

Relationship of Abdominal Oblique Strength on Biomechanics in Adolescent Baseball Pitchers

Henry T. Eilen, BA*; Wesley Kokott, PT, DPT†; Cody Dziuk, BS*;
Janelle A. Cross, PhD*

*Department of Orthopaedic Surgery, Medical College of Wisconsin, Milwaukee; †Freedom Physical Therapy, Mukwonago, WI

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 Measure(s): 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 Visual3D motion capture software. Descriptive statistics, including means and SDs, were calculated. A Shapiro-Wilk test confirmed that the data were normally distributed. Scatter plots determined linear associations, so a 2-tailed Pearson correlation with Fisher option was used

to examine associations between oblique strength measurements and biomechanical metrics.

Results: Three kinematic measures were identified, with $P < .05$ and $r > 0.5$ demonstrating strong correlations with abdominal oblique strength. Maximum pelvis rotation velocity was positively correlated with throwing arm oblique strength ($r = 0.52$, $P = .02$). Glove arm oblique strength was positively correlated with both maximum pelvis rotation velocity and maximum torso rotation velocity ($r = 0.69$ and $P = .001$ and $r = 0.52$ and $P = .02$, respectively).

Conclusion: These data highlight the moderate to strong positive relationship that 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 in upper extremity joint loading, which is important in optimizing performance and injury prevention.

Key Words: abdominal oblique strength, kinematics, injury prevention, pitching biomechanics

Key Points

- Glove arm abdominal oblique strength was positively correlated with maximum pelvic and torso rotation velocity.
- 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 to 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 Although 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 to 2010 in Major League Baseball, the majority (78%) of abdominal muscle strains occurred contralateral to the pitcher's 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 effectively rotate the trunk.⁴ Electromyography data demonstrate that the left external oblique (glove arm) in right-handed throwers reaches maximal activity before 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

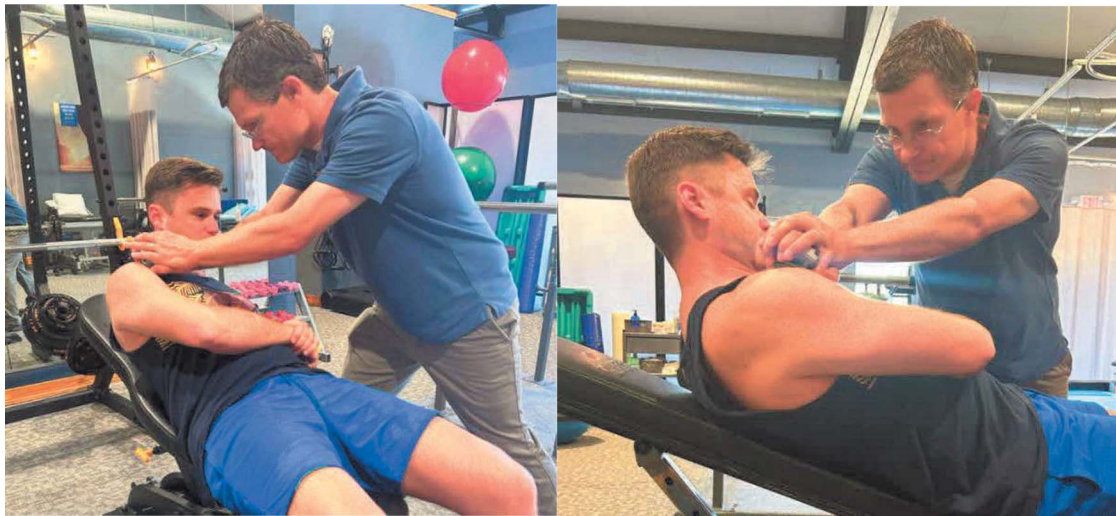


Figure 1. Pictures depicting the testing position and dynamometer placement for oblique strength testing. The pitcher was placed supine on an incline bench set at 30° of trunk flexion.¹² The handheld dynamometer was placed at the musculotendinous junction of their pectoral muscle, and each participant was asked to lift their ipsilateral scapula off the bench.¹³

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 that 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 (ie, 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 2 years of competitive pitching experience. Participants were excluded if they were outside the age range,

had current arm pain, or had any prior throwing arm surgical history. With all pitchers being right-handed, the throwing arm was defined as the right arm and the glove arm as the left arm. Participants underwent 1 data collection session, which included a clinical and biomechanical assessment. The study was approved by the local institutional review board. Before participation, all participants and their guardians provided written assent and consent, respectively.

