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Organizational risk profiling and education associated with reduction in professional pitching arm injuries: a natural experiment

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A R T I C L E I N F O

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Level of evidence: Level II; Prospective Cohort Study

Background: Risk profiling and education are strategies implemented to help reduce injury risk; however, currently. there is little evidence on the effect of these interventions on injury incidence. The purpose of this study was to evaluate the influence of risk profiling and education on upper extremity injury incidence in minor league (MiLB) pitchers and to stratify by injury severity.

Methods: A prospective natural experiment study was conducted from 2013 to 2019 on MiLB pitchers. Beginning in the 2015 season, pitchers were examined and risk profiled for upper extremity injury. Shoulder external, internal, total range of motion, horizontal adduction, and humeral torsion were measured. Organizational risk profiling and education was implemented starting in 2015, based on preseason assessments. Chi-squared test was performed to investigate potential differences between shoulder range of motion risk categories between 2013-2014 (pre) and 2015-2019 (post) seasons. Interrupted time series analyses were performed to assess the association between organizational risk profiling and education on arm injury in MiLB pitchers and were repeated for 7-27 and 28+ day injury severity.

Results: 297 pitchers were included (pre: 119, post: 178). Upper extremity injury incidence was 1.5 injuries per 1000 athletic exposures. Pitchers in the 2015-2019 seasons demonstrated increased preseason shoulder injury risk for internal ($P = .003$) and external ($P = .007$), while the 2013-2014 seasons demonstrated greater horizontal adduction risk ($P = .04$). There were no differences between seasons for total range of motion risk ($P = .76$). Risk profiling and education resulted in an adjusted time loss upper extremity injury reduction for the 2015-2019 seasons (0.68 (95% CI: 0.47, 0.99)), which impacted 7-27 days (0.62 (95% CI: 0.42, 0.93)) but not for 28+ days (0.71 (95% CI: 0.47, 1.06)) time loss. There was no reduction in combined trunk and lower extremity injuries for the 2015-2019 seasons (1.55 (95% CI: 0.79, 3.01)).

Conclusions: Organizational risk profiling and education appear to reduce professional pitching overall and 7-27-day upper extremity injury risk by 33%-38%. There was no difference in trunk and lower extremity injuries over the period, strengthening the reduction in upper extremity injury risk results. This suggests that while injury risk increased over time, organizational risk profiling mitigated the expected increase in upper extremity injury rates. Risk profiling and education can be used as a clinical screening and intervention tool to help decrease upper extremity injuries in professional baseball populations.

PRISMA Health Institutional Review Board approved this study IRB protocol #: Pro00004915.

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Baseball has a high injury incidence,[41] and these injuries continue to increase.[6,12] The greatest injury incidence is to the shoulder and elbow, with pitchers having a higher injury incidence and prevalence than position players.[6,9,11,41] These injuries have a high health care cost,[26] incur work time loss,[10] and inhibit performance.[40] Due to the severity and burden of baseball arm injuries,[6,12,26] baseball organizations have attempted to initiate injury risk and injury prevention programs.[16,19,46]

One method to assess injury risk is through risk profiling.[25,51,60,61] Risk profiling is defined as the ability to screen individuals and subsequently identify individuals at high risk for the outcome (ie, injury).[25] Within baseball, risk profiling has been performed, with shoulder range of motion (ROM) used as the risk profile gold standard.[51,60,61] In a meta-analysis, pitchers had a greater upper extremity injury risk with deficits greater than 5° between dominant and nondominant shoulder IR rotation ROM.[4] Pitchers were 6 times more likely to sustain an upper extremity injury with deficits greater than 15° between dominant and nondominant shoulder horizontal adduction (HA).[51] Injured pitchers exhibited greater than 5° difference between dominant and nondominant humeral torsion (HT) compared to noninjured pitchers.[37]

While injury risk profiling is performed throughout baseball,[51,60,61] without proper education and interventions, identifying high injury risk athletes is inconsequential.[53] Specific interventions have been employed for shoulder ROM deficits, including stretching and manual therapy.[2] However, despite the integration of injury risk profiling, education, and individualized interventions for high injury risk athletes, it is currently unclear how these strategies affect injuries in professional baseball pitchers.

