THE ASSOCIATION BETWEEN TRUNK ENERGY FLOW AND PEAK SHOULDER DISTRACTION FORCE IN COLLEGIATE SOFTBALL PITCHING

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The purpose of the study was to determine the association between trunk energy flow (proximal energy inflow (IF) and distal energy outflow (OF) on the pitching arm side) and peak shoulder distraction force during the acceleration phase of the windmill softball pitch. Fifty-five collegiate softball pitchers participated. Regression analysis revealed proximal energy IF was not associated with peak shoulder distraction force during the acceleration phase of the pitch [$F(1,53) = .026$; $p = .87$), $r = .02$]. Distal trunk OF was also not associated with peak shoulder distraction force during the acceleration phase of the pitch [$F(1,53) = .920$; $p = .342$), $r = .13$]. Thus, it was concluded proximal trunk energy IF and distal trunk energy OF on the pitching arm side are not associated with peak shoulder distraction force during the acceleration phase of the pitch.

KEYWORDS: energy transfer, upper extremity kinetics, windmill softball pitch

INTRODUCTION: Successful performance of the windmill softball pitch is hypothesized by sports medicine clinicians to depend on the efficient transfer of energy through the kinetic chain (Kibler, 2013). Energy generated in the proximal lower extremity, pelvis, and trunk is transferred to the distal upper extremity prior to ball release. Therefore, decreases in energy flowing into the proximal kinetic chain and out to the distal pitching arm may result in upper extremity compensation to maintain performance. Upper extremity compensation may place undue stress on the shoulder and increase susceptibility to overuse injury. Although higher shoulder distraction forces at ball release have been reported in collegiate softball pitchers with upper extremity pain, the association between proximal energy flow and shoulder kinetics has yet to be determined.

This hypothesized association between energy flow and upper extremity kinetics has been studied in baseball pitching (Aguinaldo & Escamilla, 2019; Wasserberger et al., 2021). Aguinaldo and Escamilla 2019 reported the timing of trunk rotation and trunk segment power were significant predictors of maximum elbow valgus torque. The findings indicate trunk energy flow and mechanics influence maximum elbow valgus torque and potential risk of upper extremity injury (Aguinaldo & Escamilla, 2019). Additionally, Wasserberger et al. 2021 determined energy transfer across the shoulder and elbow were significant predictors of elbow valgus torque. The results further suggest magnitude of energy flow may be related to upper extremity kinetics during baseball pitching (Wasserberger et al., 2021). Although the association between energy flow and shoulder kinetics has yet to be examined in softball pitchers, trunk mechanics have been compared between collegiate pitchers with and without upper extremity pain. Oliver et al. 2018 reported collegiate pitchers with upper extremity pain presented with altered trunk kinematics and greater shoulder distraction force. It was suggested altered trunk kinematics may disrupt energy flow through the kinetic chain and increased shoulder stress (Oliver et al., 2018). Thus, research is warranted to determine the association between trunk energy flow and shoulder stress during the windmill softball pitch.

However, it is unknown if proximal trunk energy flow influences upper extremity kinetics in softball pitching. Thus, an investigation into trunk energy flow during the windmill softball pitch is necessary to further understand potential injury susceptibility. The purpose of the study was to determine the association between trunk energy flow (proximal energy inflow (IF) and distal energy outflow (OF) on the pitching arm side) and peak shoulder distraction force in collegiate windmill softball pitchers.

