



Original research

The influence of mound height on baseball movement and pitching biomechanics



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ARTICLE INFO

Article history:

Received 24 October 2018

Received in revised form

17 December 2018

Accepted 22 January 2019

Available online 29 January 2019

Keywords:

Kinetics

Elbow

Shoulder

Fastball

Curveball

ABSTRACT

Objectives: To determine whether mound height is associated with baseball movement (velocity, spin and break) and baseball pitching biomechanics (kinematics and kinetics).

Design: Controlled laboratory study.

Methods: Twenty collegiate baseball pitchers threw five fastballs and five curveballs from four different mound heights (15 cm, 20 cm, 25 cm, 30 cm) in a randomized order. Ball movement was computed by a ball tracking system, while pitching biomechanics were calculated with an 11-camera optical motion capture system. Repeated measures analysis of variance was utilized to detect significant differences among the four different mound heights ($p < 0.05$) for the fastball and curveball pitches.

Results: There were no significant differences observed for ball movement. There were seven significant kinematic differences for fastballs and eight kinematic differences for curveballs. Although these differences were statistically significant, the magnitudes were small, with most joint angles changing by less than 2° . There were no significant kinetic differences for curveballs, but five kinetic parameters (elbow varus torque, elbow flexion torque, elbow proximal force, shoulder internal rotation torque, and shoulder anterior force) varied with mound height for fastballs. In general, fastball kinetics were 1%–2% less from the lowered (15 cm, 20 cm) mounds than from the standard (25 cm) or raised (30 cm) mounds.

Conclusions: Lowering the mound may not affect a pitcher's ball movement, but may slightly reduce shoulder and elbow kinetics, possibly reducing the risk of injury.

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Practical implications

- Varying mound height does not affect performance (ie. ball velocity, spin, break).
- Varying mound height may lead to small changes in pitching kinematics.
- Lowering the pitching mound results in slightly lower fastball elbow and shoulder kinetics, which may have implications about injury risks.

1. Introduction

While youth baseball pitching mounds vary from flat ground to adult height,¹ all leagues from high school to professional levels adhere to standards set by Major League Baseball (MLB). Starting in 1903, the height of the pitching mound was restricted to a maximum of 38 cm (15 in.) with no minimum height specified.²

In 1968, known as “The Year of the Pitcher”, mean MLB batting average fell to 0.237 and mean run scoring hit an all-time low of 3.42 runs per team per game.^{2,3} In response to this dramatic drop in offensive performance, MLB made changes before the 1969 season which included lowering the mound from 38 cm to 25 cm (10 in.). In 1969, mean batting average increased to 0.248 and mean run scoring increased by 19%.^{2,3} Run scoring remained at fairly constant levels for the remainder of the twentieth century, but from 2000 to 2014 there was a steady decline, leading to calls to once again lower the mound.^{4,5}

Some researchers and baseball experts have suggested that lowering the pitching mound may reduce the stress on the throwing arm,^{6–8} and two studies have examined the effect of mound height on pitching biomechanics.^{1,7} The first study, by Nissen et al. compared the biomechanics of 15 adolescent pitchers throwing from a standard 25 cm (10-in.) mound versus flat-ground.⁷ Their results indicated differences in lower body kinematics (stride length & lead knee flexion) between the mound and flat-ground conditions. Additionally, they found a 6% increase in shoulder and elbow torques when pitching from the mound. The second study, by Fleisig et al. examined the biomechanical differences in adolescent pitchers

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Fig. 1. The biomechanical testing setup at the USA Baseball Training Complex in Cary, NC included four custom dirt mounds of varying mound heights (15 cm, 20 cm, 25 cm, 30 cm). For biomechanical testing purposes, the mounds were built in pairs (15 & 20 cm, 25 & 30 cm) in order to allow two 11-camera motion capture systems to surround each pair of mounds.

throwing from three different mound heights (flat-ground, 15 cm, 25 cm).¹ They also reported kinematic differences, with a majority occurring at the instant of lead foot contact. Although differences were found, further analysis revealed no differences between the 15 cm and 25 cm mound, finding only differences between flat-ground pitching and the two raised mound conditions. Consistent with the Nissen et al.,⁷ pitchers landed with a shorter stride and more knee flexion at the instant of foot contact when pitching from flat ground.¹ However, Fleisig et al. differed in finding no significant differences in joint kinetics. Regarding pitching performance measures, neither study was able to find a significant effect of mound height; however, ball velocity was the only performance-related variable investigated.

