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Biomechanical Comparison Between Elite Female and Male Baseball Pitchers

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The purpose of the current study was to identify the biomechanical features of elite female baseball pitching. Kinematics and kinetics of eleven elite female baseball pitchers were reported and compared with eleven elite male pitchers. Results suggested that females share many similarities with males in pitching kinematics, with a few significant differences. Specifically, at the instant of stride foot contact, a female pitcher had a shorter and more open stride and less separation between pelvis orientation and upper torso orientation. From foot contact to ball release, a female pitcher produced lower peak angular velocity for throwing elbow extension and stride knee extension. Ball velocity was lower for the female. Foot contact to ball release took more time for a female pitcher. Maximal proximal forces at the shoulder and elbow joints were less for a female pitcher.

Keywords: pitching, gender differences, kinematic, kinetic

For more than a hundred years, baseball has been considered primarily a sport for men. However, many people may be surprised to know that women have participated in baseball for almost as long as the history of baseball itself. According to Berlage (1994), the first documented amateur women's baseball team can be traced to 1867 at Vassar College. Although there is a long history of participation, to most people, female baseball has only been played during the era from 1943 to 1954, as shown in the movie *A League of Their Own*. After this time, female baseball then returned to amateur status. With decreased media attention, female baseball became obscure to the public, and thus lost its popularity for 40 years.

However, female baseball is beginning to flourish again. According to the National Federation of State High School Associations, there were 1,382 high school girls participating in varsity girl's baseball in 94 programs in the United States in the 2005-06 school year (2005-06 High School Athletics Participation Survey, 2006). More and more female baseball teams and leagues are appearing in the United States. They play a short regular season, and many of the best teams gather annually to play in several national championship series.

Since 2004, there has been a biennial Women's World Cup championship hosted by the International Baseball Federation (IBAF). As the IBAF has started to promote female baseball internationally, the participation of females in baseball is expected to increase significantly throughout the world. As the number of participants and competitive opportunities continue to increase, the demand for evidence-based knowledge to improve performance, minimize injury, and develop training methods specific to females is needed. However, although much research exists about the pitching biomechanics of male baseball pitchers, very little is known about the pitching biomechanics of baseball as performed by females.

Among all of the defensive positions in baseball, the pitcher is the most crucial. Baseball pitching is also one of the most rapid human motions ever documented (Fleisig et al., 1996a). Further, this high-demanding motion is executed repeatedly during practices and competitions, which may relate to increased risk of overuse injury (Lyman et al., 2002). Inappropriate pitching motions may also be related to higher risk of injury (Fleisig et al., 1999). The application of biomechanical concepts has been used to understand not only pitching techniques and motions (kinematics) and the causes of movement (kinetics), but also how to exploit the underlying mechanics to improve performance. An understanding of the mechanics of pitching injury also is emerging. Even though there is a body of published bio-

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mechanical research in baseball pitching, almost all of the studies used male pitchers as participants.

Compared with males, females have smaller body size and muscle mass, less body height and weight, shorter limbs, and decreased absolute muscle strength (Wells, 1991). Therefore, female athletes generate less muscle torque and power, and the maximum muscle force output occurs later during muscle contraction (Riegger-Krugh & LeVeau, 2002). Because of these morphological and physiological differences, the hypothesis of the current study was that female baseball pitchers display different kinematics and produce lower kinetics compared with their male counterparts. An understanding of this will ultimately lead to more appropriate training and coaching for female pitchers. To test the hypothesis, we quantified the biomechanical features of fastball pitches performed by skilled female pitchers at a national-level baseball competition, and compared our outcomes to those displayed by male pitchers at comparable level.

Methods

Eleven female baseball pitchers were videotaped in a national competition of female baseball. To compare and contrast, eleven male age-matched participants were selected from 48 pitchers previously videotaped during Olympic competition, from the database of the American Sports Medicine Institute (ASMI). Data for the 48 Olympic pitchers were previously published, and grouped by nationality (Escamilla et al., 2001). We believed that the players of both gender groups represent elite amateur baseball pitchers. The participants' physical characteristics were provided to the public for the competition events, and are presented in Table 1.

