doi:10.4085/1062-6050-0195.24

# Relationship of Abdominal Oblique Strength on Biomechanics in Adolescent Baseball Pitchers

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# Relationship of Abdominal Oblique Strength on Biomechanics in Adolescent Baseball Pitchers


## Abstract

**Context:** The pitching cycle is a highly dynamic task, and the trunk and abdominal obliques are key contributors in efficient kinetic transfer.

**Objective**

To determine the relationship between abdominal oblique strength and pitching biomechanics in adolescent baseball pitchers.

**Design:** Cross-sectional study.

**Setting:** Biomechanics laboratory.

**Patients or Other Participants:** Nineteen healthy right-handed high school male baseball pitchers (age = 17.1 ± 1.1 years, height = 183.7 ± 6.5 cm, mass = 83.1 ± 10.1 kg).

**Main Outcome Measures:** The main outcome was full body biomechanics captured at key points during the pitching cycle. The main variable of interest was abdominal oblique strength (glove arm and throwing arm). Kinematics and kinetics were calculated using Visual 3D motion capture software. Descriptive statistics including means and standard deviations were calculated. Shapiro-Wilk test confirmed the data were normally distributed. Scatterplots determined linear associations, so a 2-tailed Pearson correlation with Fisher option was used to examine associations between obliques strength measurements and biomechanical metrics.

**Results:** Three kinematic measures were identified with $p < 0.05$ and $r > 0.5$ demonstrating strong correlations with abdominal oblique strength. Maximum pelvis rotation velocity was positively correlated with throwing arm oblique strength ($r = 0.52$, $p = 0.02$). Glove arm oblique strength was positively correlated with both maximum pelvis rotation velocity and maximum torso rotation velocity (r = 0.69, p = 0.001, and r = 0.52, p = 0.02, respectively).

**Conclusion:** These data highlight the moderate to strong positive relationship abdominal oblique strength has on both maximal pelvic and torso rotational velocity. Training to improve the strength of the abdominal obliques may increase both maximal pelvic and trunk rotational velocity, while avoiding a significant increase upper extremity joint loading, which is important in optimizing performance and injury prevention.

**Abstract Word Count: 277**

**Body of Manuscript Word Count: 2125**

**Key Words:** Abdominal oblique strength, kinematics, injury prevention, pitching biomechanics.

**Key Points:**

1. Glove arm abdominal oblique strength was positively correlated with maximum pelvic and torso rotation velocity.
2. Throwing arm abdominal oblique strength was positively correlated with maximum pelvic rotation velocity.

In baseball, the pitching cycle is a highly dynamic task that involves coordinated linear and rotational movement and kinetic energy transfer from the lower extremities through the pelvis and trunk, and eventually to the arm, forearm, and hand. [1] Ultimately, this bottom-up kinematic sequence, known as the kinetic chain, allows a pitcher to throw at high velocities; however, it also creates a substantial amount of force on the upper extremities, which could lead to injury[1]. While substantial research has focused on upper extremity kinetics and kinematics, much less research has focused on the trunk, a key contributor in kinetic energy transfer.

During the pitching cycle core abdominal musculature (rectus and transverse abdominis, and internal and external obliques) transmit force to the upper extremities and abdominal oblique injuries represent a significant reason players miss time in Major League Baseball. [2,3] From 1991 – 2010 in Major League Baseball the majority (78%) of the abdominal muscle strains occurred contralateral to the pitchers throwing arm.[3] The abdominal obliques, namely the external and internal obliques, play an integral role in both trunk lateral flexion, rotation, and trunk stabilization during dynamic movements.[3] During trunk axial rotation, the external oblique acts contralateral and the internal oblique acts ipsilateral in tandem to affectively rotate the trunk.[4] Electromyography data demonstrates that the left external oblique (glove arm) in right-handed throwers reaches maximal activity prior to the right external oblique (throwing arm), which functions to provide a muscular stretching effect known colloquially by pitching coaches as "hip-to-shoulder separation."[5] This effect acts to store elastic energy that can be dissipated later in the pitching cycle.[5,6] During a pitch, it has been reported that over 50% of the kinetic energy transfer to the distal upper extremities is mediated through the legs and the trunk.[7] Improper trunk movement stifles efficient energy transfer, which leads to increased upper extremity joint loading.[8] Oyama et al. investigated the role of trunk lean toward the glove side at maximal external rotation and ball release in the coronal plane, termed contralateral trunk tilt, and found that although increases in contralateral trunk tilt lead to greater ball velocity, they also increase upper extremity joint loading.[8]