While previous research found significant differences between flat-ground and mound pitching in adolescent pitchers,^{1,7} no previous study has explored this effect in adult pitchers with moderate changes in mound height from the standard 25 cm (10 in.) mound. Furthermore, no study has investigated the influence of mound height on newer measures of ball movement such as spin and break. Therefore, the purpose of this study was to determine the effect of mound height (15 cm, 20 cm, 25 cm – standard, 30 cm) on baseball movement and pitching biomechanics for adult baseball pitchers. Three hypotheses were proposed, namely that mound height would affect the pitcher's (1) ball movement (e.g., velocity, spin and break); (2) full-body kinematics; and (3) shoulder and elbow kinetics.

2. Methods

This study was approved by the the Institutional Review Board at St. Vincent's Health System (Birmingham, AL, USA). A total of 20 healthy, active pitchers were recruited from universities in the Raleigh, NC area. All testing was performed at the USA Baseball Training Complex in Cary, NC where four custom dirt mounds of various heights (15 cm, 20 cm, 25 cm, 30 cm) were built outdoors and covered by a tent. All four mounds were constructed with the same slope according to Major League Baseball specifications, namely starting six inches in front of the pitching rubber the mound begins to slope downward at a rate of one inch per one foot over a distance of six feet. Two 11-camera motion capture systems (Motion Analysis Corporation, Santa Rosa, CA) were set up, with each surrounding a pair of mounds (Fig. 1). For each mound, a home plate was positioned 18.44 m away from the pitching rubber and a baseball tracking system (Rapsodo Baseball System, Rapsodo Inc.

Fishers, IN) was positioned 1.83 m behind home plate. The baseball tracking system utilized high speed video sampling at 240 frames per second and radar technology sampling at 50 KHz to calculate ball movement and spin. Depending upon each team's preference, the pitchers threw to either a catcher or a net with a strike zone target. Each participant arrived at the testing site where a member of the research staff explained the testing procedures and obtained informed consent. Each participant was instructed to change into tight-fitting spandex shorts, socks and baseball cleats. Anthropometric measures were collected and 38 retro-reflective markers were attached to the participant as previously described.⁹ Once the markers were placed on the participant, he was instructed to warm-up. Each participant's warm-up included stretching, throwing and non-throwing drills, followed by an unspecified number of warm-up pitches from each mound. After conclusion of the warm-up, data for 40 pitches were collected, in which pitchers were instructed to throw five full-effort fastballs and five full-effort curveballs from each mound. The order of the mounds was randomized, and for each pitcher-mound combination, the pitch type order was randomized as well (i.e., fastballs before curveballs or curveballs before fastballs). For all trials, three-dimensional motion data were collected at 240 Hz with an average residual (error of three-dimensional point location) of 0.5 mm, while the ball tracking system captured the ball speed, spin and break. From the captured motion data, 31 kinematic and kinetic variables were calculated for each pitch as previously described.^{10–12} The eleven kinematic variables measured at the instant of foot contact included: stride length, lead foot position, lead foot angle, lead knee flexion, pelvis rotation, trunk separation, trunk lateral tilt, shoulder abduction, shoulder horizontal abduction, shoulder external rotation, and elbow flexion. The maximum values of shoulder external rotation and elbow flexion were calculated during arm cocking. The five variables at the instant of ball release included: lead knee flexion, trunk forward tilt, trunk side tilt, shoulder abduction, and elbow flexion. Between the instant of foot contact and ball release, maximum angular velocities of pelvis and upper trunk rotation, shoulder internal rotation, and elbow extension were quantified. Maximum values for seven kinetic variables were also calculated which included: four near the instant of maximum shoulder external rotation (elbow varus torque, shoulder horizontal adduction torque, shoulder internal rotation torque, and anterior shoulder force), and three near the instant of ball release (elbow flexion torque, elbow proximal force, and shoulder proximal force).

For each of the eight test conditions (4 mound heights \times 2 pitch types), the magnitudes of ball movement and biomechanical parameters were averaged for each participant. Repeated measures analysis of variance (ANOVA) was utilized to detect significant differences among the mound heights for fastballs and curveballs separately. When a significant difference ($p < 0.05$) was found among the four mound heights, pairwise differences were analyzed with a Tukey post-hoc test ($p < 0.05$).

3. Results

The pitchers were (mean \pm SD) 19.7 \pm 1.2 years old, 186 \pm 5 cm tall, and had a mass of 93 \pm 9 kg. No significant differences were observed for ball velocity, spin, or movement when pitching from the four mound heights for both the fastball and curveball pitches. The mean ball velocities for the fastball and curveball pitches were 35.9 \pm 2.71 m/s and 31.4 \pm 2.66 m/s, respectively. Twelve biomechanical variables were found to be significantly different when comparing mound height for the fastball pitches (Table 1). Seven of the fastball differences were kinematic, while the remaining five were kinetic. When assessing the curveballs thrown from the dif-

Table 1
Significant differences found for fastball pitches thrown from various mound heights.