To record the female pitching motions during the games, one high-speed video camera (Pulnix TM-640, JAI Pulnix Inc., San Jose, CA; 120 Hz, shutter speed = 1/500 s) was located between home plate and first base, and the other between home plate and third base. Similar two-camera settings have been widely used in previous field studies (Escamilla et al., 2001; Feltner, 1989; Murray et al., 2001; Pappas et al., 1985; Werner et al., 2002). A radar gun (Stalker Sports, Applied Concepts Inc., Plano, TX) located behind home plate was used to record the pitched ball velocity. The experimental setup

Table 1 Physical Characteristics of Females and Males Participants

	Female (n = 11)	Male (n = 11)
Right or Left-handed	R = 10, L = 1	R = 9, L = 2
Body Height (cm)	169 ± 8	187 ± 9
Body Mass (kg)	74.2 ± 17.2	84.1 ± 7.6
Age (yr)	29 ± 10	26 ± 5

used for collecting the male pitching data were very similar (Escamilla et al., 2001). A 25-point Peak calibration frame (Peak Performance Technologies Inc., Englewood, CO) was set on the pitcher's mound before or after the day's recording session, defining a calibration space of approximately 2.2 m × 1.6 m × 1.9 m, which was sufficient to cover the locations of the pitcher's body during pitching. The same model of high-speed cameras and calibration frame were used for collecting the male data, but the locations of the cameras were slightly different (one camera behind home plate, the other located at third base), and the shutter speed was set at 1/1000 s. These differences were due to the different designs of the baseball stadium and weather conditions during videotaping. However, it is believed that these differences did not affect the validity of the locations of the reconstructed three-dimensional coordinates. A different model of radar gun (Jugs Tribar Sport, Jugs Pitching Machine Co., Tualatin, OR) was used capture the male pitchers' ball velocities. A pilot test performed in the ASMI laboratory ensured that the two guns reported either the same or varied within 1 mph, in the females' ball velocity range.

For each participant, the fastest pitch videotaped was analyzed to represent the pitcher's fastball mechanics (Feltner & Dapena, 1986; Fleisig, 1994). For female data, 14 points were manually digitized (Escamilla et al., 2001; Feltner, 1989; Murray et al., 2001; Pappas et al., 1985; Werner et al., 2002) for both sides of body: the estimated joint centers of shoulders, elbows, wrists, hips, knees, ankles, and the roots of shoe tongues (approximately the position of the third metatarsals), to reconstruct three-dimensional coordinates using Peak Motus software (v. 9.0, Vicon, Lake Forest, CA). For male pitchers, the video had been manually digitized and reconstructed before following the same protocol but using a previous version of the same software (Peak5, Peak Performance Technologies Inc., Englewood, CO). The mean square error for three-dimensional reconstruction accuracy was 0.008 m. To test the accuracy and reliability of the digitizing process, seven video fields during the fastest-moving arm cocking and acceleration phase (Figure 1) from two pitching trials were redigitized three weeks after the initial digitizing. The redigitized trials yielded differences of less than 0.014 m for the humerus and radius lengths compared with the originally digitized trials. The interdigitizer reliability also had been established with a <0.02-m difference of comparing digitized segment lengths (Escamilla et al., 2001). The reconstructed three-dimensional coordinates were filtered using a fourth-order low-pass Butterworth filter at the cut-off frequency of 13.4 Hz. This cut-off frequency has been used previously to reduce the digitizing noise for baseball pitching, without losing data (Escamilla et al., 2001, Fleisig, 1994). The filtering process was performed with EVa Real-Time software (v. 5.0, Motion Analysis Corp., Santa Rosa, CA).

