Workload Risk Factors for Pitching-Related Injuries in High School Baseball Pitchers

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Background: Pitch counts are only one measure of the true workload of baseball pitchers. Newer research indicates that workload measurement and prevention of injury must include additional factors. Thus, current monitoring systems gauging pitcher workload may be considered inadequate.

Purpose/Hypothesis: The purpose of this study was to develop a novel method to determine workload in baseball pitchers and improve processes for prevention of throwing-related injuries. It was hypothesized that our pitching workload model would better predict throwing-related injuries occurring throughout the baseball season than a standard pitch count model.

Study Design: Cohort study; Level of evidence, 2.

Methods: This prospective observational study was conducted at an academic medical center and community baseball fields during the 2019 to 2023 seasons. Pitchers aged 13 to 18 years were monitored for pitching-related injuries and workload (which included pitching velocity; intensity, using preseason and in-season velocity as a marker of effort; and pitch counts).

Results: A total of 71 pitchers had 313 recorded pitcher outings, 11 pitching-related injuries, and 24,228 pitches thrown. Gameday pitch counts for all pitchers ranged from 19 to 219 (mean, 77.5 ± 41.0). Velocity ranged from 46.8 to 85.7 mph (mean, 71.3 ± 5.8 mph). Intensity ranged from 0.7 to 1.3 (mean, 1.0 ± 0.08). The mean workload was 74.7 ± 40.1 for all pitchers. Risk factors significant for injury included throwing at a higher velocity in game (P = .001), increased intensity (eg, an increase in mean velocity thrown from preseason to in-season; $P < .001$), and being an older pitcher (P = .014). No differences were found for workload between injured and noninjured pitchers because the analysis was underpowered.

Conclusion: Our workload model indicated that throwing at a higher velocity, throwing at a higher intensity, and older age were risk factors for injury. Thus, this novel workload model should be considered as a means to identify pitchers who may be at greater risk for injury.

Keywords: baseball; injury; pitching; workload

As of 2021, there were >15 million baseball players and >2 million youth league players in the United States.[19,41] According to the National Federation of State High School Associations, >480,000 individuals participate in high school baseball.[31] Because of the popularity of baseball, a significant number of chronic, throwing-related baseball injuries occur. In the United States, the shoulder injury rate at the high school level is 2.15 per 10,000 athlete-exposures across all sports.[37] Baseball has a shoulder injury rate of 1.39 per 10,000 athlete-exposures and an elbow injury rate of 0.86 per 10,000 athlete-exposures at the high school level, with chronic and overuse injuries accounting for 40% to 57% of all injuries.[38] Moreover, injuries to the ulnar collateral ligament (UCL) of the elbow associated with overhead throwing continue to increase. The number of UCL surgical reconstructions has increased throughout all levels of play for the past 20 years, most notably at the youth and high school levels, which saw a >6-fold increase from 1994 through 2011.[2,10,14,33] Alarmingly, adolescent baseball pitchers have been shown to have 4 to 36 times higher risk of sustaining an injury due to overuse and fatigue compared with those adolescent baseball pitchers who do not have a history of overuse.[32]

As a result of the volume of overuse throwing injuries, particularly in baseball players, there has been a push to reduce this trend in recent years. Known risk factors for overuse throwing injuries include a lack of adherence to recommended pitch counts, year-round pitching, pitching for >1 team, rotator cuff weakness, kinetic chain deficits, scapular dyskinesis, altered shoulder rotation, and pitching with arm pain and fatigue.[49] Major League Baseball developed Pitch Smart, a website that provides information to players, coaches, parents, and health care practitioners on the prevention of overuse injuries in young pitchers.[21] Unfortunately, pitch counts are only accounted for during live game competition. Studies at the high school and professional levels found that the volume of pitches thrown off a mound during a gameday outing is

The American Journal of Sports Medicine
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DOI: 10.1177/03635465241246559

actually 42% to 45% greater than live game pitches.[11,49] Thus, there is a critical problem with accurate monitoring of workload for high school baseball pitchers.

