

# Effects of Mound Versus Flat-Ground Pitching and Distance on Arm Mechanics and Elbow Torque in High School Pitchers

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**Background:** Although the monitoring of a pitcher's throwing arm workload has become a hot topic in both research and the pitching world, the impact of mound height and distance still remains unclear.

**Purpose:** To compare the kinetics and kinematics between pitches from a mound and flat ground at 2 different distances.

**Study Design:** Descriptive laboratory study.

**Methods:** A total of 21 healthy high school varsity baseball pitchers (age,  $16.2 \pm 1.3$  years; weight,  $73.6 \pm 11.0$  kg; height,  $181.3 \pm 6.4$  cm) participated in this study. Players were fitted with a motusBASEBALL sensor and sleeve. Each pitcher was instructed to pitch 5 fastballs under 4 conditions: mound at 60.5 ft (regulation distance), flat ground at 60.5 ft, mound at 50.5 ft, and flat ground at 50.5 ft. Linear mixed-effects models were used to account for both intra- and interplayer variability. A multivariable model was used to evaluate the association of mound pitching, flat-ground pitching, and their distances (50.5 ft and 60.5 ft), and their interaction to arm speed, arm slot, arm rotation, elbow varus torque, and ball velocity.

**Results:** There were no statistically significant effects of mound, flat-ground, or distance variation on arm speed or shoulder rotation. Arm slot was significantly higher ( $+3.0^\circ$ ;  $P = .02$ ) on pitches from the mound at 60.5 ft compared with 50.5 ft. Elbow varus torque was lower ( $-1.5$  N·m;  $P = .02$ ) on mound pitches at 60.5 ft compared with 50.5 ft. Pitches thrown from the mound displayed significantly faster ball velocity compared with flat-ground pitches at both distances ( $P < .01$  for both), with pitches at 60.5 ft having higher velocity ( $+0.7$  m/s;  $P < .01$ ).

**Conclusion:** Contrary to long-standing notions, the study results suggest that pitching from the mound does not significantly increase stress on the elbow compared with flat-ground pitching. Lower elbow varus torque and faster ball velocity at the regulation distance compared with the reduced distance indicate that elbow stress and ball velocity may not correlate perfectly, and radar guns may not be an appropriate surrogate measure of elbow varus torque.

**Clinical Relevance:** A better understanding of the kinetic and kinematic implications of various throwing programs will allow for the designing of programs that are driven by objective data with aims directed toward injury prevention and rehabilitation in baseball pitchers.

**Keywords:** elbow; torque; workload

The incidence of elbow and shoulder injuries in baseball continues to rise. This is best exemplified by the 6-fold increase in ulnar collateral ligament surgical intervention rates over the past 20 years among youth and high school players.<sup>8,12,26</sup> The cause of this injury is likely multifactorial. Previously identified risk factors include year-round throwing, poor pitching mechanics, inconsistent workload management, pitching while fatigued, and pitching through pain.<sup>17,18,21,25,26,30</sup> Identifying the number of pitches thrown is considered key in the management of a

player's throwing arm workload due to the high loads placed on the throwing arm during the pitching motion.<sup>14</sup> In attempts to address this injury epidemic, Major League Baseball developed Pitch Smart, a system of guidelines for in-game pitch counts and rest days for players based on age, beginning at age 7.<sup>19</sup> However, pitch count monitoring for high school and collegiate pitchers has been shown to neglect as much as 10% to 42% of pitches made outside of game activity (ie, long-toss, bullpen, and warm-up pitches),<sup>15,31</sup> suggesting that pitch count monitoring does not appropriately capture the overall workload of a pitcher. Appropriate workload monitoring and throwing volume adjustments during both games and training are needed to keep a player healthy.

