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Sport Specialization and Overuse Injuries in Adolescent Throwing Athletes: A Narrative Review

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A significant number of adolescent athletes throughout the world participate in various throwing-dominant sports, including but not limited to baseball, cricket, handball, softball, track and field throwing events, and water polo. Due to the unique stresses placed on the throwing arm and entire body in these sports, a robust volume of literature has highlighted concerns about sport specialization in these athletes and an associated increased risk of injury, particularly to the dominant shoulder and elbow, with sport specialization. This review will highlight the evidence-based literature for this athletic niche, focusing on risk factors for injury, national and international organizations' recommendations for limiting overuse injuries, principles of conditioning and rehabilitative programs, and potential future areas of research to curb the growing incidence of throwing-related injuries among adolescent throwing athletes.

Key Words: pediatric athletes, pediatric injuries, pitching, upper extremity

Substantial numbers of adolescents (aged 10–19 years[1]) participate in throwing-dominant sports in the United States and around the world. In our review, we will address baseball, cricket, handball, softball, track and field (throwing events), and water polo. As of 2009, millions of adolescents pursued baseball recreationally, including more than 400 000 high school players in the United States.[2] In total, more than 900 000 athletes in US high schools played throwing-dominant sports such as baseball, softball, and water polo.[3] These data do not include throwing positions in other sports, such as quarterbacks in American football or throwers in track and field. In addition, according to the Sport & Fitness Industry Association,[4] participation in sports such as baseball and softball continues to increase in the adolescent age group, with a 12.9% increase in baseball from 2017 to 2018 and more than 4 million slow-pitch softball participants in the United States aged 13 years or older.[5] Cricket, a popular international sport, had more than 1.3 million participants in Australia as of 2016, with a 1-year increase in participation of more than 8%.[6] Handball, which is also popular worldwide, has extremely high participation rates, with more than 2 million teams and more than 27 million players, according to the International Handball Federation.[7]

EPIDEMIOLOGY

Due to the popularity of throwing sports, a significant number of throwing-related injuries occur.[8] Youth baseball players reported throwing-arm pain 74% of the time.[9] In addition, over a 10-year period, injury rates for the shoulder and elbow among high school baseball players were 1.39 per 10 000 athlete-exposures (AEs) and 0.86 per 10 000 AEs, respectively; pitchers sustained 39.6% of shoulder and 56.9% of elbow injuries.[10] In skeletally immature throwing athletes, the shoulder and elbow account for a large percentage of injuries (Table 1). Nearly a quarter of all female adolescent handballers reported shoulder problems during the course of a single season,[15] and male and female handballers aged 14 to 18 years demonstrated a rate of 1.4 shoulder injuries per 1000 playing hours.[17]

Most concerning is the increasing frequency of ulnar collateral ligament (UCL) surgical reconstructions in baseball players during the past 20 years.[18,19] One report[18] suggested the number of UCL reconstructions between 2003 and 2014 increased 343%, with 56.6% in those aged 15 to 19 years. Furthermore, whereas the overall rate of UCL reconstructions has increased an average of 18.5% annually, the rate among adolescents increased more quickly than that among individuals older than 18.[18] Given the volume of participation by adolescents in throwing sports and the rising injury rates,[20] we will review the associated risk factors for injury and the current injury-prevention recommendations from national and international governing bodies. We will also provide an overview of injury-prevention and intervention practices and suggest areas of future research.

RISK FACTORS

External Risk Factors

Early sport specialization (ESS) is a theoretical external risk factor for throwing-related overuse injuries of the shoulder and elbow. Understanding the association between

Table 1. Shoulder and Elbow Injuries of Skeletally Immature Athletes in Selected Throwing Sports

Sport	Percentage	
	Shoulder	Elbow
Baseball	25–35[11,12]	17–35[11,12,13]
Handball	23[15]	6–8[16]
Softball	61[14]	22[14]
Track and field[a]	NA	NA

Abbreviation: NA, not available.

