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# A Review of Workload-Monitoring Considerations for Baseball Pitchers

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Because of the unique demands of a pitch, baseball players have the greatest percentage of injuries resulting in surgery among high school athletes, with a majority of these injuries affecting the shoulder and elbow due to overuse from throwing. These injuries are believed to occur because of repeated microtrauma to soft tissues caused by the repetitive mechanical strain of throwing. Researchers and practitioners have suggested that baseball pitchers' workloads are a significant risk factor for injury in adolescent players, resulting in lost time and slowing of performance development. The purpose of our review was to investigate the current research relative to monitoring workload in baseball throwers and discuss techniques for managing and regulating cumulative stress on the arm, with a focus on preventing injury and optimizing performance in adolescent baseball pitchers.

***Key Words:*** injury prevention, elbow, shoulder

**Key Points**

- Baseball requires a specific balance between recovery, to prevent injury and overtraining, and workload to result in improved performance and protection against injury.
- Current techniques for monitoring baseball pitchers' workloads have relied exclusively on in-game pitch counts. The volume and intensity of throws during warm-up, plyocare, long toss, bullpen, flat grounds, and even pitches between innings are neglected in current workload standards.
- Using multiple techniques to monitor workload can potentially provide clinicians, athletic trainers, and coaches with a better understanding of all the factors influencing injury risk in players.

## BASEBALL INJURIES

More than half of adolescents participating in baseball experienced shoulder or elbow pain during a competitive season,[1,2] which increased their future risk of overuse injury by 7.5 times.[3] Even in the absence of pain, regularly pitching with fatigue has been associated with 36 times greater odds of injury requiring surgery.[4] Modifiable, noncontact mechanisms comprise the majority of injuries across all positions, particularly pitchers, in whom 60.3% of injuries are due to overuse.[5,6]

In high school baseball, shoulder and elbow injuries accounted for 63% of all injuries, and pitchers were at 3.6 times greater risk of upper extremity injury than position players.[5,6] Shoulder injuries were responsible for 32.1% of all these injuries,[6] two-thirds of which were associated with noncontact mechanisms.[5,7] The financial cost of a shoulder injury was estimated to be $13 245, more than the cost of injury to any other joint.[8] Previous trauma to the shoulder is the most significant risk factor for future rotator cuff injury, increasing the risk by 2.5 times[9] and costing an estimated $50 302 per successful rotator cuff repair.[10] Given the high financial and quality-of-life burdens, along with a greater risk of reinjury, researchers must investigate the primary prevention of injuries to the shoulder among high-risk populations, such as youth baseball pitchers.

Injuries to the elbow typically result in more favorable outcomes after injury,[11,12] but the rate of injuries has increased to what some have deemed "epidemic" levels.[13] Authors[14] of a New York state study showed a 3-fold increase in the rate of reconstructions to the ulnar collateral ligament (UCL) over the past decade, primarily driven by an increased incidence rate for 15 to 18 year olds. Although the extent to which this increase is due to participation in baseball remains unknown, overhead throwing is the most common mechanism for tears to the UCL. Similar trends have been reported by the American Sports Medicine Institute: approximately 25% of UCL reconstructions were performed in youth and high school-aged baseball players after 2003, compared with 0% to 10% before 1998.[15,16] Younger athletes in particular are also susceptible to growth plate–related injuries, such as medial epicondylar apophysitis, avulsion fracture, and bone spur formation on the olecranon, with a rare occurrence of olecranon stress fracture.[17–22]

These injuries are believed to result from repeated microtrauma to the soft tissues caused by the repetitive strain induced by extreme ranges of throwing.[23] Minimizing this accumulated damage is crucial to preventing injury,

