BIOMECHANICAL ANALYSIS OF THE FASTBALL THROWN FROM THE WIND-UP AND THE STRETCH

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This study assessed the biomechanics associated with the fastball thrown in two conditions. Fifteen men pitched from the wind-up and stretch beginning and landing on force platforms. Doppler radar was used to assess ball velocity. A paired samples *t*-test was used to determine differences in ball velocity, propulsive and landing phase kinetics, as well as time, distance, and subject velocity from the propulsive to landing phase. The stretch produced 5.55% more horizontal ground reaction force, a higher horizontal to vertical force ratio, 35.05% greater vertical rate of force development (RFD) in the propulsive phase, and 8.85% higher horizontal and 24.65% vertical RFD upon landing ($p \leq 0.05$). The wind-up produced 39.49% greater horizontal RFD in the propulsive phase ($p \leq 0.05$). These variations of the fastball use different mechanisms to achieve similar ($p = 0.77$) ball velocities.

KEYWORDS: baseball, pitching, Doppler radar, kinetics, kinematics

INTRODUCTION: Pitching ability is a critical part of team success in baseball. As a result, a number of studies assessed biomechanical factors associated with pitching. These analyses include the study of kinematics and/or ground reaction forces and their effect on limb or ball velocity, for descriptive purposes or to compare groups such as pitchers with differing ability. There currently is some debate about how to best throw the fastball. A consumer publication cited a decrease in the use of the wind-up in favor of the stretch for a number of high profile Major League Baseball pitchers (Diamond, 2017).

Research examined kinematic factors that may influence pitching. Some studies used only motion analysis (Dun et al., 2008), or motion analysis combined with force platforms (Elliot et al., 1988; Guido & Werner, 2012; Kageyama et al., 2014; MacWilliams et al., 1998; McNally et al., 2015; Oyama & Myers, 2017). In some cases, kinetic information was derived from kinematic data using inverse dynamics (Dun et al., 2008).

Biomechanics studies assessed kinetic variables associated with baseball pitching using a single force platform to assess the propulsive leg (Elliot et al., 1988; Oyama & Myers, 2017), the landing leg (Guido et al., 2012) or two platforms to assess each leg (Chen, et al., 2014; Kageyama et al, 2014; McNally et al., 2015, MacWilliams et al., 1998). Vertical and anterior-posterior kinetics (Elliot at al., 1988; 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 evaluated the role of ground reaction forces on upper body movements and pitching mechanics (Elliot et al., 1988; Guido & Werner, 2012; Kageyama et al., 2015) or compared the kinetic and kinematic differences based on age (Kageyama et al., 2015) or ability (Kageyama, et al., 2014). Other studies assessing ball velocity demonstrated differences between high and low velocity pitching groups (Kegeyama et al., 2014), or used a radar gun to differentiate between high and low velocity pitchers (Kageyama et al., 2015).

Some of this research was designed to determine the relationship between pitching kinetics and the subsequent arm, wrist, or pitched ball velocity. Evidence shows that propulsive phase anterior force was correlated to wrist velocity (MacWilliams et al., 1998). On the other hand, ground reaction forces sometimes demonstrates no correlation with ball velocity (Oyama & Myers, 2017). Most studies specifically examined the fastball (Guido & Werner, 2012; Kageyama et al., 2014; Kegeyama et al., 2015; McNally et al., 2015; Oyama & Myers, 2017) either for descriptive purposes, to compare subjects of different ability, or to assess pitching surfaces (Chen et al., 2014; Kageyama et al., 2014; Kageyama et al., 2015). The difference between the fastball from the windup versus the stretch has infrequently been studied. When it was, no kinetic differences between conditions were found (Dun et al., 2008; Elliot et al., 1998) and the kinetic analysis was limited to select aspects of the upper body (Dun, et al., 2008). One example (Diamond, 2017) of numerous anecdotal and consumer publications reports that a number of Major League Baseball pitchers are no longer using, and pitching coaches are no longer recommending, pitching from the wind-up. Therefore, the purpose of this study was to assess kinetic and kinematic aspects of the propulsive and landing phase of fastballs pitched from the wind-up and stretch position, and compare ball velocity in each condition.