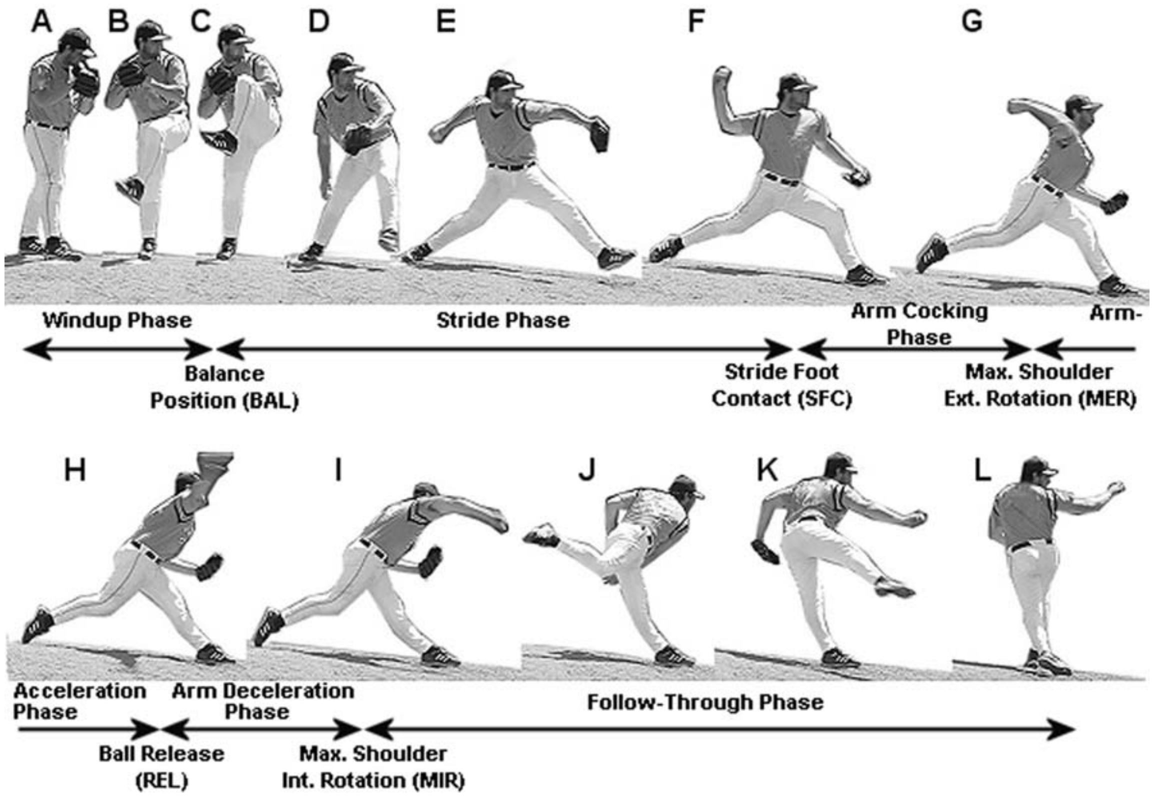

Figure 1 — The critical events and phases in baseball pitching motion.

Baseball pitching was divided into six phases by five critical events (Fleisig et al., 1999), as shown in Figure 1. From the event of stride foot contact to maximum internal rotation, 28 kinematic, 9 temporal, and 4 kinetic variables were selected for the current study. To calculate these variables and decide critical events, the methodology of Fleisig (1994) was followed, using customized Matlab (v. 7, MathWorks Inc., Natick, MA) programs. Kinematic variables selected (Figure 2) described foot positions, trunk orientations, shoulder and elbow angles, and angular velocities. Temporal variables described total time elapsed during pitching, defined as from foot contact to ball release, and the timing of the maximum angles and angular velocities occur during pitching. Kinetic variables (Figure 3) described the net forces and torques applied at the throwing shoulder and elbow. Equations of Zatsiorsky (2002) were used to generate anthropometric values for female pitchers, for the calculation of kinetic variables using inverse Newtonian dynamic methodology.

Gender differences were tested for each variable using Student's *t* tests (SPSS version 11.5, SPSS Inc., Chicago, IL) with significance level set at $p < .05$. Four kinematic variables for females at balance position were reported only for reference and not run into statistical tests, as data for males were not available.

Results

Females displayed significantly slower ball velocity (Table 2). Six of 24 kinematic variables showed significant differences between genders (Table 2). Specifically, at the time of stride foot contact, the female pitchers had a shorter stride length, more open stride foot placement (Figure 2, open: positive value; closed: negative value) and less upper torso/pelvis separation. The female pitchers produced less elbow extension velocity and stride knee extension velocity, and had more stride knee flexion at the time of ball release. Two of the nine temporal variables reached significance level (Table 3). Specifically, the time from stride foot contact to ball release was greater for the females. In addition, stride knee extension velocity peaked after ball release for the females but before ball release for the males.

The males' kinetic variables we calculated were with high variations. For example, the maximum shoulder proximal force for males was 1231 ± 419 N. Although these males' mean values were comparable to those previous published (Feltner & Dapena, 1986; Fleisig et al., 1995, 1999, 2006), and variations for kinetic variables over 200 N or 55% of mean values have been reported in some studies (Fleisig et al., 1996c, 1996d), these numbers could not pass Levene's test for

