# LOWER BODY CONTRIBUTIONS TO PELVIS ENERGY FLOW AND PITCH VELOCITY IN COLLEGIATE BASEBALL PLAYERS

**Arnel Aguinaldo,[1] Kristen Nicholson[2]**

**Kinesiology, Point Loma Nazarene University, San Diego, CA[1]**
**Orthopaedic Surgery, Wake Forest School of Medicine, Winston Salem, NC[2]**

The aims of this study were to examine the generation, absorption, and transfer of energy through the pelvis at the drive hip, stride hip, and lumbosacral joints and to determine predictors of ball speed during baseball pitching. Motion capture and ground reaction force (GRF) data from 20 collegiate pitchers were analysed using energy flow and LASSO regression analyses. Energy was transferred from the drive leg to the pelvis during the stride phase while energy was transferred from the pelvis to the stride leg and trunk during arm-cocking. Drive leg GRF, impulse, and stride hip generation contribute to pitch velocity.

**KEYWORDS:** mechanical energy, segmental power, kinetics, overarm throwing.

**INTRODUCTION:** The pitching motion in baseball is a complex activity that is performed with an open kinetic chain through which mechanical energy purportedly flows in a proximal-to-distal fashion to accelerate the throwing arm (Aguinaldo & Escamilla, 2019). Optimal timing of segmental rotations, specifically pelvic and trunk rotations, has been shown to maximize efficiency of the pitching motion (Aguinaldo, Buttermore, & Chambers, 2007). While previous research have primarily focused on the biomechanics of the upper body segments during pitching (Chalmers et al., 2017), the drive (back) and stride (front) legs play important roles in facilitating energy flow through the kinetic chain. However, the mechanisms by which the lower body joint torques generate, absorb, and transfer energy “up the chain” are unclear. Howenstein et al. (2020) reported that the transfer of translational energy to the pelvis and trunk is related to the propulsive kinetics of the drive leg while the braking impulse on the stride side influences energy flow into the pitching arm. Likewise, results from previous segmental power analyses suggest that the torques at the thoracolumbar and lumbosacral joints transfer a substantial amount of energy from the pelvis to the trunk (Aguinaldo & Escamilla, 2019; Kimura et al., 2020). These findings provide evidence to support the notion that the pelvis acts as the “root” segment through which mechanical energy flows between the lower and upper body segments during pitching. Yet, no study to date has analysed the energy distribution among the joints and segments of the drive limb, stride limb, pelvis, and trunk during pitching. Therefore, this study aimed to examine the energy generation, absorption, and transfer across the drive hip, stride hip, and lumbosacral joints during pitching in collegiate baseball players. A secondary aim was to determine which of these energetic factors along with bilateral ground reaction force (GRF) and impulse metrics can best predict ball speed.

**METHODS:** This retrospective study was approved by the institutional review board of the Wake Forest School of Medicine. Secondary analysis was performed on experimental data from 20 collegiate pitchers (age = 20.1 ± 1.3 years, height = 1.86 ± 0.06 m, mass = 92 ± 9 kg), who each threw a sequence of fastball and off-speed pitches to a catcher at a regulation distance (18.4 m). One representative fastball was extracted for this study in which 3D motion data was collected using a 38 reflective marker set (Aguinaldo et al., 2007) and a 12-camera motion analysis system (Qualisys, Göteborg, Sweden) at a sampling rate of 400 Hz. Ground reaction forces (GRF) were collected with three force platforms (AMTI, Watertown, Massachusetts) embedded in the Perfect Mound (Porta-Pro Mounds Inc, Sauget, Illinois) according to Major League Baseball (MLB) specification. 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. GRF data were collected at 1200 Hz. Ball speed was recorded with a pitch flight analysis device (Trackman, Scottsdale, Arizona).

Joint kinematic and kinetic data were calculated using a previously described 14-segment full-body model (Aguinaldo et al., 2007). The pelvis segment was defined by markers overlying the two anterior superior iliac spines and the sacrum while the trunk was defined as three rigid segments by markers on the right clavicle and six bilateral scapular landmarks (Aguinaldo et al., 2007). The hip and lumbosacral joint locations were estimated using pelvis landmark data scaled to each pitcher (Reed, Manary, & Schneider, 1999). The 26 degrees-of freedom (DOF) model was configured in Visual3D (C-Motion, Germantown, Maryland) using adult male inertial properties with the joint forces and torques calculated using a Newton-Euler inverse dynamics distal-to-proximal approach (Aguinaldo et al., 2007; Stodden et al., 2001).
The joint force powers (JFP), which indicate the rates of passive energy transfer, at the drive hip, stride hip, and lumbosacral joints were expressed as the dot product of the respective joint reaction force ($\boldsymbol{F_j}$) and linear joint velocity ($\boldsymbol{v_j}$):

$$JFP = \boldsymbol{F_j} \cdot \boldsymbol{v_j}$$

The rates of work done on adjacent proximal ($STP_p$) and distal ($STP_d$) segments by the joint torque were computed as the dot product of the joint torque ($\boldsymbol{\tau_j}$) and the angular velocity of the proximal ($\boldsymbol{\omega_p}$) and distal ($\boldsymbol{\omega_d}$) segments, respectively:

$$STP_p = \boldsymbol{\tau_j} \cdot \boldsymbol{\omega_p} \; ; STP_d = \boldsymbol{\tau_j} \cdot \boldsymbol{\omega_d}$$