All participants performed a 20-minute dynamic stretching and pitching drill warm-up described previously.¹¹ Following the warm-up, abdominal oblique strength was assessed via unilateral isometric contractions by a licensed physical therapist using a handheld 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° of trunk flexion.¹² The handheld dynamometer was placed at the musculotendinous junction of their pectoral muscle, and each participant 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 3 trials was used for data analysis.

Intrarater reliability of strength measures was excellent, with intraclass correlation coefficient values ranging from 0.963 (95% CI = 0.920 to 0.985) to 0.973 (95% CI = 0.941 to 0.989) for throwing arm and glove arm abdominal strength measures, respectively. Intraclass correlation coefficient estimates and their 95% CIs were calculated with SPSS (version 26; IBM Corp) using a 2-way mixed-effects model with absolute agreement.

Biomechanical Analysis

Forty-seven markers were placed on the participants, and 8 Raptor-E cameras were placed around the mound to capture full body biomechanics during the pitching cycle.

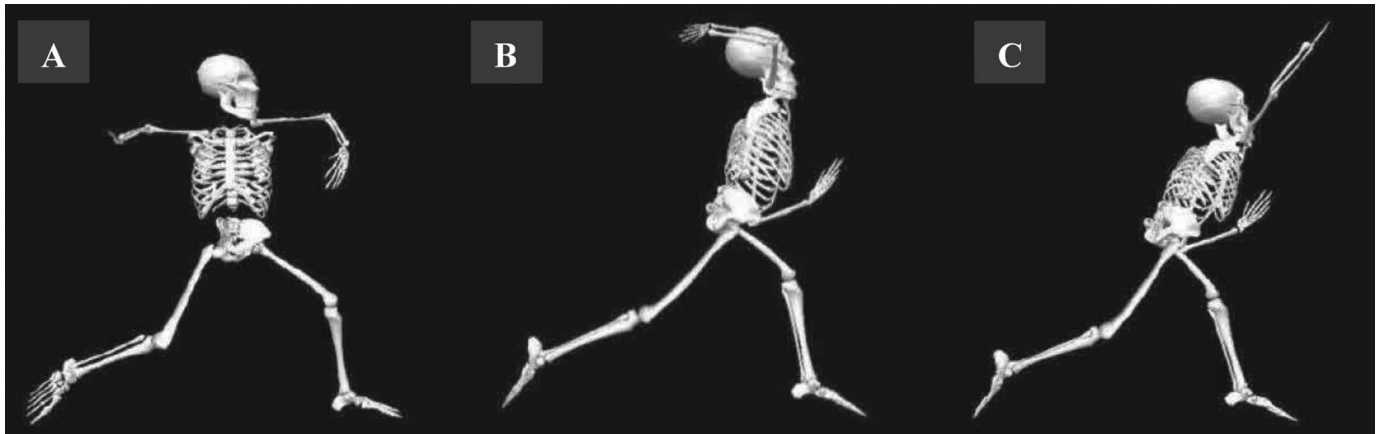


Figure 2. Three critical points in the pitching cycle. From left to right: stride foot contact, throwing arm shoulder maximum external rotation angle, and ball release.

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 participant performed a static trial, followed by pitching trials. Each participant 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 participant's 6 best fastballs (based on speed and location) were calculated and averaged using Visual3D 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, throwing arm shoulder maximum external rotation angle, and ball release (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 SDs, were calculated for all metrics. A Shapiro-Wilk test confirmed that the data were normally distributed. Scatter plots determined that the associations were linear, so 2-tailed Pearson correlations with the Fisher option were used to examine associations between oblique strength measurements and biomechanical metrics. Correlation coefficients (r), CIs, and P values 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 participants 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 $P < .05$ and $r > 0.5$, demonstrating strong correlations with abdominal oblique strength. Maximum pelvis rotation velocity was positively correlated with throwing arm oblique strength ($r = 0.52$, $P = .02$; Table 3). Glove arm oblique strength was positively correlated with both maximum pelvis rotation velocity ($r = 0.69$, $P < .001$) and maximum torso rotation velocity ($r = 0.52$, $P = .02$; Table 4). Scatter plots 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 adolescents pitchers, 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 electromyography activation of the glove arm oblique musculature is greater than that of the throwing arm, with the greatest difference occurring at maximal

Table 1. Kinematics at Key Points in the Pitching Cycle^a

	Foot Contact		Maximal External Rotation		Ball Release	
	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

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

Table 2. Kinematics and Kinetics of Adolescent Pitchers

Kinematics	Mean	SD
Maximum BSA, °	35.4	5.8
Timing of max BSA, %PC	7.0	8.4
Maximum pelvis rotation velocity, °/s	685.9	86.0
Maximum torso rotation velocity, °/s	1054.4	75.4
Torso flexion velocity, °/s	347.7	46.9
Timing of maximum pelvis rotation velocity, %PC	26.7	8.7
Timing of maximum torso rotation velocity, %PC	40.4	5.1
Timing of maximum 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

Abbreviations: BSA, body separation angle; PC, pitching cycle.

