[Athletic Training]

A Biomechanical Comparison of Pitching From a Mound Versus Flat Ground in Adolescent Baseball Pitchers

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Background: Baseball professionals believe that pitching from a mound can increase the stresses placed on the body.

Hypothesis: There is no difference in kinematics or kinetics in pitching from a mound versus flat-ground conditions in adolescent baseball pitchers.

Study Design: Laboratory investigation.

Methods: The fastball pitching motions of 15 adolescent baseball pitchers, including upper extremity kinematics and kinetics and lead- and trail-leg kinematics, were evaluated while pitching from the mound and flat ground. Student *t* tests were used to determine the differences between the 2 testing conditions.

Results: Maximum external glenohumeral rotation was similar between the 2 conditions ($134^\circ \pm 14^\circ$ mound vs $133^\circ \pm 14^\circ$ flat ground, $P = 0.10$). Ankle plantar flexion of the lead leg at ball release was greater in the flat-ground condition ($-20^\circ \pm 10^\circ$ mound vs $-15^\circ \pm 12^\circ$ flat ground, $P = 0.01$). A statistically significant increase in glenohumeral internal rotation moment (33.6 ± 12.1 Nm mound vs 31.7 ± 11.6 Nm flat ground, $P = 0.01$) and an increase in elbow varus moment (33.3 ± 12.3 Nm mound vs 31.4 ± 11.8 Nm flat ground, $P = 0.02$) was measured when pitching from the mound as compared with flat ground.

Conclusion: Pitching from the mound causes increased stress on the shoulder and elbow of adolescent pitchers as compared with that from flat ground.

Clinical Relevance: The differences in kinematics as well as increased moments in the shoulder and elbow are helpful for pitchers and their coaches to know at the beginning of their season or as they return from injury or surgery. Pitchers in these situations should start their pitching progression on flat ground and progress to the mound.

Keywords: baseball pitching; adolescent athletics; motion analysis

The incidence of shoulder and elbow injury in adolescent baseball pitchers has risen over the past decade.^{3,5,6} While the cause of this is not fully understood, the causes are likely multifactorial. In response to this growing concern, a number of baseball organizations have taken steps to reduce the risk of injury by instituting limits on the number of pitches thrown per game and requiring days of rest between pitching.⁸ Some organizations have also established age limits on the types of pitches thrown, most notably breaking pitches such as the curveball.^{1,2}

Baseball professionals and coaches have long held the belief that pitching from a mound increases stresses on the shoulder

and elbow. Fleisig et al⁵ compared the pitching kinematics and kinetics of 17 college-aged pitchers from a 10-in mound 60 ft, 6 in away from a target with throwing "hard, on a horizontal line" from flat ground toward a target that was 120 to 180 ft away, as well as maximum distance thrown with no constraint on trajectory. There were kinematic differences at foot contact and ball release when the participants threw from the flat ground versus a mound. Also, shoulder and elbow torque in these adult-aged pitchers was greater when performing long throws.⁵

Understanding the kinematic and kinetic differences experienced with pitching from a mound or flat ground could

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The authors reported no potential conflicts of interest in the development and publication of this manuscript.

DOI: 10.1177/1941738113502918

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Figure 1. Illustration of the percentage of the pitching cycle.

assist with injury prevention in adolescent pitchers as well as provide a basis for coaching practices. It was hypothesized that pitching from a mound would result in greater moments in the glenohumeral (GH) and elbow joints.

METHODS

Participants

This study was approved by the Institutional Review Board of the Connecticut Children's Medical Center, and appropriate consent forms were signed by all study participants and their parents before data collection. Inclusion criteria included male athletes between the ages of 9 and 14 years with at least 2 years of pitching experience. Exclusion criteria were current elbow or shoulder injury, prior surgery to the dominant arm, throwing-related injury to the dominant arm within the past 12 months, and any pain or discomfort in the dominant arm during study throwing sessions.

Data Collection

Brief medical and pitching histories were obtained from each participant. Anthropometric measurements were taken, and 38 reflective markers were attached to specific bony landmarks to form 16 body segments. This allowed for the estimation of joint centers and the determination of the 3-dimensional body segment locations.⁵ Two markers were placed on the ball to calculate the ball velocity and aid in the inverse dynamic calculations for upper extremity joint kinetics.