A plethora of research is available on workload and injury monitoring in the lower extremity athlete involving rugby, soccer, and running.[16,23,35,42] However, the literature is not nearly as robust in overhead throwing athletes, specifically baseball players. Currently, only 1 study is available in overhead throwing athletes that combined factors such as total volume (combining all pitches thrown off the mound, incorporating bullpen, warm-up, and game pitches) and intensity to develop a workload model.[28] Further, a systematic review of monitoring workloads in throwing-dominant sports concluded that although there is a relationship between workload and injury, inconsistent monitoring systems and a paucity of research are available examining how intensity factors into workload.[5,27,47] Furthermore, no research was been published combining pitch count and velocity to develop a workload assessment for pitchers.

Although overuse monitoring systems with pitch count recommendations have seen significant improvement,[21] the volume of injuries in high school baseball players has not decreased.[34,38] Further, previous data have demonstrated that pitch velocities >80 to 85 miles per hour were predictive of throwing injuries in adolescent pitchers.[32,33] Thus, the overarching goal of this research project was to develop and evaluate a novel pitching workload model combining volume, pitch count, and intensity. We hypothesized that our pitching workload model would better predict throwing-related injuries occurring throughout the baseball season than a standard pitch count model.

METHODS

Institutional review board approval was obtained from our institution, as well as separate approval from the high school principals, athletic directors, and head baseball coaches of the teams included in the study. Our study team obtained consents and assents (as applicable) from all participants and their parents or legally authorized representatives. This investigation was developed as a prospective, observational study with the primary outcome being throwing-related injuries. Our study population included all eligible high school baseball pitchers during the 2019 to 2023 seasons, irrespective of socioeconomic and cultural background, from local public and private high schools in Gainesville, Florida. The mean age of the pitchers was 16.9 ± 1.2 years (range 13-18 years). Gainesville is a diverse city with 63% to 65% White, 20% to 22% African American, 8% to 10% Hispanic, 5.5% Asian, and approximately 3% other populations.[43,44] Our study team included physicians, researchers, and athletic trainers from multiple academic departments with sex and career balance (senior, mid-career, and early) as well as individuals who are African American, Asian, White, Hispanic, and Native American. Given that all high schools and student-athletes in the study population have athletic trainers provided by our institution, none of the student-athletes had any disadvantages in terms of timely evaluations, accessibility, and treatment of an injury. The STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) cohort reporting guidelines were used.[45] The statistical analysis and presentation are consistent with the CHAMP (Checklist for Statistical Assessment of Medical Papers) statement.[24]

Variables Definitions

Injury. An injury was defined as any musculoskeletal condition that resulted in missed time from competition and/or practice associated with throwing or pitching during a baseball-related activity (eg, a game or practice).

Gameday Pitch Count. As defined from previously published research, gameday pitch count included bullpen pitches, warm-up pitches, and live game pitches at sanctioned high school baseball games.[49] Each pitcher's total number of pitches thrown off a pitching mound were recorded to ensure that only pitches completed in a similar manner were counted. Standard pitch counters (Tally Counter; Berm, silver) were used to count pitches.

Velocity. Velocity was defined as the speed of a given pitch at any point from its release to the time it crosses home plate.[22] Maximum pitch velocity was obtained using a standard radar gun (Model PR1000-BC; Pocket Radar). Research assistants who were trained in proper use of a radar gun attended all games and practices to record pitch velocity.

Intensity. During games, we collected and recorded ball velocity using the radar gun for the first 10 pitches of each inning. The radar gun was used to record the ball velocity for pitches thrown from a mound. We divided the mean

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Submitted October 24, 2023; accepted February 19, 2024.

One or more of the authors has declared the following potential conflict of interest or source of funding: This research was funded by the Orthopaedic and Research Education Foundation (OREF) Prevention of Musculoskeletal Youth Sports Injuries Research Grant in Honor of James Andrews, MD (https://www.oref.org/grants-and-awards/current-grant-recipients). Funding was made possible in part by the Aircast Foundation. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

fastball velocity thrown throughout the gameday and/or practice by the maximum fastball velocity recorded at the start of each season. For example, if a pitcher had a maximum velocity of 90 mph and a mean gameday velocity of 85 mph, the intensity was calculated as 85 ÷ 90 = 0.94.

