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# The relationship between pitch velocity and shoulder distraction force and elbow valgus torque in collegiate and high school pitchers

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**Background:** The relationship between pitch velocity, shoulder distraction force, and elbow valgus torque is not well understood. The purpose of this study was to (1) determine the association between baseball pitch velocity and shoulder distraction force and (2) determine the association between baseball pitch velocity and elbow valgus torque. A subpurpose was to determine these same associations within subgroups of college baseball and high school baseball pitchers.

**Methods:** Collegiate and high school baseball pitchers were biomechanically analyzed; variables extracted from the pitching reports included fastball pitch velocity, shoulder distraction force, and elbow valgus torque. Linear regression was performed to analyze the relationship between fastball velocity and shoulder and elbow kinetics. Subgroup analyses were then performed for college and high school pitches. Coefficients and 95% confidence intervals (95% CI) were calculated, with R squared ($r^2$) used to assess model fit.

**Results:** A total of 70 pitchers (college: n = 23; high school: n = 47) were included in this study. There was a positive weak linear relationship between pitch velocity and shoulder distraction force (3.24 %body weight [BW] [95% CI: 2.07, 4.40], $r^2 = 0.32$, $P < .001$) and elbow valgus torque (0.16 %body weight × height [BW × H] [95% CI: 0.11, 0.20], $r^2 = 0.44$, $P < .001$). College pitchers did not exhibit a relationship between pitch velocity and shoulder distraction force (1.44 %BW [95% CI: −2.50, 5.38], $r^2 = 0.02$, $P < .001$), whereas high school pitchers did exhibit a weak positive linear relationship between pitch velocity and shoulder distraction force (3.69 %BW [95% CI: 2.25, 5.14], $r^2 = 0.36$, $P < .001$). Both college and high school pitchers exhibited a weak positive relationship between pitch velocity and elbow valgus torque (college: 0.15 %BW × H [95% CI: 0.05, 0.25], $r^2 = 0.29$, $P < .001$; high school: 0.16 %BW × H [95% CI: 0.09, 0.22], $r^2 = 0.36$, $P < .001$).

**Discussion:** Pitching velocity exhibited a weak positive linear relationship with both shoulder distraction force and elbow valgus torque. However, only high school pitchers were observed to have a weak positive linear relationship between pitch velocity and shoulder distraction force, whereas both college and high school pitchers exhibited a weak positive relationship between pitch velocity and elbow valgus torque. These findings suggest that older pitchers may attenuate shoulder forces with increased pitch velocity due to physical maturity or increased pitching mechanical skill in comparison with younger pitchers.

**Level of evidence:** Basic Science Study; Kinesiology



**Keywords:** Baseball; biomechanics; pitching; fastball; injury; adolescent athlete

Injuries among baseball players are highly prevalent, and continue to rise,[8,16,25,30] with shoulder and elbow injuries attributing to the greatest incidence.[25] One factor that may contribute to shoulder and elbow injury is pitch velocity.[4,6,18,22] Increased pitch velocity has been associated with higher risk of ulnar collateral ligament

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(UCL) injury in professional pitchers[6,27] and upper extremity injury in adolescent pitchers,[22] with pitchers throwing at the highest velocities having the greatest risk.[4,22] However, there are conflicting studies demonstrating a lack of association between increased pitch velocity and upper extremity injury in professional pitchers.[18] These discrepancies between pitch velocity and upper extremity injury risk have been previously attributed to differences in fundamental shoulder and elbow joint loading during pitching.[3,17,26] Because of this, clinicians and scientists have sought to establish how pitch velocity relates to shoulder and elbow joint loading.