The current ambiguity in baseball injury risk profiling effectiveness is caused by the infeasibility of performing randomized control trials in sports.[23] Randomized control trials require designating athletes into treatment and control groups, which may not be approved due to competitive or ethical reasons.[18,23] However, within sports, different interventions are performed team and organizational wide, with a specific demarcation between prior and following the implemented intervention. This constitutes a natural experiment, which is extensively used in population health to assess the effectiveness of law or medical interventions on a population level.[14] For example, a recent Nobel Prize study examining labor markets used this approach to elucidate cause and effect relationships of minimum wage policies.[1] Thus, a natural experiment provides an opportunity to provide clarity and measure the effectiveness of risk profiling and education strategies to help reduce injuries in professional baseball pitchers. Therefore, the purpose of this study was to evaluate the influence of risk profiling and education on upper extremity injury incidence in minor league (MiLB) pitchers and stratify by injury severity.

Materials and methods

Procedure

A prospective natural experiment study was conducted from 2013 to 2019 on MiLB pitchers in one organization. Prior to testing, all participants were detailed the risk and benefits of participation in verbal and written form. If a participant spoke a language other than English, an interpreter was used to verbally detail the study, and written consent forms were given in their own language. Participants were tested at the beginning of spring training (preseason). Two test administrators with combined over 40 years of sports medicine experience performed all measurements throughout the entire study. All test administrators were blinded to hand dominance.[51] Participants were tested for shoulder ROM and HT. Following testing, participants were followed for the entire season for total athletic exposures and upper extremity injuries by athletic training staff. All participant information was deidentified and coded into an encrypted centralized database. The Strengthening the Reporting of Observational Studies in Epidemiology for Sport Injury and Illness Surveillance were followed,[24] per recommendation by the Medical Research Council guidelines on natural experiments.[14] This investigation received favorable ethics approval from the University Institutional Review Board.

Participants

MiLB pitchers, from every professional level, at one major league baseball club were included in this study. Participants were included if they were able to participate in all practices and competitions and were under a MiLB contract at time of testing. Participants were excluded if they were currently injured or not participating in all spring training activities at time of testing, participating in major league baseball spring training at time of data collection, or signed a professional contract in the middle of the season (eg, draft, free agent, or international signing).[61] Participants that signed a professional contract in the middle of the season were included at the next preseason testing session.

Physical testing

Shoulder external and internal rotation range of motion

Shoulder external (ER) and internal (IR) ROM has been found to have high validity and reliability in general athletic,[49,57] overhead athlete,[49,57,58] youth overhead athletes,[33] and baseball populations.[37,49,52,57] Participants were placed supine on a standard plinth treatment table. Participants' shoulders were positioned in 90° of shoulder abduction and elbow flexion. A small towel roll was placed under the humerus to maintain humeral position. Both dominant and nondominant shoulders were measured.[28,32] Shoulder and scapula were stabilized by a study examiner placing a posterior pressure by the thenar eminence and thumb on the coracoid process before shoulder rotation.[15,17,28,57] Shoulder ER and IR were performed passively, with gravity acting upon the arm. A digital inclinometer was placed on the forearm midline and aligned to the olecranon process. Two examiners performed both ER and IR measurements, with one stabilizing the shoulder, and the other measuring shoulder rotation (Supplementary Appendix S1).[3] Prior to data collection, all measures were assessed for reliability and demonstrated acceptable intra-rater reliability (intraclass correlation coefficient [ICC] $_{(2,1)}$ = 0.92-0.99) and reliability was maintained throughout the study. Two trials were administered per shoulder, and the average of both trials was used in data analyses.[52]