Prior research has also shown maximal trunk angular velocity to be predictive of ball velocity and elbow varus moment.[9, 10] In collegiate athletes, Cohen and colleagues found maximum trunk rotation velocity was positively associated with ball velocity and elbow varus moment, demonstrating that increases in trunk rotation velocity may increase upper extremity joint loading. [10] Thus, it stands to reason that increased abdominal oblique strength may lead to greater trunk rotational velocity, upper extremity joint loading, and ultimately ball velocity.

The goal of this study was to examine the relationship between abdominal oblique strength and pitching biomechanics in adolescent baseball pitchers. Understanding the relationship between abdominal oblique strength and upper extremity joint loading is important in injury mitigation, optimizing performance, and may help elucidate correlations between trunk biomechanics and downstream shoulder and elbow forces. Having a more detailed understanding of trunk biomechanics and its association with various phases of the pitching cycle (i.e., foot contact, maximum external rotation, and ball release) will allow for a more comprehensive biomechanical picture. Potential bottlenecks in energy transfer can be identified by shifting the focus to earlier in the pitching kinetic chain.[10] The researchers hypothesized that correlations exist between abdominal oblique strength, maximal trunk rotation velocity, and ball velocity.

**Methods:**

Nineteen right-handed high school male baseball pitchers (age = 17.1 ± 1.1 years, height = 183.7 ± 6.5 cm, mass = 83.1 ± 10.1 kg) from a local competitive baseball program volunteered to participate in the study. Each participant met the following eligibility criteria, screened by the study team: between 14 and 19 years old, currently arm pain-free with no prior history of throwing arm surgery and had at least two years of competitive pitching experience. Subjects were excluded if they were outside the age range, had current arm pain, or any prior throwing arm surgical history. With all pitchers being right-handed, the throwing arm was defined as the right arm and glove arm as the left arm. Subjects underwent one data collection session, which included a clinical and biomechanical assessment. The study was approved by the local institutional review board. Prior to participation, all subjects and their guardians provided written assent and consent, respectively.

All participants performed a 20-minute dynamic stretching and pitching drill warmup described previously.[11] Following the warm-up, abdominal oblique strength was assessed via unilateral isometric contractions by a licensed physical therapist using a hand-held dynamometer. Each pitcher's abdominal oblique strength was measured in a random order, determined via a coin-flip, between the right and left side. A MicroFET2 dynamometer (Hoggan Health Industries) recorded isometric strength measurements to the tenths using established standardized test positions for measuring abdominal obliques. The pitcher was placed supine on an incline bench set at 30 degrees of trunk flexion.[12] The hand-held dynamometer was placed at the musculotendinous junction of their pectoral muscle and each subject was asked to lift their ipsilateral scapula off the bench (Figure 1).[13] Make tests rather than break tests were used due to the former's higher reliability.[14] Three trials of a 5-second maximal voluntary isometric contraction were performed for each strength measurement. The mean value of the three trials was used for data analysis. Intra-rater reliability of strength measures was excellent, with intraclass correlation coefficient (ICC) values ranging from 0.963 (95% confidence interval: 0.920 to 0.985) to 0.973 (95% confidence interval: 0.941 to 0.989) for throwing arm and glove arm abdominal strength measures, respectively. ICC estimates and their 95% confident intervals were calculated with SPSS (version 26; IBM Corp) using a two-way mixed-effects model with absolute agreement.