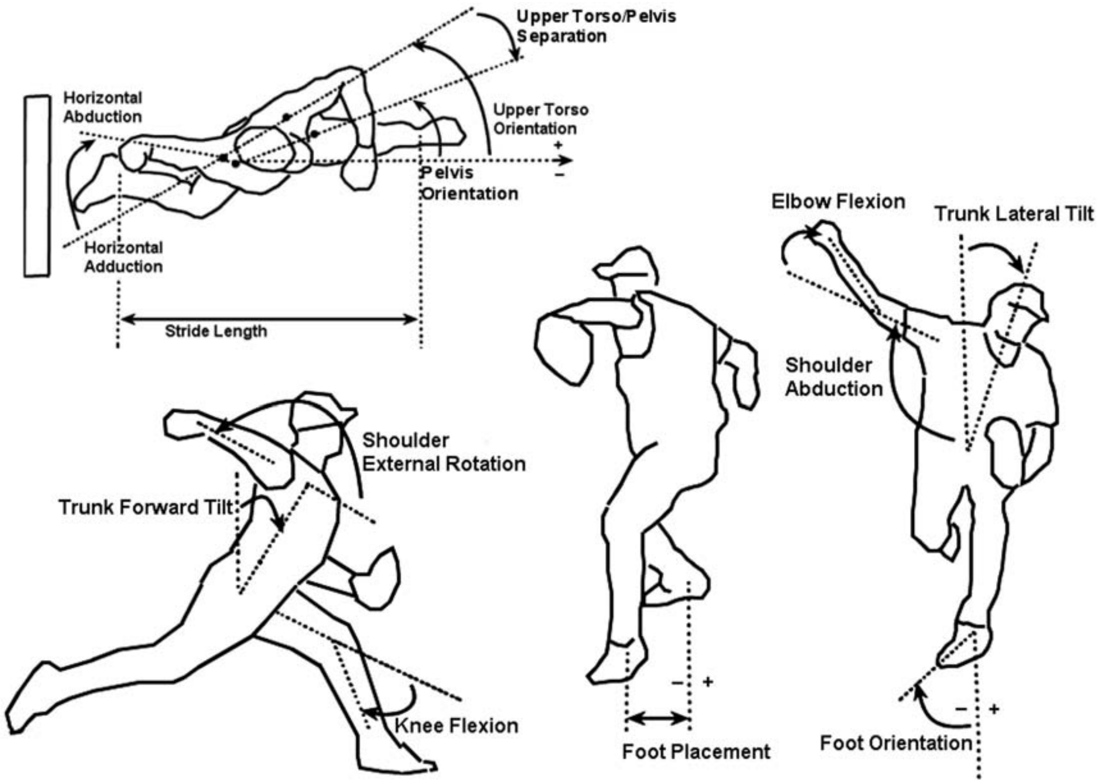

Figure 2 — Definition of kinematic variables.

equal variance to satisfy the assumption of *t* test. Instead, we list previously published male values to compare with our kinetic numbers of females (Escamilla et al., 2002; Fleisig et al., 1995, 1999).

Discussion

Kinematic values for males were generally comparable to previous studies (Dillman et al., 1993; Elliott et al., 1986, 1998; Fleisig et al., 1999, 1996b, 1996c, 1996d). Kinematic differences between genders might appear very early, at the balance position. Females rotate their pelvis and upper torso considerably less than males, reported by Stodden et al. (2001) (−30 ± 13° and −36 ± 13°, respectively). Female pitchers lifted their stride knee only 3.2 ± 13.9 cm above the hips, compared with 33.1 ± 4.1 cm reported for males by Elliott et al. (1986). These differences might be due to less muscle strength for females to rotate the trunk back and keep the balance with a high leg kick, and might lead to subsequent differences. For example, at foot contact, the significantly shorter stride for females might be the consequence of that lower leg kick creating less potential energy to be used. The shorter stride might also indicate less strength in the lower body.

Theoretically, the less closed foot placement for the female pitcher may have been related to more open pelvis orientation at stride foot contact. However, pelvis orientation (defined in Figure 2 as “Upper torso orientation” plus “Upper torso/pelvis separation”) was approximately the same for both genders, averaging 35° (−5 + 40) for females and 39° (−17 + 56) for males. Therefore, some other factors might have contributed to the more open foot placement in females, such as greater stride hip internal rotation, greater stride knee valgus, or both. Unfortunately, with the simple digitizing model of human body in the current study, it is hard to identify these potential factors. A more complex model with three-dimensional segmental definitions of lower body with external markers attached to participants’ body would help to address this issue.