Horizontal adduction

Shoulder HA has been found to have high validity and reliability in overhead athletes[36] and baseball populations.[27,36,52] Both dominant and nondominant shoulders were measured. Subjects were placed supine on a standard plinth treatment table. The scapula was retracted and stabilized via the thenar eminence of one examiner placing an anterior to posterior pressure to the lateral scapular border. The upper extremity was then placed in 90° abduction in zero° rotation.[27,36,52] The upper extremity was then passively horizontally adducted across the body.[27,36] A digital inclinometer was then placed on the posterior border of the humerus, in line with the olecranon and acromial processes. The angle between the humerus and the horizontal plane, from the superior aspect of the shoulder was then measured (Supplementary Appendix S1).[36,52] Prior to data collection, all measures were assessed for reliability and demonstrated acceptable intra-rater reliability ($ICC_{(2,1)} = 0.92$-0.99) and reliability was maintained throughout the study. Two trials were administered per shoulder, and the average of both trials was used in data analyses.[52]

Humeral torsion

HT indirect ultrasonographic measurement has been found to be valid and reliable in overhead athletes[35] and baseball players.[35,37] The standard error of measure (SEM) has been observed to range from 2 to 3.8°.[35,37] Participants were placed supine on a standard plinth treatment table. Participants' shoulders were positioned in 90° of shoulder abduction and elbow flexion. A 5-MHz transducer (Sonosite Inc., Bothell, WA) was placed level on the anterior shoulder and aligned perpendicular to the long axis of the humerus (Supplementary Appendix S1). The humerus was then rotated so that the intertubercular groove can be seen, with the apexes of the greater and lesser tubercles parallel to the horizontal plane. A digital inclinometer was then placed on the ulnar side of the forearm, measuring the forearm angle in the horizontal plane. These measurements indirectly measured the HT, in respect to the epicondylar axis.[37] HT reliability (ICC (2,1) = 0.97; SEM = 2.5; ICC (2,K) = 0.97 SEM = 2.6) was determined to be excellent.

Exposure definition

An athlete-exposure (AE) was defined as one athlete participating in one practice or competition where a player was at risk of sustaining an injury.[41-43] Baseball exposure was defined from the beginning of preseason (ie, spring training) to the end of the minor league season.[38] All exposure was recorded by the athletic training staff.

Seasonal pitch load and number of pitching appearances

The number of pitches and pitching appearances in a season were collected from team reports. However, due to the contractual agreement between the researchers and the major league baseball organization, pitch count was not reported until 2016, which consisted of 75% of all pitch count data. As a result, the remaining pitcher season pitch counts were accessed and recorded via publicly available data (thebaseballcube.com and baseball-reference.com). As these publicly available websites do not record the actual number of pitches in a season, indirect calculations were performed. Box score statistics including batters faced, strike outs, and walks were obtained from the publicly available websites and then calculated via a pitch count estimator formula ($3.3 \times$ Batters Faced $+ 1.5 \times$ Strike Outs $+ 2.2 \times$ Walks).[50] This pitch count formula has found to be have excellent reliability (ICC = 0.98), with error of three pitches per season.[50]

Injury definition

An injury was defined as an injury to a tendon, ligament, nerve, muscle, or bone that occurs during any baseball team sponsored activity or event[45] and was followed by at least one day of missed practice or at least one missed baseball game.[51] If a player was unavailable to play for injury prevention reasons (ie, has reached league or individually determined pitch or innings count limits), then their absence was not considered as an injury.[38] Injuries were defined by the Orchard Sports Injury Classification system and upper extremity injuries stratified by shoulder/clavicle, upper arm, elbow, and forearm.[44] All other injuries and illness were also recorded, and time loss was taken into account for overall exposure.[39] All other injuries were combined into trunk and lower extremity injury. Injury severity calculated as overall time loss,[39] with further injury severity stratified by 7-27 and 28+ days.[51] Injuries were further stratified into early (March, April), middle (May, June), and late (July, August, and September).

