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Drive leg ground reaction forces and rate of force development over consecutive windmill softball pitches

Ground reaction force during softball pitch

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BACKGROUND: Windmill softball pitching is a highly skilled movement, combining whole body coordination with explosive force. Successful pitching requires sequential movement to transfer energy produced by the lower extremity to the pitching arm. Therefore, drive leg ground reaction force (GRF) and the time over which a pitcher can develop force during push off, defined as rate of force development (RFD), is essential for optimal performance. The purpose of this study was to examine GRF and RFD in the drive leg during the windmill softball pitch, as well as pitch velocity, throughout a simulated game.

METHODS: Fourteen softball pitchers (17.9±2.3 years, 166.4±8.7cm, 72.2±12.6kg) pitched a simulated game. Pitch velocity and anterior-posterior and vertical GRF and RFD, each normalized to body weight, were collected for each inning. Average pitch speed remained consistent across all seven innings, 49.57±0.42mph. Changes in GRF and RFD were assessed, with level of significance set as $p<0.05$.

RESULTS: A one-way repeated measures analysis of variance showed no significant differences in apGRF%BW ($p=0.297$), vGRF%BW ($p=0.574$), apRFD (BW/s) ($p=0.085$) and vRFD (BW/s) ($p=0.059$).

CONCLUSIONS: Training programs can be improved with the knowledge of the magnitude and rate in which forces are developed by the drive leg during push-off of the windmill softball pitch.

Key Words: fast pitch softball; kinetic chain; lower extremity

Introduction

Windmill softball pitching is a highly skilled movement, combining whole body coordination with explosive force. Ground reaction forces (GRF) during the windmill softball pitch are crucial to the generation and transfer of energy from the lower extremity to upper extremity and finally to the ball for maximal pitch velocity.(1) As a softball pitcher pushes off the mound with their drive leg (pitching arm side), a downward force is exerted against the ground, which in turn, creates an equal and opposite reaction force pushing the pitcher upward and forward.(2) Energy generated during this push off is transferred upward through the kinetic chain and contributes to the linear and angular momentum of the trunk and upper extremity.(3, 4) Though the kinetic chain concept is documented in softball pitching kinematics (5, 6) and stride leg kinetics,(7-9) there has yet to be an examination of drive leg kinetics used to initiate the windmill pitch.

During the softball pitch, stride leg (glove arm side) GRF are generated to slow forward momentum of the body, to provide both a stable base of support during ball release,(8) as well as transfer momentum distally to the upper extremity and ball.(10) However, drive leg GRF have been minimally studied in softball pitchers, even though there is a need to drive the body forward with maximal velocity during the pitch.(11) Initial push-off, to accelerate the body forward, represents a significant point of kinetic energy creation. Quantifying drive leg GRF during push-off is important to understand the magnitude of force generated and used throughout the windmill pitch, to develop appropriate training programs. Previous research has examined drive leg GRF in elite pitchers(12) or across a wide age range of pitching athletes(13) but not specifically in lower level collegiate pitchers within a narrower age demographic. In the 2018-19 season, Division I softball athletes made up only 31% of all National Collegiate Athletic

Association female athletes,(14) not including National Association of Intercollegiate Athletics and National Junior College Athletic Association athletes. Due to the large number of softball athletes participating at lower collegiate competition levels, it is beneficial to analyze performance variables specific to their demographic.

The dynamic ballistic upper extremity movement of the windmill softball pitch requires total body contribution for efficient performance.(5, 9) Thus, understanding the amount and timing of drive leg GRF contributions could prove beneficial. Specifically, quantifying the development of maximal force with respect to time, known as rate of force development (RFD) may be of particular interest.(15) RFD is often associated with explosive strength and is connected to the ability to accelerate one's body mass.(16) Explosiveness is a key component of many sports and previous research has suggested that greater RFD can lead to better athletic performance.(17-19) While the push phase of the windmill pitch is rapid, high GRF are required to push the pitcher forcefully towards the plate. Therefore, both high GRF and fast RFD are necessary to accrue high pitch velocities.