One of the most important variables in pitching was the separation angle between pelvis and upper torso. A separation between the pelvis and upper torso is a sign of mature throwing mechanics (Stodden et al., 2006). The sequence of pelvis rotation followed by upper torso rotation produces upper torso/pelvis separation, and then followed by high activation of the abdominal oblique muscles to reduce the separation (Watkins et al., 1989). Less separation for females allows less stretch for the abdominal oblique to store elastic energy and

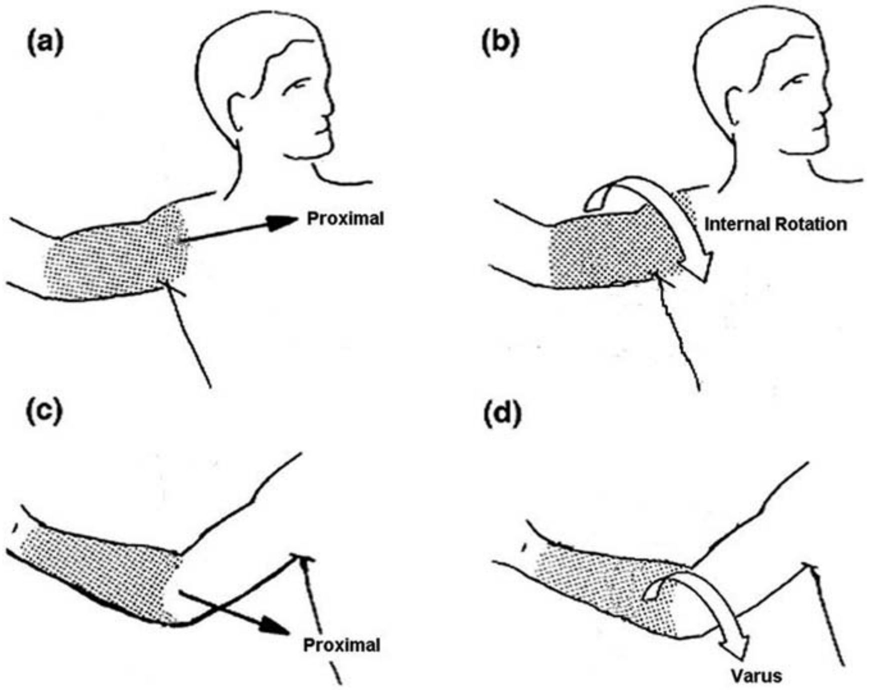

Figure 3 — Definition of kinetic variables: (a) forces applied by the trunk to the upper arm at the shoulder; (b) torques applied by the trunk to the upper arm about the shoulder; (c) forces applied by the upper arm to the forearm at the elbow; (d) torques applied by the upper arm to the forearm about the elbow.

contribute to the rapid rotation of upper torso (Fleisig et al., 1996a). Surprisingly, with less "twist" between the pelvis and upper torso, females produced peak upper torso angular velocity comparable to that of males. Females had their maximum shoulder external rotation angle comparable to males, which is a predictor of good ball velocity (Matsuo et al., 2001), but also an indicator of potential shoulder injury (Fleisig et al., 1995).

In the current study, females were found to have significantly less elbow extension angular velocity than males. Females generated 31% less elbow velocity, which was similar to Atwater's classic work comparing males (3,000 °/s) and females (2,000 °/s) throwing softballs (Atwater, 1970). Elbow extension is produced not only passively from the centrifugal force of upper torso rotation but also actively by elbow extensors. Evidence includes the fact that baseball pitchers with triceps paralyzed could only generate 80% of the original ball velocity (Roberts, 1971). As triceps was found highly active in the arm acceleration phase (Jobe et al., 1984), the lower elbow extension angular velocity in females could be a sign of insufficient triceps strength.

Although there were significant differences between the genders in elbow angular velocity, there was surprisingly no difference in shoulder internal rotation angular velocity. However, a joint's contribution to ball linear velocity is the product of the joint angular velocity and the radius of rotation. Assuming the females had proportionally shorter arms due to shorter body height (Table 1), comparable shoulder angular velocity produced less ball linear velocity.

When pitching, the stride leg absorbs the impact of contact with initial knee flexion, and then stops the forward movement of the lower body and provides a firm support for the body weight shifting forward with moderate knee extension. Next, pitchers with higher ball velocity rapidly extend the stride knee as they accelerate their arm through ball delivery, bracing the body and converting the linear momentum of the whole body generated during the stride into angular momentum of trunk flexion (Matsuo et al., 2001). Overall, the knee flexion angle should be less at the instant of ball release than at stride foot contact, and the knee should be extending at ball release. The male pitchers in the current study all followed this two-task pattern (and Figure 4 shows an example knee flexion pattern for male pitchers). In contrast, 8 of our 11 female pitchers had their stride knees more flexed at ball release than at stride foot contact. Some female pitchers moderately extended their stride knee after the initial, but did not extend the knee through arm acceleration, and started flexing or maintained the angle instead. Some female pitchers were even not able to perform the moderate knee extension to stop the forward movement of their lower body, but kept flexing their knee throughout the pitch (see Figure 4 for example). At the ball release, 4 of the 11 female pitchers were flexing their stride knee. That lack of knee extension for females indicates that too much energy is absorbed in