**Biomechanical Analysis:**

Forty-seven markers were placed on the subjects and 8 Raptor-E cameras were placed around the mound to capture full body biomechanics during the pitching cycle. Following the dynamic warm-up and strength assessment, players performed their typical throwing warm up to prepare to pitch. To start the motion assessment, each subject performed a static trial, followed by pitching trials. Each subject threw 20 to 25 pitches, cycling through pitches in their normal bullpen routine, to a catcher at a standard 60 feet 6 inches, in which velocity, pitch type, and pitch location were noted for each pitch. Kinematics and kinetics of each subject's six best fastballs (based on speed and location) were calculated and averaged using Visual 3D motion capture software (C-Motion, Inc). Pelvic rotation angle, torso rotation angle, trunk lateral flexion angle, body separation angle, pelvis rotation velocity, and torso rotation velocity were measured at stride foot contact (FC), throwing arm shoulder maximum external rotation angle (MER), and ball release (BR) (Figure 2). Two kinetic measurements were analyzed, including peak elbow varus torque and peak shoulder internal rotation torque. Torque was normalized by height (m) and body weight (N). These measures were chosen due to their strong association with injury prevalence in pitchers. [15]

Descriptive statistics including means and standard deviations were calculated for all metrics. The Shapiro-Wilk test confirmed that the data were normally distributed. Scatterplots determined the associations were linear, so 2-tailed Pearson correlation with the Fisher option were used to examine associations between obliques strength measurements and biomechanical metrics. The correlation coefficient (r), confidence intervals and p-value were generated. Correlations were assessed as weak ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.5$), or strong ($r > 0.5$).[16] The p-value was set at .05. SPSS (version 26; IBM Corp) was used to analyze the data.

**Results**

The average fastball of the 19 subjects was 36.8 ± 2.2 m/s (82.3 ± 4.9 mph). The kinematics at key points during the pitching cycle are presented in Table 1. Pitching biomechanics data including timing are presented in Table 2. Three kinematic measures were identified with $p < 0.05$ and $r > 0.5$, demonstrating strong correlations with abdominal oblique strength. Maximum pelvis rotation velocity was positively correlated with throwing arm oblique strength ($r = 0.52$, $p = 0.02$, Table 3). Glove arm oblique strength was positively correlated with both maximum pelvis rotation velocity ($r = 0.69$, $p < 0.001$) and maximum torso rotation velocity ($r = 0.52$, $p = 0.02$) (Table 4). Scatterplots demonstrating the correlations between abdominal oblique strength and pelvic and torso rotation velocity are illustrated in Figure 3. No correlations between abdominal oblique strength and peak elbow varus torque or peak shoulder rotation internal rotation torque were noted.

**Discussion**

Glove arm abdominal oblique strength was shown to be strongly correlated with both maximum pelvis and trunk rotational velocity. Moreover, the present study found that in adolescent pitcher's glove arm oblique strength was not associated with an increase in elbow varus moment. This result is consistent with the initial hypothesis, as the internal abdominal oblique is highly activated with trunk rotation toward the ipsilateral side.[17] Throughout the pitching cycle, the relative EMG activation of the glove arm oblique musculature is greater than that of the throwing arm, with the greatest difference occurring at maximal external rotation. [18] However, these studies did not separate the relative activation patterns of the internal and external obliques. According to Hirashima and colleagues, the throwing side external oblique rotation activates just prior to the flat foot during the pitching cycle, which corresponds to our finding that glove side abdominal oblique strength was strongly associated with maximum pelvic rotation velocity. [5] During this time, the glove leg acts as a pivot point for the pelvis to rotate around, with significant ground reaction forces posteriorly and vertically.[19] Thus, explaining how greater oblique strength helps rotate the pelvis at greater velocity to the ipsilateral side.

