to Maximal Thorax Velocity	-0.522*	-0.567*					
Time from Foot Strike to Maximal Knee Flexion	-0.722*	-0.132	0.419				
Dominant YBT-LQ Composite Score	0.524*	0.161	-0.468*	-0.214			
Non-Dominant YBT-LQ Composite Score	0.550*	0.225	-0.450*	-0.249	0.959*		
Hip Abduction Strength Difference	-0.358	-0.289	0.346	0.195	-0.459*	-0.388	
Dominant Hip Total Rotational Motion	-0.660*	-0.259	0.484*	0.439	-0.610*	-0.668*	0.482*

* indicates statistical significance $p<0.05$.