THE RELATIONSHIP BETWEEN TRUNK ENERGY FLOW AND COLLEGIATE SOFTBALL HITTING PERFORMANCE

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The purpose of this study was to determine the relationship between trunk energy flow and performance (exit velocity) during collegiate softball hitting. Nineteen collegiate softball athletes (age: 19.6 ± 1.0yrs) performed three maximal effort swings off a pitching machine. Kinematic data were collected using an electromagnetic tracking system. A segmental power analysis was performed to quantify peak rates of trunk energy flow (proximal inflow (IF) and distal outflow (OF) on front and back sides). Regression analyses determined exit velocity was best predicted by peak rate of distal trunk energy OF on the front side. On average, the model showed exit velocity increased by .9 mph for every 100 W increase in distal trunk energy OF on the front side while holding body mass constant.

KEYWORDS: BATTING, EXIT VELOCITY, SEGMENT POWER, INFLOW, OUTFLOW

INTRODUCTION: Softball hitting requires precise coordination of segments to maximize performance (exit velocity). The primary phases of the softball swing include the load, stride, acceleration, and follow-through (Bordelon et al., 2021). The load and stride phases initiate pelvis to trunk separation and create an eccentric pre-stretch to store elastic potential energy in preparation for the acceleration phase. The subsequent acceleration phase involves a high-velocity rotation towards the pitcher to transfer kinetic energy in a proximal to distal manner through the lower extremities, pelvis, trunk, humerus, forearm, and finally hand immediately prior to ball contact (Welch et al., 1995). Based on kinetic chain theory, the lumbopelvic-hip complex (LPHC) is considered an important region for generating and transferring energy from the proximal lower extremities, pelvis, and trunk to the distal upper extremities (Kibler, Press, & Sciascia, 2006). However, the importance of energy flowing out of the trunk has yet to be studied in elite softball hitters. Additionally, although energy flow rhetoric is frequently utilized in instruction by coaches and in hitting research, prior studies have focused on other biomechanical parameters such as joint angles, forces, and moments (Washington & Oliver, 2018; Washington & Oliver, 2020). Directly analyzing mechanical energy flow can provide a deeper understanding of how the kinetic chain influences performance.

Emerging research has provided insight into energy flow during baseball hitting. Horiuchi et al. (2017) examined the relationship between energy flow through the lower extremities and trunk during amateur baseball hitting. Their findings indicated the front and back-side hips were important sites of energy generation, and the trunk was an important pathway for energy transfer. Horiuchi et al. (2021) further investigated energy flow through the trunk during baseball hitting and identified a positive association between bat head speed and energy flowing into the pelvis from the front (closest to the pitcher) and back (closest to the catcher) hip joints and energy flowing into the trunk. Their results showed energy flowing into the proximal end of the pelvis and thorax is important for maximizing hitting performance. However, the influence of energy flowing out of the distal aspects of the trunk (at front and back shoulders) on hitting performance has yet to be examined. Distal energy flow is important since the kinetic chain theory posits maximizing energy flow out of the trunk to the distal extremities to maximize performance. Further, to the author's knowledge, only one study has

investigated energy flow during softball hitting. Bordelon et al. (2021) performed a segmental power analysis to describe energy flowing into and out of the pelvis, trunk, and upper extremity segments. It was determined the trunk was an important site of energy flow throughout the acceleration phase of the swing. However, the relationship between trunk energy flow and softball hitting performance has yet to be investigated. Therefore, the purpose of this study was to determine the relationship between trunk energy flow and collegiate softball hitting performance. Based on prior results from Horiuchi et al. (2021) examining baseball hitting, it was hypothesized exit velocity would increase as trunk energy flow increased.

METHODS: Nineteen Division I National Collegiate Athletic Association softball athletes [(right-handed = 14) age: 19.6 ± 1.0 yrs; height: 172.4 ± 5.0 cm; mass: 71.7 ± 8.8 kg] were recruited to participate in the study. Inclusion criteria were (1) active on a team roster, (2) injury free for the past six months, and (3) had experience hitting off a pitching machine. Prior to the data collection, all participants completed an informed consent. All procedures were approved by the University's Institutional Review Board. Any participants under 19 years of age also had a parent assent to their participation.