The joint torque powers (JTP) at the drive hip, stride hip, and lumbosacral joints were calculated as the dot product of the joint torque and joint angular velocity:

$$JTP = \boldsymbol{\tau_j} \cdot (\boldsymbol{\omega_d} - \boldsymbol{\omega_p})$$

Positive and negative joint torque power indicate the rates of energy generation and absorption, respectively, by the joint torque. If the segments are rotating in the same direction, the joint torque can also transfer energy between segments at the rate of the slower moving segment (ET) with the direction of transfer determined by the polarity and magnitudes of the proximal and distal STP (Carvalho et al., 2021; Robertson & Winter, 1980):

$$ET = \frac{|STP_p| + |STP_d| - |JTP|}{2}$$

JFP and ET were then summed to yield the rate of net energy transfer across a joint.
Four phases in the pitching motion were defined temporally by the instances of maximum knee height (MKH) of the stride limb, stride foot contact (SFC), maximum external rotation (MER) of the throwing shoulder, ball release (BR), and maximum internal rotation (MIR) of the throwing shoulder: stride phase (MKH to SFC), arm-cocking (SFC to MER), arm-acceleration (MER to BR), and follow-through (BR to MIR). Energy generation (or absorption) and transfer at the drive hip joint were computed by integrating the JTP and ET, respectively, in the stride phase. Likewise, energy generation (or absorption) and transfer at the stride hip and lumbosacral joints were computed by integrating the JTP and ET, respectively, in the arm-cocking, arm-acceleration, and follow-through phases. Descriptive statistics were calculated for all energy terms. Peak propulsive and vertical GRF and impulse metrics from both limbs were also extracted and inputted into a least squares model along with the energetic factors to predict ball speed. With 31 discrete features, we used a regularized regression model based on the least absolute shrinkage and selection operator (LASSO), which allows for the reduction of predictors to prevent model overfitting (Tibshirani, 1996). A subgroup (N=13) of our sample was used to train the model and estimate its coefficients using a 10-fold cross-validation to determine the optimal size of the tuning parameter (λ) that penalizes collinear features. We used the root mean square error (RMSE) in units of m/s and an ordinary least squares (OLS) coefficient of determination to assess model performance. All statistical analyses were performed in RStudio (version 1.2) using the *tidyverse* and *glmnet* packages.

**RESULTS:** Pitchers threw with an average ball speed of 39.2 ± 1.2 m/s. The rates of energy absorption, generation, and transfer for the drive hip, stride hip, and lumbosacral joints throughout the pitching motion are shown in Figure 1. The total energy absorbed, generated, and transferred at the drive hip joint during the stride phase were -109 ± 49 J, 96 ± 67 J, and -192 ± 57 J, respectively (Figure 2). The stride hip joint absorbed, generated, and transferred -87 ± 55 J, 9 ± 11 J, and 21 ± 41 J, respectively, during the arm-cocking phase, while absorbing, generating, and transferring -22 ± 28 J, 7 ± 11 J, and 46 ± 27 J, respectively, during the arm-acceleration phase (Figure 2). The stride hip also transferred 139 ± 68 J in the distal direction during the follow-through phase. The lumbosacral joint absorbed, generated, and transferred -73 ± 33 J, 82 ± 29 J, and 93 ± 66 J, respectively, during the arm-cocking phase while absorbing, generating, and transferring -19 ± 28 J, 22 ± 24 J, and -44 ± 40 J, respectively during the arm-acceleration phase (Figure 2). Table 1 lists the model coefficients after LASSO regularization shrank the coefficients of 26 out of the 31 ball speed predictors to zero. The remaining predictors include stride hip generation during the arm-acceleration (AA) phase, drive hip transfer, stride leg braking impulse, and the vertical GRF and impulse on the drive leg. This LASSO model predicted ball speed with a RMSE of 2.8 m/s ($r^2$ = .498, $p$ = .009).

