SEX-BASED ANALYSIS OF THE BIOMECHANICS OF PITCHING

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INTRODUCTION

Athlete biomechanics influences pitching performance. Research focused on the biomechanics of softball evaluated only the push-off phase (Nimphius et al., 2016) or landing phase (Guido et al., 2009; Oliver & Plummer, 2011) of pitching. In addition to studies assessing softball pitching, biomechanics studies of baseball pitching have used one force platform to assess lower body kinetics (Elliot et al., 1988; Oyama & Myers, 2017). These studies sought to evaluate the role of ground reaction forces (GRF) on upper body movements and pitching mechanics (Elliot et al., 1988), 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) while GRF was not correlated with the ball velocity (Oyama & Myers, 2017).
Only one study included a 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). No previous study has examined the biomechanics of men and women baseball and softball pitchers. 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 the sex-based differences in these kinetic variables and the relationship between these variables and ball speed.

METHODS

Subjects included 15 men (age = 19.47 ± 1.18 yr) and 15 women (age = 20.07 ± 2.17 yr). The subjects provided informed written consent. The study was approved by the institution's internal review board.
During testing, all subjects threw six fastballs from the full wind-up motion. The subjects pitched off of a pitching rubber that was bolted to the first of two force platforms (Accupower, Advanced Mechanical Technologies Incorporated, Watertown, MA, USA) in series. The first and second force platforms captured the subject's propulsive phase and landing phase, respectively. Data were acquired at 1000 Hz and analyzed in real time with proprietary software.
Velocity of each pitch was determined by Doppler radar (Speedster III, Bushnell Outdoor Products, Overland Park, KS).
Data were evaluated 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 GRF. 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·s-1) than women (22.52 ± 1.47 m·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 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 ≤ 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 ≤ 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 ≤ 0.001
V-GRF/BW	1.39 ± 0.13	1.67 ± 0.30	p ≤ 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 ≤ 0.001
V-RFD/BW ($N \cdot s^{-1}$)	16.41 ± 1.55	20.41 ± 3.66	p ≤ 0.001
H-RFD ($N \cdot s^{-1}$)	4250.74 ± 994.65	6189.38 ± 1823.74	p ≤ 0.001
H-RFD/BW ($N \cdot s^{-1}$)	5.34 ± 1.15	7.74 ± 1.93	p ≤ 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 / CONCLUSION

This is the first study to compare the biomechanics of men and women baseball and softball players. Results show a difference in propulsive H:V and almost all of the landing phase kinetic demands between men and women. Others showed more knee flexion upon landing for women compared to men, when assessing baseball pitchers (Chu, et al., 2009).
In the current study, men and women demonstrated vertical GRF during landing that was 1.43 and 1.9 times body weight, respectively. 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 GRF during landing in the current study was 0.44 times body weight for men and 0.38 times body weight for women. Others 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 GRF, whereas women develop more vertical GRF 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 (Elliot et al., 1998; Oyama & Myers, 2017).
The current study demonstrated no differences in whole body velocity, in contrast to the only other sex-based analysis of pitching which 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).
None of the biomechanical variables in the current study were correlated to ball velocity consistent with some reports (Guido et al., 2009). Others found pitched softball velocity was correlated to peak propulsive phase vertical GRF and time between peak forces (Nimphius, et al., 2016) as well as vertical GRF during the landing phase (Oliver and Plummer, 2011).
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 GRF 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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