[a] Among high school–aged boys and girls, 5.9% and 6.7%, respectively, sustained dominant-arm injuries from throwing, but the sites of the injuries were not identified.[8]

ESS and throwing volume is critical to reducing injury risks and rates. For example, high levels of ESS in baseball, independent of fatigue, age, and workload, place adolescent athletes at increased risk of injury and serious overuse injury.[21] Pitchers 9 to 14 years old who pitched more than 8 months per year were at 5 times greater risk of having surgery compared with those pitching fewer than 8 months per year.[22] Furthermore, Little League World Series (LLWS) pitchers who exceeded pitch counts during the LLWS had a greater risk of UCL reconstruction as Major League Baseball (MLB) pitchers compared with those who did not exceed pitch counts during the LLWS.[23]

Much of our continuing concern about and growing recognition of risk factors in this population is directly related to specialization and overuse injuries via throwing workload and volume and throwing while fatigued or in pain. Authors of a recent systematic review[24] examined risk factors for elbow and shoulder injury in adolescent baseball pitchers (Table 2). Pitchers were at 4 to 36 times greater risk of sustaining an injury due to overuse and fatigue when pitching with pain or fatigue.[22] Overuse factors potentially placing these athletes at risk include the number of total months dedicated to throwing, playing as a catcher when not pitching, and pitching in a separate league at the same time.[11,22,25] Although many of these factors continue to be examined, the evidence to date has suggested that pitchers were at 3 to 7 times greater risk of developing shoulder or elbow pain or injury if they regularly threw with arm fatigue,[11,22,26] threw more than 75 pitches per game, played catcher when not pitching,[25] or threw more than 600 pitches per year.[11] Furthermore, adolescent pitchers who try to play through symptoms of pain or fatigue run the risk of a minor injury progressing into a more serious malady. Adolescent pitchers were at 2 to 5 times greater risk of requiring shoulder or elbow surgery or ending their baseball career if they also played catcher,[25,27] threw more than 80 pitches per game,[22] threw more than 100 innings per year,[27] or threw more than 8 months per year.[22] The most perilous factor for these players, however, was regularly throwing with arm fatigue, which may place them at 36 times more risk of requiring surgery or ending their baseball career.[22] Whereas less evidence has addressed risk factors in sports other than baseball, among adolescent fast-pitch softball pitchers, pitching on 2 to 3 consecutive days led to progressive increases in shoulder weakness, fatigue, and pain.[28] Among adolescent cricket fast bowlers, a *heavy workload* (defined as bowling greater than 2.5 days per week or more than 50 deliveries per day) was a risk factor for overuse injury.[29] In youth handballers, a spike of more than 60% in the weekly volume of *handball load* (defined as training and competition hours combined) relative to the weekly average amount during the prior 4 weeks led to an increase in the shoulder-injury rate.[30] Adolescent baseball players who pitched for a second team (eg, a traveling team or at showcases) were at greater risk of sustaining an arm injury,[31] developing elbow pain,[11] or experiencing general arm fatigue or pain.[26,32] Thus, measures of workload volume in throwing athletes that may be easily quantified include the number of months per year the athlete is participating as well as the number of pitches thrown per game and per year.[33,34]

Table 2. Risk Factors for Elbow and Shoulder Injuries in Adolescent Baseball Pitchers[24]

Factors
Risk factors
Age
Height
Playing for multiple teams
Pitch velocity
Arm fatigue
Pitches per game
Do not appear to be significant risk factors
Innings pitched per game
Showcase participation
Games pitched per year
Training (pitching-specific) days per week
Pitch type
Shoulder external rotation and total range of motion
Inconclusive risk factors
Weight
Number of months pitching per year
Number of innings or pitches per year
Playing catcher when not pitching
Shoulder horizontal adduction
Glenohumeral internal-rotation deficit

In baseball, a long-held belief was that beginning to throw curveballs as a youth led to elbow injuries.[35] Although a rapid growth stage may leave elbow physes and apophyses vulnerable, any association between curveballs and injury is based largely on preliminary associations between pitch type and elbow or shoulder pain.[26,27,36] In fact, biomechanical data suggested that shoulder and elbow injuries in adolescent pitchers may not be caused by curveball mechanics.[37] However, the risk of developing elbow pain does increase in pitchers between ages 8 and 12 years, regardless of pitch type.[11] Researchers who assessed magnetic resonance imaging (MRI) of 10- to 13-year-old baseball players before and after a season may help explain this phenomenon. Compared with the preseason, 48% (12/25) displayed abnormalities on their MRIs, primarily at the medial elbow.[38] The investigators scrutinized dozens of variables, including position, games played, innings pitched, number of pitches, throwing breaking balls, arm pain or tenderness, and shoulder and elbow range of motion, to identify risk factors for those with abnormal MRIs. The only factor associated with an abnormal postseason MRI was playing baseball more than 8 months per year.[38]