While research is beginning to highlight the importance of the drive leg in windmill softball pitching, more work is needed to understand the effect of both the magnitude of GRF and RFD to maintain optimal performance. The overall goal of the windmill pitch is to generate large forces through the drive leg, transfer those forces to the upper extremity through coordinated movement, ending with high ball velocity. Due to the lack of pitch count restrictions in softball, a pitcher can throw 1,200-1,500 pitches in a 3-day period compared to 100-150 for a baseball pitcher.(9) The cumulative workload of a rigorous schedule can cause a break down in the kinetic chain, leading to decreased performance and increased risk of overuse injuries, as research has shown fatigue is a primary risk factor for injury.(20, 21)

Softball pitchers are expected to maintain high performance, and stave off injury for such long competitive periods, it is important to understand how or when these variables change over the course of a pitching bout. To keep pitchers at optimal performance and decrease injury susceptibility, an understanding of forces generated by the drive leg over an acute bout of pitching is needed. Therefore, the purpose of this study was to examine the GRF and RFD in the drive leg during the windmill softball pitch, as well as pitch velocity, throughout a simulated game. It was hypothesized that GRF and RFD would remain consistent throughout one simulated game. Study findings can be used to inform and direct coaches and athletes in developing position specific training programs.

Materials and methods

Fourteen female softball pitchers (17.9±2.3 years, 166.4±8.7cm, 72.2±12.6kg) completed this study (Table 1). All participants were currently active on an American high school (n=6) or collegiate (n=8) roster as softball pitchers, participating in softball related activity at a minimum of 3 times per week, with at least one-year varsity experience pitching with a windmill style softball pitch. Participants were asked to refrain from engaging in exercise or additional physical activity other than their daily living activities for the 24 hours prior to the testing session. Approval of the study was given by the University's Institutional Review Board. Written informed consent was obtained from all participants, with written parental consent obtained from participants under the age of 18.

Please insert Table 1 here.

Protocol: Prior to data collection, each participant was allowed her normal pitching warm-up routine until she verbally stated that she felt warmed up and comfortable with the testing environment. Participants pitched similar to a softball game, with 105 total pitches broken up between 15 pitches in 7 innings. A 4-minute rest was given between innings to represent the second half of the inning. Ground reaction forces for the last 5 pitches of each inning were captured for data analysis.

A 2.1m by 2.1m (7ft x 7ft) Portable Bow Net, with 0.36 m x 0.71 m strike zone, was set up behind home plate. A pitching location was taped off 9.14 m from the back end of home plate. This pitching location was on a level platform built around the force plates. Drive leg ground reaction forces were collected using a 60cm x 40cm force platform (Type 9286A, Kistler Instrument Corp., Amherst, NY) at a sampling frequency of 1500 Hz. Peak pitch velocity was collected with a sports radar gun (Stalker Solo 2, Applied Concepts, Inc., Plano, TX) to monitor consistency of output in each participant.

All GRF data were recorded using the Vicon Nexus software. Ground reaction force data was filtered using a low-pass, zero-lag fourth-order Butterworth filter with a cutoff frequency of 50Hz within MATLAB (R2015b, Mathworks Inc., Natick, MA).(22) Peak vertical and anterior-posterior GRF were recorded (Newtons, N) and normalized to body weight (%BW). Minimum GRF, just prior to maximum GRF, were manually marked through graphs produced in MATLAB of each pitch's ground reaction force components. Rate of force development was calculated as the difference between peak and minimum vertical ground reaction forces divided by the time from minimum to peak ground reaction force. Rate of force development was recorded in Newtons per second (N/s) (Equation 1) and normalized to body weight, measured in Newtons (Equation 2).(23)

$$\frac{\text{Peak GRFz} - \text{Minimum GRFz}}{\text{Time Peak} - \text{Time Minimum}} = \text{Rate of Force Development (N/s)} \quad (1)$$

$$\frac{\text{RFD (N/s)}}{\text{BW (N)}} = \text{Normalized RFD} \quad (2)$$

Statistical Analysis: All data were tested for normality using Shapiro Wilk tests. If the assumption of normality was met, one-way repeated measures analyses of variance (ANOVA) was used to assess changes in GRF and RFD between innings during a simulated game. If the assumption of normality was not met, the corresponding non-parametric test (Friedman ANOVA) was used. Statistical significance was set *a priori* at alpha = 0.05, two-sided. All analyses were performed using the SPSS software package (Version 21, IBM Corp., Armonk, NY).

