Journal of Strength and Conditioning Research Publish Ahead of Print
DOI: 10.1519/JSC.0000000000001980

The relationship between the push off ground reaction force and ball speed in high school baseball pitchers

Running title: Push off force in high school pitchers

The study data collection was conducted at the Sports Medicine Research Laboratory at the University of North Carolina at Chapel Hill

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Conflicts of Interest and Source of Funding:

There is no conflict of interest or funding source to disclose

Abstract

Baseball pitching is a sequential movement that requires transfer of momentum from the lower extremity to the throwing arm. Therefore, the ground reaction force (GRF) during push off is suggested to play a roll in production of ball speed. The purpose of this study was to investigate the correlation between GRF characteristics during push off and ball speed in high school baseball pitchers. A total of 52 pitchers performed fast pitches from an indoor pitching mound. A force plate embedded in an indoor mound was used to capture the push off GRF. The GRF characteristics (peak anterior, vertical, and resultant forces, vertical and resultant forces at the time of peak anterior GRF, and impulse produced by the anterior GRF) from the three fastest strike pitches from each pitcher were used for analyses. Spearman's rank correlation coefficients were used to describe the relationships between ball speed and the GRF characteristics. Ball speed was only weakly correlated with peak resultant force (ρ=.32, p=.02), and vertical (ρ=.45, p<.001) and resultant (ρ=.42, p=.002) forces at the time of peak anterior force. The ball speed was not correlated with other variables. The correlation between ball speed and push off force in high school pitchers was weak, especially when compared to what was reported for adult pitchers in other studies. Unlike for adult pitchers, higher push off force is only weakly correlated with ball velocity in high school pitchers, which suggests that training to better utilize body momentum may help high school pitchers improve ball speed.

Key Words: Forces, ball speed, coaching, performance

INTRODUCTION

Baseball has been a popular sport among people of all ages since the nineteenth century, and is one of the most popular high school sports in the United States.(1) As every play in the game starts with a pitch, a pitcher's ability to produce ball speed is one of the determinants for the team's success. Pitching kinematic parameters that affect ball speed have been identified in previous studies.(16, 28, 29) In addition to the kinematic variables, evidence suggests that the ground reaction forces acting through the pitcher's feet may be linked to ball speed. During push off, a pitcher exerts downward and posterior force on the mound. In turn, the reaction force from the ground pushes the pitcher upward and forward to generate momentum toward the home plate.(2, 14) The linear momentum generated during the push off is transferred to the upper body and contributes to linear and angular momentum of the trunk and the throwing arm after the stride foot contact.(24, 25)

Despite the perceived importance of a push off force in producing ball speed, there are a limited number of studies that examined it during baseball pitching.(3, 10, 11, 13, 17)_ENREF_8 The study by MacWilliams et al(13) was the first to describe the push off force characteristics during pitching. In this study, it was described that peak anterior reaction force and vertical and resultant reaction forces at the time of peak anterior reaction force were strongly (r = 0.86-0.87, r^2=0.76-82) correlated with hand velocity. The studies by Kageyama et al(10, 11) on the effects of push off forces on pitching performance supported this finding. The studies demonstrated that peak anterior reaction force and vertical and resultant reaction forces at the time of peak

anterior reaction force were greater for collegiate pitchers compared to adolescent pitchers(10), and for collegiate pitchers with high ball velocity compared to the ones with low ball velocity(11). On the contrary, the ground reaction force was demonstrated to have no correlation to ball speed in two other studies by McNally et al(17) and Elliot et al.(3)

The relationship between ball speed and ground reaction force reported in previous studies have been inconsistent. Furthermore, all previous studies were conducted on adult pitchers, and thus the relationship between ground reaction force and ball speed in younger and less skilled high school pitchers has not been examined. Therefore, the purpose of this study was to investigate how the ground reaction force characteristics during push off relate to ball speed in high school baseball pitchers. The observations from this study may be used to design training programs and develop strategies to improve performance in high school pitchers.

METHODS

Experimental Approach to the Problem

Cross-sectional study design was used to examine the correlation between the ground reaction force characteristics during push off and ball speed. The specific ground reaction force characteristics that were examined were selected based on what was examined in the previous studies,(13, 17) and are described in the method section.