Additionally, throwing arm abdominal oblique strength was associated with maximum pelvic rotational velocity, but not trunk rotational velocity. This premise may be due to greater rotation at the pelvis compared to the trunk for the throwing side during wind up. [20] Activation of the glove side external abdominal oblique before the flat foot phase could allow for the trunk to remain closed to allow for pelvis to rotate toward the target. [5] Increasing external oblique strength may allow for greater coiling during the wind-up phase during pitching, which may increase rotational velocity.

Interestingly, we found no correlations between either side oblique strength with ball velocity or elbow varus torque at any of the three key points of the pitching cycle. Earlier studies demonstrated trunk rotation velocity to be correlated with both ball velocity and elbow varus moment in colligate pitchers.[10] The present study included high-school aged pitchers and instead found stronger correlations between throwing arm oblique strength and maximal pelvic rotational velocity when compared to maximal trunk rotational velocity. Perhaps this premise could be explained by differences in timings throughout the pitching cycle or the pitchers age and level of experience. Numerous studies have demonstrated increased injury risk and increased shoulder and elbow varus forces with early trunk rotation. [21,22] Likewise, prior research has shown that those who achieve maximal trunk rotation later in the pitching cycle generate less internal shoulder and elbow torque.[23,24] This notion lends credence to the importance of relative firing of pelvic and trunk musculature during the pitching cycle. Our study found the maximal pelvic rotational velocity was at 26.7% during the pitching cycle, which was defined as foot contact to maximal internal rotation. Oyama (2014) showed peak pelvic velocity at 34.5% in high school pitchers did not have worse posterior shoulder impingement or elbow varus forces compared to the slower peak pelvic velocity (57.8%).[8] It should be noted Oyama (2014) study defined the pitching cycle from foot contact to ball release. [8] This difference in relative timing then could explain why abdominal oblique strength measurements in the present study were not correlated with increased shoulder and elbow forces.

Many research articles have shown increased contralateral trunk lean to have deleterious forces at the shoulder and elbow velocity. [8,17,25,26] According to Oyama (2017), youth pitchers that had a more dominate glove side oblique strength compared to the throwing side (1.1 ratio) had a greater contralateral lean.[25] Greater contralateral trunk lean is associated with increased elbow varus and internal glenohumeral moments and increased ball velocity. [8,17,26] This study included adolescent pitchers and had a ratio between glove arm and throwing oblique strength was 1.03, which could explain why no significant correlations between abdominal oblique strength and upper extremity joint loading, or ball velocity were observed. Greater than 30 degrees of contralateral trunk lean has been correlated with a 10 percent increase in forces at the shoulder and elbow. [25] The current study had an average contralateral trunk lean at MER of 26.1 ± 7.7 degrees. Future research should investigate the unique interplay between abdominal oblique strength, biomechanics of the pelvis and trunk, and upper extremity joint loading.

Limitations of this study include the following. The present study only showed correlations between abdominal oblique strength and pitching biomechanics at three critical points in the pitching kinetic chain. Although increases in abdominal oblique strength were associated with increases in trunk and pelvic rotational velocity, the researchers cannot necessarily state that stronger abdominal obliques lead to greater trunk rotational velocity. Likewise, internal and external abdominal oblique strength were not differentiated in the present study. While our study identified significant correlations, it is important to acknowledge wide confidence intervals. The wide confidence intervals suggest that while there is a relationship between the variables, the exact strength and direction of these relationships may not be as stable as the point estimates suggest. The findings should be interpreted with caution, as the true correlations could be substantially different from the reported values. Further investigations should determine the exact individual contribution abdominal oblique strength has to pelvis and trunk rotation velocity. Additionally, the abdominal obliques perform a variety of biomechanical roles and are not the sole determinate in axial trunk and pelvic rotation. The obliques act alongside the rectus abdominis and lumbar multifidus during rotation; therefore, contributing this data solely to the abdominal oblique strength is not entirely correct. Further, this study included a small group of high school aged pitchers and thus, may not be generalizable to the professional or youth level.

