Identifying Risk Factors of Upper Extremity Injuries in Collegiate Baseball Players: A Pilot Study

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Background
Repetitive pitching places tremendous forces on the shoulder and elbow which can lead to upper extremity (UE) or lower extremity (LE) overuse injuries.

Purpose
The purpose of this study was to evaluate pre-season physical measurements in collegiate baseball players and track in-season baseball throwing volume to determine which factors may predict throwing overuse injuries.

Study Design
Retrospective Cohort study.

Methods
Baseline preseason mobility, strength, endurance, and perception of function were measured in 17 collegiate baseball pitchers. Participants were then followed during the course of the season to collect rate of individual exposure, estimated pitch volume, and rating of perceived exertion in order to determine if changes in workload contributed to risk of injury using an Acute-to-Chronic Workload ratio (ACWR).

Results
Participants developing an injury had greater shoulder internal rotator strength (p=0.04) and grip strength in a neutral position (p=0.03). A significant relationship was identified between ACWR and UE injuries (p <0.001). Athletes with an ACWR above or below 33% were 8.3 (CI 1.8-54.1) times more likely to suffer a throwing overuse injury occurring to the upper or lower extremity in the subsequent week.

Conclusion
ACWR change in a positive or negative direction by 33% was the primary predictor of subsequent injury. This finding may assist sports medicine clinicians by using this threshold when tracking pitch volume to ensure a safe progression in workload during a baseball season to reduce the risk of sustaining overuse upper or lower extremity injuries.

Level of Evidence
3b

INTRODUCTION
Tremendous forces occur on the shoulder and elbow during repetitive pitching that can lead to overuse injuries in collegiate baseball.

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tation (NCAA) over a 16 year period averages 1.85 and 5.78/1000 practice and game athlete-exposures, respectively.3

Between the NCAA, National Association of Intercollegiate Athletics (NAIA), and National Junior College Athletic Association (NJCAA), there are an estimated 50,000 college baseball players.4 Assuming the injury rate is consistent across an average of a 30 game season and 121 practices in a spring season, this would estimate 20,000 injuries to collegiate baseball players of which 45% occur to the upper extremity (UE).3,4

Research has identified shoulder mobility deficits, shoulder strength deficits, trunk mobility deficits, and kinetic chain considerations as a risk for future injury in baseball players.2,5 Aragon et al6 reported that limited trunk rotation increases the amount of load placed on the shoulder and elbow during a pitching sequence. This limited trunk mobility predisposed an individual to be up to 2.75 times more likely to sustain an injury. Limited shoulder mobility increased the odds of injury by 2.5 in professional pitchers and approximately four times more likely in high school athletes.5,7 Pitching with a fatigued arm was a strong predictor (OR≥4) of adolescents reporting shoulder and elbow pain.8 Collegiate baseball pitchers also demonstrated a strong correlation (r=−.72) between throwing volume and arm soreness.9 Another overhead sport that is associated with increased risk of upper extremity overuse injuries is cricket.10 Although throwing mechanics differ than baseball, the volume of overs, or throws, is monitored similarly to baseball.10 Cricket bowlers’ injuries were tracked over multiple years and observed 3.3 relative risk of injury associated with increased total number of balls bowled, and 2.1 relative risk when total number of balls bowled decreased from previous workloads.10 It is clear that overuse injuries have several risk factors ranging from mobility deficits to pitch volume to consider when attempting to minimize injuries.2,5–10

Research results suggest that a positive relationship between training load and injury exists.11,12 Monitoring training load throughout a competitive season allows clinicians to objectively measure changes in performance, reveal fatigue, and minimize the risk of non-functional fatigue, illness, and injury.12 Training load is the combination of internal workload (relative biological stressors) and external workload (objective work done during athletic competition or training).11 One method used to analyze training load is the acute-to-chronic workload ratio (ACWR).11 This model describes acute training load (training load of one week) to chronic load (the rolling average of 4 weeks) to determine the preparedness of an athlete.11 Mehta et al13 showed that high school baseball pitchers with an ACWR of 1.27 (the acute workload was 27% greater than the chronic workload) were 14.9 times more likely to sustain an injury.

