SEX-BASED ANALYSIS OF THE BIOMECHANICS OF PITCHING

Madison J. Blankenship, Hunter L. Frisk, Evan M. Martin, and William P. Ebben

Biomechanics Research Unit, Exercise Science Research Laboratory, Lakeland University, Plymouth, WI

This study assessed sex-based differences in the lower extremity kinetics and ball velocity during pitching. Fifteen men baseball players and fifteen women softball players threw fastballs on two force platforms, to assess propulsive and landing biomechanics. Doppler radar was used to assess ball velocity. Kinetic and kinematic data comparing men and women were analyzed with independent samples *t*-test. Paired samples *t*-test were used to assess difference between the propulsive and landing phases. Pearson's bivariate correlations were used to assess the relationship between study variables and ball velocity. Few sex-based difference in the magnitude and rate of propulsive force development exist. Sex based differences ($p < 0.05$) were found for all but one landing phase variable. None of the biomechanical variables assessed were related to ball velocity.

KEYWORDS: baseball, softball, gender, ground reaction force, Doppler radar

INTRODUCTION: Athlete biomechanics is believed to have an important influence on pitching performance. Previous research examined a variety of biomechanical variables and their effect on softball pitching. Similarly, biomechanics studies assessed baseball pitching. Only one study focused on the sex-based differences in the kinematics and kinetics variable associated with pitching a baseball.

Research focused on the biomechanics of softball pitching included assessment of the vertical plane (Nimphius et al., 2016; Oliver & Plummer, 2011) or vertical, medio-lateral and anterior-posterior planes (Guido et al., 2009) of motion. These studies evaluated only the push-off phase (Nimphius et al., 2016) or landing phase (Guido et al., 2009; Oliver & Plummer, 2011) of pitching. In the process, the role of kinetic variables on softball pitching mechanics such as lower limb angles and stride length have been studied (Guido et al., 2009; Oliver and Plummer, 2011).

In addition to studies assessing softball pitching, biomechanics studies of baseball pitching have used one force platform to assess the push-off leg (Elliot et al., 1988; Oyama & Myers, 2017), the landing leg (Guido et al., 2009) or two platforms to assess each limb (Kageyama et al., 2015; MacWilliams et al., 1998). Vertical and anterior-posterior kinetics (Elliott at al., 1988; Kageyama et al., 2015; Oyama & Myers 2017) or vertical, medio-lateral, and anterior posterior kinetics (Guido & Warner, 2012; Kageyama et al., 2015; MacWilliams et al., 1998; McNally et al., 2015) were assessed. These studies sought to evaluate the role of ground reaction forces on upper body movements and pitching mechanics (Elliott et al., 1988; Guido & Werner, 2012; Kageyama et al., 2015), or to compare the kinetic and kinematic differences based on subject age and level (Kageyama et al., 2015).

Baseball pitching research assessed wrist or pitch velocity as well. Propulsive phase kinetics were correlated to wrist velocity (MacWilliams et al., 1998). In contrast, ground reaction forces were not correlated with the ball velocity (Oyama & Myers, 2017).

Only one study included the sex-based analysis of pitching a baseball, demonstrating a number of similarities and few differences between the sexes when using motion analysis (Chu et al., 2009). Another study compared the analysis of softball players (Guido et al., 2009) to baseball players (MacWilliams et al., 1998). No previous study has examined the biomechanics of men and women baseball and softball pitchers, respectively within the same study. Therefore, the purpose of this study was to assess the relationship between propulsive and landing phase kinetics, athlete whole body velocity, and pitched ball speed as well as assess sex-based differences in these kinetic variables and the relationship between these variables and ball speed.

METHODS: Subjects included 15 men (mean ± SD, age = 19.47 ± 1.18 yr; body mass = 84.96 ± 10.75 kg; height = 179.83 ± 8.70 cm) and 15 women (mean ± SD, age = 20.07 ± 2.17 yr; body mass = 80.32 ± 22.94 kg; height = 169.33 ± 5.97 cm). Subjects included current or former high school and college baseball and fast-pitch softball pitchers. The subjects were informed of the risks associated with the study and provided informed written consent. The study was approved by the institution's internal review board.
Subjects performed a general, dynamic, specific, and sport-specific warm-up. The general warm-up included low intensity jogging for approximately four minutes. The dynamic warm-up included exercises performed sport specific planes of motions, with increasing intensity. The specific warm-up included activating all of the muscles used in the throwing motion. The sport specific warm-up included a range of warm up pitches in increasing intensity from approximately 50-100% of the subject's maximum velocity.
During testing, all subjects threw six fastballs from the full wind-up motion with at least fifteen seconds rest between pitches. The subjects pitched off of a pitching rubber that was bolted to a force platform and threw into a net with a strike zone ten meters away. The test pitches were performed on two force platforms (Accupower, Advanced Mechanical Technologies Incorporated, Watertown, MA, USA) in series, which were countersunk and mounted flush to the floor. The first force platform captured the subject's propulsive phase and the second captured the landing phase of the pitch. The force platforms were calibrated prior to the testing session. Data were acquired at 1000 Hz and analyzed in real time with proprietary software (Accupower, Advanced Mechanical Technologies Incorporated, Watertown, MA, USA).
Velocity of each pitch was determined by Doppler radar (Speedster III, Bushnell Outdoor Products, Overland Park, KS). The three highest velocity pitches were included for analysis consistent with previous research (Nimphius et al, 2016).
Data were analyzed with a statistical software program (SPSS 26.0, International Business Machines Corporation, Armonk, New York) using independent samples *t*-tests to assess the differences in subjects background, pitch velocity, propulsive phase biomechanics, and landing phase biomechanics. A paired samples *t*-test was used to determine the differences between propulsive phase and landing phase ground reaction forces. Pearson's bivariate correlations were used to assess the relationship between the biomechanical variables and pitched ball velocity. Intraclass correlation coefficients (ICC) and coefficients of variation (CV) were determined for all dependent variables. The *a priori* alpha level was set at $p \leq 0.05$. All data are expressed as means ± SD.

