Injury Prevention and Rehabilitation of Throwing Athletes

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ABSTRACT

This monograph begins with a review of popular throwing sports and the throwing-related injuries to the upper extremity that are prevalent in each. Subjective and objective findings for common injuries are provided to aid in diagnosis. A biomechanical breakdown of the basic overhead throwing motion of baseball pitching and a comparison of that motion within different age groups are presented to the reader. A phased-rehabilitation approach is described for the overhead-throwing athlete using evidence-based interventions to reduce injury risk during rehabilitation and return to sport. Return to throwing guidelines and recommendations for arm care are discussed. The monograph concludes with four patient case scenarios to illustrate the application of clinical reasoning skills and integrate the concepts of evaluation and rehabilitation of throwing athletes. The four cases involve: (1) an 18-year-old male college javelin thrower, (2) a 15-year-old female softball player, (3) a screening for injuries for a local baseball organization, and (4) a 15-year-old football-baseball player.

Key Words: elbow, overhead athlete, return to sport, shoulder, throwing

LEARNING OBJECTIVES

Upon completion of this monograph, the participant will be able to:

1. Classify the phases of the throwing motion.
2. Recognize common faults seen in the throwing motion.
3. Identify and evaluate common shoulder and elbow pathologies in throwing athletes.
4. Understand pertinent physiological and environmental considerations specific to pediatric throwing athletes.
5. Implement a phased-rehabilitation approach to treating throwing athletes.
6. Develop a return to throwing program for operative and non-operative management plans.
7. Apply current return to sport and injury prevention recommendations to athlete educational interventions.

INTRODUCTION

Humans are not the only creatures who can pick up and throw an object, but evolution has made us the most proficient.[1] The act of throwing dates back millions of years; the bony development of some of the world's oldest fossils serves as evidence.[1–3] Similar bony development can be observed in throwers today.[1,3,4] Humans first threw rocks and spears to hunt animals and defend against predators. From hunting, throwing evolved to warfare and finally to modern sports.[1,5] These sports range from baseball to javelin in North America; in other parts of the world, throwing evokes images of team handball and cricket. The most discussed and significantly researched throwing sports are baseball, softball, and American football.

Baseball, softball, and American football are popular throughout the United States. Most throwing athletes in high school and collegiate settings participate in either baseball or softball, with more than 850,000 combined participants in high school and 57,000 across college divisions.[6–8] While both football and track and field draw a significant number of participants, throwers represent only a small percentage of athletes in these sports; football quarterbacks and javelin throwers are the predominant throwing athletes outside of baseball and softball. Participation rates have remained steady for high school; however, the number of college teams for all throwing sports has increased over the past decade.[7–9] With throwing activities beginning early in life and continuing through adolescence and beyond, physiological adaptations in response to stress may occur. These adaptations may potentially both decrease and increase an athlete's risk for injury.[1,3,4,10]

Based on sports popularity and available research, this monograph centers around the following overhead-throwing sports: baseball, football, and javelin. Fastpitch softball and its unique qualities will be discussed in a separate monograph. While injuries to throwing athletes are not exclusively in the upper extremity, the shoulder and elbow are the most commonly impacted.[11–18] Upper extremity injury rates vary, ranging in baseball from 0.98 – 4.0 injuries per 1000 athletic exposures. The shoulder and elbow are frequent injury sites for adolescent and adult athletes across all throwing sports.[13–26] All athletes are at risk for sustaining an upper extremity injury, but pitchers and other individuals who throw at high volume and effort are the most likely to get hurt.[14,16–19,24–28] Many of these injuries are not the result of isolated incidents; instead, they are cumulative injuries acquired from overuse without sufficient recovery. Not all throwing-related injuries require prolonged recovery; however, research does show that injuries to the elbow ligaments and the shoulder labrum result in the greatest time lost from sport.[13,14,16–19,27,29] Deficits in range of motion (ROM) or strength of the throwing arm are often present before injury.[20,30–35]

Due to the unique requirements of throwing sports and injury concerns among these athletes, physical therapists should be aware of sport, age, and positional differences within this population. This monograph will introduce the clinician to the biomechanical concepts of throwing, describe common upper extremity pathologies, and discuss the effective integration of clinical and sports performance observations into the rehabilitation and return to sport processes for throwing athletes.