## Conclusion

These data highlight the relationship between glove arm and throwing arm abdominal oblique strength and pelvic and torso rotational velocity in adolescent pitchers as well as the effects timing of the trunk and pelvic musculature has on shoulder and elbow forces. While this study found no correlations between abdominal oblique strength and upper extremity joint loading, efficient energy transfer from the lower extremity through the trunk and to the distal segments of the upper extremity is vital to pitching kinetic chain. Furthermore, the data collected in this study was from high school pitchers whose ability to transfer forces up the kinetic chain is likely different than their skeletally mature counterparts.  More research is needed to elucidate the individual contribution truck musculature has on pitching biomechanics and joint loading. Training to improve the strength of the abdominal obliques may increase both maximum pelvic and trunk rotational velocity, which is not only important in optimizing performance, but also in injury prevention.

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**Legends to figures**

**Table 1. Kinematics at key points in the pitching cycle; Foot Contact (FC), Maximal External Rotation (MER), and Ball Release (BR).**

*A negative metric indicates the segment was rotated in a counterclockwise direction and a positive metric indicated the segment was rotated in the closed position in a right-handed pitcher.

**Table 2. Kinematics and Kinetics of Adolescent Pitchers (Mean and SD).**

**Table 3. Correlations between Throwing Arm Abdominal Oblique Strength and Pitching Biomechanics.**

* Indicates a correlation ($P < 0.5$).

**Table 4. Correlations between Glove Arm Abdominals Oblique Strength and Pitching Biomechanics.**

* Indicates a correlation ($P < 0.5$).

**Figure 1** Pictures depicting the testing position and dynamometer placement for the oblique strength testing. The pitcher was placed supine on an incline bench set at 30 degrees of trunk flexion. [12] The hand-held dynamometer was placed at the musculotendinous junction of their pectoral muscle and each subject was asked to lift their ipsilateral scapula off the bench. [13]

**Figure 2.** Three critical points in the pitching cycle. From left to right: stride foot contact (FC), throwing arm shoulder maximum external rotation angle (MER), and ball release (BR).

**Figure 3.** Scatterplots of significant correlations. A) Throwing arm oblique strength and maximal pelvic rotation velocity. B) Glove arm oblique strength and maximal torso rotation velocity. C) Glove arm oblique strength and maximal pelvis rotation velocity.

