DIFFERENCES IN THE ENERGY FLOW, GROUND REACTION FORCE, AND IMPULSE DURING BASEBALL TEE BATTING BETWEEN HIGH SCHOOL AND COLLEGIATE BASEBALL PLAYERS

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The purposes of this study were to examine the differences in the peak impulses and ground reaction forces (GRF) of the lead and back legs as well as how energy flows (energy absorption, generation, and transfer) in the back hip, front hip, and L5S1 joints during the baseball swing phases between high school and collegiate baseball players. The findings indicate that the mechanical energy flows down the chain from the L5S1 joint to the pelvis into the lead leg during the bat acceleration phase of the swing in both participant groups. It is hoped that these findings may help coaches and athletes understand which kinetic components of the swing improve bat speed. Thus, coaches may develop training strategies to improve bat speed and player performance.

KEYWORDS: baseball, energy flow, hitting, impulse, high school, collegiate

INTRODUCTION: The current literature lacks evidence that indicates the differences in the GRF, impulse, and energy flow patterns between high school and collegiate baseball batters. The existing data in the literature suggests that as baseball batters mature their maximum bat swing and ball velocity increases as well as their lead elbow and hip segment maximum angular velocity at ball contact (Inkster et al., 2011). However, no study to date has analyzed the differences in the kinetics of various aged groups broken down into the phases of the batting sequence regarding the GRF, impulse, and energy flow. Therefore, this study sought to determine the differences in the peak vertical, medial-lateral and anterior-posterior impulse and GRF of the lead and back legs as well as how the energy is absorbed, generated, and transferred through the back hip, front hip, and lumbosacral (L5S1) joints during the phases of hitting between high school and collegiate baseball players. Based on the current research on energy flow and GRF in baseball batting (Ae et al., 2017; Horiuchi et al., 2020; Kageyama et al., 2015; Takata & Aguinaldo, 2022), it was hypothesized that there would be difference in peak vertical, medial-lateral and anterior-posterior impulse and GRF of the lead and back legs as well as absorption, generation, and transfer of energy through the back hip, front hip, and L5S1 joints between high school and collegiate baseball players throughout the batting phases.

METHODS: 26 healthy baseball players volunteered to participate in this study. 13 high school participants (age = 14.7 ± 1.3 years, height = 1.70 ± 0.07 m, mass = 59 ± 9.8 kg) and 13 college participants (age = 19.4 ± 0.8 years, height = 1.83 ± 0.04 m, mass = 82 ± 3.8 kg). All participants and their respective parents or guardians signed informed consent forms prior to participating in the study, which was approved by the university's institutional review board. Participants batted off a tee while their kinematics and GRF were recorded using an 8-camera 3D motion capture system (Motion Analysis Corp., Santa Rosa, CA) sampling at 240 Hz and two force platforms (AMTI, Watertown, MA) sampling at 1200 Hz. Swing speed was recorded using an inertial measuring unit (IMU) sensor (Blast Motion, San Marcos, CA) placed at the knob of the bat. The joint kinetics and kinematics were extracted from the participant's fastest bat swing and calculated using the 14-segment, 26 degrees-of freedom (DOF) full-body model configured in Visual3D (C-Motion, Germantown, MD) from the energy flow analysis described in Aguinaldo and Nicholson (2021). The joint torque powers (JTP) and segment torque powers (STP) at the lead hip, back hip, and L5S1 joints were calculated using methods previously mentioned in the literature