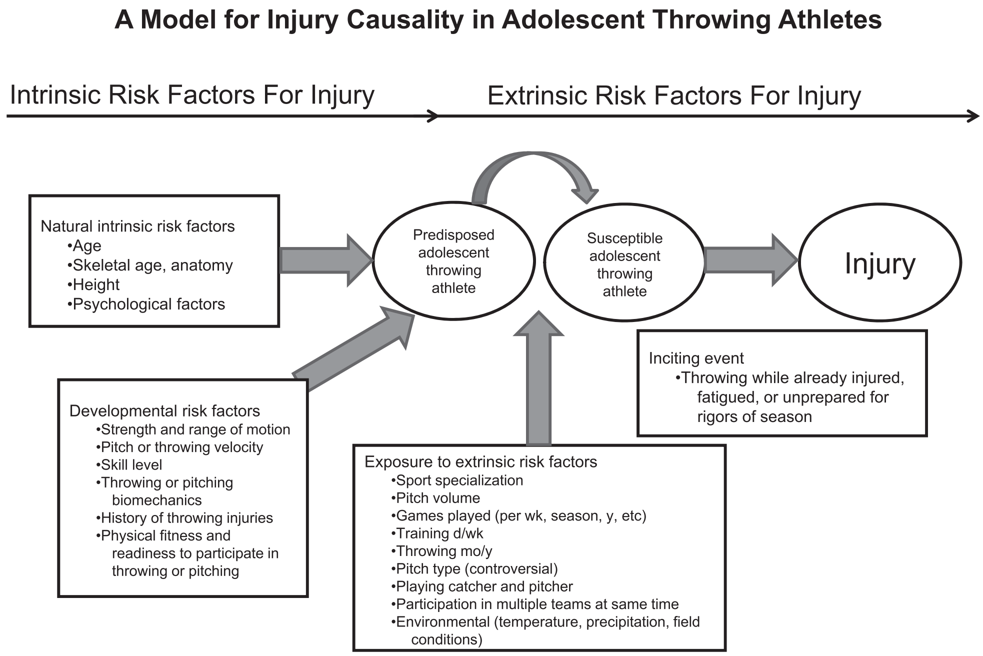

Figure. A model for injury causality in adolescent throwing athletes.

Intrinsic Risk Factors

Intrinsic risk factors such as age, height, and pitch velocity should be taken into account when considering a pitcher's workload (Figure). Adolescent pitchers over the age of 12 years and taller pitchers were at increased risk of injury.[24] Also, baseball pitchers who threw faster than 85 mph (137 kph) had a 2.5 times greater risk of requiring elbow or shoulder surgery.[22] These factors can also interact with one another, meaning that older and taller adolescent pitchers are at greater risk of shoulder and elbow injuries, presumably because they throw more forcefully and are potentially more skilled.[24] Thus, it is reasonable to suggest that greater throwing velocity and skill lead to more success for these throwers; yet that success may lead to additional pitching opportunities, greater usage, specialization, and eventual injury.

Whereas it is important to identify individual risk factors, a comprehensive model for injury causation includes not only intrinsic and extrinsic risk factors but the mechanism of injury as well. Based on the works of multiple authors,[39–41] the Figure illustrates our model of injury causality, focusing solely on adolescent throwing athletes.

CURRENT INSTITUTIONAL RECOMMENDATIONS

High-volume throwing by adolescent athletes without adequate short-term (between-games) and long-term (taking a season off throwing) recovery can result in arm pain, fatigue, and very often injury. Following appropriate workload recommendations, such as rest days by pitch count and maximum pitches per game, will benefit adolescent throwers and reduce injuries. Therefore, in addition to understanding and identifying risk factors for overuse throwing injury, caregivers must be aware of institutional recommendations for reducing the throwing-injury risk. Baseball-specific recommendations have evolved since the early versions in 2004. Many baseball and softball organizations adopted pitch-volume guidelines based on MLB's Pitch Smart policy (MLB Pitch Smart[34]; Table 3) or Little League baseball regulations[42] and may add general recommendations from the American Academy of Pediatrics' policy statement on baseball and softball.[43] Similar guidelines exist in Japan, including restricting baseball pitchers younger than 12 years old to 50 pitches per day and 200 pitches per week.[44] As of the 2016–2017 academic year, the National Federation of State High School Associations[45] began requiring each state to develop a pitching-restriction policy based on the number of pitches thrown in a game rather than innings. Unfortunately, these regulations are for state high school associations and may not apply to travel ball and recreational leagues.