During the pitching motion, high forces are sustained within the glenohumeral joint, specifically during late cocking through the deceleration phases.[20,33] The shoulder distraction forces created during deceleration produce a shear force on the humeral head as it moves posterior to anterior.[33] In order to counteract these forces, the rotator cuff provides an eccentric contraction, attenuating these forces and stabilizing the humeral head.[34] High levels of shoulder distraction force have been postulated to contribute to rotator cuff tensile failure and labrum pathology.[20,21,33,34] However, only 1 study has investigated the relationship between pitch velocity and shoulder distraction force and observed a weak association in collegiate pitchers.[26]

Elbow valgus torque has been proposed to be a significant factor in sustaining elbow injury.[3] Pitching places a high stress on the medial elbow during the late cocking phase, with forces recorded up to 115 N m.[9,32,35] Studies assessing the interplay of pitch velocity and elbow valgus torque have not been conclusive.[17,26] A positive association was found between pitch velocity and elbow valgus force in adolescent pitchers.[17] However, in another study, no association was observed in collegiate pitchers.[26] In addition, Luera et al[19] found no relationship between pitch velocity and absolute elbow varus torque in professional pitchers while observing a strong correlation between pithing velocity and absolute elbow varus torque in high school athletes. The differences in elbow joint force have been attributed to pitching biomechanical efficiency.[13] Distal joint loads (ie, the upper extremity) have been shown to be modulated by hip and trunk kinematics.[1,28] Proper mechanical timing and efficiency allows for forces to be transferred to ball propulsion, instead of dissipating into the upper extremity.[1,12,23] Higher competition levels have been observed to pitch at greater velocities and generate more force in comparison with lower competition levels.[13] However, these pitchers have greater pitching efficiency and skill,[11] potentially allowing for greater amount of force to be directed to ball propulsion in comparison with joint loading. It is currently not understood how competition level and skill affect upper extremity joint loading in relation to pitch velocity.

The relationship between pitch velocity, shoulder distraction force, and elbow valgus torque is not well understood.[17,26,31] A strong association between ball velocity and joint kinetics may indicate that pitching at a higher velocity puts more stress on joints. No association between ball velocity and joint kinetics would indicate that other variables besides pitch velocity are contributing more to increases in joint kinetics. Medial elbow injuries are linked to excess elbow valgus torque, and peak shoulder distraction force may contribute to rotator cuff injuries. Understanding the relationship between velocity and biomechanics may aid in the identification and prevention of upper extremity injuries in pitchers. Furthermore, these data can provide a foundation for throwing and pitching loading strategies for rehabilitation and return to sport programs after upper extremity injuries. Therefore, the purpose of this study was to (1) determine the association between baseball pitch velocity and shoulder distraction force and (2) determine the association between baseball pitch velocity and elbow valgus torque. A subpurpose was to determine these same associations within subgroups of college baseball and high school baseball pitchers.

## Materials and methods

### Study design

After undergoing institutional research board approval, data from reports generated as part of a pitching evaluation were retrospectively reviewed. A total of 70 baseball pitchers (college: n = 23 [left handed: n = 6 (26%)]; high school: n = 47 [left handed: n = 9 (19%)]) from the local university, regional high schools, and baseball academies participated in a pitching evaluation at our institution's biomechanics pitching laboratory. Inclusion criteria consisted of baseball players, from all competition levels, indicated pitcher as their primary or secondary position, aged 14-25 years. Participants were able to participate in all training, practices, and competitions at initial testing. Participants were excluded if they reported pain during any testing, had undergone surgery in the past 12 months, or were not participating in all baseball-related training, practices, or games.

### Biomechanical analysis

Three-dimensional motion data were collected using the 41 retro-reflective marker set required for PitchTrak (Motion Analysis Corporation, Santa Rosa, CA, USA) and a 16-camera motion analysis system (Motion Analysis Corporation). Motion data were collected at 250 Hz. Pitchers threw from a Perfect Mound (Porta-Pro Mounds Inc., Sauget, IL, USA). The mound was engineered to meet the major league specification. Pitchers were allowed to wear their cleats. Ball velocity was recorded with a Trackman device (Trackman, Scottsdale, AZ, USA).