THROWING BIOMECHANICS

In 1998, Andrews and Fleisig[36] stated that the most impactful time to prevent throwing-related injuries is at the beginning of a player's career when good sports habits and body mechanics are developed. Educating coaches, parents, and players on proper throwing and pitching mechanics at the youth level provides clinicians with a unique opportunity to mitigate damage to growing tissue from repetitive stress. This has the potential to prevent future throwing-related injuries as sports careers progress.[37–40] The shoulder and elbow joints and surrounding tissue are the most common sites for repetitive stress in overhead athletes, particularly baseball players.[15,17,20,41,42] While 'proper' throwing and pitching mechanics vary greatly based on age and skill set, most agree that efficient throwing and pitching mechanics involve the use of the entire kinetic chain.[36,43–47] Dysfunction at any point can impair movement efficiency, potentially putting excess stress on a player's body. Excessive stress is linked to impaired athletic performance, increased injury risk, and decreased athlete durability. These consequences can negatively impact a player's ability to participate in sports.[44,47–51]

Phases of Throwing (Pitching)

Throwing and pitching motions have been described in the literature more extensively in connection with baseball compared to other throwing sports[43,52–55]; therefore, this section will focus primarily on baseball players. Unique biomechanical factors specific to football and javelin throwers will be discussed in additional subsections, and windmill softball pitching will be covered in a separate monograph.

While similar, throwing and pitching place different stress levels on the body.[44] Throwing is performed on flat ground by position players who may or may not exert maximal effort to transmit the ball to the intended target. Pitching is performed on an elevated, inclined surface with the pitcher using maximal or near maximal effort to try and deceive the hitter as the ball is thrown toward home plate.[44,51] Pitching and throwing activities are typically divided into phases or stages in the literature for easier observation and analysis.[54,56,57]

Baseball pitchers perform 51% of all active throws completed during a game, with the remaining 'active throws' done by catchers (29%), infielders (17%), and outfielders (3%).[44,58] Barrett and Burton[58] described an active throw as one in which the player threw the ball in a direct attempt to get an opposing player out. Most pitchers' throws are from a fixed distance of between 46 feet and 60 feet 6 inches from home plate, depending on age and level of competition.[52] Position players' throws vary in distance and effort levels; however, the increased volume and effort expended during pitching must be considered when examining injury risk and athletic performance by position.[44,59,60]