Subjects

A total of 74 high school baseball pitchers (13-19 years old) who have pitched in at least two baseball seasons participated in the research project. The benefit and risk associated with the study was fully explained to the participants. The informed consent approved by the university Institutional Review Board was obtained from all participants and one of their parents. The pitchers who were unable to throw pain-free were excluded from the study. Additionally, data from pitchers' whose stance feet were not completely on the force plate during push off were excluded from the analyses. Some pitchers (n=22) pitched from the edges of the rubber, causing parts of their feet to be off the force plate. This was inevitable since evaluation of ground reaction force was not the primary aim of the project, and the pitchers were asked to pitch the way they normally pitch. As a result, data from a total of 52 pitchers (Dominance: Right/Left = 40/12, age: 15.4±1.2years, height: 1.8±0.1m, body mass: 72.0±9.7kg) were included in our analysis.

Procedures

The data collection took place inside a biomechanics laboratory. Upon arrival to the laboratory, participants' demographics such as age, years of experience, and injury history and anthropometrics (height and mass) were captured. Participants were then given unrestricted time to warm-up as they normally would before practices or games. After the warm up, the participants changed into tight-fitting clothing, were fitted with reflective markers (not used for analysis in this paper), and proceeded to pitching trials.

All pitches were performed from the indoor pitching mound, instrumented with a force plate (Model: 4060-10, Bertec Corporation, Columbus, OH). A pitching "rubber", which was fabricated using an aluminum plate (0.415m W * 0125m L * 0.015m H), was fitted on the force plate on the top of mound so that the force exerted on the rubber can be captured. The force plate captured GRF during push off at a sampling frequency of 900Hz. From the mound, the pitchers were instructed to pitch as fast as possible from a wind up, aiming at the "X" marked on the center of the strike zone on the back stop (Dimensions: 0.64m H* 0.38m W) that was placed at a distance of 18.4 m. The pitchers continued to pitch until a minimum of three strike pitches were captured. The average values from the three fastest strike pitches were used for analyses.

The force data were filtered using the 4th order zero-lag low-pass Butterworth filter with a cutoff frequency of 30Hz. The ground reaction force data during a push off were used for analysis. The beginning of the push off was defined as when the stride knee started descending after a wind up based on the kinematic data, and the end of the push off was defined as when the stance foot came off the force plate based on the force plate data. The peak vertical, anterior, and resultant forces, vertical and resultant forces at the time of peak posterior force, and impulse produced by the posterior force during a push off were identified. The impulse was calculated by integrating the posterior force in the time domain during a push off. Based on the impulse-momentum relationship, the impulse produced on the body results in the increased forward momentum of the body as the pitcher strides forward.(13) However, the relationship between this variable and ball speed has not been investigated. The other ground reaction force variables were selected based on what were examined in the previous

studies on ground reaction force during pitching in adult pitchers.(10, 11, 13, 17) All ground reaction force data were normalized to participants' body weight (=body mass x $9.81 m/s^2$) prior to analysis.

Two high-speed (300 frames per second) video cameras (Model: Exilim FX-1, Casio Computer Co., Ltd., Tokyo, Japan) were also used to capture the frontal and sagittal view of the pitching motion. The video footages were used to confirm that the pitcher's stance feet were on the force plate. A radar gun (Sport Radar Ltd., Homosassa, FL, Model: SR3600) was used to capture ball speed.

Statistical Analysis

Group means and standard deviation of the body-weight normalized variables were calculated to examine how the data compare to the data from previous studies.(4, 6, 13) Reliability of the variables were calculated using intraclass-correlation coefficients ($ICC_{2,k}$) and standard error of measurement (SEM). Most of our variables were not normally distributed, based on the normality testing using the Shapiro-Wilk test. Therefore, Spearman rank correlation coefficients were calculated to examine the relationships between each variable and ball speed. The correlation was considered weak, moderate, and strong, when the coefficient was 0.25-0.5, 0.5-0.75, and above 0.75, respectively.(21) A priori alpha level was set at 0.05. All analyses were conducted using SAS software.

