EFFICIENCY INDEX USED TO ASSESS SHOULDER STRESS IN COLLEGE SOFTBALL PITCHERS THROUGHOUT A SIMULATED GAME

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Shoulder distraction forces in softball pitching are known to have a positive impact on performance yet a negative impact on musculoskeletal health. The purpose of this study was to assess changes in shoulder stress across innings pitched using Efficiency Arm-Stress Index (EASI) scores. Motion capture was used on collegiate softball pitchers pitching a simulated game. Peak shoulder distraction force was obtained using inverse dynamics procedures and used to calculate an EASI score (fastball velocity divided by peak shoulder distraction force in percent body weight). A RM·ANOVA revealed inning had no effect on EASI score ($F[6,7]=1.28$, $p=0.286$). Understanding a pitcher's efficiency score may help shape individual pitching loads. Future work should investigate clinically meaningful changes in efficiency scores and mechanisms behind low efficiencies.

KEYWORDS: Injury, Performance, Shoulder Distraction

INTRODUCTION: Shoulder distraction forces in softball pitching are related to pitch performance, with higher shoulder distraction forces associated with faster pitch velocities in the fastball (Bordelon et al., 2022). However, large shoulder distraction forces are also theorized to increase injury risk in softball pitchers (Barrentine et al., 1998). Previous research has identified that softball pitchers who experience pitching related upper extremity pain had higher shoulder distraction forces than their pain-free peers (Oliver et al., 2018, 2019). Due to the implications of increased shoulder distraction forces in softball pitchers, a level of efficiency between shoulder stress and pitch velocity should be established to ensure both optimal performance while reducing injury risk.

With the potential performance benefit and injury risk associated with increased shoulder distraction forces in softball pitchers, an Efficiency Arm-Stress Index (EASI) score may provide valuable information about shoulder stress. The EASI score determines how efficiently a pitcher uses shoulder forces that result in increased fastball velocity. A similar efficiency measure (Biomechanical Efficiency (BE)) was applied to baseball pitchers to examine elbow stresses and their relationship to fastball velocity (Crotin et al., 2022). In the examination of BE between professional and collegiate baseball pitchers it was found that professional pitchers have greater BE than collegiate pitchers (Crotin et al., 2022). This suggests that professional pitchers are getting a greater return in pitch velocity for the quantity of stress they are placing on their elbows compared to college pitchers (Crotin et al., 2022). While there has been an efficiency measure (expressed as BE) in baseball pitching, investigation is warranted in softball pitching since no such metric has been developed.

This study aimed to identify if there is a biomechanical efficiency index that can be applied to softball pitching and understand how this index would differ with extended bouts of pitching. The researchers hypothesized that EASI scores would significantly suffer in later innings of a softball simulated game, meaning that pitchers would experience greater shoulder distraction forces despite a constant pitch velocity or that pitchers would experience the same shoulder distraction forces while their pitch velocity decreased.

METHODS: Seven National Collegiate Athletic Association (NCAA) Division I female softball pitchers (19.1 ± 0.78 yrs, 1.80 ± 0.04 m, 83.63 ± 10.04 kg) participated. Nine simulated games were completed. Two pitchers completed two simulated games each at least two weeks apart for the purpose of increased sample size. One pitcher was excluded from statistical analysis due to a difference in innings pitched. In total, eight simulated seven-inning games were analyzed, with six unique pitchers participating. All testing procedures were approved by the University's Institutional Review Board. Inclusion criteria required participants to be active on a team roster as a pitcher as well as injury and surgery free for the past six months. Position data were collected at 240 Hz and filtered using a 4th order