METHODS: Fifty-five National Collegiate Athletic Association (NCAA) Division I softball pitchers (20.2 ± 2.0 yrs, 173,1 ± 7.5 cm, 78.2 ± 11.6 kg) participated. All testing procedures were approved by the University's Institutional Review Board. Inclusion criteria required participants to be actively competing on the team roster as a pitcher and surgery free for the past six months. Kinematic and kinetic data were collected at 100 Hz with an electromagnetic tracking system (trackSTAR Ascension Technologies Inc.' Burlington, VT, USA) synched with the MotionMonitor (Innovative Sports Training, Chicago, IL). Fourteen electromagnetic sensors were attached to the participants using previously established standards (Oliver et al., 2018; Wasserberger, 2021). Position and orientation of body segments were consistent with International Society of Biomechanics recommendations (Wu, 2005). Joint forces and torques were calculated using inverse dynamics methods in the MotionMonitor software (Gagnon & Gagnon, 1992). Following sensor attachment, participants were given an unlimited amount of time to perform a dynamic warm-up. Testing required participants to throw three maximum effort rise-ball pitches for strikes to a catcher at regulation distance (13.11 m). The average of the three pitches thrown for strikes was used for analysis. The pitching motion was examined during the acceleration phase (foot contact to ball release) as illustrated in Figure 1. A Bertec™ force plate (BertecCorp., Columbus, OH, USA) was used to determine the instance of foot contact during the pitch.

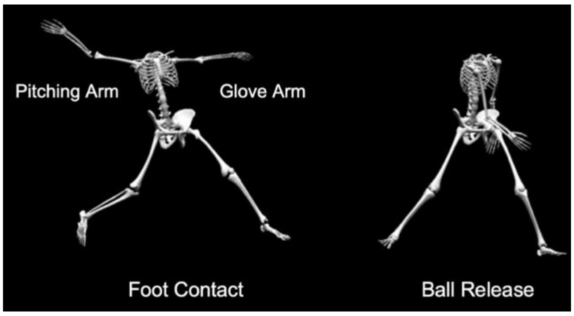

Figure 1. Acceleration phase of the softball pitch from foot contact to ball contact.

A segment power analysis was used to quantify trunk energy flow. 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 proximal (Equation 3) and distal (Equation 4) ends of each segment. Segment endpoint powers were integrated over the time they were negative to calculate total energy OF (work done by segment on the distal segment). Similarly, segment endpoint powers were integrated over the time they were positive to calculate total energy IF (work done on the segment by proximal segment).

$$JFP = (\text{joint reaction force}) \cdot (\text{linear joint velocity}) \qquad \text{(Equation 1)}$$
$$STP = (\text{joint torque}) \cdot (\text{segment angular velocity}) \qquad \text{(Equation 2)}$$
$$SP_P = (JFP_{proximal} + STP_{proximal}) \qquad \text{(Equation 3)}$$
$$SP_D = (JFP_{distal} + STP_{distal}) \qquad \text{(Equation 4)}$$

Statistical analyses were performed using SPSS software (version 28; IBM Corp). Variables of interest included total proximal trunk energy IF, total distal trunk energy OF, and peak shoulder distraction force during the acceleration phase of the pitch. A simple linear regression was used to determine the association between total proximal trunk energy IF and peak shoulder distraction force. A second simple linear regression was used to determine the association between total distal trunk energy OF and peak shoulder distraction force. To account for two simple linear regression analyses, a Bonferroni correction was applied a prior to control for type I error. Statistical significance for each regression analyses was set to $p < .025$.

RESULTS: Descriptive statistics and correlations of variables are presented in Table 1, respectively. Proximal and distal trunk segment power graphs are presented in Figure 2a and 2b, respectively. Proximal trunk energy IF was not associated with peak shoulder distraction force during the acceleration phase of the pitch [F (1,53) = .026; p = .87), r = .02]. Distal trunk energy OF on the pitching arm side was not associated with peak shoulder distraction force during the acceleration phase of the pitch [F (1,53) = .920; p = .34), r = .13].

Variable	Mean (SD)
Peak Shoulder Distraction Force (N•m)	930.7 (177.7)
Total Proximal Trunk Energy Inflow (Joules)	169.6 (105.9)
Total Distal Trunk Energy Outflow (Joules)	123.8 (47.3)

Table 1. Mean and standard deviations (SD) for shoulder distraction force and trunk energy flow variables.