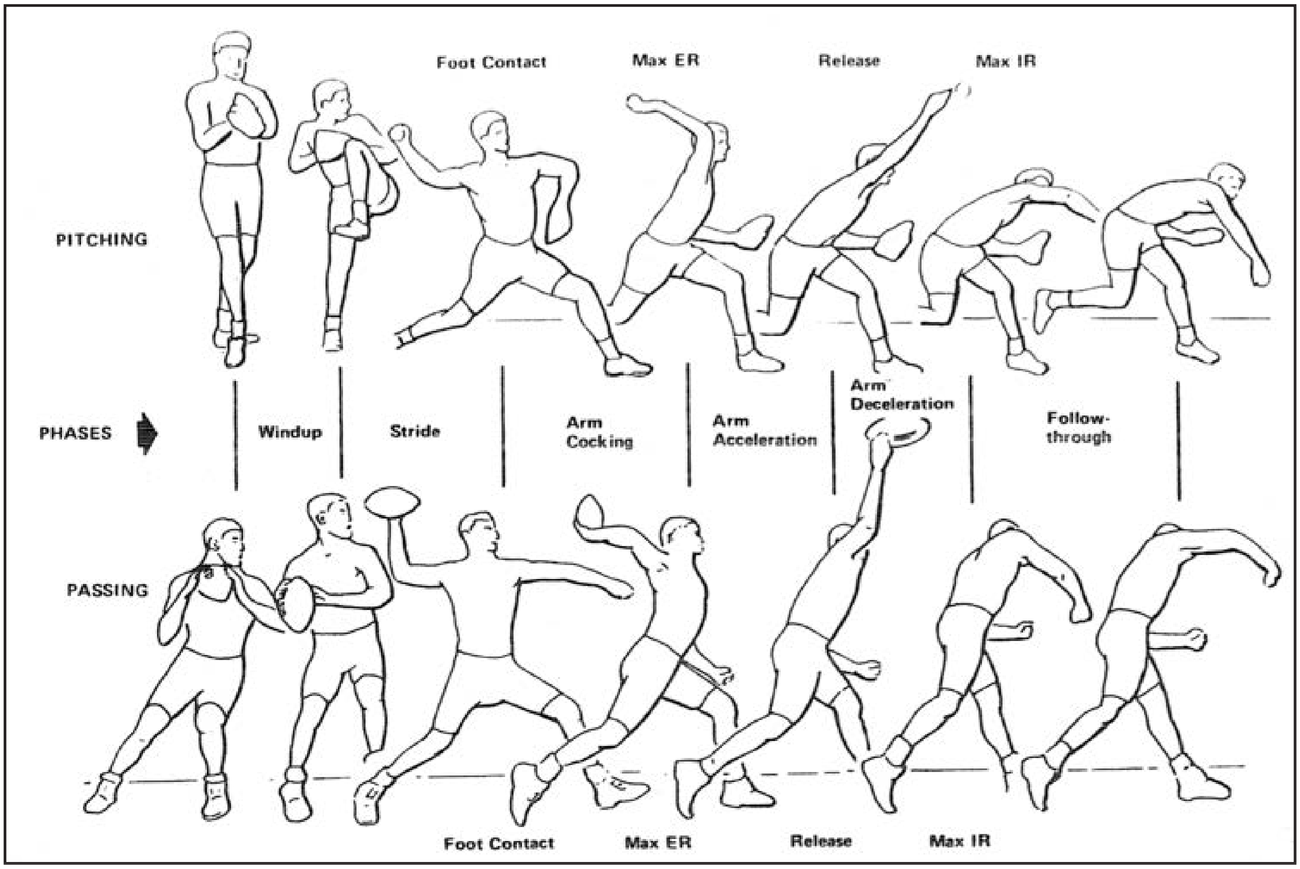
The most common method of analyzing the pitching motion uses a 6-phase approach. This includes wind-up, stride, arm cocking, arm acceleration, arm deceleration, and follow-through.[54,56,57] Key elements are assessed at the end of each phase of a pitcher's motion, which include initial motion and balance point, stride foot contact (SFC), maximal shoulder external rotation (ER), release, and maximal shoulder internal rotation (IR) (**Figure 1**). These key elements and other parameters are frequently examined to understand the biomechanics of throwing better.[55,57,58] While the throwing motion lacks the initial wind-up phase involved in pitching, it can be described using the other 5 phases listed above. As the majority of biomechanical research focuses on pitchers, the following sections will outline the kinetics and kinematics of the pitching motion using the 6-phase approach.

Pitching mechanics

Phase 1: Wind-up

The initiation of the pitching motion differs from player to player based on factors like age, skill level, and preference.[52,57] Pitchers using efficient pitching mechanics arrive at a similar balance point on their stance leg just prior to the start of the stride phase. However, the starting positions and initial motions used during the wind-up phase vary greatly.[52,61] Some pitchers start in the 'wind-up' position, facing the hitter in dual-limb stance and then rotating away from home plate onto their stance leg before striding down the mound. Others choose an abbreviated approach and start in the 'stretch' position, perpendicular to home plate in dual-limb stance before moving onto their stance leg and striding down the mound.[46,52,54,61] Both the 'wind-up' and 'stretch' starting positions are accepted variations in the wind-up phase as no statistical differences have

Figure 1. Phases of Throwing: Baseball Pitcher and Quarterback



[a]Reprinted with permission from Fleisig GS, Escamilla RF, Andrews JR, Matsuo T, Satterwhite Y, Barrentine SW. Kinematic and kinetic comparison between baseball pitching and football passing. *J Appl Biomech*. 1996;12(2):207-224. https://doi.org/10.1123/jab.12.2.207 © 1996, Human Kinetics, Inc.

been found in joint kinetics, kinematics, timing, or pitching performance.[61]