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) who were college or former high school pitchers, and were experienced in throwing fastballs in each of the two study conditions. Subjects 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 dynamic stretching 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 pitches of increasing intensity up to the subject's maximum velocity.

During testing, all subjects threw six fastballs from the full wind-up motion as well as six fastballs from the stretch, into a net with a strike zone ten meters away. The pitch type was counterbalanced to reduce possible order effects associated with potentiation or fatigue. After each throw, subjects rested at least fifteen seconds. The test pitches were performed on two force platforms (Accupower, Advanced Mechanical Technologies Incorporated, Watertown, MA, USA) deployed in series, and were countersunk and mounted flush to the floor. A pitching rubber was mounted to the first platform in the series. 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). Pitch velocity was determined by Doppler radar (Speedster III, Bushnell Outdoor Products, Overland Park, KS), and deployed in a manner similar to previous methods (Oyama & Myers, 2017). The three pitches with the highest velocities were included for analysis consistent with previous research (Oyama & Myers, 2017). Data from the radar, as well as the kinetic data derived from the force-time records were used in the post-processing.

Data were analyzed with a statistical software program (SPSS 26.0, International Business Machines Corporation, Armonk, New York). To evaluate the wind-up and stretch conditions, a paired samples *t*-test was used to compare differences in ball velocity, propulsive phase peak horizontal ground reaction force, peak vertical ground reaction force, peak anterior horizontal to peak vertical ground reaction force ratio (propulsive H:V), rate of vertical force production, and the rate of horizontal force production.

Landing phase variables include peak horizontal ground reaction force, peak vertical ground reaction force, peak anterior horizontal to peak vertical ground reaction force ratio (landing H:V), rate of vertical force production, and rate of horizontal force production. Other variables in the analysis included the time, distance, and whole body velocity from the peak vertical ground reaction force during the propulsive phase to the peak vertical ground reaction force during the landing phase. The trial-to-trial reliability of the dependent variables were assessed using average measures Intraclass correlation coefficients (ICC) and coefficients of variation (CV). The *a priori* alpha level was set at $p \leq 0.05$. Data are presented as mean ± SD.

RESULTS: Results of the analysis of the data for the fastball pitched in the wind-up and stretch conditions are shown in Table 1. The ICC's for the test exercises and all dependent variables ranged from 0.77 to 0.96 for the horizontal ground reaction force data, and 0.87 to 0.98 for the vertical ground reaction force data. Coefficients of variation (CV) for all data ranged from 13.9% to 28.5%. Horizontal kinetic data produced the higher CV than the vertical kinetic values.

Table 1. Data (mean ± SD) for the fastball from the wind-up and stretch (N = 15).

	Fastball - Wind-Up	Fastball - Stretch	Significance
Ball Velocity ($m \cdot s^{-1}$)	33.17 ± 2.21	33.13 ± 2.40	0.77
Propulsive V-GRF (N)	1124.48 ± 150.86	1115.84 ± 135.77	0.69
Propulsive H-GRF (N)	419.32 ± 86.62	443.04 ± 78.72	0.008
Propulsive H:V	0.37:1 ± .05:1	0.40:1 ± .05:1	0.001
Propulsive V RFD ($N \cdot s^{-1}$)	13240.41 ± 1767.18	20382.69 ± 2467.79	0.001
Propulsive H RFD ($N \cdot s^{-1}$)	4617.98 ± 1767.18	2794.78 ± 498.31	0.001
Landing V-GRF (N)	1190.19 ± 184.05	1158.56 ± 159.71	0.59
Landing H-GRF (N)	366.06 ± 108.14	363.92 ± 109.56	0.70
Landing H:V	0.31:1 ± .07:1	0.35:1 ± .16:1	0.32
Landing V-RFD ($N \cdot s^{-1}$)	14520.35 ± 2231.72	19270.73 ± 3509.31	0.001
Landing H-RFD ($N \cdot s^{-1}$)	6925.94 ± 2043.40	7597.17 ± 2296.29	0.001
Whole Body Time (seconds)	0.41 ± 0.09	0.38 ± 0.10	0.10
Whole Body Distance (meters)	1.57 ± 0.10	1.55 ± 0.11	0.30
Whole Body Velocity ($m \cdot s^{-1}$)	4.08 ± 0.86	4.28 ± 1.07	0.17

GRF = ground reaction force; Propulsive H:V = ratio of the horizontal anterior to vertical ground reaction force; RFD = rate of force development. Landing H:V = ratio of the horizontal posterior to vertical ground reaction force; V = Vertical; Propulsive H = horizontal anterior; Landing H = horizontal posterior.

