RELATIONSHIP BETWEEN GROUND REACTION FORCE AND THROWING ARM KINETICS IN HIGH SCHOOL AND COLLEGIATE BASEBALL PITCHERS

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The purpose of this study was to examine the relationship of ground reaction force (GRF) of the drive and stride leg and kinetics of the throwing arm in high school and collegiate baseball pitchers. Several studies have examined the relationship between GRF and ball velocity, but no one has examined the effect of GRF on maximum shoulder rotation torque (MERT) and maximum elbow valgus torque (MEVT). Understanding this relationship will be important to both enhancing performance and avoiding injury. Data that were previously collected during a pitching evaluation were analyzed. Twenty-two high school pitchers and 13 collegiate pitchers had received a pitching evaluation. Multiple regression analysis was used to examine the relationships between variables. Only the drive leg medial force (β = .372, p = .015) and stride leg braking force (β = .401, p = .009) were significant predictors of MERT.

KEYWORDS: pitching, kinetics, ground reaction force.

INTRODUCTION: Throwing a baseball requires the transmission of forces generated in the lower extremity, through the trunk, to the upper extremity, and ultimately to the ball. Muscles of the lower extremity generate kinetic energy and provide a stable base of support for the movements of the upper extremity. Lower extremities and the trunk generate 50 to 55% of total force and kinetic energy (Kaczmarek et al., 2014). A disruption in the functioning of the lower extremities could lead to altered upper extremity kinematics and increased load exerted on the shoulder and elbow. Arm motion can also be more efficiently and safely generated with a stable base (Kageyama, Sugiyama, Kanehisa, & Maeda, 2015).

Based on understanding of the kinetic chain, it is clear that GRF and lower extremity function of both the drive leg and stride leg can affect the kinetics of the throwing arm. However, due to the emphasis placed on ball velocity in throwers of all ages, many previous studies have focused on how GRF affects throwing velocity (Kageyama, Sugiyama, Takai, Kanehisa, & Maeda, 2014; Macwilliams, Choi, Perezous, Chao, & Mcfarland, 1998; McNally, Borstan, Onate, & Chaudhari, 2015; Oyama & Myers, 2018). Guido and Werner (2012) examined how GRF of the stride leg influenced maximum elbow flexion torque and maximum shoulder external rotation torque (MERT) in collegiate baseball pitchers, but did not include analysis of the drive leg. Additionally, they neglected to examine the effects of GRF on maximum elbow valgus torque (MEVT), a key indicator in UCL injuries.

Additionally, it has been shown that kinematic parameters are similar between high school and college pitchers, but kinetics and ball velocity are different (Fleisig et al., 2016). Further understanding of the role of ground reaction forces of the drive and stride leg to throwing arm kinetics in all ages will aid training program development to enhance performance and avoid injury. Therefore, the purpose of this study was to examine the relationship of GRF and MERT and MEVT in high school and college baseball pitchers.

METHODS: In this retrospective review, data were examined from reports generated as part of a pitching evaluation. Twenty-two high school pitchers (age = 16.8 ± 0.7 years) and thirteen college pitchers (age = 20.4 ± 1.1 years) had previously received a pitching evaluation. As part of the evaluation, 3D motion data were collected using the 38 reflective marker set required for PitchTrak (Motion Analysis Corporation, Santa Rosa, California), and a ten-camera motion analysis system

(Motion Analysis Corporation, Santa Rosa, California). Motion data were collected at 250 Hz. Ground reaction forces were collected with three multicomponent force plates (AMTI, Watertown, Massachusetts) embedded in the Perfect Mound (Porta-Pro Mounds Inc, Sauget, Illinois). The mound was engineered to meet major league specification. The force plates were mounted on concrete poured to allow the force plate surfaces to be level with the fiberglass surface of the mound. One plate was positioned under the pitching rubber with the front edge 6 inches in front of the rubber. The other two plates were angled at 4.8° and covered the landing zone. Each plate was covered with 1 ¾ inch infilled artificial turf to match the rest of the mound. Force plate data were collected at 1000 Hz. Pitchers were allowed to wear their cleats. Ball velocity was recorded with a Trackman device (Trackman, Scottsdale, Arizona) (Figure 1).