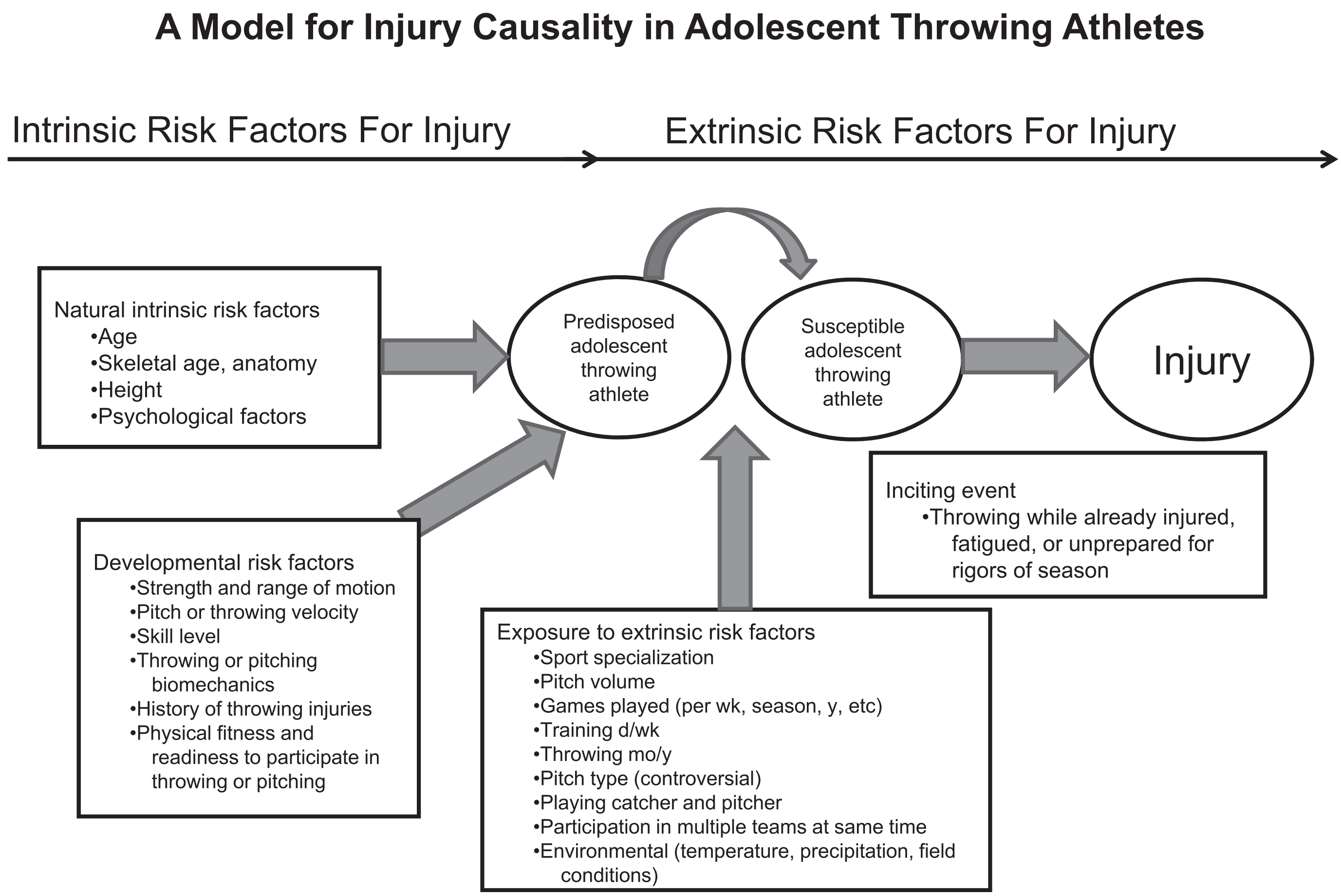


**Figure 1. A model of injury causality in adolescent baseball pitchers developed by Zaremski et al, 2019.[53] Reprinted with permission.**

which can theoretically be accomplished by minimizing the volume of throws in a fatigued state, improving joint kinetics, or increasing the body's ability to handle those loads. The rising injury rates seen in both youth and professional baseball are widely believed to result from an interaction of intrinsic, extrinsic, and developmental factors (Figure 1). This review focuses on the effect of workload on extrinsic and developmental factors and its interaction with injury risk.