(Aguinaldo & Nicholson, 2021). Energy generation and absorption by a joint torque are indicated by positive and negative JTP, respectively. Segments rotating in the same direction also result in energy transfer determined by the rates of energy flow in the proximal and distal segments (Aguinaldo & Nicholson, 2021). The variables analyzed included back and lead leg anterior-posterior and vertical GRF, back hip joint torque power (JTP), back hip segmental energy power (STP), lead hip JTP, lead hip STP, L5S1 JTP, and L5S1 STP. The key phases in the batting motion were defined as the stance phase (SP) marked by foot off, drive phase (DP) indicated by foot contact to maximum trunk rotation (MTR), bat acceleration (BA) from MTR to ball impact (BI), ending with the follow-through (FT) from BI to swing finish. To determine differences in the JTP and STP of the lead hip, back hip, and L5S1 joint time-series curves throughout the entire batting motion between the two groups, statistical parametric mapping *t* tests (SPM{t}) were performed in Python (version 3.7) using *Spyder* (version 3.3) and the *spm1d* package (Pataky et al., 2013). Random field theory was employed to determine the critical threshold at which the *t* statistic would cross in 5% (α = .05) of observed clusters of smooth, random data. An independent t-test was used to compare the differences in the peak vertical, medial-lateral and anterior-posterior impulse and GRF of the lead and back legs as well as the maximum absorption, generation, and transfer of energy through the back hip, front hip, and L5S1 joint between groups. All data was normalized by body weight in kilograms and peak values were analyzed using the *tidyverse* package in Rstudio*.*

RESULTS: The mean bat speed was higher in collegiate hitters (30.7 ± 1.91 m/s) than it was in high school hitters (27.1 ± 2.66 m/s, $p < .001$). No statistically significant differences in peak GRF or impulse were observed between the two groups. Table 1 lists the peak energy flow variables observed as statistically significant during various phases of the batting cycle. Figure 1 depicts the rate of energy generation and absorption in the L5S1 joint throughout the batting cycle. Collegiate hitters generate energy in the late stance and early stride phase. High school hitters generate energy during the bat acceleration phase while collegiate hitters absorb energy. Figure 2 depicts the rate of energy transfer in the L5S1 joint. During the bat acceleration phase high school hitters are observed transferring energy from the L5S1 joint distally while collegiate hitters transfer energy proximally.

Table 1: Back hip, lead hip, and L5S1 energy flow (J/kg) during the batting phases. SP = stride phase; DP = drive phase; BA = bat acceleration; FT = follow through.

Variable	College		HS		
	M	*SD*	*M*	*SD*	*P*
Lead Hip Generation (DP)*	0.2	0.2	0.4	0.3	0.038
L5S1 Absorption (DP)*	-0.1	0.1	-0.4	0.3	0.002
L5S1 Generation (DP)*	0.1	0.1	0.3	0.3	0.007
L5S1 Transfer (DP)*	0.0	0.2	0.9	0.9	0.003
Lead Hip Transfer (BA)*	0.5	0.2	0.2	0.3	0.017
L5S1 Absorption (BA)*	-0.7	0.4	-0.1	0.2	<0.001
L5S1 Generation (BA)*	0.1	0.2	0.4	0.3	0.006
L5S1 Transfer (BA)*	-1.0	1.3	1.5	1.2	<0.001
L5S1 Absorption (FT)*	-0.4	0.3	-0.9	0.4	0.001
L5S1 Transfer (FT)*	0.0	0.6	-1.9	1.0	<0.001

*M = mean; SD= standard deviation; P = significance level; *p < .05.*

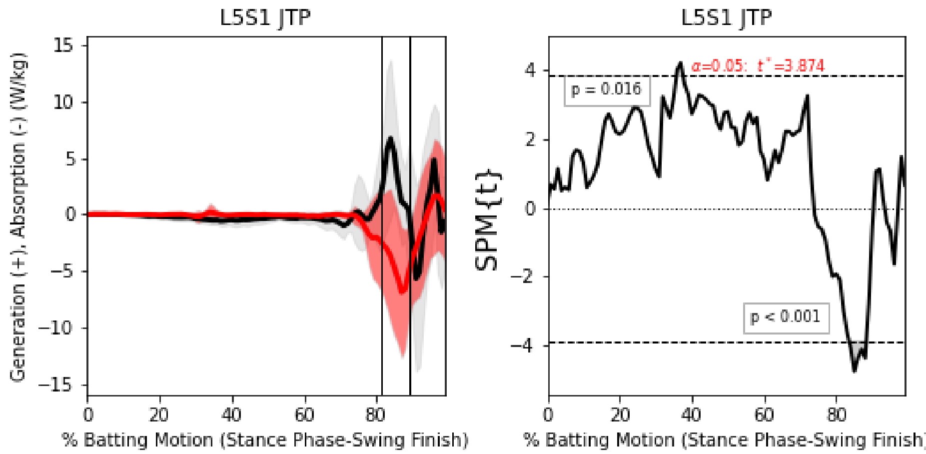

Figure 1: L5S1 energy generation and absorption (left) for high school (black) and collegiate (red) hitters. SPM{t} scalar field (right) showing a suprathreshold region in the bat-acceleration phase. First vertical line = MTR, second vertical line = BI; MTR = maximum trunk rotation; BI = ball impact.