Pre-season and in-season upper and lower extremity injury risk factors exist in baseball pitchers, that have not been studied specifically in college baseball pitchers. Therefore, the purpose of this study is to evaluate pre-season physical measurements in collegiate baseball pitchers and track in-season baseball throwing volume to determine which factors may predict throwing overuse injuries. The primary hypothesis is that pre-season range of motion (ROM), strength, and patient perception measurements will be diminished in those who develop injuries during the season as compared to those who do not develop injuries. The secondary hypothesis is that in-season workload changes above and below a threshold will predict overuse injuries in the upper or lower extremity. This study will allow clinicians to target efforts to mitigate overuse injuries in the future.

METHODS

This retrospective cohort study has three primary components: pre-season baseline assessment, a daily pitching volume recording to examine pitch volume weekly totals, and a daily tracking of athletic exposure and treatment recording for each pitcher. This data was captured to determine if injury occurrences were associated with baseline measures or in-season throwing volume changes. This study was approved by the university institutional review board.

PARTICIPANTS

A convenience sample of 17 collegiate baseball pitchers from a single Division-I baseball program (mean ± SD age 20.1 ± 0.09 y, height 186.8 ± 26.9 cm, mass 96.5 ± 8.8 kg) participated in this study. Participants included in this study were all pitchers on the team roster in the fall of 2019. Participants were excluded from the study if their position was not solely as a pitcher. Participants were also excluded if they were under the medical care of a physician prior to the start of the study that restricted them from participation in sport. Participants were not excluded for previous injury or surgery to the throwing arm.

MEASUREMENT PROTOCOLS

Range of motion, strength, and endurance measurements were collected in November and December following the conclusion of the fall season. This time point ensured athletes were not fatigued and served as a baseline measurement as the fall season had just been completed. All measurements were collected bilaterally.

Participants were asked to fill out the Kerlan-Jobe Orthopaedic Clinic (KJOC) Shoulder and Elbow questionnaire in January, prior to the season. The KJOC Shoulder and Elbow11 evaluates the individual’s perceived level of function in performing overhead sports and is a sensitive measurement tool for detecting subtle changes in upper extremity performance.14

RANGE OF MOTION

All participants had their passive range of motion (PROM) assessed for shoulder external rotation, internal rotation, horizontal adduction, flexion, volar forearm compartment, and trunk rotation. Two trials were averaged to represent each measurement and all measures were taken bilaterally except for trunk rotation where three trials were averaged.2 All measures were captured by two certified athletic trainers working directly with the baseball program and de-identi-
Shoulder strength measurements were assessed isometrically using a hand-held dynamometer (Lafayette Instrument Evaluation, 01165, Lafayette, IN, USA). Prone internal and prone external shoulder rotators were tested with the participant positioned prone on a table with their arm abduced to 90° and elbow flexed to 90°. Two make tests were performed asking the athlete to exert maximal force against the dynamometer which was placed 5cm proximal to the proximal wrist extension and wrist flexion crease, respectively. Shoulder elevators in the scapular plane were assessed with the participant seated upright with their back against a wall. The arm was abducted to 90° and horizontally abducted to 45° with the forearm in a neutral “thumbs-up” position. The dynamometer is placed 5cm proximal to the proximal wrist extension crease. The participant is instructed to maximally elevate their arms for two repetitions.

Grip strength was assessed using a Jamar Technologies Hydraulic Hand Dynamometer (Patterson Medical, 5030J1, Warrenville, IL, USA) in a standard seated position with elbow flexed to 90° and forearm neutral rotation. The participant was instructed to squeeze the hand-held dynamometer with maximal contraction for two seconds following a five second break. Power position grip strength was measured in a similar manner; however, the participant was seated with the arm abducted to 90°, elbow flexed to 90°, and forearm pronated.

Two trials were averaged to represent each measurement and all measures were performed bilaterally.