Each pitcher went through a normal pregame warm-up period of 15 minutes. This warm-up was composed of an

**Table I** Descriptive statistics

| | All pitches | College pitches | High school pitches |
|---|---|---|---|
| Height (m) | 1.87 (SD, 0.07) | 1.89 (SD, 0.08) | 1.85 (SD, 0.08) |
| Weight (kg) | 86.81 (SD, 11.69) | 93.26 (SD, 8.16) | 82.36 (SD, 11.92) |
| Number of pitchers (n) | 70 | 23 | 47 |
| Pitch velocity (mph) | 79.34 (SD, 5.23) | 85.09 (SD, 3.37) | 79.23 (SD, 5.23) |
| Shoulder distraction force (%BW) | 145.60 (SD, 35.25) | 151.74 (SD, 36.38) | 138.98 (SD, 32.86) |
| Elbow valgus torque (%BW × H) | 4.44 (SD, 0.02) | 4.90 (SD, 0.01) | 3.96 (SD, 0.01) |

*BW*, body weight; *H*, height; *SD*, standard deviation.

individualized routine, which consisted of a dynamic warm-up and throwing to 36 m. To continue pitching specific routines and to best simulate accustomed practice and training, the dynamic warm-up and throwing counts were not regulated. After warm-up, 41 retroreflective markers were placed on anatomic landmarks on the pitcher's body. This robust marker set allowed for the calculation of full body kinematics and kinetics. A static trial was taken to establish segment coordinate systems and build the individual's model. After the static trial, pitchers threw fastballs, breaking balls, and changeups to a catcher receiving throws at a regulation distance (18.4 m). Only the fastball data were analyzed for this study. Data were processed, and variables were calculated with Visual3D (C-Motion, Inc., Germantown, MD, USA). Pitching models were defined using the PitchTrak model, and segment coordinate systems were defined according to International Society of Biomechanics recommendations.[1,37] Kinematics and kinetics were calculated from the entire pitching cycle and analyzed throughout the cycle and at key time points (high knee, front foot contact, ball release, follow through). For the upper body segments, a top-down (distal-to-proximal) inverse dynamics approach was used for calculations.[10] Shoulder distraction force is the component along the long axis of the segment coordinate system. Elbow valgus torque is the moment about the anterior/posterior axis of the segment. Variables extracted from the pitching reports included pitch velocity, shoulder distraction force, and elbow valgus torque. Shoulder distraction force and elbow valgus torque were normalized by body weight (BW) (N) and body weight times height (BW × H) (N m), respectively.

## Statistical analyses

Mean and standard deviations (SD) were calculated for descriptive statistics (ie, height and mass), pitch velocity, shoulder distraction force, and elbow valgus torque. Each pitcher's kinetics and kinematics were averaged for analyses, and continuous covariates were assumed to have nonlinearity. As a result, multivariable linear regressions with fractional polynomial regressions were used to investigate the relationship between pitch velocity, shoulder distraction force, and elbow valgus torque. However, after analyses, there was only a linear relationship using fractional polynomials. A restricted cubic spline analysis was then performed with 3 and 4 knots to further investigate the potential nonlinear relationship between pitch velocity, shoulder distraction force, and elbow valgus torque. After this analysis, there was only a linear relationship. As a result, a linear regression was performed. A post hoc power analysis was performed for the relationship between pitch velocity and shoulder distraction force and pitch velocity and elbow valgus torque (G*Power version 3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). It was determined that there was over a 0.99% probability of observing a true effect from these analyses. Subgroup analyses were then performed for college and high school pitchers, and then for pitches that were thrown above 85 mph. Coefficients and 95% confidence intervals (95% CI) were calculated, with R squared ($r^2$) used to assess model fit. All assumptions for a linear regression were evaluated and satisfied.[29] All analyses were performed in R version 3.5.1 (R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org/) using the dplyr package[36] for cleaning and coding, the mfp package for fractional polynomial regression,[14] and the rms package for restricted cubic splines.[15]

## Results

A total of 273 pitches were included in this study, with 144 pitches thrown by college pitchers and 129 pitches thrown by high school pitchers. Of these, there were a total 28 pitchers who threw pitches above 85 mph, for a total of 101 pitches (Table I).