DISCUSSION: This is the first study to demonstrate significant biomechanical differences between pitching from the wind-up compared to the stretch. Only two other studies assessed these two pitches. One of these studies showed that the ground reaction forces were similar between these pitches (Elliot et al., 1988). The other featured motion analysis and found no temporal, kinematic, or kinetic differences (Dun et al., 2008). The current study may have found differences when others did not, due to dissimilar methodology and variables assessed including the used of ground based kinetics accrued via force platforms, instead of inverse dynamics and a focus on upper body kinetics (Dun et al., 2008).

In the current study, the stretch condition produced 5.55% more horizontal ground reaction force, a higher propulsive H:V, and 35.05% higher vertical rate of force development in the propulsive phase, and a 24.65% higher vertical rate of force development upon landing. Previous research demonstrated no significant differences in either the vertical or horizontal forces between these pitches (Elliot et al., 1988). It has been suggested that pitching from the stretch may produce less kinetic energy from the legs and that the body does not travel as far (Dun et al., 2008). Results from the present study found no difference in vertical ground reaction force, no difference in distance, but greater horizontal ground reaction force, when pitching from the stretch.

Pitching from the stretch was thought to be quicker than from the wind-up (Diamond, 2017; Dun et al., 2008). In the current study, the mean time was 7.32% lower and whole body velocity 4.68% higher when pitching from the stretch, but not arising to the level of significance. Previous research also showed no difference in either time from foot contact or maximum external shoulder rotation to the point of ball release between the wind-up and stretch conditions (Dun et al., 2008).

In the current study, the propulsive H:V in the stretch condition was similar to the ratio derived from other research (Oyama & Myers, 2017) and the propulsive phase vertical and horizontal forces for both pitches were similar to those previously demonstrated (Elliot et al., 1988; Oyama & Myers, 2017). Landing phase vertical ground reaction forces in current study were higher than the propulsive phase, but lower than the landing phase values previously found for pitching from a mound (Kageyama et al., 2015). The current study used a pitching rubber mounted to a force platform in a non-mound configuration. Research specifically comparing mound versus non-mound force platform pitching demonstrated that there was no significant difference in ball velocity between conditions (Chen et al., 2014). However, propulsive forces were approximately 20% greater when pitching from a mound, and landing leg breaking and ground vertical ground reaction forces were 8% and 17% higher, respectively (Chen et al., 2014). Furthermore, landing vertical ground reaction force in the current study was about 25% less than values derived from pitching off a mound (Guido & Werner, 2012). Thus, it is likely that the kinetic data in the current study are somewhat lower than that which may occur when pitching off of a mound, even though these kinetic differences may not effect ball velocity (Chen et al., 2014).

The pitching velocity of the subjects in the current study averaged slightly over 33 m·sec^{-1}, while others threw 34.87 m·sec^{-1} (Guido & Werner 2012), 35.2 m·sec^{-1} (Kageyama et al., 2015), 37.7 m·sec^{-1} (Oyama & Myers, 2017) and 38.5 m·sec^{-1} (Dun et al., 2008). Thus, subjects in the current study were in the low end of the range of those previously assessed. In the current study, the kinetic differences between pitches resulted in a non-significant 0.04 m·sec^{-1} difference in ball velocity. This result was similar to the 0.1 m·sec^{-1} difference previously found between the wind-up and the stretch (Dun et al., 2008).

CONCLUSION: Pitching from the wind-up and stretch is accomplished using different biomechanical strategies. Training to improve pitching from the wind-up should feature exercises that accentuate the development high horizontal rates of force production in the propulsive phase. Training to improve pitching from the stretch should focus on improving horizontal ground reaction force and a higher H:V in the propulsive phase, and the ability to manage the horizontal and vertical rate of forces production upon landing. Despite these differences, this study shows that pitching from the wind-up and stretch results in similar ball velocities.

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