Butterworth filter with a cut-off frequency of 13.4 Hz using an electromagnetic tracking system (trackSTAR Ascension Technologies Inc., Burlington, VT, USA) synced with The MotionMonitor (Innovative Sports Training, Chicago, IL, USA) biomechanical analysis software (Bordelon et al., 2022). Prior to sensor attachment, an unlimited amount of time was provided for participants to complete a non-throwing dynamic warm up that they would routinely perform prior to a typical competitive period. Following their dynamic warm up, a total of fourteen electromagnetic sensors using were affixed to participants using previously established standards (Oliver et al., 2018; Wasserberger et al., 2021; Bordelon et al., 2022). Position and orientation of local joint coordinate systems were consistent with International Society of Biomechanics recommendations (Wu et al., 2005). Following sensor attachment, participants performed their own pitching specific warmup. Pitching warmups were comprised of, but were not limited to, overhand throwing, underhand snap throws, the use of weighted and plyometric softballs, and the use of other pitch training devices. Testing required each pitcher's coach to formulate a pitch script that was unique to the individual. The script included all pitch types thrown in competition and was of similar pitch volume to what the athlete would perform in a competitive scenario. All pitchers threw to a catcher positioned at a regulation distance for college softball pitching (13.11 m). Participants were required to have three minutes of rest between innings, as prescribed by the coaching staffs of the pitchers. The first fastball of each inning was captured and analyzed. Shoulder distraction forces were examined using inverse dynamics in The MotionMonitor software and were defined as the intersegmental force of the shoulder in the Y relative to the upper arm using a linked segment model. Shoulder distraction was normalized to each participant's body weight prior to analysis (Gagnon & Gagnon, 1992). Pitch velocity was recorded to the nearest mile per hour using a Stalker Pro II Series radar gun (Stalker Sports, Richardson, TX, USA) and converted to meters per second. Peak normalized shoulder distraction forces during the pitch were extracted using custom MATLAB (The MathWorks, Inc., Natick, MA, USA) code, which were then exported into Microsoft Excel where EASI scores were derived (see Equation 1).

$$EASI = (\text{pitch velocity (m/s)}) / (\text{peak normalized shoulder distraction force (\%BW)})$$

Equation 1. Used to calculate EASI scores for an individual fastball pitch. This equation is a ratio of pitch velocity and normalized shoulder distraction forces.

Based on Equation 1, results with a higher EASI score would indicate a pitcher is more efficient with the stress they are putting on their shoulder. For example, if a pitcher threw a fastball at 30m/s with 60% of their body weight in shoulder distraction forces, they would have an EASI score of .5, whereas if the same pitcher threw the same 30m/s pitch with 100% of their body weight in shoulder distraction forces, the EASI score would be .3.

Statistical analysis was performed using Jamovi Version 2.3. A repeated measure analysis of variance (RM·ANOVA) was performed to determine if inning influenced EASI score in softball simulated games. Statistical significance was determined *a priori* with an alpha level set at .05.

RESULTS: Means and standard deviations of EASI scores across inning are as followed: Inning 1 = 0.329 ± .032; Inning 2 = 0.343 ± .024; Inning 3 = 0.339 ± .031; Inning 4 = 0.336 ± .030; Inning 5 = 0.325 ± .035; Inning 6 = 0.328 ± .032; Inning 7 = 0.338 ± .024. Results of the RM·ANOVA revealed that inning had no significant effect on EASI score in a simulated softball game ($F[6,7]=1.28$, $p=0.286$).

DISCUSSION: The author's hypothesis was not supported, since there was no main effect between innings pitched and EASI score. A few scenarios may explain the current findings. The first is fastball velocity and shoulder distraction forces are potentially decreasing at the same relative rate; thus, there is no significant change in the efficiency of the use of shoulder distraction forces to generate fastball velocity. The second scenario is that there is no significant change in both shoulder distraction forces and fastball velocity, meaning that

EASI scores would remain unchanged throughout the simulated game. In the current study, the second scenario seems to be correct. The mean fastball velocity did decrease from the first inning (28.3 m/s) to the seventh inning (27.8 m/s), and the shoulder distraction forces were higher in the first inning (86% BW) compared to the seventh inning (83% BW), but the changes in pitch velocity and shoulder distraction forces from the first inning to the seventh inning were not statistically significant when compared with a paired samples *t*-test (p=.20 and p=.10 respectively). While the group means of EASI and its components were not statistically significant across innings, it should be noted that it is important to examine EASI scores individually since athletes can demonstrate unique efficiency trends. Observing EASI scores at the individual level across a game may allow for practitioners to better understand when each pitcher may be experiencing fatigue and when they are starting to put more stress on their shoulder while not getting the same pitch velocity of their fastball. Specifically, when observing the trend lines for each individual, the current study showed seven out of the nine simulated games had decreasing trends in their EASI score, while one participant remained relatively stable, and one had an increased score (Figure 1). These individual participant discrepancies require further investigation to determine why certain pitchers are decreasing in their efficiency while others are maintaining or increasing their efficiency.