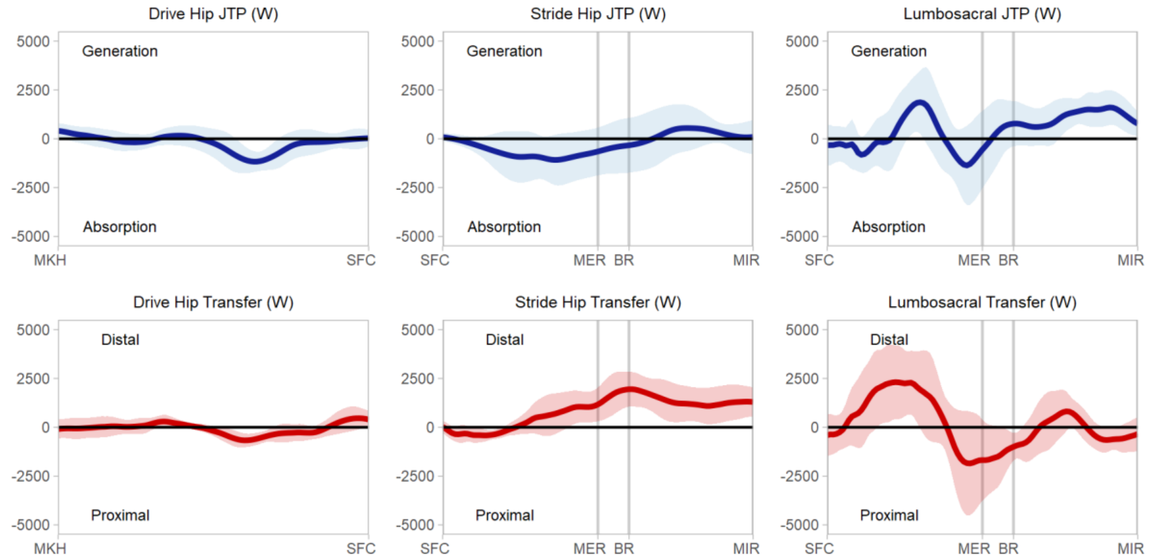


**Figure 1: Mean ± SD bands of joint torque powers (blue) and rates of energy transfer (red) for the drive hip (stride phase), stride hip, and lumbosacral joints**

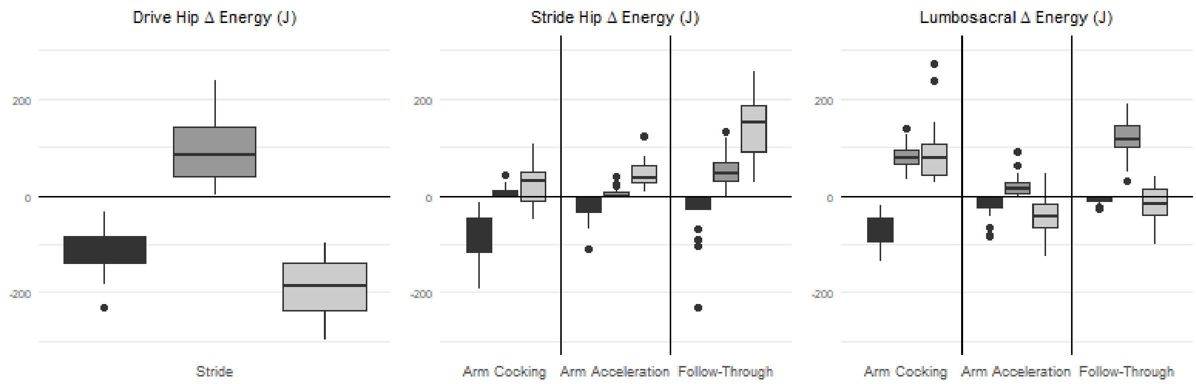


**Figure 2: Energy absorption (dark grey), generation (grey), and transfer (light grey) for the drive hip, stride hip, and lumbosacral joints in collegiate baseball pitchers (N=20)**

**Table 1: Coefficients of energy, GRF, and impulse predictors after LASSO regularization**

| Predictor | Coefficient |
|---|---|
| Stride Hip Generation (AA) | .026 |
| Drive Vertical GRF | .001 |
| Drive Vertical Impulse | .006 |
| Drive Hip Transfer | -.005 |
| Stride Braking Impulse | -.051 |

**DISCUSSION:** To the extent of our knowledge, an examination of partitioned energy flow (generation, absorption, transfer) at the drive hip, stride hip, and lumbosacral joints in adult baseball pitchers has not been previously reported. The results support the general belief that energy is transferred from the drive leg to the pelvis through the drive hip joint during the stride phase as the pitcher accelerates towards home plate (Chu et al., 2016; Howenstein et al., 2020). Conversely, the energy flow analysis indicated that the stride hip joint transfers energy distally from the pelvis to the stride leg, which act to provide a stable foundation on which the pelvis and trunk can rotate throughout the pitching motion. This finding provides further evidence that the stride hip does not transfer energy in the proximal direction (Naito, Takagi, & Maruyama, 2011). A distal energy flow from the pelvis also occurs at the lumbosacral joint, the structures of which generate and transfer a substantial amount of energy to the trunk. These findings support the proposition that upper torso rotation draws its energy from the pelvis rotating (Kimura et al., 2020) on a stabilised stride leg (Howenstein et al., 2020). This mechanism was further supported by the results of the LASSO regression, which showed that the energy generated at the stride hip joint and the braking impulse of the stride leg were found to be predictors of ball speed along with the vertical GRF, impulse, and hip joint transfer on the drive leg.

**CONCLUSION:** The findings of this study provide evidence that shows that the energy through the kinetic chain flows from the drive leg to the pelvis during the stride phase and from the pelvis to the stride leg and trunk during the arm-cocking phase. Likewise, the GRF and energy flow results define the roles that the drive and stride legs play in generating pitch velocity.

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