ENERGY FLOW AND IMPULSE PREDICTORS OF BAT SPEED DURING BASEBALL TEE BATTING USING THE LEAST ABSOLUTE SHRINKAGE AND SELECTION OPERATOR (LASSO) REGRESSION

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The purposes of this study were to examine how energy is generated, absorbed, and transferred through the pelvis during the baseball swing and to identify the best model of ground reaction force (GRF) and energy flow (EF) predictors of bat speed using a LASSO regression, which reduced the dataset to a model of four EF and two impulse variables that best predicts bat speed. The findings indicate that the mechanical energy flows from the trunk to the lead leg via the pelvis as these segments rotate during the swing. It is hoped that these findings will aid coaches and athletes in better understanding which elements of the swing movement are most closely related to bat speed. Thus, coaches may be able to develop and implement training strategies accordingly to improve bat speed and player performance.

KEYWORDS: baseball, hitting, impulse, energy flow, regularized regression

INTRODUCTION: Unlike baseball pitching, there currently is limited research on baseball batting to explain which biomechanical factors can best predict bat speed. Data in the existing literature suggests that braking/propulsive ground reaction forces (GRF) and energy transfer through the trunk can influence bat speed (Ae et al., 2017; Horiuchi et al., 2020). However, no study to date has concurrently analyzed the effects of energy flow (EF) and GRF factors in generating bat head speed. Therefore, this study aimed to examine the energy generation, absorption, and transfer through the lead hip, back hip, and lumbosacral (L5S1) joints during baseball tee-batting and to determine which of these EF factors along with GRF factors best predict bat speed. Based on the current baseball pitching literature (Aguinaldo & Nicholson, 2021; Howenstein et al., 2020), it was hypothesized that the energy generation at the lead and back hip joints in the early phases of the swing, energy absorption at the lumbosacral joint during the acceleration phase, and energy transfer into the torso from the pelvis throughout all phases are the strongest predictors of bat speed in the swing.

METHODS: Nine healthy position players from an NCAA Division II collegiate men's baseball team between the ages of 19 and 23 volunteered to participate in the study. All participants signed informed consent forms before participating in the study, which was approved by the university's institutional review board prior to data collection. Players performed tee batting while their movements and GRF were recorded using an 8-camera 3D motion capture system (Motion Analysis Corp., Santa Rosa, CA) and two force platforms (AMTI, Watertown, MA) at data capture rates of 240 Hz and 1200 Hz, respectively. Bat speed was recorded using an inertial measuring unit (IMU) sensor (Blast Motion, Carlsbad, CA) fixed to the knob of the bat. Biomechanical metrics were extracted from a total of 33 swings for energy flow and impulse analysis using a 14-segment, 26 degrees-of freedom (DOF) full-body model configured in Visual3D (C-Motion, Germantown, MD). The rates of energy generation, absorption, and transfer and their respective totals through the pelvis were computed using an energy flow analysis as detailed by Aguinaldo and Nicholson (2021). The key events of the hitting motion were identified as foot-off (FO), maximum trunk rotation (MTR), ball impact (BI), and swing finish. The EF and impulse variables were further extracted by the phases of the hitting motion defined as the stance (FO to MTR), acceleration (MTR to BI), and follow-through (BI to swing finish) phases. A set of 27 discrete variables that includes all components of the peak GRF, impulse, and energy terms for the drive and stride legs was entered into a regularized regression model based on the least absolute shrinkage and selection operator (LASSO), which is a machine learning approach frequently used to reduce high-dimensional data (Tibshirani, 1996). The model was trained using a subgroup (N=25) of our sample and a 10-fold cross-validation in a process aimed to filter out variables that are not closely related to bat speed. Model performance was assessed using the root mean square error (RMSE) in units of m/s and an ordinary least squares (OLS) regression coefficient of determination (r^2). The descriptive statistical and regression analyses were performed in RStudio (version 1.2) using the *tidyverse* and *glmnet* packages.

RESULTS: Players hit off the tee with a measured bat speed of 30.4 ± 1.3 m/s. The LASSO model predicted bat speed with a RMSE of 1.0 m/s ($r^2 = .597$, $p < .001$) and included the back leg vertical impulse, lead leg propulsive impulse, lumbosacral (L5S1) energy absorption and transfer in the acceleration phase, and the lead hip energy absorption during follow-through (Table 1). Power generated by torques in both hip joints peaked during the acceleration phase (Figure 2). Energy transferred from the pelvis to the lead thigh through the lead hip joint while the highest rate of enery transfer was observed in the L5S1 joint, where the net torque transferred energy from the trunk to the pelvis (Figure 3).