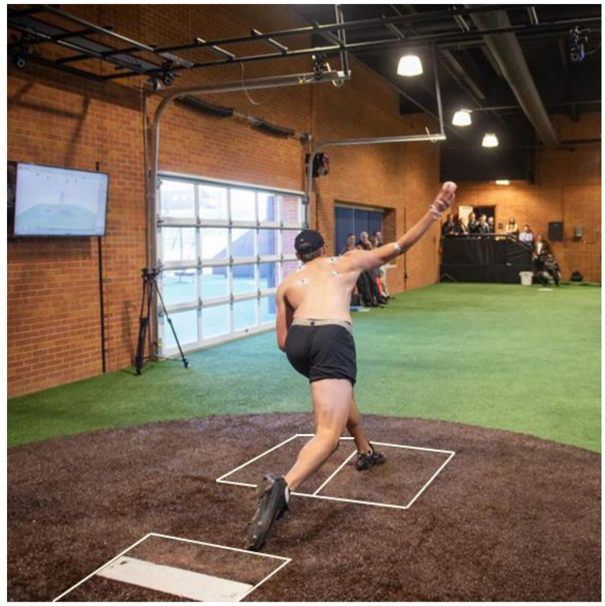

Figure 1: Image of setup. Approximate location of the force plates outlined in white.

Each pitcher went through a normal pregame warm-up period, before pitching four fastballs, four breaking balls, and four change ups to a catcher receiving throws at a regulation distance. One representative fastball was reviewed for this study. Data were processed and variables were calculated with PitchTrak.

The peak vertical, propulsive, and medial-lateral ground reaction force data for the drive leg (rubber side) were extracted during the stride phase, defined from the time of maximum height of the stride knee (MKH) to stride foot contact. The stride leg GRF data were extracted during the arm-cocking and arm-acceleration phases, defined from foot contact to the moment of ball release. In addition, the resultant ground reaction force was calculated as the determinant of the vector from the three force components. All GRF data and joint torques were normalized by body weight (bw) and the product of body weight and height (h), respectively.

Independent t-tests were performed to determine whether mean differences in drive GRF, stride GRF, joint kinetics, and ball speed between high school and college pitchers existed. The extracted GRF data were entered into a multiple stepwise regression analysis to determine the linear model that best predicts MERT and MEVT at a significance level of .05. Ball speed was also evaluated to determine its relationship with these predictor variables using linear regression. The regressions were performed within each group as well as for the entire sample. Using the Shapiro-Wilk test, the normality of distribution for each of the variables was confirmed with the exception of ball speed. Consequently, Spearman rho (ρ) correlation coefficients were calculated to evaluate the relationship of the drive and stride GRF variables with ball speed. All statistical analyses were performed using commercially available statistical software (SPSS Statistics v21; IBM Corp, Armonk, New York, USA) at an *a priori* significance level of 0.05.

RESULTS: Height, weight, ball velocity and MERT were significantly different between high school and college pitchers (Table 1). There was no difference in MEVT of high school and college pitchers. The ground reaction force profiles of both the drive and stride legs for a representative pitch are shown in Figure 2. No significant differences in drive GRF or stride GRF were found between groups with the exception of the drive leg medial force, which was higher in college pitchers (9% ± 3% bw) than it was in high school pitchers (7% ± 2% bw, $p = .010$) (Table 2). When examining the stepwise regression analysis on the entire sample of 35 pitchers, the drive leg