There was a weak positive linear relationship between pitch velocity and shoulder distraction force (3.24 %BW [95% CI: 2.07, 4.40], $r^2 = 0.32$, $P < .001$; Fig. 1) and between pitch velocity and elbow valgus torque (0.16 % BW × H [95% CI: 0.11, 0.20], $r^2 = 0.44$, $P < .001$; Fig. 2) for the entire sample. When separated by level, college pitchers did not exhibit a relationship between pitch velocity and shoulder distraction force (1.44 %BW [95% CI: −2.50, 5.38], $r^2 = 0.02$, $P < .001$), whereas high school pitchers did exhibit a weak positive linear relationship between pitch velocity and shoulder distraction force (3.69 %BW [95% CI: 2.25, 5.14], $r^2 = 0.36$, $P < .001$). Both college and high school pitchers exhibited a weak positive relationship between pitch velocity and elbow valgus torque (college: 0.15 % BW × H [95% CI: 0.05, 0.25], $r^2 = 0.29$, $P < .001$; high

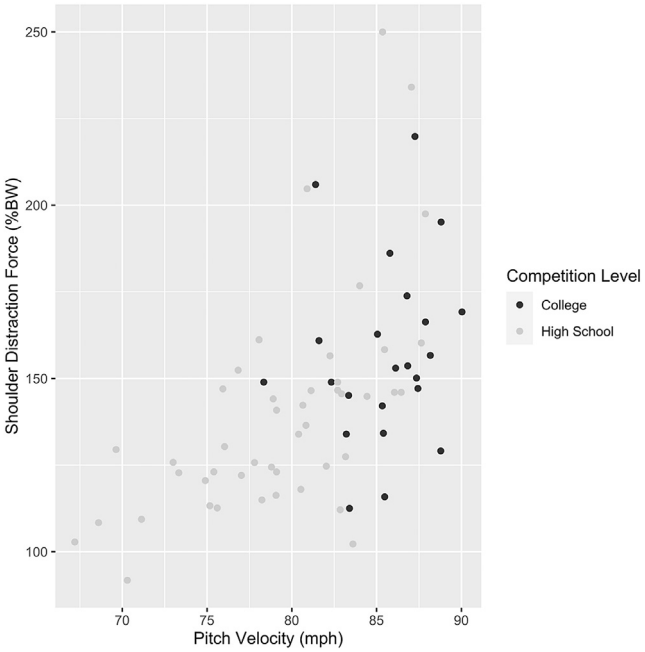


**Figure 1** The relationship between pitch velocity and shoulder distraction force. *BW*, body weight.

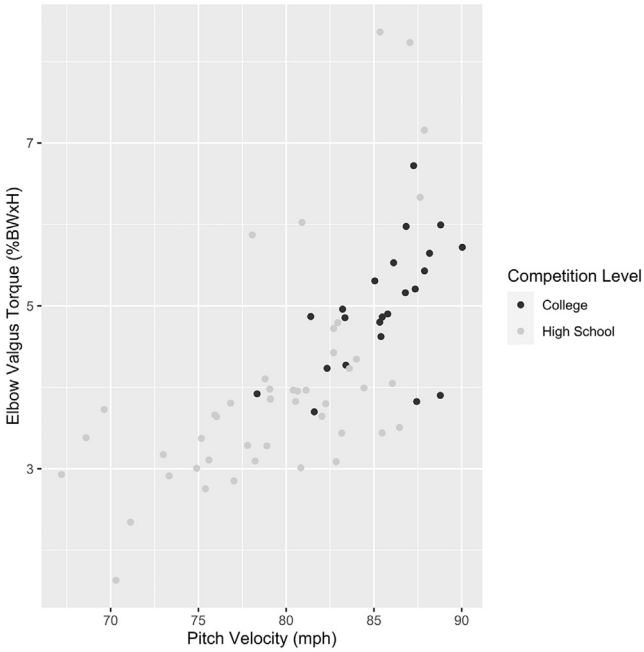


**Figure 2** The relationship between pitch velocity and elbow valgus torque. *BW*, body weight; *H*, height.

school: 0.16 %BW × H [95% CI: 0.09, 0.22], $r^2 = 0.36$, $P < .001$).

