

KINETIC DIFFERENCES IN LOWER EXTREMITY BETWEEN BASEBALL PITCHING FROM PITCHER'S MOUND AND FLAT-GROUND

Po-Chieh Chen, Chen-Fu Huang, Chun-Lung Lin and Bo-Jen Ko

Department of physical education, National Taiwan Normal University, Taipei, Taiwan

The purpose of this study was to investigate the kinetic differences in lower extremity between pitching from a mound and flat-ground. A motion capture system and two force plates were used simultaneously to collect the dynamic data of 8 baseball male pitchers. The results revealed that pitching from the mound generated higher propulsive force at the trailing leg as well as greater braking force and vertical ground reaction force at the lead leg ($p < .05$). The trailing leg in the mound condition generated greater knee posterior joint force while the lead leg had greater axial joint force at ankle and knee, as well as greater extension moment at ankle, knee and hip ($p < .05$). It was concluded that pitching from the mound generated higher ground reaction force, which resulted in higher joint forces and moments and thus might increase stresses at lower extremity.

KEY WORDS: biomechanics, pitcher, joint moment.

INTRODUCTION: The lower extremity mechanics are an important part of the pitching motion, which provide the beginning of the kinetic chain and transmit force to the upper segments (Pappas, Zawacki, & Sullivan, 1985). Previous study has demonstrated that the linear wrist velocity at ball release correlated highly with ground reaction force (MacWilliams, Choi, Perezous, Chao, & McFarland, 1998). Previous studies suggested that pitcher should drive toward the target with maximal effort by their lower extremity (MacWilliams et al., 1998; Ryan, Torre, & Cohen, 1977). It was considered that the high levels of force generated from lower extremity might result in great joint forces and loadings.

Pitching from a mound was considered to generate higher ground reaction forces in comparison with pitching from the flat-ground due to the aid of gravity. Some researchers suggested that pitchers with lower extremity injury should perform pitching on the flat-ground before returning to the mound for their rehabilitation (MacWilliams et al., 1998). The kinematics differences between pitching from a mound and flat-ground have been investigated (Nissen, Solomito, Garibay, Öunpuu, & Westwell, 2013). However, little is known about the kinetic mechanism of lower extremity while pitching from a mound or flat-ground. It is important to understand the kinetic differences experienced for assisting with injury prevention in pitchers and also providing a basis for coaching instructions. It was hypothesized that pitching from a mound would cause greater joint force and moments in the lower extremity. The purpose of this study was to investigate the differences in ground reaction forces, joint forces and joint moments of lower extremity between pitching from a mound and flat-ground.

METHODS: Participants: Eight baseball male pitchers (3 left-handers, 5 right-handers; age: 16.8 ± 0.7 yrs, height: 178.4 ± 4.7 cm, weight: 73.0 ± 8.1 kg) with at least 2 years of pitching experience were recruited from national high school tournaments. Exclusion criteria were current throwing-related injury, neuromuscular and musculoskeletal problems within the past 12 months. This study protocol was approved by the local Institutional Review Board and all participants provided written informed consent prior to data collection.

Data collection: A 200 Hz 8-camera motion capture system (VICON MX13+; Oxford Metrics Ltd, Exford, England) was used to capture the 3-dimensional coordinate of retro-reflective markers attached on the subject's body during pitching. Ground reaction force data were collected by two Kistler force plates (9281, 60×40 cm², 9287, 90×60 cm²; Kistler Instrumente AG, Winterthur, Switzerland) at a sampling frequency of 1,000 Hz. Force plates were set up differently in two conditions. In the pitching mound condition, two force plates were attached to two rigid steel frames and embedded in a customized wooden pitching mound. One plate

was set below a pitcher's plate to record the ground reaction force of the trailing leg while the second unit was placed on a 4° tilted rigid steel frame under a sloped section of the pitching mound to record the landing force of the lead leg. The pitcher's plate was in 25 cm height and abutted a sloped section at a 12.5-cm distance that dropped 4° to the level ground. In the flat-ground condition, two plates were embedded in the flat wooden floor with a 10-cm distance between two plates. A total of 32 retro-reflective markers (~8-mm diameter) were attached on the following anatomical landmarks bilaterally: head (located approximately over the temple and two back head markers on the horizontal plane of the front head markers), torso (C7 spinous process, T7 spinous process, clavicle, sternum, and a right back marker), arm (tip of the acromion, lateral humeral epicondyle approximating elbow joint axis, lateral wrist, the proximal extremity of the third metacarpal bone), pelvis (ASIS and PSIS), leg (lateral/medial epicondyle of knee, lateral/medial malleolus), foot (second metatarsal head of mid-foot, fifth metatarsal head, and heel). Four markers were placed on the ball to calculate the ball velocity. Participants were instructed to pitch 10 maximum-effort fastball toward a target (40 cm wide, 60 cm long, and 80 cm height above the ground) with a 3-m distance from the pitcher's plate for each condition in two different days. The first 3 trials in which all reflective markers were visible and ball successfully contacted to the target for each condition were analyzed for each participant.

Data processing: All data were processed and analyzed using Vicon Nexus software. Kinematic and force plate data were low-pass filtered at 13.4 Hz and 20 Hz using fourth-order zero-lag Butterworth filters, respectively. Joint moments were calculated for the lower extremity as the net internal moments by using an inverse dynamic approach. Body segment mass and inertia properties incorporated in the inverse dynamics analyses were based on published anthropometric data (Dempster, 1955). Ground reaction force and joint force were normalized to the body weight, while joint moments were normalized using the body weight × height method (Moisio, Sumner, Shott, & Hurwitz, 2003).