Posterior shoulder endurance test was assessed as previously described by Evans et al. First, the participant’s body weight in pounds and arm length in centimeters were measured. Both measurements were entered into an equation to determine a hand-held weight that was used to obtain 20Nm of force. The participant was positioned prone on a table with the arm placed into horizontal abduction and externally rotated with the thumb pointing towards the ceiling while holding the weight. A metal vice grip was attached to a PVC pole to provide feedback. The participant was instructed to hold the position against the metal vice grip until failure. Failure was determined by the participant extending their trunk, not keeping their arm against the metal vice grip after one reminder, rotating the torso, or bending the elbow. The time the participant could hold the position was recorded. The procedure was then repeated on the opposite limb.

**IN-SEASON FACTORS**

For the secondary purpose of the study, participants were followed during the course of the season to collect rate of individual athletic exposure (Table 1), estimated pitch volume representing the external workloads, and rating of perceived exertion representing the internal workloads in order to determine if changes in workload contributed to risk of injury. Participants were asked to estimate the number of throws they completed on a daily basis in each category defined below. Participants were identified as being injured if they sustained an overuse, upper or lower extremity injury during the season requiring them to miss at least one day of participation. An overuse injury is defined as not traumatic, but rather gradually worsening, injury to the upper or lower

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extremity during the season.

This study defined the throwing categories based on the definitions used by Lazu et al: catch, long toss, flat ground, bullpen, game day bullpen, game day pitches, and other. Catch was performed at 30-50% intensity at a distance of approximately 70 feet. Long toss was performed at greater intensity at distances ranging from 120-150 feet with the intention of getting the ball to the partner on the fly or on one hop. Flat ground was thrown at 60 feet with varying intensity. Bullpen during practice varied based on the day, athlete, and coaching instructions but was performed on a pitching mound. Game day bullpen followed a similar format but with the intent of preparing the athlete to pitch in a game. Game day pitches was performed on a pitching mound in a game against another team. Other was performed during field work drills during practice with the intent to prepare for different game situations.

After each practice or game, a certified athletic trainer asked the pitchers to estimate their perceived exertion for that day's exposure and pitch volume for each of the seven categories. The Borg Perceived Exertion Scale ranging from 0 (no exertion at all) to 10 (extremely strong/heavy) was used to represent that day's internal workload. The same athletic trainer recorded the athlete's exposure type (Table 1). To expedite data collection, all information was captured using a text messaging system.

DATA REDUCTION

Each day the pitch volume and RPE data was entered into GideonSoft (Horizon Performance, Raleigh, NC, USA). This software was used to store all the data collected over the course of the season for every pitcher where a spreadsheet was then generated for data analysis. All pitchers were coded to protect their identity. In excel, the daily workload was calculated by multiplying the internal by the external workload to create a unitless measure. Each week these daily workloads were summed to represent weekly totals. The acute-to-chronic workload ratio (ACWR) was the relative change in total workload. The acute workload was represented by the current week's workload while the chronic workload included the average of the three weeks total workload (current week plus previous two weeks). Unfortunately, the season was cut short due to the COVID-19 virus outbreak; therefore, the data collection ended in the middle of the 9th week of the season. All de-identified data were shared with the principal investigator for statistical analysis.

STATISTICAL METHODS

The frequency counts of athletic exposures were captured daily to identify participation status of a player. This allowed us to compare pre-season measurements between two groups: those that sustained an upper or lower extremity injury, requiring missing participation for at least one day (Injured) to those who did not (Non-Injured).

Preseason descriptive statistics for range of motion, strength, and outcome measures were analyzed for normal distribution using the Shapiro-Wilk test. The data was found to be normally distributed, and the pre-season data was compared between injured and non-injured groups using independent t-test with significance set at p ≤ 0.05 to determine differences in pre-season measures between the two groups.