In all pitchers who threw ≤85 mph, there was a weak positive linear relationship between pitch velocity and shoulder distraction force (2.42 %BW [95% CI: 0.99, 3.85], $r^2 = 0.21$, $P = .001$) and between pitch velocity and elbow valgus torque (0.11 %BW × H [95% CI: 0.06, 0.15], $r^2 = 0.34$, $P < .001$). In pitchers who threw above 85 mph, there was no relationship between pitch velocity and shoulder distraction force (2.06 %BW [95% CI: −9.20, 13.33], $r^2 = 0.15$, $P = .381$), nor between pitch velocity and elbow valgus torque (0.15 %BW × H [95% CI: −0.30, 0.60], $r^2 = 0.47$, $P = .503$).

## Discussion

The overhand pitch is one of the fastest known human motions and leads to large forces and torques on the shoulder and elbow. There have been many studies that have associated an increased pitch velocity with increased risk for shoulder and elbow injury.[4,6,17,22] However, it is unclear if there is a direct relationship between pitch velocity and shoulder distraction force and elbow valgus torque. The main findings of the current study were that weak positive linear relationships were observed between pitch velocity and shoulder distraction force and pitch velocity and elbow valgus torque in all pitchers. When stratified by competition level, college pitchers did not exhibit a relationship between pitch velocity and shoulder distraction force, but a weak positive relationship was observed between pitch velocity and elbow valgus torque. High school pitchers were observed to have a weak positive relationship between pitch velocity and both shoulder distraction force and elbow valgus torque. Furthermore, in pitchers who threw at or below 85 mph, a weak positive linear relationship between pitch velocity and shoulder distraction force and pitch velocity and elbow valgus torque was also observed. However, there was no relationship between pitch velocity and shoulder distraction force or elbow valgus torque in pitches thrown above 85 mph.

Pitchers exhibited weak positive linear relationships between pitch velocity and shoulder distraction force and pitch velocity and elbow valgus torque. However, college pitchers were only observed to have a weak positive relationship between pitch velocity and elbow valgus torque. These results were in contrast to the results of Post et al,[26] who reported no significant association between pitch velocity and elbow valgus torque in college baseball pitchers. Similarly, although Luera et al[19] reported a strong relationship between pitch velocity and absolute elbow valgus torque in high school athletes, they identified no relationship between pitch velocity and absolute elbow valgus torque in professional athletes. Our results correspond with the results of Hurd et al,[17] who found that increased ball velocity was associated with increased varus moments at the elbow in high school pitchers, and Fleisig et al,[13] who asserted that ball velocity, elbow varus torque, shoulder internal-rotation torque, and shoulder compressive force increased with increasing level of competition. Of note, the average pitch velocity of our college cohort was higher than

that of Post et al[26] (83.4 mph [SD, 3.6 mph]) and similar to the professional cohort of Luera et al,[19] whereas our high school cohort had a much higher pitch velocity than the high school cohort of Luera et al[19] and Hurd et al[17] (Luera et al: professional: 86.3 mph [SD, 2.2 mph], high school: 70.7 mph [SD, 5.1 mph]; Hurd et al: 70.9 m/s [SD, 6.0 mph]).