During the wind-up phase, both hands and the ball are brought together in front of the chest as pitchers move through their initial motion to achieve a single-leg balance point.[52] The thoracic spine then rotates at least 90° toward the throwing side, with the amount of rotation varying considerably based on the type of starting position.[62] Pitchers who throw from the 'wind-up' typically demonstrate greater thoracic rotation than pitchers who throw from the 'stretch' position.[52,61]

For the lower extremities, starting position again dictates movement during the initial pitching phase. Pitchers who throw from the 'wind-up' position start in a dual limb stance with both feet facing the hitter. The stance foot, or throwing arm side, is then rotated toward the throwing side to become parallel with the pitching rubber as the stride leg begins to move.[61] The difference in starting from the 'stretch' position is that the feet are already parallel to the pitching rubber when the stride leg begins to move.[61] As a pitcher's bodyweight transfers to the throwing side, the stride hip and knee flex toward the pitcher's chest until a balance point is reached on the stance leg. This point indicates the end of the wind-up phase of pitching.[44,46,52]

In baseball literature, improper throwing mechanics are linked to increased injury risk and decreased pitching performance.[44,57,63,64] While impairments and dysfunction are rare in the wind-up phase, decreased hip ROM, lumbopelvic and lower extremity muscle weakness, and poor balance on the stance leg can impair a pitcher's motion.[62,65] The inability to achieve a stable balance point just before the start of the stride phase will negatively impact efficiency and the entire kinetic chain for the remaining phases of a pitch.[44,62,65]

Phase 2: Stride

The second phase of the pitching motion begins more uniformly than the first. Following reaching a balance point, the pitcher separates the hands, pushes off from the rubber and strides down the mound toward the hitter.[46,52] Their throwing shoulder abducts, and the elbow extends as bodyweight shifts from the stance leg to the stride leg and from a single-limb to a dual-limb stance position.[46,52] The stance hip internally rotates as the pitcher's trunk rotates toward home plate, with the stride hip rotating externally just before landing.[62,65] The stride foot's initial contact with the ground, known as SFC, indicates the end of the stride phase of pitching.[46,52]

Multiple kinetic and kinematic parameters are assessed at SFC. These parameters are typically organized by body region and may differ based on age and level of competition.[52] Upper extremity parameters include shoulder abduction, ER, and horizontal adduction angles bilaterally, as well as elbow flexion angle in the throwing arm.[45,52,57] Trunk and pelvis angles are also assessed at SFC to capture thoracic spine rotation.[52,61] While baseball research does not agree on what 'proper' pitching mechanics entail, existing studies indicate that efficient pitchers demonstrate good separation between their shoulders and hips during the stride phase.[52,61] The lower extremities are crucial in any phase of throwing; however, the stride leg is particularly significant in this second phase. A pitcher's stride foot position, stride foot angle, stride knee angle, and stride length are the lower extremity parameters typically assessed at SFC.[52,57]

A pitcher's stride foot should contact the ground within 10 cm in either direction of the center of home plate with a closed angle (ie, toward the throwing side) of approximately 15° to maximize the transfer of force from the stance leg to the stride leg.[43] At SFC, the stride knee flexion angle should be between 40°-50° before moving toward extension during the next phase.[57,65] The final parameter assessed at SFC is stride length, defined as the distance the pitcher travels down the mound and toward the hitter.[46] Several biomechanical studies have examined this parameter and found that pitchers' stride lengths are size-dependent and should measure at least 85-87% of their total height.[43,52,57,63]

"Critical points" indicate when pitchers are more likely to experience throwing-related dysfunction during the throwing motion.[43] Stride foot contact is the first critical point where errors in movement can not only impair throwing performance, but can significantly increase the kinetic and kinematic stresses sustained by a pitcher's body.[43,62,65] Deficits in the throwing shoulder ROM during the stride phase are typically visible in the height of a pitcher's arm slot. Pitchers who lack sufficient throwing shoulder abduction or ER will demonstrate a drop in elbow position (decreased shoulder abduction), resulting in increased valgus stress across the shoulder and elbow joints.[44,45,57] While arm slots range from 'submarine' or side-arm to completely overhead, studies agree that the throwing shoulder should be in a position of slight horizontal adduction (ie, in front of the body) during the stride phase.[44,52,57,66] Hyperangulation occurs when the throwing shoulder moves into horizontal abduction (ie, behind the body) instead of horizontal adduction. This error in movement results in greater stresses across the anterior throwing shoulder and may negatively affect pitching performance.[52,57]