## Baseball Throwing Workload

The baseball pitching motion has been described as one of the most violent motions in sport, with the shoulder reaching nearly 180° of external rotation and accelerating to internal-rotation velocities greater than 9000°/s.[24–26] The elbow undergoes up to 64 Nm of torque during the late cocking phase of the pitch, and the glenohumeral joint experiences up to 1070 N of distractive force at ball release.[27] With each throw, this stress is placed on the throwing arm and accumulates over the course of a week, season, year, and career. This results in inflammation, microtrauma,[28,29] and musculoskeletal adaptations[30,31] to the throwing arm. Because of the acute loads and chronic adaptations seen in baseball throwing, studying and managing the workload is important so that we can understand how it affects the potential for injury and the steps to take to minimize risks and promote healthy participation and performance improvement.

Establishing a clear definition of *load* is vital before relationships can be established among load, injury, and performance. Load can be divided into 2 groups, internal and external, and each can lead to a different risk profile.[32] *Internal workload* is classified as a measure of *effort* (eg, rate of perceived exertion, heart rate, lactate concentrations, heart rate variability), and *external workload* refers to the load placed on the body from external sources such as the number of pitches or distance covered. In baseball, the external workload has received the most attention.[33,34] *Full body workload* refers to the cumulative external load placed on the body and has been a focus of injury prevention across athletes in multiple sports.[35] Authors[2,36] of the earliest landmark studies to define the relationship between workload and injury showed that more than half of adolescent baseball pitchers reported shoulder or elbow pain over the course of a season. Investigating the risk factors associated with pain, researchers[2] identified throwing $>$ 75 pitches in a game or $>$ 600 pitches in a season and playing for multiple teams as significant risk factors for subsequent injury. In follow-up research, 13- to 14-year-old pitchers who threw $>$ 75 pitches in a game were 1.59 and 2.17 times more likely to have experienced pain or injury in the shoulder or elbow, respectively, during the season.[1] Lastly, athletes throwing $>$ 400 pitches in a year had 2.81 and 2.34 times greater odds of experiencing pain or injury in the shoulder or elbow, respectively, demonstrating the relationship between cumulative workload and injury in young pitchers. Olsen et al[4] reported similar results after comparing adolescent pitchers who underwent shoulder or elbow surgery with healthy control individuals. Before injury, athletes who were later injured threw, on average, 2.2 months more per year, played 1.3 more innings per start, and pitched an additional 21.6 times per game. As a result, the injured pitchers threw an average of 1293.8 additional pitches each year, more than double the pitches of the uninjured group. Among adolescent baseball pitchers, those who experienced arm tiredness were 4.36 times more likely to have played in back-to-back games and 3.37 times more likely to have pitched for multiple teams in a season.[3] Particularly startling was that pitchers who sustained a pitching-related injury were 7.88 times more likely to have had arm tiredness before the injury. Based on research, "Pitch Smart" was a collaborative effort between USA Baseball and Major League Baseball. The guidelines were designed to minimize risk factors by limiting playing for multiple teams, ensuring adequate rest time, and providing age-specific pitch-count limits and rest time to minimize the injury risk due to an excessive workload.[37] Additionally, beginning in 2017, the National Federation of State High School Associations mandated that all states must establish pitch-count limits in high school baseball.[38] Some have argued that the established guidelines are too lax. Olsen et al[4] reported that pitchers who threw $>$ 80 pitches per game were at 4 times greater risk of injury requiring surgery than those who pitched $<$80 pitches per game. To put this in perspective, "Pitch Smart" currently recommends that 13- to 16-year-old pitchers throw $\leq$ 95 pitches per game and 19- to 22-year-old pitchers throw $\leq$ 120 pitches per game.[37] Despite the perceived importance of pitch counts in youth baseball, data on the effectiveness of the "Pitch Smart" implementation program have not yet been published. Adherence by coaches, parents, and clinicians to these guidelines is crucial, yet several groups[39–41] found that stakeholders demonstrated poor understanding of and compliance with the guidelines. In a survey of 82 youth baseball coaches, 56% reported they did keep track of pitch counts for their athletes, but 92% reported not keeping track of pitches based on the "Pitch Smart" guidelines.[42]

