KINEMATIC AND KINETIC COMPARISON BETWEEN AMERICAN AND JAPANESE COLLEGE PITCHERS

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The purpose of this study was to investigate the kinematic and kinetic differences between American and Japanese baseball pitchers. Kinematic and kinetic data were analyzed for 11 American pitchers (21±2 y, 190±6 cm, 93±9 kg) and 11 Japanese pitchers (21±1 y, 180±6 cm, 81±7 kg) using 3D motion capture (480 Hz). The American pitchers generated faster ball velocities and increased throwing arm kinetics. At foot contact, the Japanese pitchers had longer stride length, greater shoulder external rotation, and greater elbow flexion. At the instant of maximum shoulder external rotation, American pitchers had less elbow flexion and greater pelvis rotation velocity. The kinematic and kinetic differences seen here may suggest a difference in pitching styles or training between cultures.

KEYWORDS: pitching, throw, biomechanics, performance, fastball

INTRODUCTION: Baseball is popular throughout the world and many believe pitching mechanics are taught differently in various countries. Understanding mechanical differences between cultures would benefit coaches and trainers to develop training programs and monitor injury risks. Moreover, understanding differences in pitching mechanics from country to country could lead to developing strategies for winning in international competition. Although there is a wealth of research from different countries on pitching mechanics, only two investigations have compared international pitchers. Escamilla, Fleisig, Zheng, Barrentine, and Andrews (2001) manually digitized video from two synchronized cameras (120 Hz) during the 1996 Olympics and compared pitchers from 9 different countries. In a study comparing American and Korean pitchers, Escamilla, Fleisig, Barrentine, Andrews, and Moorman (2002) used 3D motion analysis (200 Hz) to examine pitching differences between the two groups. Two countries with perhaps the highest level of play, based upon success in international competition and the salaries in professional leagues, are the United States and Japan. However, to date, no studies have specifically examined differences between American and Japanese pitchers. Therefore, the purpose of this study was to compare kinematic and kinetic differences between American and Japanese college baseball pitchers.

METHODS: Twenty-two healthy college pitchers with comparable skill level, 11 American (age 21±2 yrs, height 190±6 cm, and weight 93±9 kg) and 11 Japanese (age 21±1 yrs, height 180±6 cm, and weight 81±7 kg) participated in this study. Each participant was born and raised in his respective country and trained for baseball solely in that country. Kinematic and kinetic data were collected at 480 Hz using an eight-camera 3D motion capture system (Motion Analysis, Santa Rosa, CA, USA). The global coordinate system was set up so that the positive Z was vertically upward, the X direction was perpendicular to Z and positive pointed towards home plate, and Y was the cross product of Z and X.
Testing was conducted in the United States, in an outdoor facility on an artificial mound. On the testing day, the participant was allowed unlimited time to perform a warm-up routine of choice and then pitched eight maximum effort fastballs to a catcher at home plate regulation distance away from the pitching rubber (18.4 m). The participant pitched at his own, set pace. Ball velocity was recorded with a radar gun (Stalker Sports Radar, Plano TX, USA).
The raw XYZ coordinates were filtered through a low-pass 14 Hz Butterworth filter. A model was built in Skeleton Builder and Kintools RT (Motion Analysis Corp., Santa Rosa, CA, USA) to compute relative segment rotations and translations of the upper trunk, pelvis, upper

arms, forearms, thighs, shanks, and feet. Kinematic data were extracted at foot contact (FC), maximum shoulder external rotation (ER), and ball release (BR) - using MATLAB (The MathWorks, Natick, MA, USA). Pelvic rotation was defined as 90° when the pelvis was aligned with the global X direction and 0° when the anterior pelvis was facing home plate (global Y). Upper trunk rotation was defined as the angle between the pelvis and upper trunk in the transverse plane. Upper trunk lateral flexion was calculated as the angle between the pelvis and upper trunk in the coronal plane and defined as 0° when the upper trunk line was parallel to the pelvic line and positive when tilted toward the glove.
Participant means were used to compute group means and standard deviations for 21 kinematic and 11 kinetic variables. Unpaired t-tests were used to compare differences between groups. The alpha level was set at 0.05. Analysis was conducted in R, version 3.1.2 (R Foundation for Statistical Computing, Vienna, Austria).