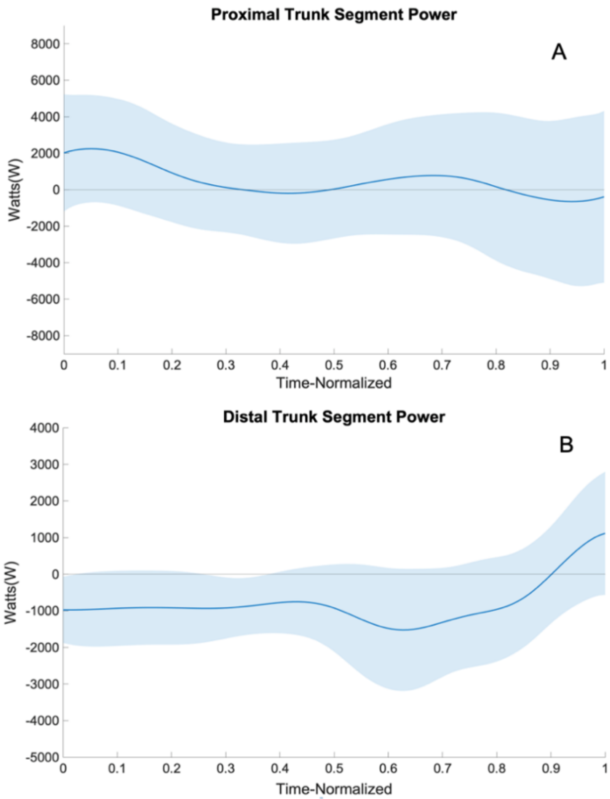

Figure 2. Proximal (A) and distal (B) trunk segment power; Watts > 0 indicates net energy flowing into the segment and < 0 indicates net energy flowing out of the segment; Time - Normalized 0 = Foot Contact, Time - Normalized 1 = Ball Release.

DISCUSSION: Proximal trunk energy IF was not associated with peak shoulder distraction force during the acceleration phase of the pitch. Distal trunk OF on the pitcher arm side was also not associated with peak shoulder distraction force during the acceleration phase of the pitch. Aguinaldo and Escamilla 2019 reported the timing of trunk rotation and trunk segment power were significant predictors of elbow joint loading during baseball pitching. Further, Wasserberger et al. 2021 determined energy transfer across the shoulder and elbow were significant predictors of elbow valgus torque during baseball pitching. Although the current study did not find a association between trunk energy flow and shoulder kinetics during softball pitching, this may be explained by the measure of different energy flow parameters compared to prior baseball studies. Aguinaldo and Escamilla 2019 measured whole trunk segment power,

whereas the current study isolated segment power IF and OF and proximal and distal ends. Wasserberger et al. 2021 more closely examined energy flow parameters by calculating energy generation, absorption, and transfer. Efficient energy generation and transfer through the proximal kinetic chain is described to improve performance and decrease stress placed on the upper extremity during softball pitching. Therefore, additional examination into the isolation of joint force powers and segment torque powers to calculate trunk energy generation and transfer is warranted to fully understand the association between proximal energy flow and shoulder kinetics.
Oliver et al. 2018 reported collegiate pitchers with upper extremity pain presented with altered trunk kinematics and greater shoulder distraction force. In addition to upper extremity loads, baseball research has indicated energy flow is related to pitch velocity (Aguinaldo, 2019; Howenstein, 2019; Wasserberger 2021). It has also been determined that increased proximal energy is related to improved upper extremity joint load efficiency (joint load per increment of pitch velocity). Therefore, future softball pitching research should also examine the association between energy, performance, and joint load efficiency.
A few study limitations should be mentioned. First, this study only examined the acceleration phase of the pitch. However, prior research shows the pitching arm experiences the largest amount of upper extremity stress during this phase (Barrentine, et al. 1998; Werner et al. 2006). Second, the windmill softball pitch utilizes the entire kinetic chain, but only trunk energy flow was included for analysis. Future research should also determine the association between energy flow through the upper and lower extremity segments with upper extremity stress. Lastly, the current study only quantified net endpoint segment powers for the trunk. Follow-up investigations should also more closely examine energy generation, absorption, and transfer by isolating joint force power and segment torque power components.

CONCLUSION: Proximal trunk energy IF and distal trunk OF on the pitching arm side were not associated with peak shoulder distraction force during the acceleration phase of the softball pitch in collegiate athletes.

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