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Coaches and clinicians have employed tactics during training and rehabilitation to protect their pitchers and regulate throwing arm workloads. For instance, the baseball community believes that throwing from a mound increases the stress experienced by the shoulder and elbow. Coaches have, therefore, historically instructed their pitchers to pitch from flat ground during aspects of training and recovery in an attempt to decrease their workload while maintaining throwing volume. Nissen et al<sup>23</sup> compared mound and flat-ground pitching in 15 adolescent pitchers (aged 9-14 years). While elbow, wrist, and forearm kinematics were reported to be similar under both conditions, there were differences in kinetics, with a 6% greater internal rotation moment of the glenohumeral joint and greater elbow varus moment when pitching from the mound. Conversely, Fleisig et al<sup>11</sup> evaluated 21 youth pitchers (age, 12.6 ± 0.5 years) pitching from variable heights, including a standard mound (25 cm), lower mound (15 cm), and flat ground. They reported no difference in shoulder and elbow kinetics; however, there were significant differences in kinematics between mound heights. While these studies are both helpful, they were limited to youth throwers, and it is unclear if these relationships hold up for older, more skeletally mature players.

Another approach used by coaches and clinicians to moderate a pitcher's workload has been to alter the throwing distance. In youth pitchers, there was a reported decrease in elbow varus torque when throwing at 46 ft compared with 60.5 ft.<sup>11</sup> In collegiate and Minor League Baseball players it has been suggested that the shoulder and elbow experience similar loads during long-toss throws (throws made from flat ground performed at increased interval distances) when compared with pitching from a mound at regulation pitching distance.<sup>9,28</sup> Long-toss studies have also demonstrated potentially detrimental changes in throwing mechanics with maximum distance throwing when compared with shorter flat-ground distances and mound pitching.<sup>9</sup> These biomechanical changes included degree of shoulder external rotation, elbow flexion, internal rotation torque, and elbow varus torque. Although there have been long-toss studies investigating the effect of increased throwing distances, there have been fewer investigations into reduced pitching distances.

The monitoring of a pitcher's throwing arm workload has become a hot topic in both research and the pitching world; however, the impact of mound height and distance still remain unclear. Accordingly, the purpose of this study was

to assess changes in throwing kinetics and kinematics for high school pitchers throwing from a mound and flat ground at regulation (60.5 ft) and shortened (50.5 ft) distances. It was hypothesized that pitching from a mound and flat ground would have no difference in arm positioning, arm speed, or elbow varus torque, and that there would be decreased elbow varus torque at the reduced throwing distance.

## METHODS

In total, 21 high school varsity baseball pitchers (age, 16.2 ± 1.3 years; weight, 73.6 ± 11.0 kg; height, 181.3 ± 6.4 cm) participated in this study. To be included, players had to be classified as pitchers actively playing high school baseball and pain-free at the time of testing and injury-free for the previous 12 months. All participating players provided assent and their parent or guardian provided consent. All players were assigned random player identifications to maintain anonymity and data deidentification. This study was approved by an institutional review board.

Relevant patient data (eg, height, weight, age, handedness, and injury history) were obtained from each participant. The pitchers were then instrumented with a motusBASEBALL sensor and sleeve (Motus Global). The sensor was placed on the medial aspect of the ulna, 5 cm distal to the medial epicondyle of the humerus. The pitchers were grouped into pairs and given unlimited time to complete their preferred warm-up routine for full-effort pitching. When ready, each pitcher was tested for 5 fastball pitches thrown to a catcher, at each of the 4 conditions: mound at regulation distance (60.5 ft), flat ground at regulation (60.5 ft), mound at 50.5 ft, and flat ground at 50.5 ft (Figure 1). The reduced distance of 50.5 ft was used in this investigation based on common coaching practices in high school players. Additionally, the reduced distance was enough for pitchers to still throw full effort while allowing catchers to still receive balls thrown at full velocity. Fleisig et al<sup>10</sup> and Leafblad et al<sup>16</sup> have shown excellent intraclass correlation coefficients for intrathrower variability for pitchers with pitches thrown from a mound and from flat ground, respectively, thus demonstrating that capturing 5 throws from each condition is appropriate to measure the metrics included in this study. The mound was at the regulation height of 25 cm (10 in) for high school players. The order of the throwing conditions was randomized for each pitcher, to eliminate any bias related to testing order. The

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Ethical approval for this study was waived by the Hospital for Special Surgery (study No. 2016-0167).