RESULTS: Subject age, weight, height, years of high school and college pitching experiences were not statistically different ($p \geq 0.05$). Men were taller than women ($p = 0.001$). Fastball velocity was significantly greater ($p = 0.001$) for men (33.17 ± 2.21 $m \cdot s^{-1}$) than women (22.52 ± 1.47 $m \cdot s^{-1}$). Table 1 shows the time, distance, and velocity of the subject from propulsive to landing phase. Results of the analysis of the propulsive phase and landing phases are shown in Tables 2 and 3, respectively. Table 4 shows the comparison of the propulsive and landing phase kinetics. There was no correlation between any of the biomechanical variables assessed and ball velocity for either men or women ($p \geq 0.05$). The trial-to-trial reliability of the dependent variables were assessed using average measures Intraclass correlation coefficients (ICC) and coefficients of variation (CV). The ICC's for the test exercises and all dependent variables ranged from 0.77 to 0.96 for the horizontal GRF data, and 0.87 to 0.98 for the vertical GRF data. Coefficients of variation for all data ranged from 13.9% to 28.5%.

Table 1. Mean ± SD data for the baseball and windmill softball for time, distance, and whole body velocity from peak V GRF during propulsion to peak V GRF during landing (N = 30).

	Men (N=15)	Women (N=15)	Significance
Distance (m)	1.57 ± 0.10	1.57 ± 0.14	$p = 0.27$
Time (ms)	0.41 ± 0.09	0.38 ± 0.04	$p = 0.86$
Velocity ($m \cdot s^{-1}$)	4.08 ± 0.86	4.17 ± 0.47	$p = 0.71$

Table 2. Propulsive phase kinetic data for the pitched baseball and softball (N = 30).

	Men (N=15)	Women (N=15)	Significance
V-GRF (N)	1124.48 ± 150.86	1101.83 ± 263.45	$p = 0.78$
V-GRF/BW	1.36 ± 0.16	1.42 ± 0.10	$p = 0.23$
H-GRF (N)	419.32 ± 83.65	352.83 ± 85.03	$p = 0.039$
H-GRF/BW	0.51 ± 0.10	0.46 ± 0.10	$p = 0.24$
H:V	0.37:1 ± .05:1	0.32:1 ± .07:1	$p = 0.04$
V-RFD ($N{\cdot}s^{-1}$)	13240.45 ± 1767.76	13060.70 ± 3107.07	$p = 0.85$
V-RFD/BW ($N{\cdot}s^{-1}$)	16.00 ± 1.80	16.83 ± 1.18	$p = 0.15$
H-RFD ($N{\cdot}s^{-1}$)	4617.50 ± 931.18	3883.98 ± 945.51	$p = 0.039$
H-RFD/BW ($N{\cdot}s^{-1}$)	5.59 ± 1.12	5.09 ± 1.15	$p = 0.24$

V = vertical; H = horizontal anterior; GRF = ground reaction force; GRF/BW = ground reaction force normalized to body weight; H:V = ratio of the vertical to horizontal anterior ground reaction force; RFD = rate of force development.

Table 3. Landing phase kinetic data for the pitched baseball and softball (N = 30).