Parameter	Mound height				Standard error	p-value
	15 cm	20 cm	25 cm	30 cm		
Foot contact						
Lead foot position (cm) ^d	20.6	22.0	17.5	16.8	2.8	0.009
Lead knee flexion (°) ^b	44.3	44.6	44.9	45.6	2.0	0.033
Shoulder abduction (°)	92.6	92.7	91.8	91.9	2.5	0.048
Elbow flexion (°) ^c	104.3	104.6	102.9	103.6	2.9	0.017
Arm cocking						
Maximum upper trunk rotation velocity (°/s) ^a	1051	1054	1059	1058	16	0.022
Shoulder horizontal adduction (°)	21.6	21.6	21.0	21.0	2.1	0.041
Ball release						
Trunk side tilt (°) ^{a,b,d}	20.0	20.3	21.7	22.1	2.0	0.002
Maximum kinetic values						
Shoulder anterior force (N) ^{a,c}	360	360	367	365	16	0.002
Shoulder internal rotation torque (N*m)	90.4	90.4	91.7	91.7	3.7	0.013
Elbow proximal force (N) ^c	1011	1009	1023	1020	33	0.027
Elbow varus torque (N*m)	89.9	89.8	91.0	91.0	3.7	0.048
Elbow flexion torque (N*m)	56.9	56.9	58.1	57.8	2.7	0.041

^a Significant post-hoc difference between 15 cm and 25 cm mound.

^b Significant post-hoc difference between 15 cm and 30 cm mound.

^c Significant post-hoc difference between 20 cm and 25 cm mound.

^d Significant post-hoc difference between 20 cm and 30 cm mound.

Table 2
Significant differences found for curveball pitches thrown from various mound heights.

Parameter	Mound height				Standard error	p-value
	15 cm	20 cm	25 cm	30 cm		
Foot contact						
Stride length (% height) ^d	81.4	81.7	81.1	80.7	1.4	0.044
Lead Knee Flexion (°) ^c	44.0	43.6	45.0	44.8	2.1	0.022
Trunk lateral tilt (°) ^c	10.3	9.9	11.1	10.5	1.2	0.013
Shoulder horizontal abduction (°) ^b	19.5	19.4	20.6	20.8	3.5	0.004
Shoulder external rotation (°) ^b	49.0	48.7	46.2	44.9	6.4	0.025
Arm cocking						
Maximum shoulder external rotation (°) ^{a,c}	158.7	158.7	157.6	158.0	1.7	<0.001
Ball release						
Lead knee flexion (°) ^c	42.7	43.6	44.4	44.6	2.9	0.037
Trunk forward tilt (°) ^{a,c}	35.3	35.4	33.8	34.2	1.6	0.001

^a Significant post-hoc difference between 15 cm and 25 cm mound.

^b Significant post-hoc difference between 15 cm and 30 cm mound.

^c Significant post-hoc difference between 20 cm and 25 cm mound.

^d Significant post-hoc difference between 20 cm and 30 cm mound.

ferent mound heights, eight kinematic variables were significantly different (Table 2).

4. Discussion

The hypothesis that ball movement (velocity, spin, and break) would vary with mound height was not supported by the results. This is not surprising when considering that 5 cm intervals between mound heights correspond to negligible differences (about 0.3°) in pitch angle to home plate located 18.44 m from the pitching rubber. So why did MLB scoring increase after the mounds were lowered for the 1969 season? It is important to note that the strike zone was also made smaller that year. Therefore, lowering the mound might not have been the primary cause of increased scoring.

The second hypothesis that there would be statistically significant differences in full-body kinematics when pitching from the different mound heights was supported. Of 25 kinematic variables tested, there were seven fastball and eight curveball differences observed. When specifically comparing the fastball differences in the current study to the previous literature, there was only one similar finding reported. Fleisig et al. reported a more closed (toward the third base side, for a right-handed pitcher) lead foot position when pitching from the lower mound (flat ground) as compared to the 25 cm mound,¹ while the current study found a similar dif-

ference when comparing the 20 cm mound and 30 cm mound. The current study also found that pitchers landed with 1° more of knee flexion when pitching from the 30 cm mound as compared to the 15 cm mound; this result differs from two previous studies which found knee flexion decreased with mound height.^{1,7} However, it is important to note that in the previous studies significant differences in knee flexion were only observed when compared to flat ground pitching. Complete removal of the mound may affect the pitcher differently than small adjustments to its height. Shoulder external rotation at the instant of lead foot contact for the curveball was also found to be different among the mound heights. It was determined that from the 15 cm mound height pitchers had more shoulder external rotation when compared to the 30 cm mound. These results were similar to those found by Fleisig et al. when specifically comparing the flat ground and intermediate mound height (15 cm).¹ In the both the current study and Fleisig et al. the lower mound heights resulted in increased shoulder external rotation at the instant of foot contact which is contrary to the thought of the increased mound height allowing more time for the arm to externally rotate during the stride phase prior to foot contact. While other significant kinematic differences were observed in the current study for both the fastball and curveball, the remaining were relatively small in magnitude, with differences in joint angles less

than 2°. Thus, a majority of the kinematic differences observed due to the change in mound height may lack practical significance.