Specialization of adolescent baseball players was discouraged in both the American Academy of Pediatrics[43] and Pitch Smart[34] guidelines. Athletes were encouraged to participate in multiple sports over the course of each year. Both policies recommended no more than 8 months of overhead throwing each year, with at least 2 consecutive months of rest from throwing.[34,43] Despite the lack of conclusive evidence, both policies advised delaying the use of curveballs in baseball until age 13 to 14 years, or when the athlete "has started to shave."[34,43] Understandably, pitching through fatigue or pain is discouraged by both statements.[34,43] Little League softball pitch-volume guidelines restrict players to a maximum of 12 innings per day and require 1 day of rest after an outing of 7 or more innings.[42] Neither the American Softball Association nor the National Collegiate Athletic Association have pitch limitations. To mitigate the effects of other sources of excessive workload, additional recommendations suggest avoiding pitching in multiple games on the same day[34,42] and playing catcher when not pitching.[34,42,43] Players are also advised to avoid pitching on multiple teams.[34,43]

Due to the relatively recent implementation of these pitch guidelines, no large-scale epidemiologic studies have been

Table 3. Major League Baseball's Pitch Smart Policy Guidelines for Adolescent Pitchers[34]

Age, y	Daily Maximum (Pitches in Game, n)	Required Rest (Pitches, n)					
		0 Days	1 Days	2 Days	3 Days	4 Days	5 Days
7–8	50	1–20	21–35	36–50	NA	NA	NA
9–10	75	1–20	21–35	36–50	51–65	66+	NA
11–12	85	1–20	21–35	36–50	51–65	66+	NA
13–14	95	1–20	21–35	36–50	51–65	66+	NA
15–16	95	1–30	31–45	46–60	61–75	76+	NA
17–18	105	1–30	31–45	46–60	61–80	81+	NA
19–22	120	1–30	31–45	46–60	61–80	81–105	106+

Abbreviation: NA, not applicable.

conducted to determine whether overuse injury rates were declining. Regrettably, preliminary data[46–49] indicated that some youth coaches in the United States and Japan did not adhere to pitch-volume recommendations or were unaware of pitch-count restrictions. Some coaches may neglect to rest an adolescent throwing athlete with an overuse injury.[50] However, if followed, well-defined state regulations required by the National Federation of State High School Associations[45] may lead to a downward trend in overuse injuries associated with sport specialization among throwing athletes.

MULTIDISCIPLINARY ATHLETES AND LONG-TERM PHYSICAL ACTIVITY

Although following institutional recommendations is one component used to reduce the risk of overhead throwing injuries, it is equally important that our adolescent athletes participate in multiple sports or free play (such as martial arts, soccer, swimming, and unstructured play) or both. Furthermore, data[51–53] consistently suggested that a highly specialized athlete who exceeded volume recommendations had a greater risk of injury. For example, athletes participating in organized sport for more hours per week than their age (eg, a 14-year-old participating in his or her primary sport for more than 14 hours per week) were more likely to report an injury.[21,51] Further risk factors for injury in sport-specialized athletes were year-round single-sport training, participation in more competitions, less age-appropriate play, and involvement in individual sports that required the early development of technical skills.[54] Thus, affording these athletes opportunities for free play is imperative. More free play promotes improved motor development.[55] Given the substantial data recommending free play and multisport participation at the adolescent level, we recommend participation in nonthrowing sports when an adolescent is not pursuing his or her throwing sport: eg, basketball or soccer as adjuncts to baseball or softball. Finally, an anecdotal concern of parents, coaches, and athletes has been that the lack of ESS may eliminate or diminish opportunities for participation at advanced levels as an athlete progresses. When focusing on throwing athletes, we found it interesting that 1 group[56] sought to report the incidence and age of sport specialization among current professional baseball players and the effects of ESS on the frequency of serious injuries sustained during the players' careers. Baseball players who specialized early reported significantly more serious injuries than those who did not. Thus, based on the available data, we recommend encouraging adolescent throwing athletes to participate in multiple sports (nonthrowing and throwing) to improve motor development and skill sets, reduce the likelihood of overuse injury, maintain their love of sports, and possibly reduce the risk of serious injury later in their careers. In addition to multisport participation, lifelong play and physical activity, even at recreational levels, is a goal we should promote for all adolescent athletes, irrespective of the sport played. Increased physical activity leads to improved fitness, decreased body fat, prevention of obesity, better bone health, reduced burnout, enhanced psychological wellbeing and cognition, and improved school performance.[12,57–60] Moreover, physical activity and exercise habits during youth may translate to similar habits during adulthood.[12,59]