Table 1
Kinematic differences between American and Japanese college pitchers (M±SD)

	American	Japanese	p value
Foot contact			
Stride length (%height)	76±5	84±6	0.003*
Elbow flexion (°)	88±21	115±14	0.002*
Shoulder abduction (°)	81±9	80±11	0.839
Shoulder horizontal abduction (°)	30±15	22±15	0.256
Shoulder external rotation (°)	40±26	72±18	0.003*
Lead knee flexion (°)	51±11	52±8	0.816
Pelvis rotation (°)	62±12	52±11	0.055
Upper trunk rotation (°)	38±12	38±12	0.940
Maximum shoulder external rotation			
Elbow flexion (°)	93±7	102±8	0.015*
Shoulder horizontal adduction (°)	8±6	10±11	0.696
Shoulder external rotation (°)	152±10	148±6	0.279
Pelvis rotation (°)	-9±6	-1±5	0.001*
Upper trunk rotation (°)	15±10	0±13	0.008*
Maximum Segment Rotational Velocity			
Maximum pelvis velocity (°/s)	751±109	664±57	0.029*
Maximum trunk velocity (°/s)	748±146	711±311	0.727
Ball release			
Elbow flexion (°)	27±4	26±6	0.764
Shoulder horizontal adduction (°)	0±6	5±13	0.207
Lead knee flexion (°)	38±16	49±11	0.080
Trunk forward flexion (°)	11±8	22±12	0.024*
Trunk lateral flexion (°)	-33±8	-25±11	0.052*
Ball velocity (m/s)	39±1	35±2	<0.000*

Note: * $p < 0.05$

RESULTS: The American pitchers were heavier ($p < 0.00$) and taller ($p < 0.00$) than the Japanese pitchers, but there were no differences in age between the two groups ($p=0.669$). There were several kinematic differences between American and Japanese pitchers (Table 1). At FC the Japanese pitchers had a longer stride length, greater elbow flexion, and greater shoulder ER. At the instant of maximum shoulder ER, the American pitchers had less elbow flexion, greater pelvis rotation, greater trunk rotation, and greater pelvis rotational velocity. At the instant of BR, the American pitchers had greater trunk lateral flexion and ball velocity while and the Japanese pitchers had greater trunk forward flexion. American pitchers had greater shoulder and elbow kinetics compared to the Japanese pitchers (Table 2); however, when the kinetics were normalized to body weight and height minimal differences were found (Table 3).

DISCUSSION: The kinematic differences between the two pitching groups suggest pitching mechanics differ between Japanese and American pitchers. Moreover, the differences

observed may have contributed to the greater ball velocity seen in the American pitchers. The increased throwing arm kinetics in the American pitchers were expected as they were heavier, taller, and threw the ball faster compared to the Japanese pitchers. When normalized for body weight the elbow proximal force was still greater in the American group. The high kinetics experienced during a pitch may predispose the American group to increased risk of injury compared to the Japanese group.

Table 2.
Kinetic differences between American and Japanese college pitchers (M±SD)

	American	Japanese	p value
Arm cocking			
Shoulder rotation torque (Nm)	93±11	67±12	0.000*
Shoulder horizontal abduction torque (Nm)	104±18	78±15	0.001*
Shoulder superior force (N)	252±48	205±79	0.014*
Elbow varus torque (Nm)	86±9	66±13	0.000*
Elbow medial shear force (N)	296±51	271±57	0.277
Arm acceleration			
Shoulder anterior shear force (N)	437±75	380±52	0.050*
Elbow anterior shear force (N)	393±45	330±71	0.022*
Elbow flexion torque (Nm)	70±6	52±10	0.000*
Arm deceleration			
Shoulder adduction torque (Nm)	60±30	48±14	0.246
Shoulder proximal force (N)	1019±128	816±179	0.006*
Elbow proximal force (N)	1023±104	769±142	0.000*

Note: * $p < 0.05$

At FC, the American pitchers had 28° less ER compared to the Japanese pitchers. It has been reported that increased shoulder rotation at FC is linked to increased kinetics at both the shoulder and elbow (Aguinaldo & Chambers, 2009; Anz et al., 2010). Surprisingly, the Japanese pitchers had smaller kinetics even though they had greater shoulder ER at FC. However, because the American pitchers threw faster the differences in kinetics might have been masked. Future research should match pitchers by ball velocity to investigate the effects of mechanics on normalized kinetics between the two groups. When comparing MER there were no differences between the two groups; however, the Americans moved their arm through a greater range of motion (ROM) during the arm cocking phase (113° compared to 76°). It is possible greater shoulder excursion from FC to BR contributed to greater ball velocity seen in the American pitchers.