The last hypothesis that there would be significant differences in shoulder and elbow kinetics was supported in the current study for the fastballs only. In general, fastball shoulder and elbow kinetics were about 1% or 2% lower from the 15 cm and 20 cm mounds than from the standard (25 cm) and raised (30 cm) mounds. By comparison, Anz et al. showed that shoulder and elbow torques were 7%–8% less in non-injured pitchers than in injured pitchers.¹³ It is unknown whether a 1%–2% decrease in kinetics due to mound height would be enough to reduce the risk of injury. However, previous studies have shown similar change (about 2%) in kinetics when varying pitch speed¹⁴ or pitching distance¹; thus, mound height has a kinetic effect similar to other potential risk factors.

5. Conclusion

Results from the current study imply that lowering the mound in college baseball may not increase run scoring, as there were no changes in fastball and curveball velocity, spin or movement. Other potential modifications, such as increasing pitching distance or altering the strike zone, are issues worth future study. Differences in pitching kinematics with varied mound height were small, and may lack practical significance. Shoulder and elbow kinetics of fastballs may be slightly less with a lowered mound, which may possibly reduce the risk of pitching injury.

Acknowledgments

This work was supported by Major League Baseball. The authors would like to acknowledge Motus Global, USA Baseball, and Major League Baseball for their assistance in conducting this study. Additionally, the authors would like to thank the players and teams who participated.

References

1. Fleisig GS, Diffendaffer AZ, Ivey B et al. Do mound height and pitching distance affect youth pitching biomechanics? *Am J Sports Med* 2018; 46(12):2996–3001.
2. McNeil WF. *The Evolution of Pitching in Major League Baseball*. Jefferson, NC, McFarland & Company, Inc., 2006.
3. MLB.com. *MLB.com – Stats*, 2017.
4. Verducci T. There are Too Many Strikeouts in Baseball: Here's How to Fix the Problem. *Sports Illustrated*. <https://www.si.com/mlb/2018/06/14/strikeouts-effect-major-league-baseball>. [Published 14 June 2018].
5. Dixon M. Former Cy Young Award Winner Rick Sutcliffe Suggests MLB. Get Rid of Pitcher's Mound. *SportsNaut*. <https://sportsnaut.com/2018/06/former-cy-young-award-rick-sutcliffe-suggests-mlb-get-rid-of-pitchers-mound/>. [Published 4 June 2018].
6. Badura JM, Raasch WG, Barber MP et al. A kinematic and kinetic biomechanical model for baseball pitching and its use in the examination and comparison of flat-ground and mound pitching: a preliminary report. *Proceedings 25th Annual International Conference IEEE Engineering Medicine Biology Society (IEEE Cat No03CH37439)* 2003:1803–1806.
7. Nissen CW, Solomito MJ, Garibay EJ et al. A biomechanical comparison of pitching from a mound versus flat ground in adolescent baseball pitchers. *Sports Health* 2013; 5(6):530–536.
8. MLB Network. *MLB network roundtable: the pitching dilemma*, 2016.
9. Fleisig GS, Diffendaffer AZ, Aune KT et al. Biomechanical analysis of weighted-ball exercises for baseball pitchers. *Sports Health* 2017; 9(3):210–215.
10. Fleisig GS, Escamilla R, Andrews JR et al. Kinematic and kinetic comparison between baseball pitching and football passing. *J Appl Biomech* 1996;(12):207–224.
11. Escamilla R, Fleisig GS, Barrentine SW et al. Kinematic comparisons of throwing different types of baseball pitches. *J Appl Biomech* 1998; 14:1–23.
12. Zheng N, Fleisig GS, Barrentine SW et al. Biomechanics of pitching, in *Biomedical engineering principles in sports*, Hung GK, Pallis JM, editors, New York, NY, Kluwer Academic/Plenum Publishers, 2004, p. 209–256.
13. Anz AW, Bushnell BD, Griffin LP et al. Correlation of torque and elbow injury in professional baseball pitchers. *Am J Sports Med* 2010; 38(7):1368–1374.
14. Slowik JS, Aune KT, Diffendaffer AZ et al. The Relationship between Fastball Velocity and Elbow Varus Torque in Professional Baseball Pitchers. *J Athl Train* <https://doi.org/10.4085/1062-6050-558-17>.