Results

All participants were able to complete the required 105 fastball pitches. Average pitch speed remained consistent across all seven innings, 49.57±0.42mph. Normalized average peak anterior-posterior (apGRF%BW) and vertical (vGRF%BW) ground reaction forces as well as anterior-posterior (apRFD (BW/s)) and vertical (vRFD (BW/s)) rate of force development can be seen in Table 2. No significant differences were seen in apGRF%BW (p=0.297), vGRF%BW (p=0.574), apRFD (BW/s) (p=0.085) and vRFD (BW/s) (p=0.059).

Please insert Table 2 here.

Discussion

The current study examined drive leg GRF and RFD to quantify the propulsive forces that initiate the windmill softball pitch. During the pitching motion, the body moves through a series of sequential and interconnected movements, starting with the initial push of the drive leg. The majority of force required to propel the ball forward is developed in the legs and trunk in a closed chain manner.(24) In fact, it's estimated that 50-55% of total energy generated by the body during an upper extremity task comes from the lower extremity.(25) Therefore, understanding GRF development during initiation of the pitch throughout a softball game is necessary for improving pitch performance.

This study is the first to document both drive leg GRF and RFD in lower level collegiate softball pitchers. The authors hypothesized pitchers would display consistent GRF and RFD throughout the progression of a simulated game, and that pitch velocity would also remain consistent. The current study found GRF and RFD to remain relatively constant over the duration of a simulated game. Similarly, there was no difference in pitch velocity, with average pitch speed (49.6±0.4mph) remaining steady through all seven innings of a simulated game.

A recent study examining youth softball pitchers during a simulated game showed that pitch velocity decreased significantly over the course of the game.(26) While this recent report examined youth athletes, the current study examined lower level pitchers older in age, who managed to maintain pitch velocity over the duration of the game. This provides insight to the improved ability of older pitchers to develop and maintain force to impact pitch velocity. Likewise, the current study also found GRF and RFD to remain constant over the duration of the simulated game. Previous work has established a high correlation with drive leg GRF and wrist velocity in baseball pitchers,(27) therefore, consistency of pitch velocity seen in this study may be related to the uniformity of initial energy produced, measured via drive leg GRF. With there being a lack of change in both pitch velocity and GRF characteristics, it can by hypothesized that the force generated from the ground up was consistently used to influence pitch velocity and may help maintain full-effort velocity throughout the simulated game.

During the windmill softball pitch, the drive leg powers the body forward(28) and greater propulsive force should suggest more kinetic energy to move the body forward. Anteriorly directed drive leg GRF can direct kinetic energy in the direction of the pitch to propel the body forward, while vertical forces can be used to generate potential energy.(27) This potential energy can then be changed into kinetic energy and transferred to the upper extremity and finally to the ball through front foot contact of the windmill pitch.(29) In the current study, drive leg vertical ground reaction forces were slightly higher (154% of body weight) as compared to softball pitchers studied by Woo and Brown (140% body weight).(13) Overall, studying the magnitude of GRF informs coaches and researchers on the energy created to be used to execute the windmill softball pitch.

Execution of the windmill pitch is done in less than one second, making the rate of force at the onset of movement crucial to consistent high performance. Previous research has calculated the time between top of the windmill pitch backswing until stride foot contact in youth pitchers as 45 ± 19 milliseconds(9) and 50 ± 16 milliseconds in Olympic pitchers.(30) Due to rapid execution of this movement, RFD, rather than absolute force itself, is a crucial factor in successful pitching performance.(31) While RFD has not been evaluated in softball athletes, previous research has reported a correlation between RFD and linear shot-put performance in female throwers,(32) starting block push phase of elite sprinters,(17) Wingate power in sprint-cyclists,(18) and golf club head speed within golfers.(19) Specifically during softball pitching, the short duration of drive leg contact time with the ground to initiate forward acceleration indicates the need for rapid RFD. Drive leg anterior-posterior GRF and vertical GRF averaged 53.8% and 154.5% of pitcher's body weight, respectively. Rate of force development averaged 3.0 BW/s in the anterior-posterior direction and 11.7 BW/s in the vertical direction. Being able to develop a large amount of force, relatively quickly helps pitchers fight inertia and begin their push off the mound.