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 before 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, thus explaining how greater oblique strength helps rotate the pelvis at greater velocity to the ipsilateral side.¹⁹ 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 than at 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, allowing the 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 and ball velocity or elbow varus torque at any of the 3 key points of the pitching cycle. Earlier studies demonstrated that trunk rotation velocity was correlated with both ball velocity and elbow varus moment in collegiate 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 than maximal trunk rotational velocity. Perhaps this premise could be explained by differences in timings throughout the pitching cycle or the pitcher's 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 that the maximal pelvic rotational velocity was at 26.7% during the pitching cycle, which was defined as foot contact to maximal internal rotation. Oyama et al showed that peak pelvic velocity at 34.5% in high school pitchers did not have worse posterior shoulder impingement or elbow

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, m/s	−0.13	−0.55	0.34	.580
Kinematics at FC				
Pelvic rotation angle, °	−0.24	−0.62	0.24	.320
Torso rotation angle, °	−0.01	−0.46	0.44	.960
Body separation angle, °	−0.27	−0.65	0.21	.250
Trunk lateral flexion angle, °	0.24	−0.24	0.63	.310
Kinematics at MER				
Pelvic rotation angle, °	−0.16	−0.57	0.32	.500
Torso rotation angle, °	0.21	−0.27	0.61	.390
Body separation angle, °	−0.27	−0.64	0.21	.260
Trunk lateral flexion angle, °	−0.03	−0.48	0.43	.900
Kinematics at BR				
Pelvic rotation angle, °	0.02	−0.44	0.47	.940
Torso rotation angle, °	0.29	−0.19	0.66	.230
Body separation angle, °	−0.3	−0.66	0.18	.210
Trunk lateral flexion angle, °	−0.06	−0.50	0.40	.800
Maximum kinematics				
Body separation angle, °	−0.29	−0.66	0.19	.210
Pelvis rotation velocity, °/s	0.52	0.08	0.79	.020 ^a
Torso rotation velocity, °/s	0.37	−0.10	0.71	.110
Torso flexion velocity, °/s	0.05	−0.42	0.49	.850
Timing of body separation angle	0.03	−0.43	0.48	.900
Timing of pelvis rotation velocity	0.25	−0.23	0.63	.290
Timing of torso rotation velocity	−0.05	−0.49	0.41	.830
Timing of torso flexion velocity	−0.02	−0.47	0.44	.950
Kinetics				
Elbow varus torque	0.18	−0.29	0.59	.440
Shoulder internal rotation torque	0.19	−0.29	0.59	.430

Abbreviations: BR, ball release; FC, foot contact; MER, maximum external rotation angle.

^a Indicates a correlation ($P < .5$).

Table 4. Correlations Between Glove Arm Abdominal Oblique Strength and Pitching Biomechanics

Variable	<i>r</i> Value	Lower 95% CI	Upper 95% CI	<i>P</i> Value
Pitch speed, m/s	0.07	−0.39	0.51	.760
Kinematics at FC				
Pelvic rotation angle, °	−0.26	−0.64	0.22	.270
Torso rotation angle, °	−0.09	−0.53	0.38	.700
Body separation angle, °	−0.19	−0.60	0.28	.420
Trunk lateral flexion angle, °	0.05	−0.41	0.49	.840
Kinematics at MER				
Pelvic rotation angle, °	−0.16	−0.58	0.31	.490
Torso rotation angle, °	0.22	−0.26	0.61	.360
Body separation angle, °	−0.33	−0.68	0.14	.160
Trunk lateral flexion angle, °	−0.08	−0.51	0.39	.750
Kinematics at BR				
Pelvic rotation angle, °	−0.07	−0.51	0.40	.780
Torso rotation angle, °	0.29	−0.19	0.66	.220
Body separation angle, °	−0.36	−0.70	0.11	.120
Trunk lateral flexion angle, °	−0.09	−0.52	0.38	.700
Maximum kinematics				
Body separation angle, °	−0.2	−0.60	0.28	.390
Pelvis rotation velocity, °/s	0.69	0.34	0.87	.000 ^a
Torso rotation velocity, °/s	0.52	0.08	0.79	.020 ^a
Torso flexion velocity, °/s	−0.15	−0.57	0.32	.520
Timing of body separation angle, °	0.02	−0.44	0.47	.940
Timing of pelvis rotation velocity	0.25	−0.23	0.63	.300
Timing of torso rotation velocity	−0.12	−0.55	0.35	.610
Timing of torso flexion velocity	−0.07	−0.51	0.39	.760
Kinetics				
Elbow varus torque	0.24	−0.24	0.63	.310
Shoulder internal rotation torque	0.24	−0.24	0.63	.310