	Men (N=15)	Women (N=15)	Significance
V-GRF (N)	1190.20 ± 184.08	1477.56 ± 325.07	$p = 0.006$
V-GRF/BW	1.43 ± 0.13	1.91 ± 0.13	$p \leq 0.001$
H-GRF (N)	366.06 ± 108.15	288.28 ± 65.76	$p = 0.024$
H-GRF/BW	0.44 ± 0.10	0.38 ± 0.10	$p = 0.14$
H:V	0.31:1 ± 0.07:1	0.20:1 ± 0.05:1	$p = 0.001$
V-RFD ($N{\cdot}s^{-1}$)	14522 ± 2231.73	18038.27 ± 3962.85	$p = 0.006$
V-RFD/BW ($N{\cdot}s^{-1}$)	17.45 ± 1.53	23.36 ± 2.59	$p \leq 0.001$
H-RFD ($N{\cdot}s^{-1}$)	6925.94 ± .2043.39	5452.83 ± 1245.65	$p = 0.024$
H-RFD/BW ($N{\cdot}s^{-1}$)	8.25 ± 1.90	7.22 ± 1.88	$p = 0.14$

V = vertical; H = horizontal anterior; GRF = ground reaction force; GRF/BW = ground reaction force normalized to body weight; H:V = ratio of the vertical to horizontal anterior ground reaction force; RFD = rate of force development.

Table 4. Comparison of the kinetics of the propulsive and landing phases (N = 30).

	Propulsive Phase	Landing Phase	Significance
V-GRF (N)	1113.05 ± 211.26	1333.88 ± 297.88	$p \leq 0.001$
V-GRF/BW	1.39 ± 0.13	1.67 ± 0.30	$p \leq 0.001$
H-GRF (N)	386.07 ± 89.51	327.17 ± 96.43	$p = 0.013$
H-GRF/BW	0.48 ± 0.10	0.41 ± 0.10	$p = 0.014$
V-RFD ($N{\cdot}s^{-1}$)	13150.58 ± 2485.44	16280.61 ± 3630.65	$p \leq 0.001$
V-RFD/BW ($N{\cdot}s^{-1}$)	16.41 ± 1.55	20.41 ± 3.66	$p \leq 0.001$
H-RFD ($N{\cdot}s^{-1}$)	4250.74 ± 994.65	6189.38 ± 1823.74	$p \leq 0.001$
H-RFD/BW ($N{\cdot}s^{-1}$)	5.34 ± 1.15	7.74 ± 1.93	$p \leq 0.001$

V = vertical; H = horizontal anterior; GRF = ground reaction force; GRF/BW = ground reaction force normalized to body weight; H:V = ratio of the vertical to horizontal anterior ground reaction force; RFD = rate of force development.

DISCUSSION: This is the first study to compare the biomechanics of men and women baseball and softball players, respectively. Results show a difference in propulsive H:V when data were normalized to body weight. Additionally, almost all of the landing phase kinetic demands are different between men and women. Others showed more knee flexion upon landing for women compared to men, when assessing baseball players (Chu, et al., 2009).

In the current study, men demonstrated vertical ground reaction forces during landing that were 1.43 times body weight, compared to women who produced 1.9 times body weight. Others showed that men produced 1.5 times body weight (MacWilliams et al., 1998), and women produced 1.39 (Guido et al., 2009) to 1.79 (Oliver & Plummer, 2011) times body weight.

The posteriorly directed horizontal ground reaction forces during landing in the current study were 0.44 times body weight for men and 0.38 times body weight for women. This was lower for men, but similar to women when compared to other studies, which found these values to be 0.72 and 0.36 times body weight for men (MacWilliams et al., 1998) and women (Oliver & Plummer, 2011), respectively. In the current study, men generated higher propulsive H:V and horizontal landing ground reaction force, whereas women develop more vertical force and a higher rate of force development during landing. Thus, the propulsive H:V in this study was significantly higher for men compared to women, with values similar to those previously shown for men (Elliott et al., 1998; Oyama & Myers, 2017).

The current study demonstrated no differences in whole body velocity measured from propulsive to landing phase peak vertical ground reaction forces. The only other sex-based analysis of pitching showed that compared to men, women had a greater time from stride foot contact to ball release when throwing a baseball (Chu et al., 2009).

Men threw with more velocity than women in the current study, consistent with previous research comparing men and women baseball players (Chu et al., 2009). The men in this study threw approximately 33.2 $m \cdot s^{-1}$, compared to others who threw 34.87 $m \cdot s^{-1}$ (Guido & Werner, 2012) and 35.2 $m \cdot s^{-1}$ (Kageyama et al., 2015). The women in the current study threw at approximately 22.5 $m \cdot s^{-1}$ compared to 24 $m \cdot s^{-1}$ (Oliver & Plummer, 2011) and 25 $m \cdot s^{-1}$ (Guido et al., 2009).

None of the biomechanical variables in the current study were correlated to ball velocity consistent with some reports (Guido et al., 2009). Others found a small number of variables were related to pitched softball velocity such as peak propulsive phase vertical ground reaction force and time between peak forces (Nimphius, et al., 2016) as well as vertical ground reaction force during the landing phase (Oliver and Plummer, 2011).

CONCLUSION: When normalized to body weight, there are few sex-based differences in the propulsive phase of pitching. Men rely more on a greater H:V during this phase, and their training strategies should emphasize horizontal more than vertical force production. Compared to men, women demonstrate higher vertical ground reaction forces and rates of force development during the landing phase. Training strategies for women should increase their capability to manage larger magnitudes and rates of vertically directed force.

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