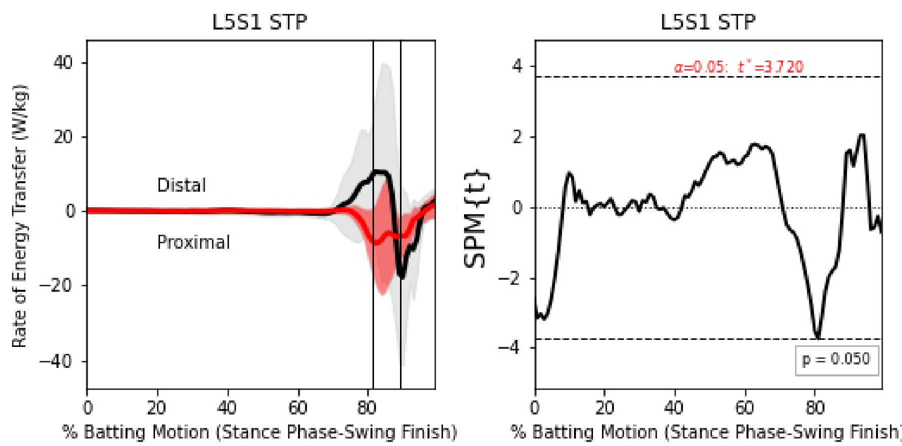

Figure 2: L5S1 energy transfer (left) for high school (black) and collegiate (red) hitters. SPM{t} scalar field (right) showing a suprathreshold region in the bat-acceleration phase. First vertical line = MTR, second vertical line = BI; MTR = maximum trunk rotation; BI = ball impact.

DISCUSSION: This study aimed to investigate the differences in energy flow, GRF, and peak impulses between high school and collegiate baseball players during the baseball swing phases. The results of the study indicate that there are significant differences in the way the two groups generate and transfer energy during the swing. In particular, the study highlights the importance of the batter's ability to contract the musculature surrounding the hip from stride foot contact to maximal bat loading in generating maximal bat speeds. These findings suggest that collegiate baseball players are more successful in adhering to the batting kinetic chain by transferring energy proximally down the chain into the pelvis, while high school players tend to transfer energy distally into the torso before transferring it proximally to the pelvis (Inkster et al., 2011; Howenstein et al., 2018). The study also found that collegiate players can stabilize the pelvis more successfully and absorb energy during the bat acceleration phase, slowing the rotational velocity of their pelvis down. In contrast, high school players struggle to adhere to the batting kinetic chain, resulting in a less efficient transfer of energy and a distal energy flow. Overall, this study provides valuable insights into the differences in energy flow and kinetics between high school and collegiate baseball players while supporting previous findings that energy does not flow up the chain (Takata & Aguinaldo, 2022). These findings can help coaches and trainers develop training strategies to improve players' bat speed and performance by emphasizing the importance of adhering to the kinetic chain and proper muscle recruitment during the swing. The study highlights the importance of developing proper swing mechanics and kinetic chain efficiency for success in baseball at higher levels.

CONCLUSION: The objective of this study was to compare the energy flow, GRF, and peak impulses during the baseball swing phases between high school and collegiate baseball players. The results showed significant differences in energy flow in the lead leg and L5S1 joint throughout the drive, bat acceleration, and follow-through phases of the batting cycle. It suggests that as batters mature, the L5S1 joint acts as a conduit for energy transfer, resulting in higher bat velocities. Coaches can focus on strengthening the musculature surrounding the pelvis in youth batters so that they may better control the deceleration of the pelvis, leading to a transfer of energy down the chain and executing the hitting kinetic chain in a more energy-efficient manner. The findings of this study may provide insights into the differences in energy flow, GRF, and impulse differences between groups of differing ages and coaches with the knowledge to determine what training strategies may improve the players' bat speed and performance.

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