Although external workloads (eg, throw or pitch counts, appearances, innings per appearance, ball velocity) can be monitored, the ability of the body to handle those stresses is also a key factor associated with injury.[34,43] In addition to higher external workloads, more injuries to baseball players have been attributed to an increase in ball velocity and the resulting load placed on the body, without the subsequent improvement in the body's ability to handle the resulting stress. Computer simulations have demonstrated that, with maximal muscle activation by the muscle-tendon actuators surrounding the elbow, the load placed on the UCL could be effectively eliminated.[44] This theoretical concept was studied by authors[45] who placed recruits in a valgus-loaded elbow position and measured the joint space in the medial aspect of the elbow. When the participants were asked to perform a maximal grip strength isometric contraction, the joint space in the medial elbow decreased by 1.03 mm, 21% less than in the loaded condition and similar to when the elbow was unloaded.

One aspect of workload management that has shown potential for identifying athletes at higher risk of injury is monitoring acute and chronic workloads, as well as the ratio between them. The focus of this workload monitoring is the relationship of injury, training volume, intensity, and frequency.[46,47] Originally applied in rugby players, the acute : chronic workload ratio (ACWR) takes into account a player's acute workload, typically during the prior 7 to 9 days, and compares it with the individual's chronic fitness level, typically an average of the prior 28 days. Spikes in the acute workload can increase the risk of soft tissue damage. Gabbett et al[35] showed that a 7-day average acute workload that exceeded 1.5 times the 4-week average doubled the risk of injury in multiple sports. Specifically, if the workload had increased $>$50% versus the prior month, the risk of injury doubled. Despite the promise of this approach, others[48] have pointed out the potential flaw in using a ratio to estimate injury risk: the effect of the acute load is rescaled and magnified, which ultimately leads to no association with injury being demonstrated. Restricting an athlete's workload may decrease the acute injury risk, yet reducing workloads during training and competition can also hinder an athlete's fitness and performance,[35] decreasing the capacity to handle higher acute workloads. Additionally, the response to a specific workload varies among players, and understanding how an individual athlete responds to the demands of training and competition is critical. Monitoring a player's acute and chronic workloads with all throws, not just in-game pitches, may provide better insight into the workload and injury risk.

## TECHNIQUES FOR MONITORING BASEBALL THROWING WORKLOAD

Methods for monitoring workload can vary widely depending on the sport, experience, time, and technical ability of coaches and staff. Although more advanced techniques tend to be more popular, basic methods involving low or no-cost resources can be effective for both monitoring workload and improving body awareness in athletes, particularly those at more novice levels. Simple techniques such as the rating of perceived exertion, self-reported mood and soreness levels, and wellness surveys have been used to monitor athletes' internal perceptions of workload and fatigue (Figure 2). Even though these methods are highly subjective and depend on the athlete for accurate reporting of training or competition volumes, they provide important information about the athlete's perception of fatigue and can increase the athlete's awareness of what the body is experiencing. In team sports, the session rating of perceived exertion (sRPE), calculated as RPE $\times$ external workload (eg, distance traveled, number of throws), is often used to incorporate measures of both internal and external workload. Among elite soccer players, those with ACWRs (calculated from sRPE questionnaires) that were greater than 1.38 had a relative risk of injury 2.2 times higher than players with ACWRs $<$ 1.0.[35]

In baseball, the external workload has traditionally been monitored as pitch count, pitch velocity, innings per appearance, total innings pitched in a season, and games pitched in a season (Figure 2). As mentioned earlier, in 2017, the National Federation of State High School Associations required states to use pitch-count limits to reduce workloads in high school pitchers. These factors are also used by USA Baseball, Baseball Canada, and Little