The second goal was to investigate whether in-season acute-to-chronic workload changes would precede events of overuse injuries. The initial goal was to use all the total workload values, but due to the large volume of catch throws (Table 2) and the unusually high correlation with RPE (r=0.73, p<0.001) another approach was taken. Previous approaches have used only high intensity throws. Therefore acute-to-chronic workload from games, practice and game bullpens pitches were calculated using the same external and internal workload calculation described above. Next, the threshold for percent change was determined to be 33% by examining the absolute values of percent change total workloads and events of injury using a receiver operating characteristics (ROC) curve. The threshold that provided the best balance between sensitivity and specificity was determined using the ROC coordinates. Seventeen pitchers were tracked for six weeks resulting in 101 pitcher-weeks (one pitcher tracked for five weeks) which were reviewed and the ACWR changes greater or less than 33% were identified. A cross tabulation (2x2 contingency table) using a Chi-Square and Fisher Exact test was carried out to determine the relationship between ACWR changes greater or less than 33% and if an overuse injury occurred in the next week. The relative risk ratio was calculated to determine the probability of sustaining an injury along with 95% confidence interval from the contingency table. Statistical analysis of all data was performed using SPSS Statistics version 25 (SPSS Science, Chicago, Illinois). For all statistical analyses, an alpha level of p < 0.05 was used. The relative risk ratio was calculated using an online calculator.

Table 1: Exposure Code

| Code | Description                                      |
|------|--------------------------------------------------|
| 0    | Off – Day of rest mandated by the NCAA or at coach's discretion |
| 1    | Game – Participation or available to participate in a game against another team |
| 2    | Practice – Participation in team practice         |
| 3    | Conditioning – Indicates that the athlete only participated in conditioning that day |
| 4    | Injured Limited – Athlete was modified during a practice due to an injury or illness |
| 5    | Injured Out – Athlete was unable to participate in a practice or game |
Table 2: Total Throws During the 2020 Season

| ID    | Role   | Catch | Long Toss | Flat Ground | Practice Bullpen | Game Bullpen | Game | Other | Pitch Total |
|-------|--------|-------|-----------|-------------|------------------|--------------|------|-------|-------------|
| BSB3  | Reliever | 1242  | 144      | 161         | 132              | 87           | 112  | 0     | 1911        |
| BSB4  | Reliever | 1666  | 265      | 87          | 190              | 210          | 205  | 0     | 2617        |
| BSB5  | Reliever | 1363  | 80       | 70          | 195              | 210          | 189  | 0     | 2104        |
| BSB6  | Reliever | 1442  | 90       | 117         | 245              | 157          | 285  | 0     | 2329        |
| BSB7  | Reliever | 1115  | 163      | 40          | 235              | 147          | 128  | 0     | 1828        |
| BSB8  | Reliever | 850   | 480      | 223         | 150              | 232          | 217  | 15    | 2167        |
| BSB9  | Starter  | 1230  | 670      | 0           | 360              | 160          | 485  | 0     | 2905        |
| BSB10 | Reliever | 840   | 235      | 5           | 225              | 0            | 0    | 0     | 1305        |
| BSB11 | Reliever | 1700  | 245      | 0           | 240              | 215          | 135  | 0     | 2535        |
| BSB13 | Reliever | 1545  | 765      | 70          | 310              | 190          | 433  | 0     | 3313        |
| BSB15 | Starter  | 1336  | 185      | 40          | 368              | 170          | 490  | 0     | 2589        |
| BSB16 | Reliever | 1445  | 222      | 0           | 210              | 185          | 236  | 0     | 2298        |
| BSB18 | Reliever | 960   | 585      | 15          | 230              | 125          | 160  | 0     | 2075        |
| BSB19 | Reliever | 1050  | 350      | 382         | 165              | 125          | 296  | 51    | 2419        |
| BSB20 | Reliever | 1018  | 0       | 20          | 300              | 70           | 65   | 30    | 1503        |
| BSB21 | Reliever | 1330  | 55       | 25          | 205              | 175          | 335  | 0     | 2125        |
| BSB22 | Reliever | 1095  | 860      | 215         | 90               | 20           | 14   | 120   | 2414        |
| Total |         | 21243 | 5395     | 1470        | 3850             | 2478         | 3785 | 216   | 38437       |
| % Total |       | 55%   | 14%      | 4%          | 10%              | 6%           | 10%  | 1%    | 100%        |

RESULTS

EXPOSURES

The frequency counts of athletic exposures revealed there were a total of 1037 exposures in the COVID-19 truncated season with the greatest exposures occurred during practices with 590 (56.9%) exposures and the least exposures observed as being injured out with 26 (2.5%) (Table 3). The frequency counts of pitch types revealed that the most common type of pitches thrown are the catch type accounting for 55% of total pitches (Table 2). Actual game pitches (10%) and bullpen pitches prior to entry into a game (6%) accounted for relatively few number of pitches, which agrees with previous collegiate pitch counts.9 (Table 2). Due to the truncated season, due to the COVID-19 pandemic, 17 pitchers only threw 38,437 pitches averaging to 2,263 pitches per pitcher in 9 weeks of the spring season.