Table 2 Kinematic Comparison Between Genders

Variable	Female	Male	*p*-value
Balance Position			
Stride Knee Max Height (%Body Height)	50 ± 9	N/A	N/A
Stride Knee Max Height (cm above stride hip)	3.2 ± 13.9	N/A	N/A
Upper Torso Orientation (°)	–24 ± 13	N/A	N/A
Pelvis Orientation (°)	–18 ± 9	N/A	N/A
Stride Foot Contact			
Stride Knee Flexion (°)	50 ± 14	55 ± 16	0.464
Stride Foot Placement (m)	–0.01 ± 0.14	–0.14 ± 0.10	0.018*
Stride Length (%Body Height)	70.3 ± 8.4	78.4 ± 6.7	0.021*
Stride Foot Orientation (°)	–5 ± 19	–5 ± 13	0.965
Upper Torso Orientation (°)	–5 ± 21	–17 ± 14	0.144
Upper Torso/Pelvis Separation (°)	40 ± 15	56 ± 15	0.018*
Shoulder Abduction (°)	99 ± 13	91 ± 7	0.082
Shoulder Horizontal Abduction (°)	19 ± 18	22 ± 15	0.666
Shoulder External Rotation (°)	59 ± 35	54 ± 24	0.679
Elbow Flexion (°)	98 ± 25	97 ± 26	0.897
Arm Cocking Phase			
Maximum Upper Torso Angular Velocity (°/s)	1190 ± 240	1250 ± 200	0.519
Maximum Shoulder External Rotation (°)	180 ± 10	171 ± 8	0.095
Arm Acceleration Phase			
Maximum Shoulder Internal Rotation Angular Velocity (°/s)	5630 ± 1590	5850 ± 2400	0.807
Maximum Shoulder Horizontal Adduction Angular Velocity (°/s)	660 ± 250	750 ± 240	0.384
Maximum Elbow Extension Angular Velocity (°/s)	2060 ± 370	2980 ± 740	0.001*
Ball Release (REL)			
Stride Knee Flexion (°)	62 ± 14	41 ± 19	0.008*
Stride Knee Extension Angular Velocity (°/s)	80 ± 190	320 ± 180	0.007*
Trunk Forward Tilt (°)	28 ± 7	33 ± 13	0.252
Trunk Lateral Tilt (°)	16 ± 11	25 ± 10	0.061
Overall Upper Torso Rotation (°)	118 ± 25	121 ± 19	0.648
Throwing Shoulder Abduction (°)	89 ± 6	90 ± 10	0.750
Throwing Shoulder Horizontal Adduction (°)	9 ± 8	7 ± 15	0.688
Throwing Shoulder External Rotation (°)	136 ± 14	122 ± 29	0.139
Throwing Elbow Flexion (°)	31 ± 10	27 ± 7	0.247
Ball Velocity (m/s)	26.8 ± 1.5	36.3 ± 1.8	<0.001*

Note. N/A = not available
*Female and male groups significantly different ($p < 0.05$).

the leg instead of transferred up to the trunk. In addition, the less knee extension angular velocity for females suggests that their quadriceps muscles of their stride leg may not be strong enough to firmly stop and brace the body.

The timing of maximum knee extension angular velocity was significantly different between genders. Stride knee extension angular velocity peaked before ball release for males, but after ball release for females. Considered with the fact that females flex their knee throughout the arm cocking and acceleration phases, it seems that females use their stride leg the most after they throw the ball to regain their balance, not to brace their body to facilitate pitching.

Although relative timings of females were very similar to males, female pitchers spend significantly

Table 3 Temporal Comparison Between Genders

Variables	Female	Male	*p*-value
Time from SFC to REL (seconds)	0.163 ± 0.026	0.141 ± 0.021	0.048*
Percent of Time Complete from SFC to REL			
Pelvis Angular Velocity (%)	33 ± 26	33 ± 32	0.997
Upper Torso Angular Velocity (%)	56 ± 17	42 ± 19	0.075
Trunk Forward Angular Velocity (%)	104 ± 27	89 ± 12	0.111
Knee Extension Angular Velocity (%)	120 ± 24	98 ± 26	0.050*
Shoulder External Rotation (%)	76 ± 10	81 ± 5	0.169
Shoulder Internal Rotation Angular Velocity (%)	107 ± 4	105 ± 7	0.309
Elbow Flexion (%)	39 ± 18	30 ± 22	0.274
Elbow Extension Angular Velocity (%)	95 ± 5	93 ± 4	0.478

*Female and male groups significantly different ($p < 0.05$).