Workload. We then calculated workload as volume multiplied by intensity. The formula is as follows:

$$Workload = (\,intensity\,(game\,velocity\,/\,preseason\,velocity) * gameday\,pitch\,count) * 100.$$

Workload was defined as the combination of external load (eg, external stimulus applied to the athlete) plus the internal load (the physiological and psychological response in an individual after the application of an external load). In a baseball pitcher, external load is the volume of pitches thrown and internal load is the physical and mental makeup of the pitcher (some examples include, but are not limited to, previous injury as well as joint range of motion, strength, and flexibility).[40]

Data Collection

Preseason data collection included recording of each pitcher's demographic information. A total of 5 high schools participated in the study. During preseason training, a data collection session involved the pitcher completing a warm-up session followed by 10 pitches thrown using his best effort. Pitchers were not informed of their ball velocities. Documentation of the velocity of each pitch was performed by our research study team. The velocity of these 10 pitches was used to determine a pitcher's mean preseason fastball velocity. Throughout the season, each pitcher's total number of pitches thrown off a mound was counted (including bullpen, inning warm-up, and game pitches). Any throws made before warming up in the bullpen and long toss in the outfield were not counted. All pitching-related injuries were verified by each team's medical staff (athletic trainers and team physicians). Additional data points included pitcher type (starter vs reliever) and number of innings pitched. In addition to the injury data, pitch counts and ball velocity were collected and used to calculate workload. Injuries sustained from pitching were recorded and cross-referenced based on pitch count, pitch intensity, number of innings pitched, starter/reliever status, and the workload model.

Statistics

Percentages and counts were used to summarize categorical measures. Means and standard deviations were used to summarize continuous measures. We used *t* tests to assess differences in pitching metrics between injured and noninjured players; the Welch *t* test was used in cases of unequal variances. For pitching metrics that had significant association with injury in univariate analysis, generalized linear mixed models (GLMMs) were used to examine associations between those pitching metrics with injury occurrence while adjusting for other factors including age, starting status, and other pitching metrics. GLMMs can allow for the consideration that pitchers are nested within schools and that some pitchers were observed in multiple seasons. Because of the low rate of injury, individual covariates were tested in separate models with pitching metrics. Additionally, intensity was rescaled (multiplied by 10) for multivariable models. Statistical significance was set at $P \leq .05$ a priori. Statistical analyses were completed using JMP Pro 17 (SAS Institute) and R statistical package.[12]

TABLE 1
Sample Characteristics

Measure	Mean	SD
Age, y	16.9	1.2
Bullpen pitches, n	13	12
Warm-up pitches, n	18	10
Live game pitches, n	46	28
Total pitches, n	77	41
Game velocity, mph	71.3	5.8
Preseason velocity, mph	70.7	5.4
Intensity	1.0	0.08
Workload	74.7	40.1

RESULTS

A total of 71 pitchers were enrolled in the study. Table 1 summarizes the study population. The mean age of the pitchers was 16.9 ± 1.2 years. There were 313 pitcher outings, 11 pitching-related injuries, and 24,228 pitches thrown. Anatomic location of injury included 4 elbow injuries, 5 shoulder injuries, 1 hip injury, and 1 wrist injury. More than half (58%; 180/313) of the recorded pitcher outings involved relief pitchers. Pitchers threw a mean of 2.9 ± 1.8 innings in each game. Gameday pitch counts ranged from 19 to 219 (mean, 77 ± 41). Velocity ranged from 46.8 to 85.7 mph with a mean of 71.3 ± 5.8 mph. Intensity ranged from 0.7 to 1.3 (mean, 1.0 ± 0.08). The mean gameday workload for all pitchers was 74.7 ± 40.1.

Table 2 reports univariate results for risk factors associated with injury. Statistically significant risk factors for injury included throwing at a higher velocity in game (P = .001), increased intensity (eg, an increase in mean velocity thrown from preseason to season; $P < .001$), and being an older pitcher (P = .014). We found no significant association with injury and pitch count (P = .75). Injured pitchers accumulated an increased workload of 3.6% compared with noninjured pitchers, and this was not significant (P = .72). Multivariable analyses using GLMMs were run to examine effects of velocity and intensity while controlling for age and starting status. Another model included velocity and intensity together. Because of the low rate of injury, GLMMs could include only 2 fixed effects. Thus, multiple models were tested (Table 3). Both velocity and intensity remained statistically significant ($P < .05$) predictors in models after adjustment for age and starting status. In the model that included both velocity and intensity, only intensity remined as a statistically significant predictor of injury (P = .034).