Injury history was obtained from player medical records and previous professional baseball seasons. A pitcher was defined as having a history of upper extremity injury if: previous elbow or shoulder surgery,[31,64] and/or sustaining 15 or more days of elbow or shoulder time loss injury in previous professional baseball seasons.[31,60]

Injury risk profiling and education

Beginning with the 2015 season, pitchers identified as at risk through preseason ROM and HT testing, were risk profiled for the Major League Baseball organization. Risk profiling was performed through calculating the difference between dominant and nondominant shoulder ROM and HT.[60,61] Shoulder ROM and HT differences were calculated for shoulder IR, ER, total range of motion (TROM), HA, and HT.[51,60,61] Pitchers were then grouped into at risk and not risk categories for IR, ER, and TROM difference and dominant HA ROM, based off of previous literature.[51,60,61] Shoulder IR ROM risk was defined as $\leq -15°$,[60,61] shoulder ER ROM risk was defined as $\geq 15°$,[60,61] shoulder TROM risk was defined as $\leq -10°$,[60,61] and dominant shoulder HA risk as $<0°$.[51] Pitchers that were not considered not at risk from these calculations were advised to continue with regular training.

The major league baseball organization, including athletic trainers, physical therapists, and strength and conditioning coaches were educated on what being risk profiled incurred. Further, the major league baseball organization was educated on potential shoulder ROM interventions. Interventions included self-stretching, manual therapy, and shoulder strengthening exercises.[2,13,34] All interventions had to be performed within the athletic training room under sport medicine supervision. Shoulder self-stretching consisted of each pitcher performing the sleeper and horizontal stretch prior to and following throwing.[13] Manual therapy consisted of instrumented soft-tissue mobilization, focusing on the teres minor and infraspinatus, following throwing and pitching sessions.[2] Participants were prone with the throwing arm in 90° shoulder abduction and elbow flexion. Treatment strokes were applied at 45°, for two minutes.[2] Shoulder strengthening consisted of a two-phase program, the first focusing on endurance, increasing up to 3×20 repetitions with proper form prior to increasing load. The second phase focused on increasing load (maintaining 3×20 repetitions), up to 2.3 kg. Pitchers performed these exercises four times a week. Pitchers were prone with 'thumbs up', and performed shoulder horizontal abduction at 90 and 145°.[34] Risk profiled pitchers were monitored throughout the season by the athletic training staff for compliance of performing the interventions.

Data reduction

Time series data were split by dummy code into 0 (2013-2014) and 1 (2015-2019). The number of professional seasons was split into one to two seasons, three to four seasons, and five plus seasons.

Table I
Pitching demographics for 2013-2019.

	All pitchers (n = 297)	2013-2014 (n = 119)	2015-2019 (n = 178)
Age (years)	23.0 (2.2)	23.4 (2.4)	22.7 (2.1)
Hand dominance			
Left	62 (21%)	25 (17%)	57 (16%)
Right	235 (79%)	123 (87%)	292 (84%)
Body mass index (kg/m^2)	24.8 (2.2)	25.1 (2.4)	24.6 (2.2)
Pitching position			
Starter	122 (41%)	58 (49%)	100 (56%)
Reliever	175 (59%)	61 (51%)	78 (44%)
Seasonal pitch load	775 (394, 1156)	600 (213, 988)	860 (502, 1217)
Number of pitching appearances	25 (14)	26 (17, 35)	25 (14, 36)
Dominant HT	9 (13)	9 (13)	9 (13)
Dominant IR	35 (11)	35 (10)	35 (11)
Dominant	125 (10)	125 (9)	125(11)
Dominant	−2 (12)	−3 (12)	−2 (13)
Dominant	160 (13)	159(12)	160 (13)
Humeral torsion difference	−18 (14)	−17 (12)	−19 (15)
Internal rotation difference	−13 (11)	−10 (10)	−14 (11)
External rotation difference	9.0 (9.1)	6.9 (8.3)	10 (9)
TROM difference	−4 (13)	−4 (12)	−4 (13)
Internal rotation risk			
Risk	42%	32%	47%
No risk	58%	68%	53%
ER risk			
Risk	44%	35%	49%
No risk	56%	65%	51%
Dominant HA risk			
Risk	62%	69%	58%
No risk	38%	31%	42%
TROM risk			
Risk	32%	31%	33%
No risk	68%	69%	67%
Arm injury history	31%	27%	33%
Arm injuries 1+ Days	98 (33%)	35 (29%)	63 (35%)
Arm injuries 7+ Days	84 (28%)	30 (25%)	54 (30%)
Arm injuries 28+ Days	64 (22%)	22 (18%)	42 (24%)
Arm injury occurrence			
Early	43 (45%)	15 (43%)	28 (48%)
Middle	28 (32%)	13 (37%)	15 (26%)
Late	22 (23%)	7 (20%)	15 (26%)
Elbow injuries	40 (13%)	17 (14%)	23 (13%)
Shoulder injuries	64 (22%)	18 (14%)	46 (26%)