Table 1: Energy flow and impulse predictor variables identified by LASSO regularization to be most closely related to bat speed ($r^2 = .597$, $p < .001$). AA = arm-acceleration; FT = follow-through

Predictor Variable	*B*	*SE B*	*p*
Intercept	58.6***	4.76	< .001
Back Leg Vertical Impulse	0.01**	0.01	.006
Lead Leg Propulsive Impulse	0.01	0.03	.670
L5S1 Absorption (AA)	0.06**	0.02	.008
L5S1 Transfer (AA)	-0.03	0.02	.123
Lead Hip Transfer	0.03	0.02	.054
Lead Hip Absorption (FT)	-0.16*	0.07	.022

*B = unstandardized coefficient; SE B = standard error of coefficient. *p < .05. **p < .01. ***p < .001*

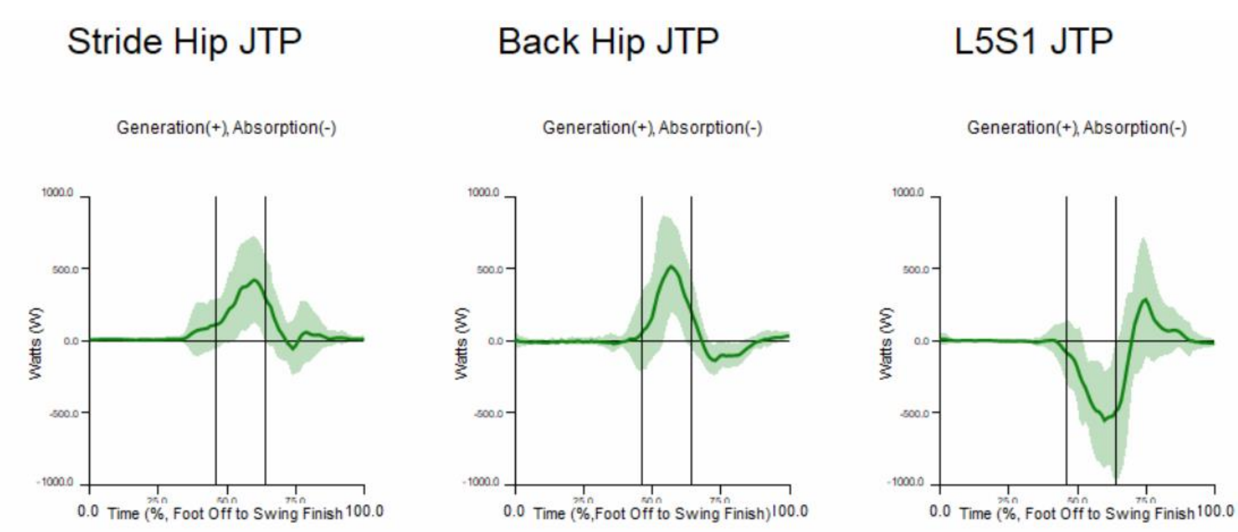

Figure 2: Mean (standard deviation ribbons) joint torque powers (JTP), which indicate the rates of energy generation or absorption in the lead hip, back hip, and lumbosacral joints throughout the

hitting motion. Vertical lines represent the maximum trunk rotation (MTR) and Ball Impact (BI) events, respectively