Effective baseball pitchers rely on deception as well as on efficient biomechanics to beat hitters. When a pitcher's throwing shoulder is in slight horizontal adduction during the stride phase, the baseball is mostly hidden from the hitter's view. This is not true for a pitcher who demonstrates hyperangulation in their throwing shoulder. In this instance, the pitcher's grip will be visible to the hitter. Any motion that gives the hitter an advantage over the pitcher, such as seeing a pitch before it is thrown, may impair a pitcher's effectiveness and ultimately increase their risk for injury.

The most common trunk and lower extremity impairments include lumbopelvic and lower extremity muscle weakness, which can negatively impact stance and stride leg balance throughout the stride phase.[44,62,65] Landing with the stride foot in an open position (ie, toward the non-throwing side) or with the stride knee in an excessively flexed or extended position will also affect a pitcher's ability to transfer forces up the kinetic chain.[46,66] The final impairment frequently identified in the stride phase is decreased stride length with respect to the pitcher's height.[57,63] Like the first phase of throwing, any dysfunction in this second phase will have consequences throughout the kinetic chain, particularly across the shoulder and elbow joints, during the remaining phases of a pitch.[44,57,62,65]

Phase 3: Arm Cocking and late Arm Cocking

The third phase of the pitching motion is the late cocking phase; this stage begins with SFC and ends with maximal ER (MER), or "lay back," in the throwing shoulder.[46,52] Following SFC, the pitcher's trunk and pelvis extend and continue to rotate toward home plate.[62,65] The throwing shoulder is placed into relative horizontal abduction before rapidly moving into horizontal adduction. The shoulder approaches 90° of abduction while moving toward MER and elbow flexion during the latter part of this phase.[45,52,57] Reaching this 'cocked' position creates torques in the shoulder and elbow used to move the throwing arm forward during the remainder of the pitch.[52,57,63] As the pitcher descends the mound, the hips continue to rotate, transferring more body weight from the stance leg to the stride leg.[46,66] The point of MER is the critical point that indicates the end of the arm cocking phase of pitching.[46,52]

Most kinetic and kinematic parameters assessed in pitching biomechanics are recorded during the arm cocking and acceleration phases.[46,52] At the throwing shoulder, maximal horizontal adduction ROM occurs as the arm rapidly moves forward with the trunk.[52,57,63] During the late cocking phase, the forearm and hand lag behind the throwing shoulder resulting in MER ROM of 165° to 180° coming from the 4 joints of the shoulder complex.[46,52] Significant shoulder IR torque is produced to stabilize these joints against large rotational forces in conjunction with an anterior shoulder force that limits excessive posterior translation of the humerus during this phase.[57,62,63] Timely activation of the rotator cuff muscles, particularly the subscapularis, infraspinatus, and teres minor muscles, support the glenohumeral joint (GHJ) throughout these extreme ranges of motion.[46,65,66] Biomechanical analyses demonstrate that elbow flexion and varus torque values at MER are associated with forces needed to stabilize the elbow joint against high elbow valgus stresses sustained during this phase.[57,63]

Trunk and pelvis motions are assessed in the frontal and transverse planes throughout the arm cocking phase.[46,52] Studies suggest that pitchers who exhibit greater trunk tilt away from their throwing side produce higher ball velocities but incur larger forces across their shoulder and elbow joints than a more vertical trunk position.[67,68] In the transverse plane, attaining a more open trunk position (ie, toward the throwing side) at MER has also been associated with higher ball velocities.[44,46,65,66] Maximal upper torso and pelvis velocities are measured to help quantify the separation between the upper and lower body during this phase.[46,52,66] This separation allows a pitcher to store energy, or "load" the body, in preparation for the acceleration phase of throwing. Lower extremity motion follows trunk and pelvis motions and is, therefore, rarely formally assessed during the late cocking phase in biomechanical studies.[46,52,66]