Figure 1

Figure 2

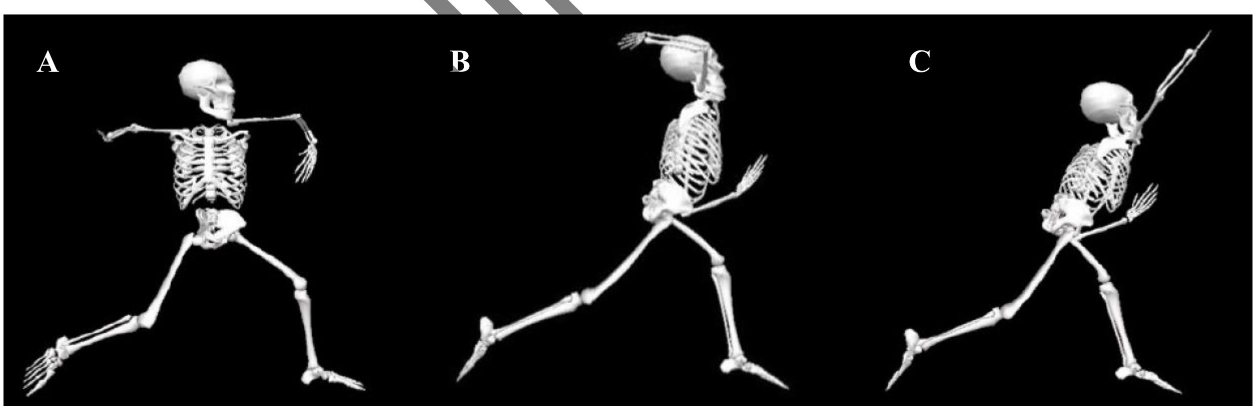
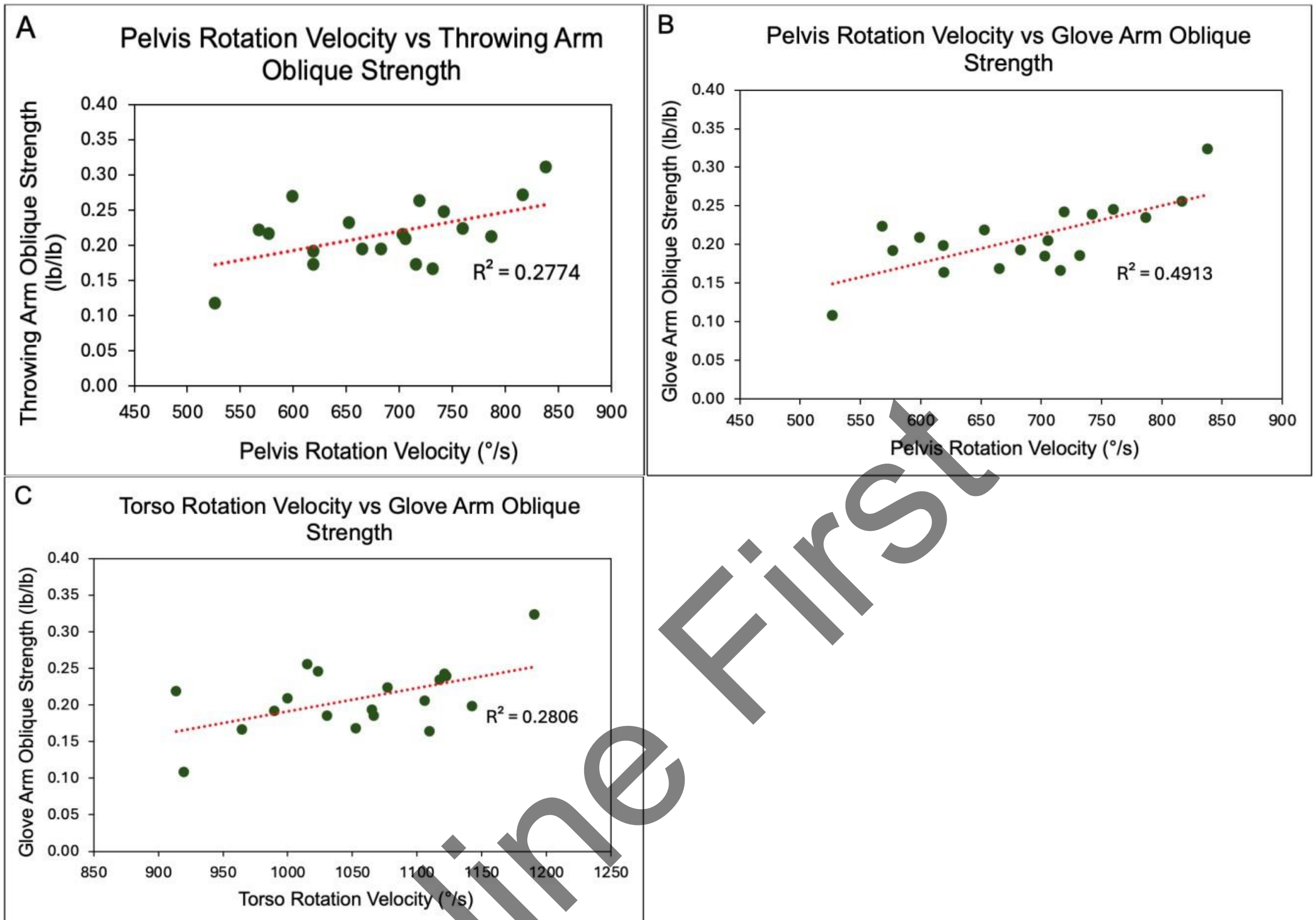