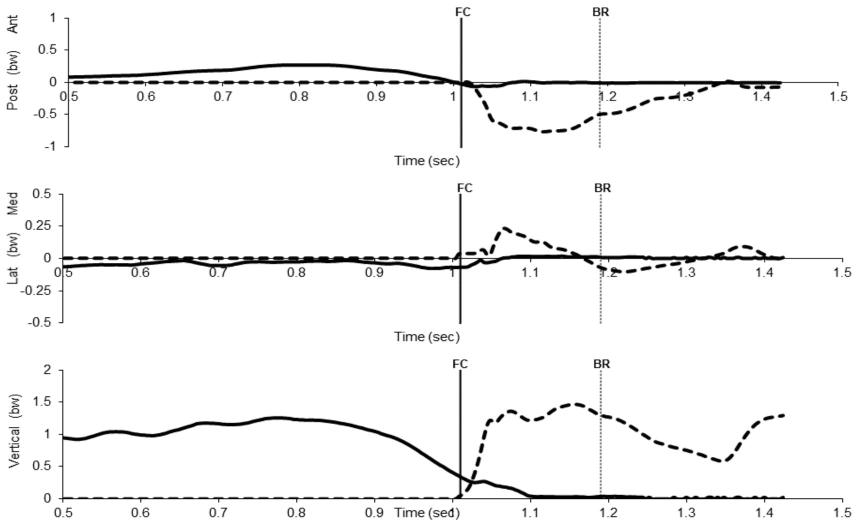

Figure 2: GRF for a representative pitch on the drive (solid) and stride (dotted) legs in the anterior-posterior (top), medial-lateral (middle), and vertical (bottom) directions. FC=foot contact. BR=ball release.

medial force (β = .372, p = .015) and stride leg braking force (β = .401, p = .009) were the only significant predictors of MERT (R^2 = .393, p < .001). However, when limiting the analysis to each group, only the laterally directed GRF on the stride leg predicted MERT in college pitchers (β = -.574, p = .040). No GRF variables on the drive or stride legs were found to be significantly related to MERT in the high school group. Furthermore, no significant GRF predictors of MEVT were found in the entire sample or within each group.

Ball speed was weakly correlated with peak resultant force (ρ = .387, p = .022), propulsive force (ρ = .387, p = .026), medial force (ρ = .361, p = .033) and vertical force (ρ = .391, p = .020) on the drive leg. There were no significant correlations between ball speed and stride leg ground reaction forces (p > 0.05).

Table 1: Demographics, ball velocity, and joint kinetics between high school and college pitchers

Parameter	High School (n=22)	College (n=13)	*p*
Height (m)	1.87 ± 7.26	1.94 ± 5.15	0.004
Weight (kg)	80.6 ± 10.3	98.5 ± 6.4	<0.001
Ball velocity (m/s)	36 ± 2	38 ± 3	0.014
MERT (% bw-h)	4.0 ± 0.5	4.5 ± 0.6	0.029
MEVT (% bw-h)	2.6 ± 0.9	2.4 ± 1.5	0.613

Table 2: Peak ground reaction forces by leg between high school and college pitchers

Leg	GRF (% bw)	High School (n=22)	College (n=13)	*p*
Drive	Propulsive	33 ± 6	32 ± 7	0.700
	Medial	7 ± 2	9 ± 3	0.010
	Vertical	138 ± 17	135 ± 28	0.556
	Resultant	142 ± 17	138 ± 28	0.570
Stride	Braking	90 ± 20	94 ± 24	0.690
	Medial	-22 ± 12	-26 ± 13	0.213
	Vertical	189 ± 42	188 ± 44	0.918
	Resultant	210 ± 46	210 ± 48	0.987

DISCUSSION: Contrary to the findings of Kageyama et. al (2014, 2015), resultant GRF of the drive and stride legs were not greater in the college pitchers despite the fact that they threw with significantly higher ball velocity than the high school pitchers. The only GRF variable that differed between the groups was drive leg medial force. Drive leg medial force along with stride leg breaking force were the only predictors of MERT, which also differed between groups. Together, these results suggest that MERT may be reduced by limiting the drive leg medial force. However, drive leg medial force along with peak resultant force, propulsive force, and vertical force of the drive leg are weakly correlated with ball velocity. Focusing on creating propulsive and vertical force in the drive leg may result in decreased MERT while still maintaining ball velocity. In the college pitchers, lateral GRF on the stride leg predicted MERT.