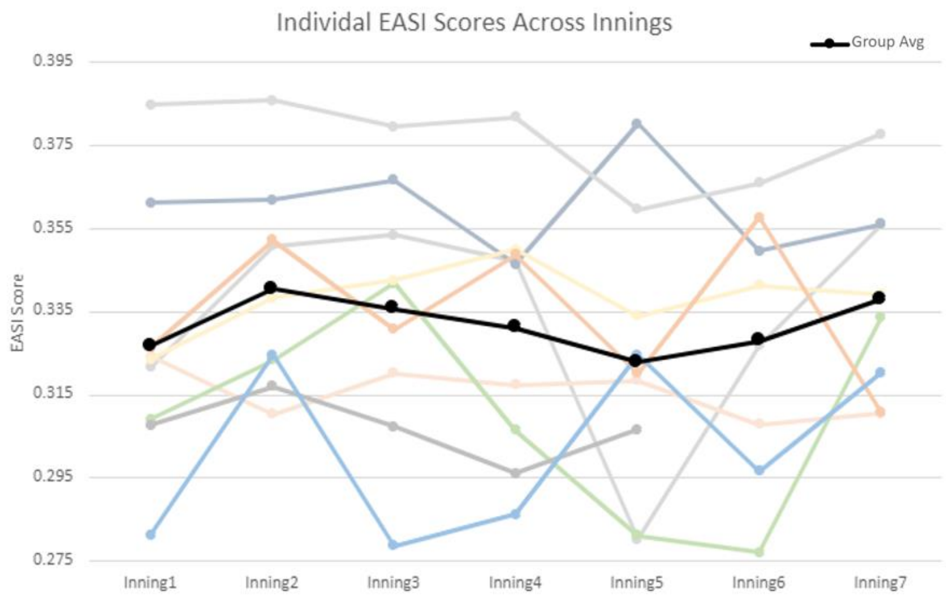

Figure 1. Changes in EASI score throughout the innings of a simulated softball game.

Note: Every simulated game completed is included in graph, even if excluded from data analysis. Black line represents the means of the group at each inning, while each color represents a different simulated game

In an attempt to determine if an efficiency metric can be applied to softball pitching in a similar fashion as BE in baseball pitching, EASI was determined to be a metric of interest that includes a kinetic variable with both performance and injury prevention implications. While the effect of inning on this efficiency metric was not established, the validity of the variable requires further consideration. Such validation should replicate the study done by Crotin et al. that displayed differences between groups of varying levels of competition. Because of the injury prevention component that is assumed with EASI, a group level comparison between those at risk of injury (pitching with pain in their throwing arm) and those who are considered healthy should be compared, along with the comparison of those at different competition levels.

A limitation of the current study is that only fastballs were analyzed. However, the fastball pitch is known to put more stress on the shoulder than other pitch types (Oliver et al., 2021), with previous research estimating over 80% of the pitcher's body weight in shoulder distraction forces (Werner et al., 2006). Higher shoulder distraction forces were also identified in a group of pitchers with upper extremity pain than those without (Oliver et al., 2018). Further, since fastball velocity is positively related to shoulder distraction forces (Bordelon et al., 2022), the EASI score helps identify a risk versus reward of stresses and performance outcomes. This would be difficult to analyze in other pitches, such as a curveball since a successful pitch is not only reliant on a high velocity.

Further studies should continue exploring efficiency in softball pitching. This should include identifying ways to incorporate additional pitch types into an efficiency rating, within subject analysis of efficiency, predicting efficiency using kinematics, and analyzing the impact a doubleheader, or tournament style play, would have on efficiency. Additionally, both subjective and objective field measures should be investigated to determine if there is a relationship between these measures and the observed efficiency metrics. Examples of the field measurements that may be of interest are isometric strength, range of motion, proprioception, and rate of perceived exertion. An investigation into the relationship between these field measures and EASI would be beneficial to determine if there are specific metrics that medical professionals can obtain throughout a game to determine if there is an increased injury risk present.

CONCLUSION: There were no significant differences in EASI scores across innings of a simulated game in NCAA Division I softball pitchers; however, within-subject variability may be of interest. Understanding the within-subject variability may allow for individualized trends to be applied to assess when decrements in performance and increase in injury risk may occur. Additional research is warranted to identify what kinematics may play into maximizing performance while minimizing injury risk in softball pitchers. Other methods to help identify the efficiency of pitchers (such as field measures and rate of perceived exertion) may be useful for predicting risk of injury and help formulate guidelines for increased workloads.

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