An electromagnetic tracking system (trakSTAR Wide-Range, Ascension Technology Corp., Burlington, VT) synched with The MotionMonitor XGen software (Innovative Sports Training, Chicago, IL) was used to collect kinematic and kinetic data at a sampling frequency at 240 Hz. Sensor orientations and positions were independently filtered using a 4th order Butterworth filter with a cutoff frequency of 13.4 Hz as performed in prior softball hitting studies (Bordelon et al., 2021; Washington & Oliver, 2020). Finally, stride foot contact was determined using a force plate (Bertec, Columbus, OH) at a sampling frequency of 1200 Hz. Exit velocity was measured using a Rapsodo ® 2.0 hitting unit (Rapsodo, St. Louis, Missouri, USA). To mimic collegiate softball pitching, JUGS Sting-Free Dimple Softballs were pitched from a regulation distance (13.11m) using an XL Pitching Machine (First Pitch, Maple Plain, MN) that was set to 50 mph (22.4 m/s). The ball was pitched to the center of the strike zone.

Participants were provided an unlimited amount of time to perform a self-selected dynamic warm-up. Fourteen electromagnetic sensors were placed on participants using previously established standards (Bordelon et al., 2021; Washington & Oliver, 2020). Sensor position and orientation were consistent with International Society of Biomechanics recommendations (Wu, 2005). Following sensor placement, participants were allotted an unlimited amount of time to perform warm-up swings off a pitching machine. Three maximal effort swings were performed. Joint forces and torques were calculated using inverse dynamics methods in The MotionMonitor XGen software. Participants used their own bat to prevent interference with their normal hitting mechanics (Bordelon et al. 2021). A successful trial was defined as (1) a line drive in fair territory indicated by the Rapsodo ® 2.0 hitting unit, and (2) verbal affirmation from the participant that the swing was a "*good swing*" (Bordelon et al., 2021; Washington & Oliver, 2020). Similar to prior hitting research (Horiuchi, Nakashima, & Sakurai, 2021), the trial with the highest exit velocity was used for analysis.

A segmental power analysis like Bordelon et al. (2021) was performed to quantify trunk energy flow during the acceleration phase of the swing (foot contact to ball contact). Joint force power (JFP) was calculated as the dot product of the joint reaction force and joint linear velocity (Equation 1). Segment torque power (STP) was calculated as the dot product of the joint torque and segment angular velocity (Equation 2). Segment power (SP) was isolated at a single proximal (Equation 3) and two distal (Equation 4) ends of the trunk. The proximal joint was considered the L5/S1 junction, while the two distal joints were considered front (closest to the pitcher) and back (closest to the catcher) shoulders. Local minimum and maximum endpoint SPs determined the peak rates of endpoint SP outflow (OF) and (IF), respectively. Specific energy flow parameters included were peak rate of proximal trunk energy IF, distal trunk energy OF (front-side shoulder), and distal trunk energy OF (back-side shoulder).

Equation (1) JFP = (joint reaction force) · (linear joint velocity)
Equation (2) STP = (joint moment) · (segment angular velocity)
Equation (3) $SP_{proximal}$ = ($JFP_{proximal}$ + $STP_{proximal}$)

$$Equation\ (4)\ SP_{distal} = (JFP_{distal} + STP_{distal})$$

Statistical analysis was performed in IBM SPSS Statistics 29 (IBM corp., Armonk, NY). Pearson product-moment correlations were used to determine bivariate correlations between trunk energy flow parameters and exit velocity. A forward multiple regression analysis was used to determine the relationship between trunk energy flow parameters and hitting performance (exit velocity). Body mass (kg) was entered first to estimate the proportion of variance accounted for by anthropometrics. The added predictive value of trunk energy flow variables above and beyond the predictive effects of body mass were determined using the change in variance accounted for by the model (Δr^2) and the proportional reduction in model error (n_p^2). Statistical significance was set a priori to $p < .05$.