While there were no differences between lead knee flexion at FC and BR between the two groups, total knee excursion (from FC to BR) was greater in the American pitchers (13°) compared to the Japanese (3°). Greater lead knee extension is thought to help the pelvis and upper extremities accelerate forward and aid in the transfer of energy through the trunk to the throwing arm. Therefore, we would expect to see greater trunk forward flexion at BR in the American pitchers; however, the Japanese pitchers had greater trunk flexion at BR.

Increased stride length has been associated with increased ball velocity (Montgomery & Knudson, 2001; Escamilla et al., 2007). However in the current study, Japanese pitchers had a longer stride length (84%) and slower ball velocity compared to the American pitchers (76%). Escamilla et al. (2001) reported similar findings in stride length and ball velocity (Japanese 86%, 37 m/s; and American 80%, 39 m/s). Conversely, when comparing college and professional pitchers, there were no reported differences in stride length between the low velocity group (33 m/s) and the high velocity group (38 m/s) (Matsuo et al., 2002). The increased stride length in Japanese pitchers may have attributed to a longer stride phase and subsequently caused the pitchers to open their lower body for greater pelvis rotation towards home plate. Additionally, the increased stride phase may allow the throwing arm additional time for greater shoulder rotation and increased elbow flexion to occur prior to FC as seen in the Japanese pitchers. Increased shoulder rotation and elbow flexion at FC also reduces the joint excursions that could be obtained by the Japanese pitchers (i.e. less 'whip

factor') through delivery. This change in timing and reduced joint excursions may have attributed to the Japanese pitchers reduced kinetic chain efficiency, thus resulting in slower ball velocity. At FC, the American pitchers had a 'closed' pelvis which provided a greater arc for the pelvis to be accelerated before BR, resulting in greater pelvis rotational velocity. While not statistically significant, pelvis orientation at FC approached significance (p=0.055) and we believe had a contribution to the increased pelvis rotational velocity seen in the American group. In accordance with the kinetic chain, increased pelvis rotational velocity allows for increased momentum to be transferred to the trunk, throwing arm, and ultimately the ball.

Table 3
Normalized kinetic differences between American and Japanese college players pitchers pitchers (M±SD)

	American	Japanese	p value
Arm cocking			
Shoulder rotation torque (% BW_BH)	5±1	5±1	0.011*
Shoulder horizontal abduction torque (%	104±18	5±1	0.078
Shoulder superior force (% BW)	28±4	25±8	0.344
Elbow varus torque (% BW_BH)	5±1	5±1	0.084
Elbow medial shear force (% BW)	33±5	34±6	0.793
Arm acceleration			
Shoulder anterior shear force (%B W)	49±6	48±5	0.664
Elbow anterior shear force (% BW)	44±3	41±8	0.298
Elbow flexion torque (% BW_BH)	4±0	4±1	0.009*
Arm deceleration			
Shoulder adduction torque (% BW_BH)	3±2	3±1	0.903
Shoulder proximal force (% BW)	114±11	102±17	0.061
Elbow proximal force (% BW)	114±9	96±13	0.001*

Note: * p < 0.05. Forces were normalized by percent body weight (% BW) and torques were normalized by percent body weight times body height (% BW_BH)

CONCLUSION: Differences were observed between the American and Japanese college pitchers. It is possible these differences stem from differences in coaching and training, but more research on coaching techniques from both countries is needed to understand if these mechanical changes are due to training. Shoulder and elbow torques and forces were greater in the American pitcher which potentially help generate ball velocity, but increased throwing arm kinetics may also lead to an increased risk of injury.

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