Abbreviations: BR, ball release; FC, foot contact; MER, maximum external rotation angle.

^a Indicates a correlation ($P < .5$).

varus forces than slower peak pelvic velocity (57.8%).⁸ It should be noted that Oyama et al defined the pitching cycle from foot contact to ball release.⁸ This difference in relative timing could then 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 et al, youth pitchers that had more dominate glove side oblique strength compared with 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 of 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° of contralateral trunk lean has been correlated with a 10% increase in forces at the shoulder and elbow.²⁵ The current study had an average contralateral trunk lean at a maximum external rotation angle of $26.1^\circ \pm 7.7^\circ$. 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 3 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. Although our study identified significant correlations, it is important to acknowledge wide CIs. The wide CIs suggest that, although 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 these data solely to 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.

CONCLUSIONS

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

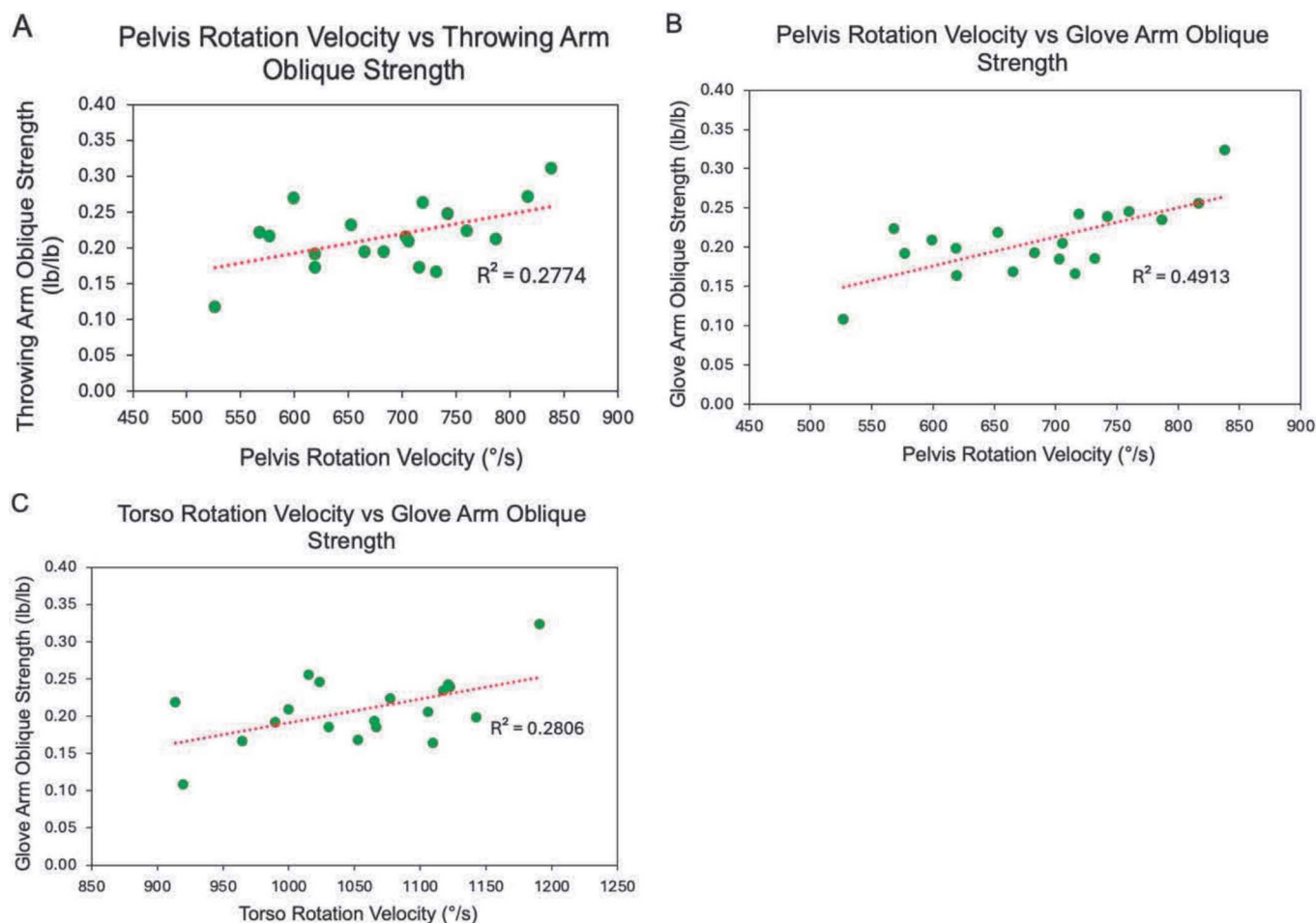


Figure 3. Scatter plots of significant correlations. (A) Throwing arm oblique strength and maximal pelvic rotation velocity. (B) Glove arm oblique strength and maximal torso rotation velocity. (C) Glove arm oblique strength and maximal pelvis rotation velocity.

on shoulder and elbow forces. Although this study found no correlations between abdominal oblique strength and upper extremity joint loading, efficient energy transfer from the lower extremity to the trunk and to the distal segments of the upper extremity is vital to pitching kinetic chain. Furthermore, the data collected in this study were 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 trunk 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 important not only in optimizing performance but also in preventing injury.

REFERENCES