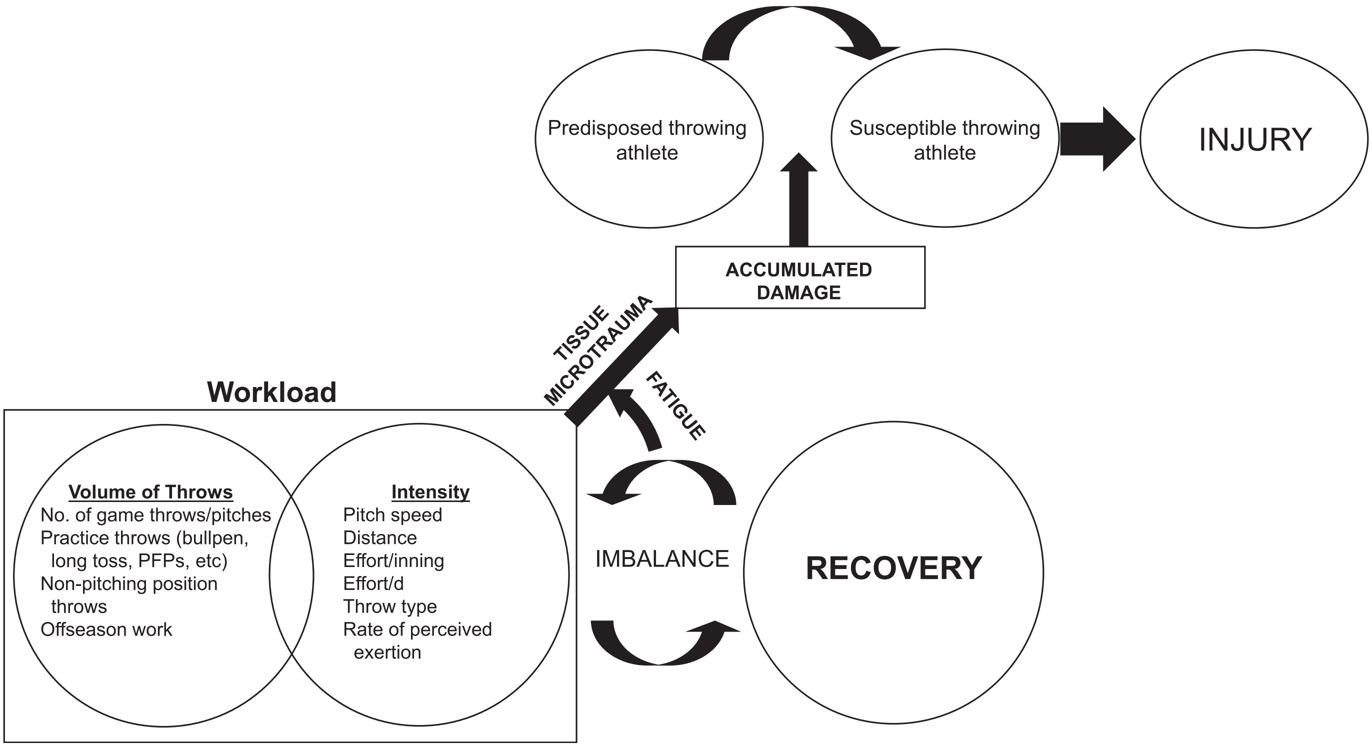


**Figure 2. As workload demand increases, recovery also needs to increase to allow for proper workload management. Imbalances in work and recovery may increase muscle fatigue, reducing dynamic constraints and increasing the amount of tissue microtrauma with each throw. These microtraumas then lead to accumulated damage and fit into the model as extrinsic factors, making a predisposed athlete susceptible and eventually crossing a threshold of pain and function into injury. Abbreviation: PFP, pitcher's fielding practice.**