RESULTS: Descriptive statistics and bivariate correlations are presented in Table 1 and 2, respectively. The mean exit velocity was 68.8 ± 4.3 mph (30.7 ± 1.9 m/s). Regression analysis indicated the first model including only body mass accounted for 17.6% of the proportion of variance in exit velocity [$F_{(1,17)} = 4.853$; $p = .042$]. The predictive model for exit velocity was improved by adding peak rate of distal trunk energy OF on the front side ($\Delta r^2 = .205$) [$F_{(2,16)} = 6.549$; $p = .008$]. On average, the second model showed exit velocity increased by .9 mph for every 100 W increase in peak rate of distal trunk energy OF on the front side while holding body mass constant.

Table 1. Descriptive statistics presented as mean ± standard deviation.

Variable	Mean ± SD
Exit velocity (mph)	68.8 ± 4.3
Weight (kg)	71.7 ± 8.8
Trunk Energy Flow	
Proximal IF (W)	3,903 ± 2,121
Distal OF – Front Side (W)	755.9 ± 241.6
Distal OF – Back Side (W)	294.6 ± 147.8

Note: mph = miles per hour; kg = kilograms; W = watts

Table 2. Bivariate correlations of weight and trunk energy flow parameters and exit velocity.

Variable	Correlation value	p-value
Weight (kg)	.471	**.042**
Trunk Energy Flow		
Proximal IF (W)	.450	.053
Distal OF – Front Side (W)	.636	**.003**
Distal OF – Back Side (W)	.342	.152

Note: Note: mph = miles per hour; kg = kilograms; W = watts; bold = significant as indicated by p < .05

DISCUSSION: It was hypothesized that exit velocity would increase as trunk energy flow increased. The results partially support the hypothesis, where exit velocity was best predicted by peak rate of distal trunk energy OF on the front side while holding body mass constant. Peak rates of proximal trunk energy IF and distal trunk energy OF on the back side were not included in the model as predictors of exit velocity.
Horiuchi et al. (2021) reported a positive association between bat head speed and energy

flowing into the pelvis from the front and back hip joints and energy flowing into the trunk. The current study showed there was not a relationship between peak rate of proximal trunk energy IF and exit velocity). The difference in energy flow analysis may partially explain the discrepancy between the findings. Horiuchi et al. (2021) quantified trunk energy generation, absorption, and transfer, whereas the current study performed an endpoint segmental power analysis. This could be considered a limitation of the current study, and future softball hitting research should aim to perform a more in-depth energy flow analysis to fully understand how energy flow through the kinetic chain impacts performance.

The amount of energy flowing out of the distal trunk on the front-side was the factor that had the greatest influence on performance, meanwhile there was no relationship found with the back-side. This may be explained by the descriptively greater peak rate of energy flowing out of the distal trunk on the front (755.9 ± 241.6 W) compared to the back-side (294.6 ± 147.8 W). This coincides with Bordelon et al. (2021) who reported a similar trend of descriptively larger net rates of energy flowing into and out of the front-side upper extremity segments compared to the back-side during collegiate softball hitting. This may be partially attributed to pelvis to trunk separation during the acceleration phase initiating an eccentric pre-stretch in the front-side trunk musculature in preparation for a high-velocity concentric contraction towards the pitcher. The findings also suggest the primary path of energy transfer from the trunk to the bat may be through the distal upper extremity segments on the front side. However, a more in-depth analysis of trunk and upper extremity energy generation, absorption, and transfer is needed to test this postulation.

CONCLUSION: Peak rate of distal trunk energy OF on the front-side was the best predictor of exit velocity in collegiate softball hitting. Specifically, exit velocity increased by .9 mph for every 100 W increase in peak rate of distal trunk energy OF on the front side while holding body mass constant. This supports prior research indicating the trunk is an important site of energy flow that positively impacts hitting performance. Exit velocity, along with launch angle and spin rate, is one of the most important performance metrics contributing to a successful hit. Even a .9 mph increase in exit velocity due to increased distal trunk energy OF can be considered practically relevant. Therefore, it is recommended strength and conditioning coaches should implement programs that target improvements in trunk strength, stability, and power. Further, coaches should note the potential implications of distal trunk energy OF on the front compared to the back-side. This may suggest the front-side serves more to acceleration the swing, while the back-side serves more to position the bat.

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