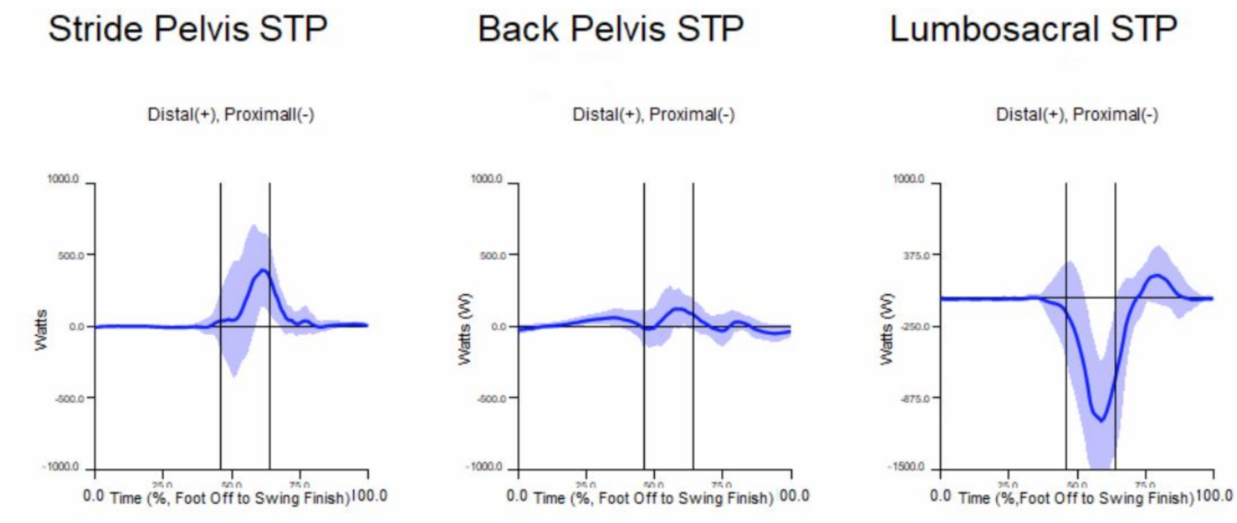

Figure 3: Mean (standard deviation ribbons) segment torque powers (STP), which indicate the rates of energy transfer in the lead hip, back hip, and lumbosacral joints throughout the hitting motion. Vertical lines represent the maximum trunk rotation (MTR) and Ball Impact (BI) events, respectively

DISCUSSION: The present study aimed to determine the energy flow and impulse predictors of bat head speed. LASSO regression reduced the predictive model to 2 impulse and 4 EF variables. Vertical impulse of the back leg and propulsive impulse of the lead leg were found to be factors of bat speed. Previous studies have shown that pelvis and trunk rotations about their long axes are essential in generating ball speed in pitching (Aguinaldo & Escamilla, 2019; Howenstein et al., 2020) and bat head speed in hitting (Ae et al., 2017). Hence, the impulses of both legs most likely correspond to the angular momentums induced by the muscles that move these segments. The findings, however, do not support the notion that energy flows “up the chain” as has been widely suggested by previous research (Horiuchi et al., 2020; Aguinaldo & Nicholson, 2021). As the lead foot contacts the ground and the pelvis continues to rotate toward the pitcher, the pre-stretch of the trunk is occurring and the energy transfers proximally “down the chain” through the lumbosacral joint and into the pelvis. Energy transfer through the acceleration phase (from maximum trunk rotation to ball impact) was found to predict bat head speed, suggesting the importance of the energy leaving the trunk and entering the pelvis through the lumbosacral joint. Previous studies suggest the pelvis as the “root segment” through which energy is transferred between the lower extremities and the trunk during pitching (Aguinaldo & Nicholson, 2021), tennis serving (Martin et al., 2014), and batting (Horiuchi et al, 2020). As the hitter reaches maximum trunk rotation away from the pitcher, his pelvis is already completing its rotation and approaching maximum velocity, and the trunk begins rotating faster than the pelvis segment (Monti, 2015, Welch et al., 2020). The net energy generated by the lumbosacral joint torque during the swing has been previously shown to have no effect on bat head speed (Horiuchi et al., 2020). However, the energy transferred and absorbed in the joint appears to play a significant role as suggested by the current findings, which also align with those reported by Horiuchi et al. (2020). These findings show that energy is not propagating up the chain as generally believed, but down into the pelvis and appears to be important in generating bat speed. Further, as the hitter pulls his pelvis into rotation, an eccentric pre-stretch occurs through the obliques and abdominal musculature (Fleisig et al., 2014) as demonstrated by the energy absorbed by the net torques at the lumbosacral and lead hip joints measured in this study. Finally, similar to previous biomechanical analyses of baseball batting (Ae et al., 2017; Horiuchi et al., 2020), the present study showed high power generation at both hips during the acceleration phase. The extensor and adductor torques at both hip joints generated and transferred these mechanical energies to the pelvis. Hence, strengthening the muscles that extend, adduct, and rotate the hip joints could potentially improve batting performance (Zipser et al., 2021).

CONCLUSION: This study provides evidence that suggests that the key factors of determining bat speed during tee batting involve the momentum generated by the legs and the energy absorbed by the lumbosacral and lead hip joints along with the energy transfer to and from the pelvis through these joints during the phases immediately before and after ball contact. Based on the findings in present study, players could benefit from training strategies that enhance the muscular strength and mobility of the pelvis and hips, thereby potentially increasing bat head speed.

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