RESULTS

The mean and standard deviation of ball speed and all ground reaction force variables from 52 pitchers are presented in **Table 1**. The reliability of the variables is reported in **Table 2**. The Spearman rank correlation coefficients are presented in **Table 3**. Ball speed was weakly correlated with peak resultant force (ρ =.32, p=.020), and vertical (ρ =.45, $p<.001$) and resultant forces (ρ =.42, p=.002) at the time of peak anterior force (**Figure**). There were no significant correlations between ball speed and other ground reaction force variables ($p>0.05$).

<Place Tables 1, 2 and 3 and Figure about here>

DISCUSSION

The general characteristics of the ground reaction force observed in this study was consistent with what was reported in previous studies.(2, 14) During push off, the vertical ground reaction force reached approximately 1.3 times the pitcher’s body weight, and the horizontal ground reaction force reached approximately half the body weight. We observed a statistically significant correlation between the ball speed and peak resultant force, and vertical and resultant forces at the time of peak anterior force, but the correlations were weak (ρ=0.32-0.45), especially compared to what was reported in the previous study (r = 0.86-87).(13) In addition to the force values at specific time points, we calculated impulse produced by the anteriorly directed ground

reaction force during push off. However, the impulse variables were also not correlated with ball speed.

The anteriorly directed ground reaction force during push off produces forward momentum of the body.(13) Since the momentum generated by the legs can be transferred to the upper body, pitcher's ability to generate momentum during push off should translate into greater ball momentum and velocity. Our results that demonstrate lack of strong relationship between ball speed and ground reaction force during push off indicates that the high school-age pitchers are not utilizing the push off ground reaction force to generate ball speed effectively, or factors such as pitching technique and anthropometrics characteristics may be more correlated to ball speed in pitchers of this age-group. In a group of youth and adolescent pitchers, greater age, height, and stride length, and observable separation of the hips and shoulders has been linked to greater ball velocity.(26)

Effective transfer of momentum from the lower to upper body requires proper sequencing of segment rotations.(8, 22, 23) It is theorized that transfer of momentum between segments is maximized when the proximal segment reaches its peak rotation velocity before the distal segment reaches its peak rotation velocity.(8, 22, 23) In pitching, this means that the peak rotation velocity of the pelvis needs to be attained before the peak upper torso rotation velocity is reached. This sequential rotation of the pelvis-trunk segments requires adequate hip and trunk muscle strength and control as well as proper stride technique.(7, 9)_ENREF_17 The weakness of the hip musculature can interfere with smooth rotation of the pelvis about the stride leg.(12, 20, 30, 31)_ENREF_19 The weakness or poor motor control of the abdominal musculature can

lead to premature opening of the upper torso, by failing to keep the upper torso from rotating with the pelvis.(7) A stride that is too short/long or too open/close can also interfere with pelvis rotation towards the hitter.(18) It is possible that some or many of the high school level pitchers do not have adequate movement awareness or muscular strength or motor control to ensure effective transfer of momentum to the upper body. As a result, momentum created by the push off ground reaction force gets lost in the kinetic chain, and not reflected in ball speed.

The previous studies that demonstrated a strong association between ball speed and push off ground reaction force were conducted using a small number of relatively homogenous elite adult pitchers. The pitchers in the study by MacWilliams et al(13) were mostly (5 out of 6) collegiate-level. The study by Kageyama et al(11) that demonstrated the push off force was greater for the pitchers with high ball speed compared to low ball speed was also conducted using collegiate level pitchers.

The relationship between the push off force and ball speed was not demonstrated in a study by McNally et al,(17) which was conducted using adult recreational pitchers who *used to* pitch in high school/college level. The relationship between the push off force and ball speed was also weak at best in our study using a group of high school pitchers. The level of conditioning and skill among recreational baseball players and high school pitchers are lower and more heterogeneous compared to the higher-level pitchers. Therefore, factors other than push off force, such as muscle strength,(19) trunk control,(19) pelvis/trunk kinematics,(15, 18, 27-29) and stride technique,(15) which affects the pitchers ability to produce ball speed, may have overshadowed the effects of push off force on ball speed.