Before data collection, each participant was given an unlimited amount of time to stretch and warm up as he usually did before a game until he felt ready to pitch. Therefore, the warm-up between participants was different in duration and number of pitches thrown. All participants were instructed

to throw fastballs only and pitch toward a target with a designated strike zone 45 ft from the pitching rubber, which is the standard distance for them. The order of pitching surface (mound versus flat ground) was varied (8 participants pitched from the mound condition first). Each participant performed 7 pitches from both flat ground and a 10-in regulation mound. Although pitch outcome in terms of strike versus ball was recorded, motion data were collected from 7 pitches in each condition irrespective of outcome. Motion data were collected using a 12-camera motion system (Vicon 512; Vicon Motion Systems, Los Angeles, California). The 12 cameras were evenly spaced around the circumference of the collection space, and motion data were collected at 250 Hz. The first 3 trials in which all reflective markers were visible for the mound and flat-ground conditions were analyzed for each participant.

Data Analysis

Initial data processing was performed in Workstation (Vicon Motion Systems) to reconstruct the marker data, create the marker trajectories, and generate kinematics and kinetics using the model previously described by Nissen et al.^{6,7} The pitching motion, or pitch cycle (PC), was divided into phases as defined previously⁴ and began with lead-foot contact and ended with maximum GH internal rotation (Figure 1). This process of normalization allowed evaluation of kinematics and kinetics parameters at specific points in the PC across pitching trials, participants, and pitch types. Joint angles were computed using the Euler equations of motion,² and the rotational sequences were chosen to best represent the clinically relevant joint motion. The rotational sequence used for all joint angles was a rotation about the *y*-axis, followed by the *x*- and *z*-axes (sagittal, coronal, transverse), with the exception of the GH joint, which required an *x*, *y*, *z* rotation sequence (coronal,

Figure 2. Elbow angle definition.

sagittal, transverse).⁶ All kinetic data were presented as internal moments. The kinematic angle definitions used were described previously.⁶ The elbow angle was the angle between the forearm and the humerus (Figure 2); the GH angle was the angle between the scapula and humerus.

The raw marker trajectories were smoothened using a fourth-order, zero-lag Butterworth digital filter with a cutoff frequency of 15 Hz. Qualitative evaluations of displacement, velocity, and acceleration data showed that a cutoff frequency of 15 Hz effectively rejected noise without attenuating kinematic or kinetic data. Joint kinetics were computed utilizing custom Matlab (MathWorks, Natick, Massachusetts) code based on standard inverse dynamics techniques.

Lead-foot contact was defined as the moment any part of the foot, toe, or heel contacted the ground. The timing was determined by finding when the z coordinate of the lead toe or heel marker was closest to 0 and when the velocity of these markers was less than -1.5 m/s. Ball release was defined as the instant when the distance between either of the 2 markers on the ball and the marker on the hand was greater than 2 cm. The timing of the PC was normalized from foot contact to maximum GH internal rotation.

Statistical Analysis

Three trials were analyzed for each participant. Three participants had fewer than 3 trials available for statistical analysis because of marker obstruction. In these cases, the available trials were used. The kinematic and kinetic data for each trial for each participant were averaged, creating a single representative trial data set for each of the 15 participants. Data were collected from the individual trial data and averaged to ensure that those variables describing the maximum and minimum were not affected by the temporal parameter. These representative data sets were then averaged across all participants to compare the group mean and standard deviation of the mound versus the flat-ground condition (Tables 1-4). A paired Student t test was used to compare the mound with the flat-ground data for the upper extremity kinematics and kinetics and the lead- and trailing-leg kinematics. A P value of less than 0.05 was considered statistically significant. Clinical significance for kinetic parameters was defined as a minimum difference of 10% between conditions.

RESULTS

This study included 15 male participants (mean age, 12.7 ± 1.3 years; mean weight, 54 ± 15.8 kg [range, 31 to 84 kg]; mean height, 1.62 ± 0.1 m) who had no history of injury to the pitching arm in the past 12 months and reported no current injuries that affected pitching ability. The self-reported pitching experience was 4.7 years (range, 2 to 9 years). Mean ball velocity was 23.5 ± 2.8 m/s (52.3 ± 6.3 mph) when the participants pitched from the mound and 23.3 ± 2.8 m/s (51.8 ± 6.3 mph) when pitching from flat ground ($P = 0.22$). The participants' stride lengths were slightly less when they threw from flat ground (1.12 m) compared with the mound (1.14 m); however, this difference was not statistically significant ($P = 0.06$).