**Figure 3**



A
Pelvis Rotation Velocity vs Throwing Arm Oblique Strength
Throwing Arm Oblique Strength (lb/lb)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
450 500 550 600 650 700 750 800 850 900
Pelvis Rotation Velocity (°/s)
R² = 0.2774
B
Pelvis Rotation Velocity vs Glove Arm Oblique Strength
Glove Arm Oblique Strength (lb/lb)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
450 500 550 600 650 700 750 800 850 900
Pelvis Rotation Velocity (°/s)
R² = 0.4913
C
Torso Rotation Velocity vs Glove Arm Oblique Strength
Glove Arm Oblique Strength (lb/lb)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
850 900 950 1000 1050 1100 1150 1200 1250
Torso Rotation Velocity (°/s)
R² = 0.2806

**Table 1**

Kinematics of at key points in the pitching cycle; Foot Contact (FC), Maximal External Rotation (MER) and Ball Release (BR).

| Kinematics at Key Point | FC | | MER | | BR | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Pelvic Rotation Angle (°) | -62.9 | 9.5 | 7.9 | 5.0 | 12.7 | 4.8 |
| Torso Rotation Angle (°) | -96.8 | 9.1 | 5.5 | 6.4 | 15.5 | 8.6 |
| Body Separation Angle (°) | 33.5 | 6.3 | 4.8 | 5.8 | -1.0 | 7.6 |
| Trunk Lateral Flexion Angle (°) | 1.2 | 9.1 | 26.1 | 7.7 | 29.3 | 7.3 |

**Table 2**

Kinematics and Kinetics Mean and SD

| Kinematics | Mean | SD |
|---|---|---|
| Maximum Body Separation Angle (°) | 35.4 | 5.8 |
| Timing of Max BSA (%PC) | 7.0 | 8.4 |
| Max Pelvis Rotation Velocity (°/s) | 685.9 | 86.0 |
| Max Torso Rotation Velocity (°/s) | 1054.4 | 75.4 |
| Torso Flexion Velocity (°/s) | 347.7 | 46.9 |
| Timing of Max Pelvis Rotation Velocity (%PC) | 26.7 | 8.7 |
| Timing of Max Torso Rotation Velocity (%PC) | 40.4 | 5.1 |
| Timing of Max Torso Flexion Velocity (%PC) | 72.2 | 4.8 |
| **Kinetics** | | |
| | Mean | SD |
| Normalized Elbow Varus Torque | 5.0 | 0.8 |
| Normalized Shoulder Internal Rotation Torque | 4.8 | 0.8 |

**Table 3**

Correlations between Throwing Arm Abdominal Oblique strength and Pitching Biomechanics.