TABLE 2
Univariate Analyses Between Pitching Metrics and Injury

Measure	No Injury		Injured		
	Mean	SD	Mean	SD	*P*
Age, y	16.8	1.3	17.1	0.6	.014
Total pitches, n	77.5	41.3	75.3	39.1	.749
Game velocity, mph	71.3	5.8	73.6	4.0	.001
Intensity	1.0	0.08	1.04	0.05	.001
Workload	74.4	39.9	77.1	41.7	.716

TABLE 3
Results From Multivariable Analyses for Injury

Model	Measures	Regression Coefficient	SD	*P*
1a	Velocity	0.10	0.04	.009
	Age	0.30	0.16	.070
1b	Velocity	0.09	0.03	.010
	Starting Status	0.10	0.18	.573
2a	Intensity	0.81	0.25	.002
	Age	0.42	0.19	.033
2b	Intensity	0.066	0.24	.008
	Starting Status	-0.08	0.19	.688
3	Velocity	0.05	0.04	.202
	Intensity	0.67	0.27	.034

DISCUSSION

A voluminous number of throwing-related injuries occur in adolescent baseball players. In fact, data have suggested that 5% to 15% of all baseball pitchers sustain an injury.[13] Of those injuries, approximately 9.7% of shoulder injuries and 5.4% of elbow injuries required surgery.[38] Given that nearly 500,000 players participate in high school baseball in the United States, with pitchers comprising typically 20% to 25% of each high school team, the importance of injury prevention in this patient population is paramount on a macroscopic level.[30] When considering workload, previous data have indicated that increased workloads are associated with injury in numerous lower extremity sports such as rugby and soccer (futbol).[15,17,46] However, limited data are available on the concept of workload and its application to baseball players and pitchers.[27,28] A further understanding of workload is also important given potential confusion of how to define workload in a baseball pitcher. Volume of pitches thrown (pitch count) has been thought to be analogous to workload, which is not accurate.[3] Although volume of pitches thrown is an important factor in the workload of a baseball pitcher, it is but 1 component of workload.[5,9] The workload of a baseball pitcher includes but is not limited to the combination of intensity, volume, and numerous other external and internal factors such as age, previous injuries to the throwing elbow and/or shoulder, sport specialization, skill level, throwing mechanics, fatigue, and readiness to participate in sport.[4,6,8,20,48] Additional factors include but are not limited to arm fatigue, height, strength, pitching mechanics, kinematic and kinetic factors including range of motion of the shoulder in multiple planes of motion, playing pitcher and catcher in the same game, playing for multiple teams in the same time period, and environmental conditions (such as extreme warmth or cold).[50]

With respect to pitch counts, our data indicated no significant association with injury and total pitches thrown (P = .75) in a game. However, we suspect it is more likely that the cumulative effect of pitch counts over a season could be a greater cause of overuse injuries. To our knowledge, the only previous study pertaining to the association of workload and throwing injuries in high school baseball pitchers during multiple seasons was a 3-year study using a wearable sleeve and sensor device during all throwing activities.[28] Similar to our study, the previous study captured 11 throwing-related injuries over a 3-year period. The previous study assessed a ratio of acute to chronic workload (ie, a ratio of activity level over a 1-week period vs a 4-week period) as a predictor of overuse throwing injury (ratios >1.2-1.5 have shown increased risk of injury).[26] Our study assessed a formula for workload that included velocity and gameday pitch counts. In an ideal scenario, using knowledge of an individual pitcher's ratio of acute to chronic workload (including total pitch counts) combined with intensity and velocity might be useful to improve prevention of overuse pitching injuries in high school baseball pitchers.

With respect to velocity, our findings concur with previously published studies showing that increased velocity is one of the risk factors for throwing-related injuries.[1,18] Additionally, older age is a risk factor for throwing-related injury. This is in part because of the physiological process of skeletal maturation, which in turn allows for greater force and power when pitching. Data have revealed an increase of 1.5 mph every year between the ages of 12 and 17 years.[39] Furthermore, recent systematic data analysis of elbow UCL injuries in baseball players demonstrated a correlation between increased velocity, increased pitch counts, and throwing with poor mechanics.[18]

Intensity, which we defined as a measure of maximum effort when pitching, was a risk factor for pitching-related injury as well. Furthermore, increasing effort translates to an increase in mean velocity thrown from preseason to regular season, based on our definition. Thus, it is interesting to observe this finding given the robust data published with respect to weighted ball velocity programs. Weighted ball velocity programs use balls that weigh more than the standard regulation baseball (5-5.25 oz) to increase pitchers' maximum throwing velocity. Although these programs have demonstrated success at improving maximum velocity, they have also been shown to pose a risk for pitching-related injury in similar patient populations.[25,29,36] This phenomenon, increased risk of injury with increased velocity, was observed in our population as well.