League Baseball (though each organization uses them slightly differently) to make recommendations for adolescent athletes. However, with the technology advances in pitch tracking, systems such as PITCHf/x (Sportvision, Chicago, IL), TrackMan (Vedbæk, Denmark), and Rapsodo (St Louis, MO) can monitor pitches from the mound and provide additional measures of workload intensity or changes associated with fatigue during games and practice. Whereas baseball has focused extensively on pitches during a game, minimal research exists on throws performed outside of game situations. The volume and intensity of sport-specific tasks (eg, throwing during warmup, plyocare, long toss, bullpen, flat grounds, and pitches between innings) are neglected in current workload standards. Each one of these tasks produces different volumes, efforts, and stress patterns among athletes and even among positions.[49–51] In fact, both adolescent and professional injured pitchers threw more warmup pitches than pitchers who remained healthy.[4,52] Pitchers can be considered within the safe limits for pitch counts during a game, but the unmeasured workload accumulation during the pregame workout, including warmup tosses, plyocare, long toss, and bullpen throws, can increase the workload and sometimes push it into the unsafe zone before they even step onto the mound. Zaremski et al[53] tracked high school pitchers on game day and reported that 42.4% of pitches performed on game day were not included in the pitch count. Pitches in the bullpen, between innings, and on the mound were counted, but other types of throws (eg, warmup, plyocare, long toss), the intensity of throws, and even the accumulated throws during the previous weeks leading up to competition were not. Among youth players observed over a full season, all throws performed during a week were significantly greater than those performed during a game.[53] During an entire collegiate season, Lazu et al[54] tracked pitchers during both game and practice days; on average, only 12% of throws occurred during a game. Furthermore, Dowling et al[55] noted that the elbow varus torque during pregame bullpen pitches was 94% of that for in-game pitches among 14 professional baseball pitchers. Pitch counts may not be the most accurate indicator of workload, but they do provide a level of accountability and simple tracking for the athlete. However, workloads in baseball players are clearly misunderstood, and future researchers should account for all throws, not just in-game throws, as well as the intensity of each.

Team sports have used video to monitor workloads during games and sometimes practices. Yet processing video for each athlete is labor intensive, prone to error, and inaccessible in real time. To replace video monitoring with more automated real-time, valid measurements, global positioning systems (GPSs) have started to gain traction for measuring the position, velocity, and acceleration of athletes and describing external full-body workloads during both competition and training conditions.[56,57] Using GPS to track athletes during all types of training and competition allows coaches and clinicians to monitor workload-specific demands for each athlete. Coaches and clinicians can not only quantify the work that is being performed but also categorize the workload based on effort level and time. In baseball, this information is particularly valuable for understanding position player workload, which is often overlooked.

Inertial measurement units (IMUs) have recently been used to monitor joint-specific workloads during the throwing motion. In particular, motusBASEBALL (Motus Global, Rockville Centre, NY) created an IMU housed in a compression sleeve that is worn on the throwing elbow during all throwing activity. The IMU measures arm speed, arm slot, and shoulder external rotation; supplies an estimate of elbow varus torque; and has been shown to be a valid and reliable tool for measurement.[58–60] Using the elbow varus torque calculated from every throw, daily workloads are measured and provide a more thorough quantification of daily effort than pitch count. Although the research is limited in baseball, high school players wearing the motusBASEBALL sensor during the 2017 season were 15.2 times more likely to sustain an injury if their ratio spiked over 1.27.[61] In addition to measuring total throws in pitchers, which we know are greatly underestimated by game pitch counts, this type of tool can be especially relevant for athletes playing multiple positions.

## FUTURE RESEARCH DIRECTIONS

In accordance with our long-term goal of maximizing performance while mitigating subsequent increases in injury risk, future investigators should focus on exploring combined internal and external workload monitoring, mechanical contributions, and physical factors that may be associated with injury risk and performance. In addition to workload, the mechanics of throwing and physical limitations in joint mobility, eccentric capacity, strength, and core stability are also important for mitigating injury risk, so the interactions among workload, mechanics, and physical limitations may provide additional insight into improving performance. Moreover, workload monitoring should consider all throws, not just in-game pitch counts, because the cumulative stress on the arm is a function of quantity, intensity, and effort. Devices that gather data on workload offer clinicians, coaches, players, and researchers considerably increased access to actionable measures to support these research directions.

## CONCLUSIONS

Baseball requires a specific balance between recovery, to prevent injury and overtraining, and workload to improve performance and protect against injury. The clinical goal should remain focused on optimizing and sustaining performance, including injury risk-reduction approaches such as workload monitoring, but conceptually, the ultimate goal is to assist the ballplayer in optimally throwing the baseball. Carefully monitoring the workload should enable pitchers to achieve the highest sustainable quantity of practice and experience to maximize their performance.

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