HT, Humeral torsion; *IR*, Internal rotation; *ER*, External rotation; *HA*, Horizontal adduction; *TROM*, Total range of motion.
Data is reported as mean (standard deviation), median (25th quantile, 75th quantile), or counts as percent.
All range of motion is reported in degrees.
TROM = Sum of shoulder external and internal rotation ROM.
Range of motion difference is calculated as dominant − non-dominant shoulder.
IR Risk = Less than or equal to −15 degrees difference between dominant and nondominant shoulder IR.
ER Risk = Greater than or equal to 10 degrees difference between dominant and nondominant shoulder ER.
Dominant HA risk = Less than 0 degrees difference on dominant HA.
TROM Risk = Less than or equal to -1- degrees difference between dominant and nondominant shoulder TROM.

Statistical analyses

All data were investigated for missingness prior to analyses. Missing data were low (shoulder range of motion: 3%, age: <1%, position: 0%), thus complete case analyses were performed. Investigation of normality was performed utilizing data visual inspection prior to analyses. Participant statistics were described using mean (standard deviation) for continuous normally distributed variables, median (interquartile range) for non-normally distributed continuous variables, and frequencies and percentages for categorical variables. Upper extremity injury and combined trunk and lower extremity incidence was calculated by sum of injuries divided by sum of person days multiplied by 1000. χ^2 analyses were performed to investigate potential differences between shoulder ROM risk categories between the 2013-2014 and 2015-2019 seasons ($P < .05$). Interrupted time series analyses with quasipoisson distributions were performed to assess the effect of risk profiling and education on upper extremity injury in professional MiLB pitchers. These analyses were repeated for injury severity of 7-27 and 28+ days. Sensitivity analyses were performed to understand the stability of the results. Sensitivity analyses were performed separately: 1) elbow and shoulder injury, 2) time to injury. A falsification analysis was also performed to assess associations for combined trunk and lower extremity injury, as this is an implausible relationship for the designed injury mitigation program. Unadjusted and adjusted odds ratios (ORs) with 95% confidence intervals (95% CI's) were reported for all analyses with alpha set at 0.05. Confounders controlled for included body mass index,[8] arm dominance (left vs. right arm),[54] seasonal pitch load, number of season pitching appearances, pitching position (ie, starter vs. reliever),[7] professional baseball seasons played, injury history,[31,64] HT difference,[22] shoulder IR difference,[4] shoulder ER difference,[4] and shoulder HA difference.[4] All assumptions for times series were assessed and met. All analyses were performed in R version 3.5.1 (R Core Team (2013). R: A language and environment for statistical computing; R Foundation for Statistical Computing, Vienna, Austria), using the *naniar* package for missingness assessment,[56] and *tsModel* for interrupted time series modelling.

Results

Participant characteristics

A total of 297 pitchers were included with a total of 119 pitchers in the 2013-2014 seasons and 178 pitchers in the 2015-2019 seasons. 14 pitchers were in both the 2014 and 2015 seasons. A total of 85,270 player days were observed, with 25,277 player days for the 2013-2014 seasons, and 59,993 player days for the 2015-2019 seasons. Overall injury history prevalence was 31%, the 2013-2014 season injury history prevalence was 27%, and the 2015-2019 season injury history prevalence was 33%. Upper extremity injury incidence was 1.15 injuries per 1000 AE's. For the 2013-2014 seasons upper extremity injury incidence was 1.38 injuries per 1000 AE's, and for the 2015-2019 seasons, upper extremity injury incidence was 1.63 injuries per 1000 AE's (Table I). All upper extremity injuries were overuse in nature. Combined trunk and lower extremity injury incidence was 0.40 combined trunk and lower extremity injuries per 1000 AE's. For the 2013-2014 seasons combined trunk and lower extremity injury incidence was 0.40 combined trunk and lower extremity injuries per 1000 AE's. For the 2015-2019 seasons combined trunk and lower extremity injury incidence was 0.40 combined trunk and lower extremity injuries per 1000 AE's.