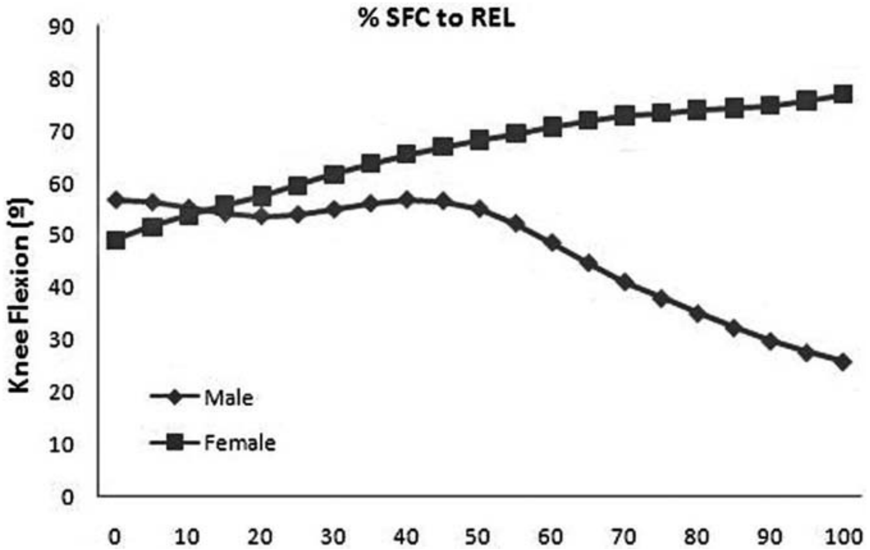

Figure 4 — Example knee flexion/extension patterns from stride foot contact to ball release of a female and a male pitcher.

longer time to accomplish the pitching process (defined from foot contact to ball release). The time spent by males was similar to those reported in most previous works (Escamilla et al., 1998; Fleisig et al., 1995, 1999; Stodden et al., 2005), indicating that the longer time females spent could be a critical difference between genders. The longer time elapsed may lead to less efficient energy transfer, which could partially explain that female pitchers, compared with males, generated comparable shoulder internal rotation angular velocity but 31% less elbow extension angular velocity, besides the strength differences discussed previously.

Ball velocity was significantly less for the female pitchers. As mentioned above, this difference might be related to the less elbow extension velocity, less knee extension velocity, and shorter segment lengths.

The decreased joint velocities and ball velocity for the females likely were produced by lower joint kinetic values. The percentages of kinetic values between genders were similar to those found comparing male and female tennis serve (Elliott et al., 2003). Near the instant of maximum shoulder external rotation, females generated their maximum elbow varus and shoulder internal rotation torque around 75% of males' values (Table 4). If normalized with body weight and height, the numbers are very similar between genders. A previously reported value of elbow varus torque, an important variable correlated to ulnar collateral ligament (UCL) injury, was generally around 60 N·m in adult male pitchers (Table 4). Fleisig, Barrentine, et al. (1996a) surmised this value to be close to the limit of nondamaging loading on the UCL, which probably explains the prevalence of UCL reconstruction surgery (a.k.a., "Tommy John" surgery) in elite male pitchers. In contrast, there was approximately an average 46 N·m elbow varus torque for female pitchers. No study has compared the biomechanical properties of female and male ulnar collateral ligaments. However, previous studies with knee cadavers have shown that females' anterior cruciate ligaments had lower percentage of collagen (Hashemi et al., 2006), less elasticity, less strength even when the size of the ligaments are considered, and failed at 70% of load compared with males' (Chandrashekar et al., 2006). Thus, female pitchers produce approximately 75% the elbow varus torque during pitching and female knee ligaments can withstand approximately 70% as much load. Based upon this limited information, it is hard to predict how such injury risk compares between female and male baseball pitchers.

In contrast, near ball release, females generated around 55% of maximum elbow and shoulder proximal forces compared with males (Table 4). These are the net forces that decelerate the arm and hold the arm from flying away. The tremendous shoulder proximal force, comparable to a male pitcher's body weight, has been related to rotator cuff tear (Fleisig et al., 1996a). These forces looked considerably lower in females, as they were still 55% compared with males even after normalized to body weight, and it makes sense as greater forces are necessary to hold the heavier and faster arm of male pitchers.