**Figure 1.** Pitchers throwing off the mound to a catcher at regulation distance (60.5 ft). The pitchers wore the sensor and sleeve, and ball velocity was tracked with a radar gun from behind the pitcher.

pitchers were instructed to pitch with gamelike effort and aim down the middle of the strike zone. Pitchers were allowed to throw at their own pace to a catcher, and ball velocity was tracked with a radar gun (Stalker Radar). All pitchers in this study threw overhead and were instructed to use their normal throwing motion (ie, no “side arm” or “submarine” pitchers participated).

Data were collected via Bluetooth LE transmission to an iOS device using the standard-issue device software, which has been used in previous investigations (Figure 2).<sup>5,7,20,24</sup> For each throw, the sensor calculated and recorded arm slot (position of the forearm at ball release relative to the ground, measured in degrees), arm rotation (maximum rotation of the forearm in relation to the ground, measured in degrees), elbow varus torque (peak torque), and forearm angular velocity (maximal rotational velocity of the forearm). Previous research has shown the Motus sensor measures to correlate well with laboratory measures<sup>3,5</sup> and to provide precise and reproducible data.<sup>20,22</sup>

### Statistical Analysis

Descriptive statistics were utilized to describe player characteristics with means and standard deviations, where appropriate. For each variable, data were summarized by computing pooled means and standard deviations for the 4 pitching conditions. Linear mixed-effects models were used to account for both intra- and interplayer variability (measurements for a single pitcher and between pitchers). A separate multivariable linear regression model was used to evaluate the association of mound pitching versus flat-ground pitching, distance (50.5 ft and 60.5 ft), and their interaction (cross-product term) on each of the following outcomes (dependent variables): arm speed, arm slot, arm rotation, elbow varus torque, and ball velocity. The level of significance for all tests was set at  $P < .05$ . All analyses were performed in Stata Version 14 (StataCorp).



**Figure 2.** Example data provided by the smartphone application when using the sensor.

### RESULTS

The means and standard deviations for each outcome under the 4 pitching conditions are listed in Table 1. There were no statistically significant effects of mound versus flat-ground or distance variation on arm speed or arm rotation (Table 2). Arm slot was significantly higher on pitches from the mound at 60.5 ft (+3.0° [95% CI, 0.4, 5.5];  $P = .02$ ). Elbow varus torque was significantly lower during longer-distance mound throwing (−1.5 N·m [95% CI, −2.8, −0.3];  $P = .02$ ). Pitches thrown from the mound were significantly faster compared with flat-ground pitches at both distances, with throws at 60.5 ft having greater velocity than those at 50.5 ft (+0.7 m/s [95% CI, 0.4, 1.0];  $P < .001$ ).

### DISCUSSION

As hypothesized, there were no changes in elbow varus torque, arm speed, or arm rotation for mound versus flat-ground pitches or between the 2 distances. The arm slot was lower (3°) on flat-ground pitches at 60.5 ft compared with mound pitches, but there were no significant differences for the other conditions. Even though there was a statistical difference in arm slot for flat-ground pitches, it is possible this may not be clinically significant and could be due to measurement error from the sensor. Overall, pitchers used similar mechanics for the 4 conditions in terms of arm rotation and rotational velocity.