PREVENTION OF INJURY VIA TRAINING AND REHABILITATION

Once risk factor analysis and institutional recommendations are implemented, sports medicine team caregivers must develop a comprehensive understanding of each thrower's competition level, ability, throwing volume, and (if possible) pitching velocity during practices and games. These factors, combined with pregame routine and game appearances, are important for developing training and rehabilitation programs.[61] We suggest that coaches and parents of athletes, as well as the athletes themselves, especially those participating in leagues before high school, take responsibility for tracking workloads, following league pitch-limit guidelines, and ensuring that sport specialization is avoided. One reason we emphasize this point is that, on average, a high school baseball starting pitcher may throw 120 pitches per game.[33] Over a 3-month season, this pitcher may throw more than 1200 pitches in just 10 starts, and this workload does not include playing other positions, participating in multiple leagues, or practice sessions. Thus, it is imperative that players follow recommendations to prevent overuse injuries.

In addition to limiting the volume of throwing, understanding how the body develops the force behind the throw is an important component in limiting stress on the arm. The overhead throw is a complicated, sequential, multisegmental series of movements that requires the proper positioning, production, and transfer of energy from the lower extremity through the trunk and upper extremity to achieve absolute ball velocity[62,63]; this is known as the *kinetic chain*.[64] Any disruptions or inefficiencies in the kinetic chain can result in more physiological stress on the distal segments, specifically the upper extremity, leading to decreased performance and, ultimately, injury.[64,65] Nearly 47% of ball velocity was attributed to lower extremity force production.[66] Therefore, practitioners and coaches alike must understand the importance of training the entire body to prepare for the season's workload and reduce the risk of injury.[61,63]

Throwing Arm

Despite voluminous research assessing risk factors associated with overuse and throwing-related injury, data on preventive screening have been inconclusive. Many risk factors have been assessed and proposed for dominant shoulder or elbow injury in the older adolescent age group (Table 2). At the youth level, a preventive strengthening and stretching program reduced the risk of elbow injury in baseball players.[67] The program included stretching of the elbow, forearm, triceps, shoulder, lower thorax, trunk, and hip. Strengthening, posture, and balance exercises addressed the dominant rotator cuff, trapezius, scapular stabilization, and core. The program resulted in an approximately 50% reduction in medial elbow injuries over a 1-year period. Deficits in total shoulder range of motion have been associated with medial elbow injury[67]; baseball players who completed the program improved their total shoulder range of motion. We suggest that strengthening the flexor forearm on the dominant side also be a part of any preseason and in-season maintenance program. Electromyographic studies have shown high levels of flexor-forearm muscle activity in throwing athletes.[68,69] Given that athletes' muscles fatigue during competition and throwing throughout a game,[70] conditioning and strengthening the flexor-forearm musculature to stabilize the elbow against the valgus torque stressors placed on it and the medial elbow from repeated throwing are recommended.[71,72]

Legs and Hips

Training and rehabilitation programs must take into account the unique characteristics of the overhead thrower. For example, a salient link exists between hip-abduction weakness and scapular dyskinesis in young overhead throwers.[61] Thus, training programs should focus on enhancing mobility in both the lead and trail legs in throwers. The *lead leg* (or *stride leg*; ie, leg contralateral to the throwing shoulder) must have sufficient hamstrings flexibility and hip external-rotation mobility, whereas the trail leg must have adequate iliopsoas and piriformis flexibility and hip internal-rotation mobility to afford proper stride length, stride-foot contact, and stride angle.[63,73,74] Restrictions and deficits in lower extremity mobility and strength increase strain along the pars interarticularis of the lumbar spine, anterior and posterior dominant shoulder capsule, glenoid labrum, and medial throwing elbow.[63,74] Once sufficient hip mobility and stability have been established, exercises should focus on strengthening the single-legged and double-legged sagittal, frontal, and transverse planes of the posterior chain. Examples of frontal-plane and sagittal-plane exercises are deadlifts, squats, lunges, and kettlebell swings. Transverse-plane exercises include rotational medicine ball exercises, sandbag squats and lunges, land-mine rotations, and matrix upper and lower body-reaching rotations.