Successful pitchers can optimally coordinate body segments and transfer energy up the kinetic chain. It has been shown that pitchers from higher competition levels produce greater pitch velocity and joint forces,[13] but also have greater pitching mechanical efficiency and skill.[11] These competition level discrepancies between pitch velocity and biomechanical efficiency may potentially attenuate a linear increase between pitch velocity and upper extremity kinetics. It appears that older pitchers are able to generate forces in the distal extremities and more effectively transfer these forces up the kinetic chain, resulting in reduced shoulder forces and elbow torques as compared with youth pitchers.[2,23] The results of this study potentially suggest that these age and competition level discrepancies continue to exist at the shoulder. Luera et al[19] found that high school pitchers are not capable of using forces generated by trunk and pelvis rotation to aid in pitching. It may be possible to improve rotational kinematics in high school pitchers to increase pitch velocity while protecting the shoulder and elbow. Elite high school pitchers are experiencing significant loads on the UCL and shoulder, perhaps without the physical maturity necessary to handle such loads. Moreover, high school pitchers who pitch at higher velocities are probably pitching more games, more innings, more pitches per game, and more pitches per year, suggesting that talented youth pitchers may be the most vulnerable to injury. Further research is needed to examine differences in mechanics between high school and college pitchers who are throwing at the same velocity. There were many successful high-velocity pitches from college pitchers who were able to limit stress on the elbow and shoulder. These observations may be due to physical and biomechanical differences between ages and competition levels. As pitchers age, physical adaptations are observed between younger pitchers (ie, high school) and older pitchers (eg, college and professional),[5,7] which may help improve pitching efficiency. For example, youth baseball pitchers were observed to have decreased hip internal range of motion, in comparison with college and professional pitchers.[7] Furthermore, professional baseball players demonstrated increased overall dynamic balance in comparison with college and high school, with college players having greater dynamic balance compared with high schoolers.[5] Potential biomechanical explanations, including altered knee flexion at ball release, early trunk rotation, loss of shoulder rotational range of motion, increased elbow flexion at ball release, and increased fatigue, may all increase shoulder forces and elbow torques. Identifying the mechanics and other meaningful contributors to pitch velocity and arm kinetics among this subgroup would help inform throwing and pitching loading strategies.

Several authors have suggested that increased pitch velocity can result in adverse outcomes and elevated risk of upper extremity injury. Petty et al[24] reported that 72% of high school baseball players who underwent UCL reconstruction had a maximum pitch velocity of greater than 80 mph. Olsen et al[22] reported that a fastball pitch velocity greater than 85 mph increased the odds of a shoulder or elbow injury by 2.58 times in adolescent pitchers. Based on these findings, an exploratory analysis was conducted on stratifying pitchers into high pitch velocity ($>$38 m/s or 85 mph) throws and low pitch velocity ($\leq$85 mph) throws to elucidate further trends and relationships. Consistent with the main analyses, there was a weak positive relationship between pitch velocity and shoulder distraction force or elbow valgus torque in pitchers who threw below 85 mph. However, there was no relationship between pitch velocity and shoulder distraction force or elbow valgus torque in pitchers who threw over 85 mph. These findings may be due to the small sample size, with only 23 pitchers throwing on average above 85 mph. Another potential explanation may be that pitchers who threw at lower velocities may not be able to increase pitch velocity without increasing joint forces. In spite of the potential explanations, further extensive research is required to investigate the relationship of high-velocity pitches and shoulder distraction force and elbow valgus torque.

There are limitations to this study. Both college and high school pitchers were found to have higher shoulder distraction forces than what has been previously reported in the literature.[20,33] As a result, these values were compared with a laboratory normative value rather than literature norms. Similarly, an elbow valgus torque laboratory normative value was used for comparisions. Differences between forces and torques calculated in this study and previous literature can be attributed to differences in model assumptions and methods of inverse dynamics calculations. There are additional characteristics of pitching that are meaningful contributors to pitch velocity, elbow valgus torque, and shoulder distraction force that were not included. This may include parameters such as arm strength, range of motion, alterations in timing of muscle recruitment, pitching mechanics, and timing of pitching mechanics. Kinetic calculations are based on estimated body-segment masses of cadavers, which may not accurately represent the body-segment masses of the study participants. In addition, there is an unavoidable amount of skin movement between the reflective markers and the anatomic landmarks they are representing. This effect was minimized by placing markers on bony landmarks.

## Conclusions

Pitching velocity exhibited a weak positive linear relationship with both shoulder distraction force and elbow valgus torque. However, only high school pitchers were observed to have a weak positive linear relationship between pitch velocity and shoulder distraction force, whereas both college and high school pitchers exhibited a weak positive relationship between pitch velocity and elbow valgus torque. These findings suggest that older pitchers may attenuate shoulder forces with increased pitch velocity due to physical maturity or increased pitching mechanical skill in comparison with younger pitchers. Further research is required to investigate the relationship between pitch velocity and upper extremity kinetics in high-velocity pitchers.

## Disclaimer

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