In a recent systematic review, interval throwing programs were shown to build up elbow varus torque levels produced in full-effort pitching.[7] Elbow torque is a metric that objectively assesses kinematics in baseball pitchers with respect to effort. However, one main difference is that we assessed maximum effort, whereas in the Dias et al[7] systematic review, maximum effort was not available in 77.8% (123/158) of the high school pitchers in the studies included in the review. Players who were injured had an increased workload of 16.7%.[7] The association between increased workload and injury was not statistically significant in our study (P = .716). This is in part attributable to the low number of injuries (11) that we recorded. In a similar study, Mehta et al[28] analyzed 49 high school baseball players over a 3-year consecutive period that captured every single athlete exposure by use of a wearable elbow sleeve device. Their study assessed all injuries, comparing chronic loads of injured versus uninjured pitchers, whereas our current study compared workload sustained during games while incorporating intensity. A likely next step would be to combine these 2 concepts (measurement of chronic workload and intensity) on a larger scale given the results of our 2 studies (ours and Mehta et al.[28]) and the volume of pitchers needed to capture enough injuries a result of pitching.

Limitations

This is the most extensive study to date assessing factors associated with workload in baseball pitchers at the high school level, but it has a few limitations. All injuries were reported to the research team by each high school's athletic trainer. We are aware that some athletes may not notify the athletic trainer of an injury or may seek care outside of our health system. We collected data only at sanctioned high school games; thus, it is possible that pitchers may have participated in other showcase- or tournament-type events, which may have affected their workload. Further, days of rest is a metric that was not collected, in part because of the variability of rest days at the high school level in comparison to greater consistency at the collegiate and professional levels. Additionally, games that were outside of our data collection range were not included, resulting in a loss of data for those instances. Specifically, we collected data for all home games as well as away games within 30 minutes of the home school. This study began January 2019 and was intended to end May 2021. However, as a result of the COVID-19 pandemic, the high school baseball season ended after 1 month in 2020, and there was reduced ability to practice and train as a team in 2021. As a result, this study ended in May 2023. However, we believe that the increased longevity of the study provided increased opportunity to collect more data, potentially providing more information after navigating the challenges of the pandemic in 2020 and 2021. Unfortunately, the study is underpowered based on the original power analysis. This occurred because the onset of the COVID-19 pandemic reduced available pitchers as well as in-person data collection by research staff. Finally, the model that sets the percentage of ball velocity equal to the percentage of workload as well as total workload using intensity, although novel, has not yet been validated.

Clinical Relevance and Implications

Our research addressed the lack of total workload monitoring systems in overhead throwing athletes, specifically high school baseball pitchers. Accurate workload determination is necessary to provide improved monitoring of these athletes. Without an accurate and implementable workload monitoring system, the likelihood of throwing-related injuries may increase or, at a minimum, may fail to improve from the current injury rates. Our approach improved upon defining the actual workload of a high school baseball pitcher that is sustained during a game and each season. Reaffirming previous data, our model indicated that pitch count is not the only important factor for workload and injury risk and that other factors need to be considered (eg, intensity, age, and pitch velocity). Knowledge of these factors may change the approach to workload and provide a more accurate assessment of total game workload in this patient population.

CONCLUSION

Our objective was to develop and assess a novel method of determining workload in baseball pitchers and to improve the processes for preventing throwing-related injuries. Our workload model indicated that throwing at a higher velocity, increased throwing intensity, and older age are risk factors for pitching-related injury. However, although our model noted that injured pitchers sustained an increased workload of 3.6%, these data were not significant and were underpowered. Thus, our workload model was able to detect specific risk factors for pitching-related injury but did not identify these injuries as a whole. Thus, this novel workload model should be considered to identify pitchers with appropriate risk factors who may be at greater risk for injury.

ACKNOWLEDGMENT

The authors gratefully acknowledge and thank the >20 research interns who attended high school baseball practices and games over the past 5 years and, in some instances, during challenging circumstances due to the pandemic.

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