TABLE 1  
Outcomes for Each of the 4 Pitching Conditions<sup>a</sup>

	50.5 ft		60.5 ft	
	Mound	Flat Ground	Mound	Flat Ground
Arm speed, deg/s	5575.2 (437.4)	5544.6 (478.2)	5586.6 (658.2)	5506.2 (496.2)
Arm slot, deg	45.2 (23.1)	44.2 (21.9)	46.0 (24.0)	43.1 (27.0)
Arm rotation, deg	160.7 (11.1)	161.2 (11.5)	160.4 (12.7)	161.8 (11.6)
Elbow torque, N·m	39.4 (11.2)	39.1 (12.5)	37.8 (11.8)	38.8 (10.6)
Ball velocity, m/s	33.9 (1.9)	33.2 (1.9)	34.2 (1.9)	33.3 (1.8)

<sup>a</sup>Data are presented as mean (SD).

TABLE 2  
Pitching Kinematics and Kinetics for the 4 Pitching Conditions<sup>a</sup>

	Mound vs Flat Ground, 50.5 ft	Mound vs Flat Ground, 60.5 ft	60.5 ft vs 50.5 ft, Flat Ground	60.5 ft vs 50.5 ft, Mound
Arm speed, deg/s	5.2 (-13.1, 23.4)	14.2 (-4.1, 32.4)	-6.4 (-24.7, 11.9)	2.6 (-15.6, 20.9)
Arm slot, deg	1.0 (-1.5, 3.5)	<b>3.0 (0.4, 5.5)</b>	-1.2 (-3.7, 1.3)	0.8 (-1.7, 3.3)
Arm rotation, deg	-0.5 (-2.2, 1.2)	-1.4 (-3.0, 0.3)	0.6 (-1.1, 2.2)	-0.3 (-2.0, 1.3)
Elbow torque, N·m	0.3 (-1.0, 1.6)	-0.9 (-2.2, 0.4)	-0.3 (-1.6, 0.9)	<b>-1.5 (-2.8, -0.3)</b>
Ball speed, m/s	<b>1.6 (1.2, 1.9)</b>	<b>2.0 (1.7, 2.3)</b>	0.3 (-0.1, 0.6)	<b>0.7 (0.4, 1.0)</b>

<sup>a</sup>Data are presented as coefficient (95% CI). Boldface text indicates statistical significance ( $P < .05$ ).

Contrary to the hypothesis, elbow torque increased and ball velocity decreased with pitching on the mound at the shorter distance (50 ft) compared with pitching at the regulation distance.

Ball velocity was greater from the mound compared with flat ground, regardless of distance. This is in contrast to previous studies by Nissen et al<sup>23</sup> and Fleisig et al,<sup>11</sup> who both reported no difference in ball velocity between mound and flat-ground pitches. However, our study population was older and more experienced than those studied by both Nissen and Fleisig,<sup>11</sup> which could contribute to the differences in velocity. Players were instructed to pitch with gamelike intensity for each condition; but it is possible that pitchers were not acclimated to pitching from the ground and thus were not throwing at their full effort. There was no difference between flat-ground pitches at 60.5 ft and 50.5 ft for ball velocity; but on the mound, pitchers threw with greater velocity at regulation distance (60.5 ft). Additionally, ball velocity was greater in pitches at regulation distance compared with the reduced distance from the mound. Although the reason for this is unclear, it may be that pitchers subconsciously reduced effort at the reduced distance for catcher protection.

Coaches, clinicians, and researchers have suggested that pitching from a mound results in increased stress experienced at the elbow.<sup>2,6,23</sup> However, this notion was not supported in this study. At both distances, there were no changes in elbow varus torque for pitches from the mound versus flat ground. Similarly, Fleisig et al<sup>11</sup> reported no change in kinetics in Little League pitchers at variable mound heights of 0 cm, 15 cm, and 25 cm (regulation

mound height). Even when investigating changes in mound heights (15-30 cm) in collegiate pitchers, no differences were found in elbow varus torque.<sup>6</sup> Conversely, Nissen et al<sup>23</sup> showed that adolescent pitchers displayed a 6% increase in both shoulder internal rotation torque and elbow varus torques when pitching from a 25-cm mound compared with pitching from flat ground. The differences seen between studies could stem from the differences in the age of pitchers investigated, as pitchers at lower levels exhibit larger variation in pitching mechanics compared with their older and more skilled counterparts.<sup>10</sup> To this point, Slenker et al<sup>28</sup> studied 29 college-aged baseball pitchers and found that flat-ground throwing at even the shorter distances had similar biomechanical loads to pitching from the mound, yet at significantly lower ball velocity, illustrating the mechanical advantage and increased efficiency of throwing from a mound.