Injury risk profiling

A total of 93 (78%) pitchers were risk profiled in the 2013-2014 season and 130 (73%) were risk profiled for the 2015-2019 seasons. Upper extremity injury incidence for risk profiled pitchers during the 2013-2014 season was 1.7 injuries per 1000 AE's and 0.9 injuries per 1000 AE's in the 2015-2019 seasons.

The 2013-2014 seasons demonstrated decreased preseason shoulder injury risk for IR shoulder risk (2013-2014: 32%, 2015-2019: 47%; $P = .003$) and ER shoulder risk (2013-2014: 35%, 2015-2019: 49%; $P = .007$) when compared to the 2015-2019 seasons.

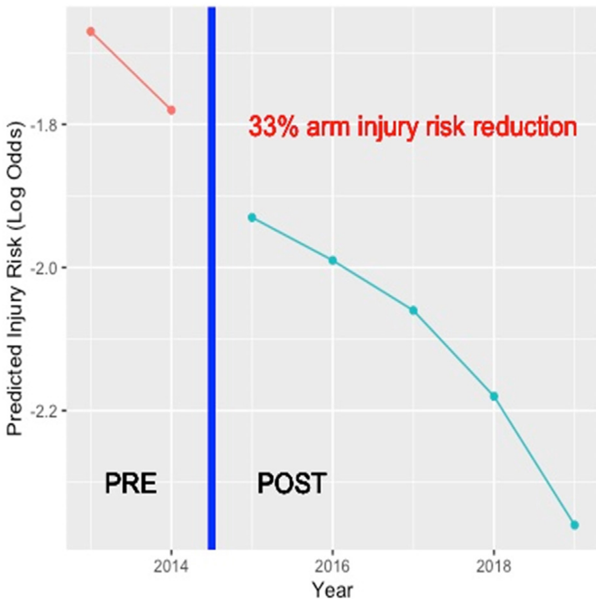

Figure 1 Following organizational risk profiling and education, there was a 33% arm injury risk reduction over the subsequent seasons while controlling for other measurable factors.

While the 2015-2019 seasons demonstrated decreased dominant HA shoulder risk (2013-2014: 69%, 2015-2019: 58%; P = .036) compared to 2013-2014 seasons. TROM risk (2013-2014: 31%, 2015-2019: 33%; P = .763) was similar across all seasons.

Interrupted time series

Risk profiling and education resulted in a reduced adjusted time loss upper extremity injury reduction for the 2015-2019 seasons (unadjusted: 0.76 (95% CI: 0.50, 1.15), P = .197; adjusted: 0.68 (95% CI: 0.47, 0.99), P = .197; Fig. 1), which impacted 7-27 days (0.62 (95% CI: 0.42, 0.93), P = .019; Fig. 2) but not for 28+ days (0.71 (95% CI: 0.47, 1.06), P = .093) time loss.

Individual body region analyses

There was a significant decrease in elbow injury for the 2015-2019 seasons (Unadjusted: 0.98 (95% CI: 0.97, 0.99), P = .039; Adjusted: 0.53 (95% CI: 0.30, 0.95), P = .034). There was no reduction in shoulder injuries for the 2015-2019 seasons (unadjusted: 1.09 (95% CI: 0.68, 1.74), P = .773; adjusted: 0.89 (95% CI: 0.53, 1.56), P = .690). There was no relationship between arm injuries time occurrence within the baseball season (unadjusted: 1.12 (95% CI: 0.78, 1.59), P = .548; adjusted: 1.07 (95% CI: 0.74, 1.56), P = .723). There was no reduction in combined trunk and lower extremity injuries for the 2015-2019 seasons (unadjusted: 1.42 (95% CI: 0.74, 2.72), P = .290; adjusted: 1.55 (95% CI: 0.79, 3.01), P = .204).