Softball pitchers must maintain high power output over thousands of pitches in back-to-back games and on back-to-back days.(9) Ideally, position specific training protocols can be developed to help pitchers maintain high force generation throughout the demands of a competitive season schedule. The power needed to initiate the windmill softball pitch should be taken into consideration when developing coaching strategies and performance optimization. Understanding the magnitude of ground reaction forces and the rate in which they are developed can help clinicians create targeted training protocols to prepare pitchers for these loads. It is known that weightlifting movements produce very high-power outputs,(33) therefore can be used to prepare and enhance a pitcher's explosive ability. Both strength and power training have elicited positive improvements in RFD in those who were already physically active.(34) Specifically, in elite Olympic weightlifters, RFD had a moderate to strong relationship with the snatch and clean and jerk.(35) A sequenced, periodized approach to training in the weight room can be used to maximize the strength and power needed during the windmill softball pitch, especially as this motion is also a sequential progression of movements from the ground up.

Limitations of this study were that participants threw inside a research laboratory and only threw fastballs. Because pitches were thrown indoors and off an embedded force plate, participants were not allowed to wear cleats and did not use a pitching rubber. Participants did wear rubber-soled shoes to minimize slipping, which may have affected how they pushed-off from the force plate with their drive leg. Another limitation of the study was the game duration. Although we sought to mimic a standard 7-inning game, with pitch counts reaching such high numbers during tournament play, GRF and RFD over the course of a tournament style simulation should also be evaluated. Results of this study showed no significant changes in GRF or RFD between innings of the simulated game. Additionally, no changes in pitch velocity were seen throughout the simulated game. This highlights the importance of the propulsion of the pitch in helping to generate and transfer energy through the kinetic chain and how constant development of high forces can lead to successful softball pitch performance over the duration of a softball game. To conclude recommendations for pitchers to decrease injury susceptibility in the wake of high rates of overuse and fatigue, it is necessary to examine how certain kinetics change over the course of a tournament. This information can help prompt future guidelines in softball and help to improve the quality and longevity of a softball pitcher's career.

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Table 1. Softball Pitchers' Demographics (n=14)

Age (years)	17.9 ± 2.3
Height (cm)	166.4 ± 8.7
Weight (kg)	72.2 ± 12.6
Tanner Stage	5.0 ± 0.0
Number of Years Pitching (years)	8.8 ± 2.1

n = number of subjects

mean ± standard deviation

Table 2. Average peak anterior-posterior and vertical ground reaction forces and rate of force development, as percentage body weight, by inning

Inning	apGRF%BW	vGRF%BW	apRFD(BW/s)	vRFD(BW/s)
1	54.31 ± 11.38	155.80 ± 22.63	2.95 ± 2.07	10.11 ± 3.46
2	53.93 ± 11.38	153.53 ± 20.86	2.87 ± 1.36	10.98 ± 4.92
3	54.82 ± 12.38	154.98 ± 18.86	2.73 ± 1.18	11.22 ± 4.74
4	53.53 ± 13.01	154.36 ± 19.40	2.86 ± 1.43	11.78 ± 4.63
5	53.10 ± 13.87	153.40 ± 20.20	2.95 ± 1.53	12.02 ± 3.19
6	53.61 ± 13.35	154.67 ± 19.90	3.39 ± 1.16	13.35 ± 4.12
7	53.00 ± 12.79	153.83 ± 18.39	2.97 ± 1.44	12.35 ± 4.59

apGRF%BW = anterior-posterior ground reaction force normalized to body weight

vGRF%BW = vertical ground reaction force normalized to body weight

apRFD(BW/s) = anterior-posterior rate of force development normalized to body weight

vRFD(BW/s) = vertical rate of force development normalized to body weight

mean ± standard deviation