Anecdotally, coaches have assumed that elbow varus torque increases with greater pitching distance, and therefore reducing pitching distance would decrease torque. However, in this study we did not find this relationship between reduced distance and torque. In fact, for both mound and flat-ground pitching, elbow varus torque was higher at 50.5 ft compared with 60.5 ft (despite velocity being lower). Coaches who instruct their players to pitch at a reduced distance to reduce their workload could be unknowingly increasing workload, potentially increasing the risk for injury.

The relationship between ball velocity and elbow varus torque remains unclear. Some reports have shown a positive correlation between ball velocity and elbow varus

torque in pitchers,<sup>4,13</sup> while others have reported no association.<sup>27</sup> An investigation evaluating intra- and inter-player relationships found poor interplayer association between ball velocity and varus torque but a strong association between these variables with intraplayer evaluation ( $R^2 = 0.957$ ).<sup>29</sup> Coaches and clinicians commonly track ball velocity as a measure of effort and an indirect measure of elbow varus torque; however, based on these findings this may not be an optimal practice. Recently, a study using the sensor found that for every 25% decrease in perceived effort, elbow varus torque only decreased 7% and ball velocity only decreased 11%.<sup>22</sup> A more appropriate measure could be pitch efficiency (PE), which is the ratio of ball velocity (m/s) to elbow varus torque (N·m).<sup>1</sup> An efficient pitch would be one that maximizes ball velocity while minimizing the stress experienced at the elbow, resulting in a higher PE ratio. In the current study, the most efficient pitch was from the mound at 60.5 ft (0.90 PE); the throws from the other 3 conditions ranged from 0.85 to 0.86 PE. It is possible that pitches from the mound at regulation distance are the most optimal pitches for training and injury loads; however, future research is warranted to investigate the relationship of PE and pitching performance as well as injury prevention.

A few limitations warrant mentioning. First, a power analysis was not performed and nonsignificant results could be due to lack of power. Second, only high school players were used in this analysis, and the findings might not be applicable to pitchers of different age groups and ability levels. Third, while using the sensor allowed for pitchers to throw in a more natural field setting, it only provided throwing arm mechanics and not full-body measures. There are multiple factors that contribute to pitching mechanics, and these vary widely between individuals. Studying the throwing arm is a great start to investigating the effects of distance and mound height, but future studies should also include lower extremity measures. Fourth, pitching maximum effort from flat ground and reduced distances might be unfamiliar to some players and could, therefore, result in changes in mechanics. Finally, only fastballs were examined in this study even though high school players throw a variety of pitch types. Future investigations should examine a full bullpen with all pitch types and the possible changes associated with mound height or pitching distance.

## CONCLUSION

The findings from this study suggest that pitching from flat ground does not significantly decrease elbow varus torque compared with pitching from the mound, contrary to longstanding notions of mound pitching being associated with increased workload. Additionally, the lower elbow varus torque and faster ball velocity at the regulation distance on the mound compared with the reduced distance (50.5 ft) indicated that elbow stress and ball velocity may not correlate perfectly and radar guns alone may not be an appropriate surrogate measure of elbow varus torque. Perhaps an even more meaningful finding was the absence of

differences for the other variables, including arm speed and arm rotation, demonstrating that pitchers were using similar mechanics at each condition. At regulation distance (60.5 ft), pitchers exhibited the same arm speed, arm rotation, and elbow varus torque from the mound and on flat ground. Flat-ground pitching during training or rehabilitation can be used to help reinforce mechanics on the mound, but coaches and clinicians should be mindful that this study found no differences in stress between these 2 conditions and should factor this into player workload calculations.

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