Discussion

The natural experiment analysis reveals that while upper extremity injury risk increased between 2013-2014 seasons and 2015-2019 seasons, risk profiling and education reduced upper extremity injury expected rates by 33%. Upper extremity injury risk profiling and education showed the greatest reduction in the 7-27-day upper extremity injury incidence by 38%; however, the wide confidence intervals decrease the strength of these findings. The upper extremity injury reduction strategy was inconclusive for 28+ day injury incidence. There were no descriptive or statistical differences for combined trunk and lower extremity injury incidence or risk between the 2013-2014 and 2015-2019 seasons. These findings may demonstrate that injury risk profiling and education are effective in mitigating upper extremity injury incidence at the organizational level.

Risk profiling and education was observed to decrease upper extremity injury risk by one third for any time loss and 7-27-day time loss upper extremity injuries. There are no comparative studies in upper extremity injury risk. Similar approaches which identify athletes at risk for injury has been observed to be effective in attenuating injury risk in other sports for anterior cruciate ligament injuries.[55] Identifying at risk athletes allows for injury prevention programs to be enacted, which have also demonstrated high efficacy in impacting sport injuries.[30,47,48] Following identifying pitchers at risk for an upper extremity injury, sports medicine providers, and the respective baseball pitchers, were educated on potential injury risk reduction strategies such as shoulder ROM stretching, manual therapy,[2] and shoulder strengthening exercises.[62] Further, these players were more closely monitored throughout the season, allowing for alterations in individualized injury prevention strategies as the season progressed.

It should be noted that the raw injury incidence was similar between both groups. However, the 2015-2019 group demonstrated greater prevalence of risk profiled pitchers and arm injury history, which have previously been observed to increased upper extremity injury risk.[31,64] Risk profiling may have attenuated the expected rise in upper extremity injury rates for the 2015-2019 group. These data suggest that performing preseason injury risk screening, and educating sports medicine providers and their respective athletes, may allow for improved observation and greater precision in injury prevention intervention in higher risked athletes, potentially decreasing their upper extremity injury risk.

Injury risk profiling and education interventions decreased elbow injury risk by 47%, but was inconclusive for shoulder injury risk. However, splitting the data decreased the power, limiting the interpretability of these findings. Elbow and shoulder injury risk factors have been previously observed to be dissimilar in professional baseball pitchers.[60,61] For example, professional pitchers who sustained an elbow injury exhibited decreased dominant total shoulder ROM and shoulder flexion, while in the same cohort, professional pitchers that sustained a shoulder injury demonstrated decreased dominant shoulder ER rotation.[60,61] These differences may be due to biomechanical changes caused by these different shoulder ROM deficits.[20] The greatest elbow valgus torque is sustained during the late cocking phase, which is a combination of shoulder rotation, scapulothoracic extension, and trunk extension.[20,59] Deficient dominant total shoulder ROM and shoulder flexion may create increased elbow valgus torque during the pitching late cocking phase due to decreased ability to produce the necessary shoulder and scapulothoracic motion.[59] In contrast, during the late cocking phase, decreased shoulder ER rotation may not allow for sufficient lay back mechanism, putting undue stress on the shoulder.[37,63]

Risk profiling and education were inconclusive for 28+ day upper extremity injuries. But, statistical power was substantially decreased for this analysis, demonstrated by the wide confidence intervals. There were no differences in time to injury before or after implementing risk profiling and education. This suggests that these interventions are indiscriminate in injury prevention concerning time. Thus, other factors such as playing load and fatigue may also play a role in time to injury within a season.[5,21,29] For example there was a proportional relationship between increased pitch count and throwing arm pain in baseball pitchers.[29] In a systematic review, increased fatigue was associated with increased arm pain in pitchers.[21] It is advised to continue to monitor pitching load,