The second critical point during a throwing motion, where dysfunction is most commonly seen, is MER at the end of the arm cocking phase.[52] Deficits in throwing shoulder ER ROM and shoulder muscle strength will significantly impact the height of a pitcher's arm slot.[45,46,65] Pitchers who lack shoulder ER ROM will 'drop the elbow' to try and gain upper extremity motion. The same visible impairment occurs in pitchers who lack the muscle strength or endurance to maintain a consistent throwing arm slot.[62,66] Decreases in shoulder abduction angle are associated with increased valgus stress at the elbow and higher upper extremity injury rates.[49,57] Excessive trunk tilt away from the throwing side will amplify the forces a pitcher sustains through their shoulder and elbow joints during the arm cocking phase.[67,68] The same dysfunction occurs when a pitcher's trunk closes (ie, faces home plate) too early within the throwing motion.[66] Like the previous phases, impaired lower extremity strength or balance will negatively affect a pitcher's ability to transfer force up the kinetic chain and to the throwing arm.[44,57,62,65]

Phase 4: Arm Acceleration

The fourth phase of the pitching motion begins with MER and ends when the ball is released from the pitcher's hand.[46,52] The arm accelerates forward when the throwing shoulder rapidly changes from a position of MER to shoulder IR, thereby creating the velocity used to throw.[62,65,66] Elbow extension begins just before the start of shoulder IR with near full extension reached by ball release.[46] A pitcher's trunk transitions from extension to forward flexion during this phase. The stride knee begins to extend as body weight is fully accepted onto the stride leg in a single-limb stance.[62,65] The point of ball release indicates the end of the arm acceleration phase of pitching.[46,52]

During arm acceleration, kinetic and kinematic parameters associated with increased ball velocity are frequently assessed, including maximal elbow extension velocity, elbow flexion torque, and maximal shoulder IR velocity.[52,57,63] Pitchers who transition quickly from MER to shoulder IR demonstrate higher ball velocities than those who transition more slowly.[46] Elbow flexor muscles eccentrically control elbow extension velocity as the throwing arm moves toward ball release.[52,54,57,63] Research demonstrates that slight elbow flexion, as opposed to full elbow extension, at the time of ball release is associated with decreased distraction forces through the throwing shoulder, which may have implications for injury prevention.[63]

When examining the trunk and pelvis during the acceleration phase, the thoracic rotation's timing and speed help quantify the separation between upper and lower body movements.[62,65,66,69] Professional pitchers tend to rotate their trunks later during a pitch compared to less efficient high school pitchers, resulting in greater shoulder and hip separation.[69] This increased efficiency of movement results in less shoulder IR torque and less elbow valgus torque during pitching.[69] In the sagittal plane, forward trunk tilt assessed at ball release is also associated with higher ball velocities.[67] Lower extremity kinetic and kinematic parameters are a progression of the previous phase of throwing. The stride knee angle is more extended at ball release than at SFC, particularly in higher velocity pitchers.[70]

Ball release at the end of the arm acceleration phase is the final critical point in a throwing motion and when dysfunction is most commonly seen.[52] Deficits in throwing shoulder IR ROM and shoulder muscle strength will significantly impair ball velocity and pitching performance.[46] Pitchers who exhibit excessive elbow extension at ball release also demonstrate greater distraction forces through their throwing shoulder.[54,57,63] Generally, the larger the force and torque placed across a joint, the greater the stress and risk for injury. Much like the previous phase, pitchers whose trunk closes (ie, faces home plate) too early in their throwing motion experience greater stress through their shoulder and elbow joints.[66] Lower extremity dysfunction typically occurs when pitchers move onto their stride leg into a single-limb stance. Excessive stride knee flexion (ie, squatting) or extension (ie, braking the body's forward motion) at ball release negatively impacts the pitcher's ability to let their trunk follow the throwing arm over the stride leg.[46,62,65,66] These inefficiencies detract from a pitcher's ability to generate force, which may lead to alterations in pitching mechanics to maintain ball velocity.

Phase 5: Arm Deceleration

The fifth phase of a pitching motion begins when the ball is released from the pitcher's hand and ends with maximal IR of the throwing shoulder.[46,52] Following ball release, the throwing arm decelerates across the pitcher's body by horizontally adducting and internally rotating at the shoulder and extending at the elbow.[62,65,66] The trunk moves forward over the stride leg as the pitcher continues in a single-limb stance.[46] Once the pitcher