Timing

Differences in the timing of events in relation to foot contact during the PC occurred as a result of a delay in foot contact for the mound condition. The PC was shorter in duration when pitching from the mound (0.19 ± 0.04 s) versus the flat ground (0.21 ± 0.02 s), although this difference was not significant ($P = 0.27$) (Table 1). The relative timing between pitching kinematic events (maximum external GH rotation and maximum GH internal rotation, ball release and maximum GH internal rotation, maximum external GH rotation and ball release) remained the same between both conditions; however, the timing relative to foot contact for maximum external GH rotation and ball release was shorter for the mound condition (Table 1). Therefore, the timing with respect to percentage of PC was also different between the mound and flat-ground conditions, with the percentage of PC of maximum external GH rotation, ball release, and select peak kinematic and kinetic variables occurring earlier for the mound condition (Table 2).

Table 1. Timing for mound and flat-ground pitching, in seconds

	Mound	Flat Ground	<i>P</i>
Pitch cycle time	0.19 ± 0.04	0.21 ± 0.02	0.27
Time between MER and MIR	0.07 ± 0.02	0.07 ± 0.01	0.46
Time between ball release and MIR	0.05 ± 0.01	0.04 ± 0.01	0.11
Time between MER and ball release	0.02 ± 0.01	0.03 ± 0.01	0.34
Time between foot contact and MER	0.12 ± 0.04	0.14 ± 0.02	0.07
Time between foot contact and ball release	0.15 ± 0.04	0.16 ± 0.02	0.07

MER, maximum external glenohumeral rotation; MIR, maximum internal glenohumeral rotation.

Table 2. Mound and flat-ground specific events, in percentage of pitching cycle

	Mound	Flat Ground	<i>P</i>
Ball release	75 ± 7	79 ± 5	0.01
Maximum glenohumeral internal rotation velocity	81 ± 5	84 ± 4	0.01
Maximum elbow extension velocity	72 ± 6	76 ± 4	<0.01
Maximum glenohumeral internal rotation moment	56 ± 8	62 ± 9	0.01
Maximum elbow valgus moment	57 ± 9	63 ± 9	0.02

Table 3. Kinematic data for mound and flat-ground pitching

	Mound	Flat Ground	<i>P</i>
GH rotation angle at MER, deg	−134 ± 14	−133 ± 14	0.10
Maximum GH internal rotation velocity, deg/s	3560 ± 500	3396 ± 400	0.05
Maximum elbow extension velocity, deg/s	1808 ± 192	1742 ± 206	0.01

GH, glenohumeral; MER, maximum external GH rotation.

Kinematics

The GH, elbow, wrist, and forearm kinematics, including flexion, extension, rotation, velocity, and acceleration, were similar in both conditions. Other than peak elbow extension velocity, which had a statistically significant difference between the 2 conditions ($P = 0.01$) (Table 3), no kinematic differences were noted.

In comparing the lower extremity kinematics of both the lead leg and the pedestal (trailing leg) between the 2 conditions, a number of parameters were statistically significant at the hip, knee, and ankle (Tables 3 and 4). Comparison of the hip, knee,

and ankle over the PC are plotted in Figure 3. The shoulder versus GH motions are separated in our model, with the GH motions reported here and previously.⁶

Kinetics

The GH and elbow joint moments were statistically significantly greater for the mound in comparison with the flat-ground condition. Peak GH internal rotation moment was 33.6 ± 12.1 Nm vs 31.7 ± 11.6 Nm ($P = 0.01$) for the mound and flat-ground conditions, respectively. Peak elbow varus moment was 33.3 ± 12.3 Nm vs 31.4 ± 11.8 Nm ($P = 0.02$), respectively.

Table 4. Kinematic data for the lead and trailing leg for mound and flat-ground pitching, in degrees (unless stated otherwise)

	Mound	Flat Ground	P
Stride length ^a	1.14 ± 0.1	1.12 ± 0.1	0.05
Lead-hip flexion-extension at foot contact	65 ± 19	63 ± 16	0.44
Maximum lead-hip abduction velocity ^b	474 ± 70	438 ± 69	0.02
Lead-knee flexion at foot contact	40 ± 15	47 ± 16	<0.01
Lead-ankle plantar flexion at			
Maximum external glenohumeral rotation	-18 ± 10	-12 ± 13	0.01
Ball release	-20 ± 10	-15 ± 12	0.01
Maximum internal glenohumeral rotation	-22 ± 10	-16 ± 12	0.01
Lead-ankle sagittal plane range of motion	17 ± 6	15 ± 8	0.19
Trailing-knee flexion at			
Maximum external glenohumeral rotation	36 ± 10	27 ± 12	<0.01
Ball release	43 ± 12	33 ± 13	<0.01
Maximum internal glenohumeral rotation	54 ± 15	42 ± 17	0.01
Trailing-knee sagittal plane range of motion	27 ± 10	31 ± 8	0.06

^aIn meters.^bIn degrees per second.