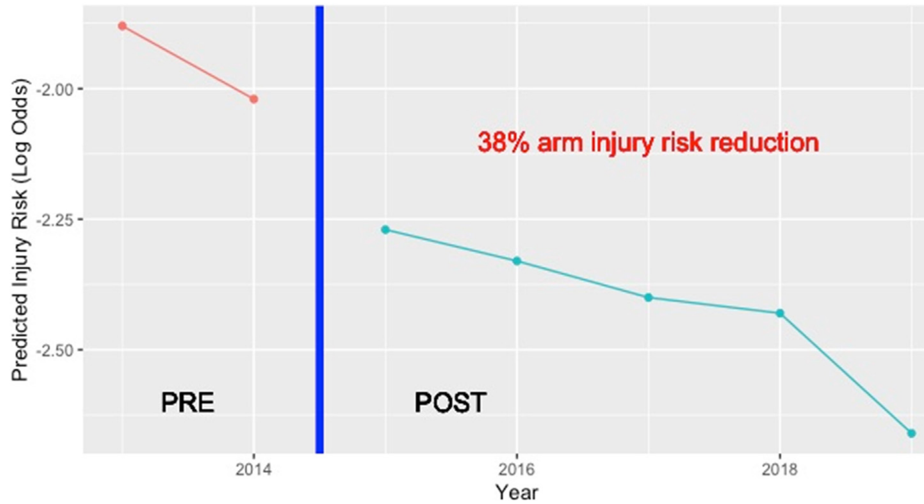

Figure 2 Following organization risk profiling and education, there was a 38% 7-27-day arm injury risk reduction over the subsequent seasons while controlling for other measurable factors.

through pitch count, and pitcher fatigue in association with risk profiling and education.

Combined trunk and lower extremity injury incidence was similar at 0.40 injuries per 1000 AE's between the 2013-2014 and 2015-2019 baseball seasons. Further, adjusted combined trunk and lower extremity injury risk was similar between cohorts. The combined trunk and lower extremity injury incidence and risk are in direct contrast to the steady decrease in adjusted upper extremity injury incidence. As baseball training and in game tactics have changed throughout the cohort time period, these modifications could have potentially explained the steady decrease in upper extremity injury risk. However, the similar combined trunk and lower extremity injury incidence and risk throughout the cohort period potentially strengthen the association between incorporating risk profiling and education and the decreased upper extremity injury risk.

Strengths

This study used a seven-year prospective longitudinal professional baseball cohort, increasing the precision of these findings. All minor league affiliates were incorporated into the sample increasing the generalizability of these findings.

Potential limitations

There were decreased number of seasons and overall exposure for the pre intervention (2013-2014) compared to the intervention (2015-2019) groups. Shoulder ROM can change between pitching appearances and throughout the season, which was not evaluated in these data. Individual pitcher compliance with interventions and fidelity to interventions were not assessed, decreasing the precision of these findings. Previous injury history that did not involve surgery, prior to signing a professional contract, was not available. As previous injury is a predictive factor of recurrent injury, there is some residual confounding on this issue. Pitch velocity, shoulder strength, or lower extremity ROM was not included in cohort data collection, which decreases clinical utility of these findings. Only investigating professional baseball players decreases the generalizability of these results. These findings should not be interpreted as causal.

Future research

These findings necessitate future research. The different relationships observed between injury risk profiling and education and elbow and shoulder injuries necessitate the need to understand how interventions potentially mitigate elbow and shoulder injuries separately. While injury risk profiling and education demonstrated a reduction in professional pitching upper extremity injuries, it is not known what the optimal dosage of injury prevention interventions needed to decrease upper extremity injuries are. Research is needed to understand the effectiveness of risk profiling and education on other playing standards, such as college, high school, and youth baseball players.

Conclusions

Organizational risk profiling and education appear to reduce professional pitching <28-day upper extremity injury risk by 33%-38%; however, the wide confidence intervals may reduce the interpretation of these findings. Risk profiling decreased elbow injury risk by 47% but was not effective in reducing shoulder injury risk. These findings suggest that while injury risk increased over time, organizational risk profiling mitigated the expected increase in upper extremity injury rates. Risk profiling and education can be used as a clinical screening and intervention tool to help decrease upper extremity injuries in professional baseball populations at an organizational level. Future research is required to understand the interplay of clinical and unmeasured factors on pitching injury risk and the individual causal effects of risk profiling and education.

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Supplementary data

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