| Variable | r value | Lower 95% CI | Upper 95% CI | p value |
|---|---|---|---|---|
| Pitch Speed | -0.13 | -0.55 | 0.34 | 0.580 |
| Kinematics at FC | | | | |
| Pelvic Rotation Angle | -0.24 | -0.62 | 0.24 | 0.320 |
| Torso Rotation Angle | -0.01 | -0.46 | 0.44 | 0.960 |
| Body Separation Angle | -0.27 | -0.65 | 0.21 | 0.250 |
| Trunk Lateral Flexion Angle | 0.24 | -0.24 | 0.63 | 0.310 |
| Kinematics at MER | | | | |
| Pelvic Rotation Angle | -0.16 | -0.57 | 0.32 | 0.500 |
| Torso Rotation Angle | 0.21 | -0.27 | 0.61 | 0.390 |
| Body Separation Angle | -0.27 | -0.64 | 0.21 | 0.260 |
| Trunk Lateral Flexion Angle | -0.03 | -0.48 | 0.43 | 0.900 |
| Kinematics at BR | | | | |
| Pelvic Rotation Angle | 0.02 | -0.44 | 0.47 | 0.940 |
| Torso Rotation Angle | 0.29 | -0.19 | 0.66 | 0.230 |
| Body Separation Angle | -0.3 | -0.66 | 0.18 | 0.210 |
| Trunk Lateral Flexion Angle | -0.06 | -0.50 | 0.40 | 0.800 |
| Maximum Kinematics | | | | |
| Body Separation Angle (°) | -0.29 | -0.66 | 0.19 | 0.210 |
| Pelvis Rotation Velocity | 0.52 | 0.08 | 0.79 | 0.020* |
| Torso Rotation Velocity | 0.37 | -0.10 | 0.71 | 0.110 |
| Torso Flexion Velocity | 0.05 | -0.42 | 0.49 | 0.850 |
| Timing of Body Separation Angle | 0.03 | -0.43 | 0.48 | 0.900 |
| Timing of Pelvis Rotation Velocity | 0.25 | -0.23 | 0.63 | 0.290 |
| Timing of Torso Rotation Velocity | -0.05 | -0.49 | 0.41 | 0.830 |
| Timing of Torso Flexion Velocity | -0.02 | -0.47 | 0.44 | 0.950 |
| Kinetics | | | | |
| Elbow Varus Torque | 0.18 | -0.29 | 0.59 | 0.440 |
| Shoulder Internal Rotation Torque | 0.19 | -0.29 | 0.59 | 0.430 |

**Table 4**

Correlations between Glove Arm Abdominal Oblique Strength and Pitching Biomechanics.

| Variable | r value | Lower 95% CI | Upper 95% CI | p value |
|---|---|---|---|---|
| Pitch Speed | 0.07 | -0.39 | 0.51 | 0.760 |
| Kinematics at FC | | | | |
| Pelvic Rotation Angle | -0.26 | -0.64 | 0.22 | 0.270 |
| Torso Rotation Angle | -0.09 | -0.53 | 0.38 | 0.700 |
| Body Separation Angle | -0.19 | -0.60 | 0.28 | 0.420 |
| Trunk Lateral Flexion Angle | 0.05 | -0.41 | 0.49 | 0.840 |
| Kinematics at MER | | | | |
| Pelvic Rotation Angle | -0.16 | -0.58 | 0.31 | 0.490 |
| Torso Rotation Angle | 0.22 | -0.26 | 0.61 | 0.360 |
| Body Separation Angle | -0.33 | -0.68 | 0.14 | 0.160 |
| Trunk Lateral Flexion Angle | -0.08 | -0.51 | 0.39 | 0.750 |
| Kinematics at BR | | | | |
| Pelvic Rotation Angle | -0.07 | -0.51 | 0.40 | 0.780 |
| Torso Rotation Angle | 0.29 | -0.19 | 0.66 | 0.220 |
| Body Separation Angle | -0.36 | -0.70 | 0.11 | 0.120 |
| Trunk Lateral Flexion Angle | -0.09 | -0.52 | 0.38 | 0.700 |
| Maximum Kinematics | | | | |
| Body Separation Angle (°) | -0.2 | -0.60 | 0.28 | 0.390 |
| Pelvis Rotation Velocity | 0.69 | 0.34 | 0.87 | 0.000* |
| Torso Rotation Velocity | 0.52 | 0.08 | 0.79 | 0.020* |
| Torso Flexion Velocity | -0.15 | -0.57 | 0.32 | 0.520 |
| Timing of Body Separation Angle | 0.02 | -0.44 | 0.47 | 0.940 |
| Timing of Pelvis Rotation Velocity | 0.25 | -0.23 | 0.63 | 0.300 |
| Timing of Torso Rotation Velocity | -0.12 | -0.55 | 0.35 | 0.610 |
| Timing of Torso Flexion Velocity | -0.07 | -0.51 | 0.39 | 0.760 |
| Kinetics | | | | |
| Elbow Varus Torque | 0.24 | -0.24 | 0.63 | 0.310 |
| Shoulder Internal Rotation Torque | 0.24 | -0.24 | 0.63 | 0.310 |