While only comprising a small portion of resultant GRF, the medial and lateral GRF seem to play a role in MERT production. Producing larger medial and lateral forces could be an indicator of imbalance or improper alignment of the lower extremity segments. Muscle strength and balance exercises could help improve GRF generation and the early activation of the kinetic chain.

Maximum elbow valgus torque was not significantly different between groups and no GRF characteristics were predictors of MEVT. These results suggest that other factors such as muscle strength, trunk control, pelvis/trunk kinematics, and stride technique may overshadow the effects of GRF on MEVT. Additionally, in this study, the average MEVT was 2.6% bw-h which is below the recommended threshold of 4% bw-h. Stronger predictors may be apparent in individuals with excessive MEVT.

Results of this study should be considered in light of limitations. The high school pitchers who participated in the pitching evaluations were part of an elite pitcher's camp or a travel ball team. Thus the high school pitchers here may have been more skilled or trained than the typical high school baseball pitcher. This may be evident as our average ball velocity among the high school pitchers was 36 m/s as compared to the high school pitchers in Oyama et al. (2018) who pitched at an average 31.7 m/s. This may explain some of the lack of significant differences between the high school and college pitchers in this study. Accuracy of ball placement in the strike zone by the pitcher was not assessed in this study. That data is available and further research should explore the effects of GRF on accuracy.

CONCLUSION: With the exception of drive leg medial force, there were no significant differences in GRF between the high school and college pitchers. Drive leg medial force and stride leg breaking force were the only predictors of MERT for all 35 pitchers. Stride leg lateral force was the only predictor of MERT in the college pitchers. Due to the limited relationships present, other factors such as muscle strength, coordination, kinematics, or stride technique may overshadow the effects of GRF in highly skilled pitchers and warrant further investigation.

REFERENCES:

Fleisig, G. S., Laughlin, W. A., Aune, K. T., Cain, E. L., Dugas, J. R., & Andrews, J. R. (2016). Differences among fastball, curveball, and change-up pitching biomechanics across various levels of baseball. *Sports Biomechanics*, *15*(2), 128–138.

Guido Jr., J. A., & Werner, S. L. (2012). Lower-Extremity Ground Reaction Forces in Collegiate Baseball Pitchers. *Journal of Strength and Conditioning Research*, *26*(7), 1782–1785.

Kaczmarek, P., Lubiatowski, P., Cisowski, P., Grygorowicz, M., Łepski, M., Długosz, J., … Romanowski, L. (2014). Shoulder problems in overhead sports. Part I - biomechanics of throwing. *Polish Orthopedics and Traumatology*, *79*, 50–58.

Kageyama, M., Sugiyama, T., Kanehisa, H., & Maeda, A. (2015). Difference between Adolescent and Collegiate Baseball Pitchers in the Kinemat- ics and Kinetics of the Lower Limbs and Trunk during Pitching Motion. *Journal of Sports Science and Medicine*, *14*(January), 246–255.

Kageyama, M., Sugiyama, T., Takai, Y., Kanehisa, H., & Maeda, A. (2014). Kinematic and Kinetic Profiles of Trunk and Lower Limbs during Baseball Pitching in Collegiate Pitchers. *Journal of Sports Science and Medicine*, *13*(April), 742–750.

Macwilliams, B. A., Choi, T., Perezous, M. K., Chao, E. Y. S., & Mcfarland, E. G. (1998). Characteristic ground-reaction forces in baseball pitching. *American Journal of Sports Medicine*, *26*(1), 66–71.

McNally, M. P., Borstan, J. D., Onate, J. A., & Chaudhari, A. M. W. (2015). Stride Leg Ground Reaction Forces Predict Throwing Velocity in Adult Recreational Baseball Pitchers. *Journal of Strength and Conditioning Research*, *29*(10), 2708–2715.

Oyama, S., & Myers, J. B. (2018). The Relationship Between the Push Off Ground Reaction Force and Ball Speed in High School Baseball Pitchers. *Journal of Strength and Conditioning Research*, *32*(5), 1324–1328.