PRE-SEASON MEASUREMENTS

Pre-season descriptive data compared measures collected on the throwing arm to replicate similar studies.2,5 Only two measures were found to be significantly different between groups. Players developing an injury were found to have greater shoulder internal rotator strength (p=0.04) and greater grip strength in a neutral position (p=0.03) in the dominant arm (Table 4). No significant differences in the remaining measures were revealed between the pitchers in the injured group compared to those in the non-injured group (Table 4).

IN-SEASON MEASUREMENTS

There were 101 pitcher-weeks exposures for the 17 athletes during the truncated season. As previously described, 12/101(11.8%) weeks resulted in an overuse injury. It was identified that 10/12 weeks were preceded by an absolute threshold of ACWR>33%. The overuse injuries that were sustained included shoulder internal impingement syndrome, rotator cuff strain, elbow extensor strain (n=2), cubital tunnel neuropathy, bicep muscle strain (n=2), hip flexor strain, and a wrist flexor strain. Due to the low number of events, the Fisher exact test was interpreted to indicate a relationship exists between ACWR>33% and overuse injuries (p=0.001) (Table 5). The relative risk ratio revealed that athletes with an ACWR greater or less than 33% were 8.3 (CI95 1.8-54.1) times more likely to suffer an overuse upper or lower extremity injury in the subsequent week compared to those whose ACWR was within 33% change.

DISCUSSION

The purpose of this study was to examine both pre-season physical measurements and in-season workload factors to identify whether these factors are indicators for increased risk of overuse upper or lower extremity injuries in collegiate baseball pitchers. Our primary hypothesis was not supported as diminished measurement differences between
Comparisons of shoulder mobility between the injured and non-injured groups revealed no significant differences in any motion. Our findings do not agree with the findings in the studies by Wilk et al.\(^2\) and Shanley et al.\(^5\). Wilk et al.\(^2\) found that 18% of major and minor league pitchers with a shoulder flexion ROM deficit of 5° in the throwing arm compared to the non-throwing arm were 2.8 times more likely to be placed on the disabled list than those without a deficit. Shanley et al.\(^5\) found that high school baseball and softball players, decreases in pre-season shoulder horizontal adduction (5.2°) and internal rotation (12.1° ± 11.8°) ROM were predictive of who developed an injury. A trend towards statistical significance was noted with reduced shoulder external rotation mobility (p=0.08) in the injured pitcher group which agrees with Camp and colleagues’ findings associated with loss of shoulder external rotation and elbow injuries.\(^{25}\) The current study findings are in one team over a truncated season likely accounting for different findings.

Results of previous studies suggest that strength deficits have a relationship to upper extremity injuries requiring surgery.\(^{15}\) Byram et al.\(^{15}\) measured strength and tracked shoulder and elbow injuries and surgeries in professional baseball pitchers over a five year window. Byram et al.\(^{15}\) identified a trend toward significance (p=0.051) of predicting shoulder injury when examining the prone external rotation strength over prone internal rotation strength ratio. A lower ratio of 0.724 was associated with a 39% increased likelihood of any throwing related injury.\(^{15}\) This ratio was also lower in those athletes identified in this study who developed a throwing overuse injury (p=0.09). The confounding finding was that the injured group was stronger in shoulder internal rotation than the non-injured group. However, relative to the Byram study,\(^{15}\) both groups in this study were identified to be weaker than the 5th percentile of professional baseball pitchers. Due to this finding the relative strength balance may be more meaningful than individual strength measures.