1. Seroyer ST, Nho SJ, Bach BR, Bush-Joseph CA, Nicholson GP, Romeo AA. The kinetic chain in overhand pitching: its potential role for performance enhancement and injury prevention. *Sports Health*. 2010;2(2):135–146. doi:10.1177/1941738110362656
2. Camp CL, Dines JS, van der List JP, et al. Summative report on time out of play for major and minor league baseball: an analysis of 49,955 injuries from 2011 through 2016. *Am J Sports Med*. 2018;46(7):1727–1732. doi:10.1177/0363546518765158
3. Conte SA, Thompson MM, Marks MA, Dines JS. Abdominal muscle strains in professional baseball: 1991–2010. *Am J Sports Med*. 2012;40(3):650–656. doi:10.1177/0363546511433030
4. Sugaya T, Sakamoto M, Nakazawa R, Wada N. Relationship between spinal range of motion and trunk muscle activity during trunk rotation. *J Phys Ther Sci*. 2016;28(2):589–595. doi:10.1589/jpts.28.589
5. Hirashima M, Kadota H, Sakurai S, Kudo K, Ohtsuki T. Sequential muscle activity and its functional role in the upper extremity and trunk during overarm throwing. *J Sports Sci*. 2002;20(4):301–310. doi:10.1080/026404102753576071
6. Stodden DF, Langendorfer SJ, Fleisig GS, Andrews JR. Kinematic constraints associated with the acquisition of overarm throwing part I: step and trunk actions. *Res Q Exerc Sport*. 2006;77(4):417–427. doi:10.1080/02701367.2006.10599377
7. Trasolini NA, Nicholson KF, Mylott J, Bullock GS, Hulburt TC, Waterman BR. Biomechanical analysis of the throwing athlete and its impact on return to sport. *Arthrosc Sports Med Rehabil*. 2022;4(1):e83–e91. doi:10.1016/j.asmr.2021.09.027
8. Oyama S, Yu B, Blackburn JT, Padua DA, Li L, Myers JB. Improper trunk rotation sequence is associated with increased maximal shoulder external rotation angle and shoulder joint force in high school baseball pitchers. *Am J Sports Med*. 2014;42(9):2089–2094. doi:10.1177/0363546514536871
9. Orishimo KF, Kremenec II, Mullaney MJ, Fukunaga T, Serio N, McHugh MP. Role of pelvis and trunk biomechanics in generating ball velocity in baseball pitching. *J Strength Cond Res*. 2023;37(3):623–628. doi:10.1519/JSC.0000000000004314