It is interesting to compare our adult female pitchers to young male pitchers. Fleisig et al. (1999) investigated the biomechanics of young male pitchers. Their youth participants had body heights (167 ± 9 cm), ball velocities (28 ± 1 m/s), and joint forces (shoulder proximal force 480 ± 100 N) similar to those of our female participants. Their high school participants had body weight (76 ± 10 kg) and joint torques (46 ± 9 N·m) comparable to those of our females. However, the young male pitchers did not show those kinematic and temporal features found in females in the current study. In fact, they pitched in an almost identical way to adult male pitchers. Therefore, body height, weight, and even shoulder and elbow joint forces and torques do not completely explain the kinematic and temporal differences found in the current study, implying that there are other contributing factors between genders.

There are some limitations to the current study. First, although participants were selected to represent elite amateur pitchers in both genders, the female pitchers are real "amateurs," whereas the male Olympic pitchers may have experienced some professional training in both facilities and schedules. In addition, while both groups should have represented the samples drafted from the population of the best amateur pitchers available in each gender, the populations of the females and males are very different. Whereas 470,671 high school boys participated in 15,290 varsity baseball programs in 2005-06 academic year, only 1,382 high school girls participated in 94 baseball programs (2005-06 High School Athletics Participation Survey, 2006). With such a huge gap of participation, the sampling from best athletes in each gender can be skewed in talent. At this moment, this sampling bias is impossible to be fixed. In contrast, this experience and sample size bias is not as strong in some other sports such as tennis, which may partially explain why the overhand tennis serve kinematics of elite females is almost identical to that of elite males (Fleisig et al., 2003).

Another potential limitation of the study was in the data collection; data accuracy may have been improved with three or more cameras, multiple trials per subject, higher sampling rate from the cameras, or more subjects.

Table 4 Kinetic Variables of Females and Previously Reported Values for Males

Variables	Female	Fleisig et al. (1995)[a]	Fleisig et al. (1999)[b]	Escamilla et al. (2002)[c]
Near Maximum Shoulder External Rotation				
Maximum Elbow Varus Torque				
Magnitude (N·m)	46 ± 9	64 ± 12	55 ± 12	
Scaled (%Body Weight × Body Height)	4 ± 1			3.9 ± 0.7
Maximum Shoulder Internal Rot. Torque				
Magnitude (N·m)	48 ± 11	67 ± 11	58 ± 12	
Scaled (%Body Weight × Body Height)	4 ± 1			4.1 ± 0.7
Near Ball Release (REL)				
Maximum Elbow Proximal Force				
Magnitude (N)	453 ± 60	900 ± 100	770 ± 120	
Scaled (%Body Weight)	64 ± 10			111.7 ± 13.3
Maximum Shoulder Proximal Force				
Magnitude (N)	510 ± 108	1090 ± 110	910 ± 130	
Scaled (%Body Weight)	73 ± 25			134.5 ± 17.2

[a]26 professional and college participants.
[b]115 college participants.
[c]11 professional participants.

Such potential limitations in data collection may create Type II error. In other words, there may be more differences between female and male pitchers than the current study was able to prove. Thus, the variables with *p*-values slightly above 0.05 may, in truth, differ between genders, and might justify further study. However, all of the variables shown to have *p*-values well above 0.05 in the current study would most likely have no meaningful differences between genders, regardless of any changes in study design.

In conclusion, even though several differences were quantified, pitching mechanics overall is not that different between females and males. For example, females can perform the most rapid part of pitching, the shoulder internal rotation, comparably to males. Some differences, such as the more open foot placement, can be addressed by a pitching coach. Other differences, specifically upper torso/pelvis separation and front knee extension, may need both technique instruction and strength and conditioning training to adjust. Timing patterns of female pitchers are comparable to those of males, whereas longer time elapsed to finish pitching is another sign of lower strength. Lower loads were applied at the throwing shoulder and elbow of female pitchers (however, it is unknown whether the lower loads related to a lower injury risk for the female athlete). Coaches should be aware of the differences described when coaching female pitchers.

The current study is among the first to describe both the kinematic and kinetic characteristics of female baseball pitching and identify features unique to female pitching. We hope that these outcomes stimulate further investigation, leading to recommendations for training and coaching female pitchers. Future researchers may recruit more female pitchers to participate, and involve indoor data collection for better data reliability.

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