The increased grip strength in the injured groups and the nearly significant increased power position grip strength (p=0.13) are interesting findings that are not easily explained. A previous study found a non-significant trend that
Table 4: Preseason Descriptive Data

|                                      | Injured | Non-Injured | P value |
|--------------------------------------|---------|-------------|---------|
| Range of Motion (degrees)            |         |             |         |
| Shoulder Internal Rotation           | 73      | 69          | 0.29    |
| Shoulder External Rotation           | 119     | 124         | 0.10    |
| Horizontal Adduction                 | 24      | 22          | 0.40    |
| Shoulder Flexion                     | 187     | 186         | 0.90    |
| Volar Compartment                    | 77      | 78          | 0.66    |
| Left Trunk Rotation                  | 85      | 83          | 0.74    |
| Right Trunk Rotation                 | 87      | 88          | 0.96    |
| Strength (kilograms)                 |         |             |         |
| Shoulder Internal Rotation           | 19.3    | 15.1        | 0.04*   |
| Shoulder External Rotation           | 17.1    | 14.7        | 0.08    |
| External Rotation/Internal Rotation Ratio | 0.89 | 1.0       | 0.09    |
| Scaption                             | 11.5    | 11.6        | 0.92    |
| Neutral Grip                         | 57.0    | 51.0        | 0.03*   |
| Power Grip                           | 53.9    | 48.8        | 0.13    |
| Posterior Shoulder Endurance Test (s) | 79.0 | 76.0      | 0.74    |
| Outcome Measures                     |         |             |         |
| Kerlan-Jobe Orthopaedic Clinic       | 82.7    | 91.1        | 0.10    |

SD = Standard Deviation; *= statistically different at p< 0.05

Table 5: ACWR and Injury contingency table

|                                      | Injured | Not injured |
|--------------------------------------|---------|-------------|
| Greater or Less than 33% Change      | 10      | 28          |
| Within a 33% Change                  | 2       | 61          |

stronger grip (>25kg) was associated with risk of elbow injuries in youth baseball players.26 The current study examined all overuse injuries and found that six of the 12 affected the wrist or elbow suggesting that the role that strong grip plays may require future studies on larger number of subjects to determine if there is detrimental effect on overuse injuries.

The use of patient-reported outcomes at baseline assessment prior to injury is relatively novel but has shown differences between those who did not have an injury history and those with an injury history that may have some underlying issues.27 Franz et al14 established normative data for KJOC scores using 203 major and minor league players. This study demonstrated differences in scores between players with a history of shoulder or elbow injury (86.7 ± 14.5) compared to players with no history of injury (96.9 ± 5.0) (p < 0.001).14 A similar trend was noticed with KJOC scores in the current study. The injured group’s KJOC scores (82 ± 11) were lower than the non-injured group (91 ± 8) which was trending towards significance (p = 0.10). The limited sample limits interpretation of these findings but it appears worth further investigation to assess the ability of the player to tell whether they are likely to develop a future injury.

Collecting data throughout the season using acute to chronic workload ratio to examine changes in training volume has recently become a popular measure to predict injuries.9,10,13,21,22,24 Previous research in baseball is limited but has identified a potential relationship between arm soreness and workload changes in a group of 7 collegiate pitchers.9 This current study expanded with more pitchers and now tracking injuries not just arm soreness. Previous research has used threshold scores ranging from 25%-200% ACWR.10,13,21 The ROC curve analysis from the current study determined that a 33% threshold would be an appropriate threshold to use. This threshold is consistent with previous baseball workload research that showed that changes of 27% revealed that baseball players were 14.9 times more likely to sustain an injury when this amount
of change occurred. The previous findings are consistent with the current study identifying an eight-fold increased likelihood of injury in baseball pitchers when workload was greater or less than 33%. The current study purposefully examined both increases and decreases in workload ratios as the literature has indicated that both a positive and negative training spike may predispose athletes to developing musculoskeletal injuries. This study observed 12 pitcher-weeks with injury and an even split of six were due to negative training and six were due to increased stress that preceded injury. The results indicate that changes in pitch volume were seen to have a greater influence regarding ACWR in the time leading to injury. It appears that changes in both directions can alter tissue’s ability to adapt to workloads placed on the upper and lower extremity in pitchers and should be considered in restarting activity following long layoffs.