10. Cohen AD, Garibay EJ, Solomito MJ. The association among trunk rotation, ball velocity, and the elbow varus moment in collegiate-level baseball pitchers. *Am J Sports Med.* 2019;47(12):2816–2820. doi:10.1177/0363546519867934
11. Albiero ML, Kokott W, Dziuk C, Cross JA. Hip flexibility and pitching biomechanics in adolescent baseball pitchers. *J Athl Train.* 2022;57(7):704–710. doi:10.4085/1062-6050-0103.21
12. De Blaiser C, Roosen P, Willems T, et al. The role of core stability in the development of non-contact acute lower extremity injuries in an athletic population: a prospective study. *Phys Ther Sport.* 2021;47:165–172. doi:10.1016/j.ptsp.2020.11.035
13. Karthikbabu S, Chakrapani M. Hand-held dynamometer is a reliable tool to measure trunk muscle strength in chronic stroke. *J Clin Diagn Res.* 2017;11(9):YC09–YC12. doi:10.7860/JCDR/2017/28105.10672
14. Malerba JL, Adam ML, Harris BA, Krebs DE. Reliability of dynamic and isometric testing of shoulder external and internal rotators. *J Orthop Sports Phys Ther.* 1993;18(4):543–552. doi:10.2519/jospt.1993.18.4.543
15. Chalmers PN, Wimmer MA, Verma NN, et al. The relationship between pitching mechanics and injury: a review of current concepts. *Sports Health.* 2017;9(3):216–221. doi:10.1177/1941738116686545
16. Cohen J. The significance of a product moment *rs*. In: *Statistical Power Analysis for the Behavioral Sciences*, revised ed. Academic Press; 1977:75–107.
17. Ng JK, Parnianpour M, Richardson CA, Kippers V. Functional roles of abdominal and back muscles during isometric axial rotation of the trunk. *J Orthop Res.* 2001;19(3):463–471. doi:10.1016/S0736-0266(00)90027-5
18. Watkins RG, Dennis S, Dillin WH, et al. Dynamic EMG analysis of torque transfer in professional baseball pitchers. *Spine (Phila Pa 1976).* 1989;14(4):404–408. doi:10.1097/00007632-198904000-00011
19. McNally MP, Borstad JD, Oñate JA, Chaudhari AMW. Stride leg ground reaction forces predict throwing velocity in adult recreational baseball pitchers. *J Strength Cond Res.* 2015;29(10):2708–2715. doi:10.1519/JSC.0000000000000937
20. Lin YC, Chou PPH, Lin HT, Shih CL, Lu CC, Su FC. A new method for evaluating pelvic and trunk rotational pitching mechanics: from qualitative to quantitative approaches. *Int J Environ Res Public Health.* 2021;18(3):905. doi:10.3390/ijerph18030905
21. Douoguih WA, Dolce DL, Lincoln AE. Early cocking phase mechanics and upper extremity surgery risk in starting professional baseball pitchers. *Orthop J Sports Med.* 2015;3(4):2325967115581594. doi:10.1177/2325967115581594
22. Bullock GS, Menon G, Nicholson K, Butler RJ, Arden NK, Filbay SR. Baseball pitching biomechanics in relation to pain, injury, and surgery: a systematic review. *J Sci Med Sport.* 2021;24(1):13–20. doi:10.1016/j.jsams.2020.06.015
23. Aguinaldo AL, Chambers H. Correlation of throwing mechanics with elbow valgus load in adult baseball pitchers. *Am J Sports Med.* 2009;37(10):2043–2048. doi:10.1177/0363546509336721
24. Aguinaldo AL, Buttermore J, Chambers H. Effects of upper trunk rotation on shoulder joint torque among baseball pitchers of various levels. *J Appl Biomech.* 2007;23(1):42–51. doi:10.1123/jab.23.1.42
25. Oyama S, Waldhelm AG, Sosa AR, Patel RR, Kalinowski DL. Trunk muscle function deficit in youth baseball pitchers with excessive contralateral trunk tilt during pitching. *Clin J Sport Med.* 2017;27(5):475–480. doi:10.1097/JSM.0000000000000396
26. Solomito MJ, Garibay EJ, Woods JR, Öunpuu S, Nissen CW. Lateral trunk lean in pitchers affects both ball velocity and upper extremity joint moments. *Am J Sports Med.* 2015;43(5):1235–1240. doi:10.1177/0363546515574060

Address correspondence to Henry T. Eilen, BA, Department of Orthopaedic Surgery, Medical College of Wisconsin, 9200 West Wisconsin Avenue, Wauwatosa, WI 53226. Address email to heilen@mcw.edu.