Trunk and Lumbar Spine

The trunk and spine and their associated musculature are key components in throwers because they are active during the cocking, acceleration, and follow-through phases, transferring force up the kinetic chain while moving the thrower toward the target, providing a stable base of support, and helping to decelerate the arm.[74] Failure to address the trunk and core may place the athlete at risk for decreased performance and increased shear forces through the glenohumeral joint (eg, capsule and labrum) and rotator cuff.[75] Training and rehabilitation programs should focus on addressing transverse-plane strengthening. Suitable exercises include land-mine rotations, diagonal D2 flexion-extension exercises, proprioceptive neuromuscular facilitation single-legged deadlifts, and acceleration-deceleration medicine ball catches.

Shoulder-Muscle Activation During the Pitching Cycle

Practitioners who care for adolescent throwing athletes must be aware of the *thrower's paradox*, the idea that the throwing shoulder needs enough mobility to perform but enough stability to withstand injury.[61] Understanding the throwing motion, muscular activation, and the actions of the muscles in each phase is key to creating appropriate treatment and rehabilitation programs (Table 4). Although a review of specific exercises for all the major joints and muscles is beyond the scope of this article, as noted above, a program focusing on stretching and strengthening the dominant arm as well as the trunk and abdominal musculature can reduce injuries in youth baseball players.[67] Throwing rehabilitation programs such as the Thrower's Ten and the Advanced Thrower's Ten are also available.[80–82] These programs are designed to be used for either rehabilitation or conditioning with a focus on neuromuscular control, strength, muscular balance, and endurance among throwing athletes. These general programs should be adapted as needed for the individual athlete.

Activities that strengthen these structures are essential for developing both endurance and power. When designing strength and conditioning programs for this population, the clinician should take the athlete's chronological age, training experience, and skill level into account. Young athletes may not be skeletally and psychologically mature and may not be able to perform certain power, strength, and plyometric-based exercises with proper technique, form, and focus.

Periodization of Training

The overhead athlete's training should be periodized, with the year divided into the postseason, off-season, preseason, and in-season, to ensure athletic health and performance. A suggested approach to year-round injury prevention and intervention is provided in Table 5. However, sport specialization and year-round participation may not permit use of this model.

Consideration as to whether one is a starter or relief pitcher is important in baseball and softball. Starting pitchers have the luxury of knowing when they will pitch

Table 4. Muscle Activation and Resulting Actions During Phases of Baseball Pitching

Selected Phases	Muscle Activation	Action
Early cocking phase[74,76]	Lower trapezius	Scapular upward rotation
	Levator scapulae, serratus anterior	
	Middle trapezius, rhomboids[77]	Scapular retraction
Late cocking phase[74,76–79]	Subscapularis	Eccentric scapular retraction and glenohumeral external rotation
	Pectoralis major, latissimus dorsi	
	Infraspinatus	Compress and centralize the humeral head in the glenoid, assisting maximal glenohumeral external rotation
	Teres minor	
	Long head of the biceps	
Acceleration[74,76,78]	Serratus anterior	Scapular elevation and protraction
	Latissimus dorsi, pectoralis major	Glenohumeral internal rotation
	Teres major	
Deceleration[77,76,79]	Posterior deltoid	Decelerate anterior humeral head translation
	Infraspinatus	
	Teres minor	
	Subscapularis	
	Serratus anterior[74,76,79]	Arm deceleration
	Rhomboid	
	Latissimus dorsi	

and a set time to recover between outings; relievers may not be afforded the same recovery period, yet they often mirror their starting pitcher counterparts in volume.[91] Both groups are subject to increased fatigue from greater pitch counts. Short relievers and closers often must quickly prepare to pitch and may be tapped on consecutive days.[91] Familiarity with the role of a position player will allow the practitioner and coach to adjust specific training and workload variables that focus on power, strength, and endurance exercises.