LIMITATIONS

The primary limitation of this study was that large number of subjects and injuries are often needed to see differences which did not occur in this study. Baseline data was only collected once prior to the start of the season. Collecting measurements throughout the season may have identified if changes in measurements could have influenced the risk of sustaining an injury. Pitch counts were recorded estimates instead of actual pitch counts due to limited resources to capture every pitch. The risk of in-season injury was only examined during a singular season which resulted in a truncated season of only 9 weeks due to COVID-19. This study only examined chronic, overuse injuries and could have included acute, traumatic injuries as well. More weekly exposures are needed as the confidence interval suggest that our estimates may be more by chance than reality. Future studies should consider collecting preseason measurements and in-season factors over multiple years with the hopes of analyzing larger data sets to further examine results.

CONCLUSION

The findings of this research suggest that ACWR change in a positive or negative direction by at least 33% was the primary predictor of subsequent injury. The authors believe that this finding may assist sports medicine clinicians by using this threshold when tracking pitch volume to ensure a safe progression in workload during a baseball season in order to reduce the risk of sustaining overuse upper or lower extremity injuries, however, this should not be the only intervention strategy utilized. Significant differences including increased shoulder internal rotation strength and grip strength in the injured group were identified in this pilot study. The current study findings do not agree with previous literature, so caution with interpretation should be taken. This study serves as pilot data that suggest further acquisition of prospective data across more years may provide collegiate baseball teams with information to reduce injury risk to the upper or lower extremity as they progressively increase or decrease training volumes.

CONFLICT OF INTEREST

No conflicts of interest to report.

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REFERENCES

1. Oyama S, P. Goerger C, Goerger B, M. Lephart S, Myers J. Effects of non-assisted posterior shoulder stretches on shoulder range of motion among collegiate baseball pitchers. *Athletic Training & Sports Health Care*. 2010;2. doi:10.3928/19425864-20100524-01

2. Wilk KE, Macrina LC, Fleisig GS, et al. Deficits in glenohumeral passive range of motion increase risk of shoulder injury in professional baseball pitchers: a prospective study. *Am J Sports Med*. 2015;43(10):2379-2385. doi:10.1177/0363546515594380

3. Dick R, Sauers EL, Agel J, et al. Descriptive epidemiology of collegiate men's baseball injuries: national collegiate athletic association injury surveillance system, 1988-1989 through 2003-2004. *J Athl Train*. 2007;42(2):183-193.

4. Athletic Scholarships. College baseball programs and scholarships. [https://www.athleticscholarships.net/baseballscholarships.htm](https://www.athleticscholarships.net/baseballscholarships.htm). Published 2019.

5. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS, Garrison JC, Thigpen CA. Shoulder range of motion measures as risk factors for shoulder and elbow injuries in high school softball and baseball players. *Am J Sports Med*. 2011;39(9):1997-2006.

6. Aragon VJ, Oyama S, Oliaro SM, Padua DA, Myers JB. Trunk-rotation flexibility in collegiate softball players with or without a history of shoulder or elbow injury. *J Athl Train*. 2012;47(5):507-513. doi:10.4085/1062-6050-47.3.11

7. Wilk KE, Macrina LC, Fleisig GS, et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med*. 2011;39(2):329-335. doi:10.1177/0363546510384223

8. Lyman S, Fleisig GS, Waterbor JW, et al. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Med Sci Sports Exerc*. 2001;33(11):1803-1810. doi:10.1097/00005768-200110000-00002

9. Lazu AL, Love SD, Butterfield TA, English R, Uhl TL. He relationship between pitching volume and arm soreness in collegiate baseball pitchers. *Int J Sports Phys Ther*. 2019;14(1):97-106.