DISCUSSION

The internal rotation moment of the GH joint and the elbow varus moment were consistently higher for all 15 participants when pitching from the mound. The differences between the moments of the GH joint and elbow, though small (1.9 Nm, or 6%, greater on the mound), were seen for each participant. Badura et al, at the 25th Annual International Conference of the Institute of Electrical and Electronics Engineers, displayed similar findings and attributed the increased joint moments in the mound condition to the decreased time from initial foot contact to ball release. Badura proposed that the increased moments might be a result of the drop from the top of the mound, which may have affected the rotational and translational accelerations required to release the ball at the proper time and position. In this study, the percentage increase in moment (6% for the elbow and the shoulder) when pitching from the mound was equivalent to the percentage decrease in the timing of specific phases of the PC. This may imply that the reduction in the time available to complete the pitch motion after foot contact may affect the peak moments; however, kinematic profiles and velocities were the same between the 2 conditions.

The differences in the lower extremity kinematics were most apparent at ankle plantar flexion throughout the PC and knee extension at foot contact. In pitching from a mound, the lead foot required greater plantar flexion to achieve flat-foot contact due to the slope of the mound. At the point of lead-foot contact in pitching on the mound, the knee was in greater extension. This occurs because of the “delay” in lead-foot contact when on the mound. The increased knee extension was an additional cause of the increased ankle plantar flexion. This difference, not reported in the work of Fleisig et al, between the 2 conditions may be attributed to the fact that the current study compared *pitching* from a mound and flat ground as opposed to *throwing* from flat ground.⁵ Though subtle, this suggests a difference between pitching and throwing that leads to changes in lower body kinematics.

The timing of peak kinematic and kinetic parameters, as well as maximal GH external rotation and ball release relative to foot contact and the PC, was consistently different between the 2 conditions throughout the PC. This was due in part to delayed lead-foot contact when participants pitched from the mound. The slant of the mound increases the time from the pedestal position to lead-foot contact because the pitcher takes longer to “fall down” the slope of the mound before foot

Figure 3. Lower extremity kinematic plots for the lead leg. Column 1, coronal plane; column 2, sagittal plane; column 3, transverse plane. The black/gray data are flat-ground pitching, and the red/pink data are mound pitching. The bands are 1 standard deviation. Vertical dotted line, maximum external glenohumeral rotation; solid vertical line, ball release.

contact. Therefore, by necessity, the PC, which starts at foot contact, is condensed into a shorter time in pitching from the mound. This explains the majority of the timing differences and may be the source of GH and elbow moment increases.

This work was a laboratory study; therefore, there is an inherent weakness of applying these results to an outdoor game situation. However, each participant's data are compared to only his own, and any similarities or differences seen in the kinematics and kinetics can be considered representative. Furthermore, the participants consistently pitched at the same effort, as determined by pitch velocity. The greatest difference in pitch velocity from one pitch to the next was 1.3 m/s, and the smallest difference was 0.1 m/s (mean, 0.49 ± 0.3 m/s), suggesting that the results were variably affected by participant fatigue.

A power analysis was not performed at the start of the investigation. We hypothesized that a difference existed between the 2 conditions but did not have a specific notion as to the extent of the difference. As in our past studies, a 10% difference was selected as being clinically significant. This value was based on review of previous work⁷ and efforts in the motion analysis laboratory to determine clinically relevant differences.

Injuries to pitchers, especially young adolescent pitchers, continue to increase. The problem is undoubtedly multifactorial and requires work on all fronts. One area of investigation on a more scientific level is the biomechanics of the pitching motion itself. Through working with pitching coaches, the theories have been scrutinized to explain the significant injury rate for these individuals. Many of these theories, established over time, have not been evaluated scientifically.

CONCLUSION

There are differences between the pitching motions for adolescent pitchers on a mound versus flat ground. These differences are most notable in the kinematics of the lower extremity, but a consistent 6% increase in both shoulder and elbow moments was noted when pitching from the mound.

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