FUTURE AREAS OF RESEARCH

Substantial research has been conducted into overuse injuries, injury prevention, and rehabilitation in throwing athletes of all ages. An area that would benefit from future exploration is the concept of workload and the *acute-to-chronic workload ratio* (ACWR). The ACWR is defined as the ratio of the acute workload in 1 week to the average chronic workload over 4 weeks.[92] A spike in ACWR may increase the risk of injury.[93] Workload monitoring has been suggested as vital to injury prevention and readiness

Table 5. Time-of-Year Activity Recommendations for Injury Prevention and Intervention

Time of Year	Primary Activity	Specifics
Postseason and immediate off-season	Rest	Address seasonal injuries and impairments Determine the mechanisms and risk factors responsible for those injuries[67] Develop prevention and treatment program Identify methods for assessing the effectiveness of the treatment program[67,83]
Off-season	Rehabilitation and/or intervention program Screening for injury in adolescent throwers Progression to power and strength exercises, particularly in the older adolescent athlete	Correct muscular imbalances, decrease pain, normalize motion, increase strength, improve neuromuscular control, and restore dynamic joint Screening for increased thoracic kyphosis, decreased elbow extension, posterior shoulder tightness, deficits in total shoulder rotational arc of motion, rotator cuff weakness (specifically the supraspinatus), decreased external-to-internal rotator strength ratios (<64%), scapular dysfunction, restrictions in hip internal rotaton, and alterations in single-legged balance[a]
Preseason	Focus on explosive sport (throwing)- and movement-specific power Throwing program	Progression of activities that focus on improving the speed of movements with increased force velocity output through full sport-specific range of motion Plyometric strengthening program[84,b]
In-season	Total body maintenance	Maintenance throwing program broken into weekly microcycles on the basis of position-specific throwing demands Weight training focusing on preserving power, strength, and force development interspersed with specific throwing loads (eg, long toss, bullpens, and recovery throws) based on the athlete's age In-season training must be carefully constructed to reduce the deleterious effects of throwing fatigue and overtraining

[a] Each of these factors has been associated with increased injury risk and decreased performance in youth overhead throwers.[67,85–88]
[b] Increase throwing velocity with carefully implemented off-season plyometric programs.[89,90]

in throwing sports.[77] Investigators[77] have underscored the importance of monitoring training and competition workloads in various sports, with a focus on volume of activity, intensity, and frequency. Workloads and injuries in rugby, running, and soccer athletes have been examined.[94–96] However, the literature is not nearly as comprehensive for overhead-throwing athletes (adolescent and adult); some of the research involved cricket bowlers and handballers.[30,77,92] Studies of baseball and softball pitchers relied primarily on throwing volume and velocity and hours of training and competition as the workload measures.[17,22,29,36,97–101] To date, factors such as total volume and velocity have not been combined to develop a workload model for overhead-throwing athletes. In fact, in the only systematic review[77] of monitoring workloads in throwing-dominant sports, the authors concluded that despite the relationship between workload and injury, monitoring systems for addressing how intensity factors into workload have been inconsistent. In their systematic review, Asker et al[102] assessed risk factors for shoulder injury and preventive measures in overhead athletes. They found that risk factors for shoulder injury in overhead sports had limited evidence, most were nonmodifiable, and limited evidence was available for injury-prevention measures. Thus, future researchers should address workloads in adolescent throwing athletes. Monitoring throwing athletes' pitch volume and intensity during the off-season and preseason might lead to more accurate load monitoring and prevent overuse during the season. In addition, improved monitoring systems will provide parents, coaches, players, and the sports medicine team with better information on how sport specialization and overuse can increase the workload and injury risk.

CONCLUSIONS

Given the volume of adolescent participation in throwing sports, a significant proportion of injuries are chronic and due, in part, to overuse associated with ESS. Minimizing extrinsic risk factors such as ESS and following institutional volume and rest recommendations are approaches that may mitigate overuse injuries. If an athlete sustains an overuse throwing injury, pursuing evidence-based training and rehabilitation programs can reduce the time lost as well as the likelihood of developing another throwing-related injury. Furthermore, participation in multiple sports and unstructured play is equally important for reducing injury, decreasing burnout, and potentially increasing success in one's primary sport. Involvement in multiple sports can also promote long-term physical activity, which will improve the overall fitness, mental and physical wellbeing, and long-term health of adolescent athletes.

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