10. Orchard JW, James T, Portus M, Kountouris A, Dennis R. Fast bowlers in cricket demonstrate up to 3- to 4-week delay between high workloads and increased risk of injury. *Am J Sports Med*. 2009;37(6):1186-1192. doi:10.1177/0363546509332430

11. Bourdon PC, Cardinale M, Murray A, et al. Monitoring athlete training loads: consensus statement. *Int J Sports Physiol Perform*. 2017;12(Suppl 2):S2161-S2170. doi:10.1123/IJSPP.2017-0208

12. Soligard T, Schwellnus M, Alonso JM, et al. How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *Br J Sports Med*. 2016;50(17):1030-1041. doi:10.1136/bjsports-2016-096581

13. Mehta S. Relationship between workload and throwing injury in varsity baseball players. *Phys Ther Sport*. 2019;40:66-70. doi:10.1016/j.ptsp.2019.08.001

14. Franz JO, McCulloch PC, Kneip CJ, Noble PC, Lintner DM. The utility of the KJOC score in professional baseball in the United States. *Am J Sports Med*. 2013;41(9):2167-2173. doi:10.1177/0363546513495177

15. Byram IR, Bushnell BD, Dugger K, Charron K, Harrell, F. E., Jr., Noonan TJ. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. *Am J Sports Med*. 2010;38(7):1375-1382. doi:10.1177/0363546509360404

16. Murray WM, Bryden AM, Kilgore KL, Keith MW. The influence of elbow position on the range of motion of the wrist following transfer of the brachioradialis to the extensor carpi radialis brevis tendon. *J Bone Joint Surg Am*. 2002;84(12):2203-2210. doi:10.2106/00004623-200212000-00012

17. Myers NL, Kibler WB, Lamborn L, et al. Reliability and validity of a biomechanically based analysis method for the tennis Serve. *Int J Sports Phys Ther*. 2017;12(5):437-449.

18. Donatelli R, Ellenbecker TS, Ekedahl SR, Wilkes JS, Kocher K, Adam J. Assessment of shoulder strength in professional baseball pitchers. *J Orthop Sports Phys Ther*. 2000;30(9):544-551. doi:10.2519/jospt.2000.30.9.544

19. Evans NA, Dressler E, Uhl T. An electromyography study of muscular endurance during the posterior shoulder endurance test. *J Electromyogr Kinesiol*. 2018;41:152-158. doi:10.1016/j.elekin.2018.05.012
20. Grant S, Aitchison T, Henderson E, et al. A comparison of the reproducibility and the sensitivity to change of visual analogue scales, Borg scales, and Likert scales in normal subjects during submaximal exercise. *Chest*. 1999;116(5):1208-1217. doi:10.1378/chest.116.5.1208

21. Hulin BT, Gabbett TJ, Blanch P, Chapman P, Bailey D, Orchard JW. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *Br J Sports Med*. 2014;48(8):708-712. doi:10.1136/bjsports-2013-092524

22. Gabbett TJ, Hulin B, Blanch P, Chapman P, Bailey D. To couple or not to couple? For acute:chronic workload ratios and injury risk, does it really matter? *Int J Sports Med*. 2019;40(9):597-600. doi:10.1055/a-0955-5589

23. Bernard Rosner. *2-Way Contingency Table Analysis*. Fundamentals of Biostatistics; 2020.

24. Lyman S, Fleisig GS, Andrews JR, Osinski ED. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *Am J Sports Med*. 2002;30(4):463-468. doi:10.1177/0363546502030004020

25. Camp CL, Zajac JM, Pearson DB, et al. Decreased shoulder external rotation and flexion are greater predictors of injury than internal rotation deficits: analysis of 152 pitcher-seasons in professional baseball. *Arthroscopy*. 2017;33(9):1629-1636. doi:10.1016/j.arthro.2017.03.025

26. Harada M, Takahara M, Mura N, Sasaki J, Ito T, Ogino T. Risk factors for elbow injuries among young baseball players. *J Shoulder Elbow Surg*. 2010;19(4):502-507. doi:10.1016/j.jse.2009.10.022

27. Sciascia A, Haegele LE, Lucas J, Uhl TL. Preseason perceived physical capability and previous injury. *J Athl Train*. 2015;50(9):937-943. doi:10.4085/1062-6050-7.05