Statistical analysis: A paired *t*-test were used comparing the differences of pitching from a mound and flat-ground with an alpha level of 0.05. All statistical analyses were performed by using SPSS 20.0 software (SPSS Inc., Chicago, IL, USA).

RESULTS: Ball velocity showed no differences between pitching from the mound (115±7 km/h) and flat-ground (115±7 km/h). The maximal velocity of participant's body center of mass (COM) in both vertical and anterior direction was faster in the mound condition than the flat-ground condition during lead leg landing. The braking force and vertical ground reaction force of the lead leg in the mound condition were significant greater than in the flat-ground condition at approximately 108 % and 117% ($p < .05$) (Table 1). The propulsive force of the trailing leg in the mound condition was also significant greater than in the flat-ground condition at approximately 120 % ($p < .05$) (Table 2). The lead leg in the mound condition showed significant increases in axial joint force at ankle and knee joint, greater anterior joint force at hip as well as greater extension moment at ankle and hip but smaller extension moment at knee compared to the flat-ground condition ($p < .05$) (Table 1). Trailing leg had greater posterior joint force at knee and external joint force at hip, but smaller axial joint force at knee ($p < .05$). In addition, there was only hip adduction moment showed increase in the mound condition than the flat-ground condition ($p < .05$) (Table 2).

Table 1. Kinetic Data of Lead Leg (n=8; Mean±SD)

Parameters	Mound	Flat-ground
Max. Vertical COM velocity at foot contact (m/s)*	0.56± .17	0.33± .18
Max. Anterior COM velocity at foot contact (m/s)*	2.37± .15	2.15± .15
Braking force (BW)*	0.84± .90	0.72± .90
Vertical ground reaction force (BW)*	1.81± .12	1.67± .10
Ankle		
Anterior joint force (BW)	0.74± .07	0.74± .06
Axial joint force (BW)*	1.85± .13	1.66± .11
Extension moment (Nm/kg-m)*	0.13± .20	0.09± .10
Knee		
Posterior joint force (BW)	0.92± .15	0.91± .19
Axial joint force (BW)*	1.66± .18	1.46± .15
Extension moment (Nm/kg-m)*	0.07± .10	0.10± .10
Abduction moment (Nm/kg-m)	0.06± .20	0.05± .02
Hip		
Anterior joint force (BW)*	1.74± .20	1.55± .12
Axial joint force (BW)	0.67± .17	0.64± .08
Extension moment (Nm/kg-m)*	0.16± .30	0.11± .30
Internal rotation moment (Nm/kg-m)	0.10± .30	0.09± .20

* $p < .05$

Table 2
Kinetic Data of Trailing Leg (n=8; Mean±SD)

Parameters	Mound	Flat-ground
Propulsive force (BW)*	0.59± .10	0.49± .07
Vertical ground reaction force (BW)	1.19± .08	1.19± .06
Ankle		
Anterior joint force (BW)	0.70± .24	0.65± .23
Axial joint force (BW)	1.06± .09	1.06± .10
Extension moment (Nm/kg-m)	0.08± .01	0.08± .01
Knee		
Posterior joint force (BW)*	0.68± .13	0.57± .10
Axial joint force (BW)*	1.00± .06	1.05± .07
Extension moment (Nm/kg-m)	0.09± .03	0.08± .04
Adduction moment (Nm/kg-m)	0.10± .01	0.10± .02
Hip		
External joint force (BW)*	0.61± .09	0.51± .04
Axial joint force (BW)	0.90± .10	0.94± .09
Adduction moment (Nm/kg-m)*	0.14± .02	0.13± .02

* $p < .05$

DISCUSSION: Pitching from the mound showed greater propulsive force (push-off force) at trailing leg, which resulted in a greater anterior COM velocity during lead leg landing. The higher knee posterior joint force and hip external joint force at the trailing leg were consequent to be generated. Greater propulsive force also required greater braking force at the lead leg during landing to slow motions of lower extremity and transmit forces to upper segments (MacWilliams et al., 1998). There was only hip anterior joint force at the lead leg showing greater in the mound condition than the flat-ground condition. This might indicate that the hip was the major joint to resist the large propulsive force.

The greater vertical COM velocity was also found in the mound condition during lead leg landing, which might be a result of the drop from the top of the mound and would cause the vertical ground reaction force of lead leg to increase. The greater axial joint forces and extension moments of the lead leg were in response to the increased vertical ground reaction force. These results suggested that pitching from the mound required stronger extensor

muscles to reinforce the lead leg for decelerating the upper body, especially at the ankle and hip joints of the lead leg. The ankle extension moment and hip extension moment about the lead leg showed the greatest increase at approximately 145% in comparison with the flat-ground condition. It supported the concept in a previous study that rehabilitation of pitchers with lower extremity injury should preform on the flat-ground before returning to the mound (MacWilliams et al., 1998).

The increased ground reaction force at both legs could generate greater forward and vertical momentum and transfer to upper limbs into a faster ball velocity (Putnam, 1993). The ball velocity, however, showed no differences between the mound and the flat-ground conditions. Similar finding was also observed in a previous study (Fleisig, Andrews, Dillman, & Escamilla, 1995; Nissen et al., 2013). Researchers demonstrated that pitching from the mound and flat-ground had similar ball velocity and stride length, but different kinematic data in pitching motion and ball releasing time (Nissen et al., 2013). These differences might affect the kinetic chain to transfer momentum into ball velocity, which need further study to investigate the kinematic differences of the whole body using a complex multisegmental dynamic model.

CONCLUSION: Pitching from the mound generated higher ground reaction force, which resulted in higher joint forces and joint moments at both lead leg and trailing leg. This study suggested that pitcher with lower extremity injury was better to perform pitching on the flat-ground before returning to the mound during their rehabilitation periods.

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