There are two schools of thought among baseball coaches regarding the proper striding technique.(4) Some instruct pitchers to push off the mound as hard as they can to increase the initial forward momentum, while the others instruct pitchers to “fall” toward the home plate in a controlled manner. One possible interpretation of our study is that the former approach does not necessarily result in higher ball speed in high school pitchers. On the other hand, it is possible that having a mixture of pitchers with different styles of push off technique could have resulted in weak correlation. However, the two styles are not as distinct in many cases, and thus separating pitchers into two groups based on the push off styles is not feasible. Assessment of whole body momentum from kinematic data may help with further analysis.

There are a few limitations that need to be acknowledged. The experiment was conducted inside a research laboratory setting. Since the pitches were performed from the indoor pitching mound, which was instrumented with force plates, the pitchers were not allowed to wear cleats during the data collection. Although subjects wore rubber-soled shoe that minimized slipping, this may have affected the way pitchers took strides. However, embedding the force plate in the pitching mound was necessary to capture the ground reaction forces during pitching. The current study only examined the ground reaction force during push off. The landing force is also considered important in baseball pitching,(5, 13) and should be investigated further in pitchers of various age groups in future studies.

PRACTICAL APPLICATION

We observed a statistically significant correlation between the ball speed and push off forces at the time of peak anterior force in high school aged pitchers. However, the correlations were weak at best, especially compared to what was reported for the collegiate pitchers,(13) which suggests that high school pitchers are not able to utilize ground reaction force to generate ball velocity as effectively as more skilled pitchers. This indicates that incorporating training that facilitates transfer of momentum from the lower body to the throwing arm may help improve pitcher's performance. The transfer of momentum during pitching requires proper sequencing of pelvis and trunk motion, which would require strength and control of hip and abdominal musculature. Incorporating core strengthening exercises that improve hip and core stability and dynamic exercises that improves coordination of pelvis and trunk rotation may be recommended for high school pitchers. Such approach has been demonstrated to improve ball velocity in college baseball and softball players.(19)

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ACKNOWLEDGEMENT

We would like to thank Robert Woodard, an Assistant baseball coach at the University of North Carolina at Chapel Hill for technical advice. We would also like to thank Mr. Philip Matta for designing and constructing the instrumented force plate. There is no conflict of interest to disclose.

Figure legend

Figure Correlation between ball speed and peak resultant force (a), vertical force at the time of peak anterior force (b), and resultant force at the time of peak anterior force (c).

Table 1: Mean and standard deviation (SD) of the dependent variables during push off

	Mean	SD
Ball speed (m/s)	31.7	2.8
Peak vertical force (N/BW)	1.27	0.11
Peak anterior force (N/BW)	0.54	0.11
Peak resultant force (N/BW)	1.35	0.13
Vertical force at time of peak anterior force (N/BW)	1.13	0.15
Resultant force at time of peak anterior force (N/BW)	1.26	0.17
Impulse of the anterior force (Ns/BW)	0.20	0.03

Table 2: Reliability of the ground reaction force measures analyzed in this study

	$ICC_{2,k}$	SEM
Peak vertical GRF (N/BW)	.888	3.8
Peak anterior GRF (N/BW)	.751	5.3
Peak resultant GRF (N/BW)	.915	3.9
Vertical force at time of peak anterior force (N/BW)	.894	5.0
Resultant force at time of peak anterior force (N/BW)	.876	6.0
Impulse of the anterior GRF (Ns/BW)	.653	.016

BW = body weight, ICC = Intraclass correlation coefficient, SEM = standard error of measurement

Table 3: Correlation between ball speed and ground reaction force variables during push off

	ρ	p
Peak vertical GRF (N/BW)	.199	.158
Peak anterior GRF (N/BW)	.221	.115
Peak resultant GRF (N/BW)	.321	.020*
Vertical force at time of peak anterior force (N/BW)	.454	<.001*
Resultant force at time of peak anterior force N/BW)	.424	.002*
Impulse of the anterior GRF (Ns/BW)	.154	.274

BW = body weight
* Statistically significant at α <0.05

Figure: Correlation between ball speed and peak resultant force (a), vertical force at the time of peak anterior force (b), and resultant force at the time of peak anterior force (c).