BIOMECHANICS OF BASEBALL PITCHING: IMPLICATIONS FOR INJURY AND PERFORMANCE

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All overhead throws share similar biomechanics. Baseball pitching is one of the most dynamic throws, with both high ball velocity and high rate of injury. An understanding of pitching biomechanics can help maximize performance and minimize the risk of injury (Fortenbaugh et al., 2009; Whiteley 2007). Although pitching is a continuous motion, it can be separated into a series of phases to better understand the kinetic chain. The description and the mean ± standard deviation values presented here are based upon healthy elite adult pitchers.

The objective of the windup phase is to put the pitcher in a good starting position. The windup begins when the pitcher initiates the first motion and ends with maximum knee lift of the stride leg. The pitcher typically begins with the weight evenly distributed on both feet. The stance foot then pivots to a position parallel with the rubber. The lead leg is lifted and the lead side (left side for a right handed thrower) faces the target. A pitcher will typically pitch “from the stretch” instead of from the windup when there are runners on base. When pitching from the stretch, the pitcher starts with his back foot parallel against the rubber and the front foot out a comfortable distance towards home plate. The pitcher then has an abbreviated leg lift. Forces in the upper extremity are low during this phase, thus shoulder and elbow injuries do not occur during this phase (Dun et al., 2008a).

In the stride phase, the pitcher strides his front leg (left leg for a right-handed thrower) towards the target. At the same time, the athlete separates his hands and swings them down, apart, and up. The coordination of these leg and arm motions is critical to enable optimal timing in the later throwing phases. At the time of front foot contact, the stride length should be 83±4% of body height and the lead knee should be flexed 45±9°. Also at this time, the pelvis should be 33±10° open to the target, but the shoulder line should be about 15° closed. Abduction of the throwing shoulder should be 93±11°. The elbow is flexed 90±15°, and the shoulder has 56±22° of external rotation. (External rotation is defined as 0 when the forearm is horizontal and 90° when the forearm is vertical.)

The arm cocking phase begins at the time of front foot contact. During this phase the pelvis and then upper trunk rotate to face the target while the throwing arm cocks back. The non-throwing arm is tucked in near the trunk in order to decrease inertia and increase velocity of the upper trunk rotation. The lag between pelvis rotation and upper trunk rotation is critical for generating energy from the trunk that is passed along to the throwing arm. Without proper timing of pelvis and upper trunk rotation, the athlete may have low ball speed and/or excessive loads in the shoulder and elbow (Stodden et al., 2005; Aguinaldo et al., 2007; Wight et al., 2004).

The arm cocking phase ends with the throwing shoulder in maximum external rotation (MER). MER is 181±8°; in other words, the forearm is approximately perpendicular to the trunk and the palm of the hand is facing up. Achieving such external rotation is strongly related to ball velocity. An athlete must cock his arm back far in order to accelerate his hand forward. Measured MER is not just rotation within the shoulder joint, but actually a combination of glenohumeral rotation, scapula motion, and arching of the back (Miyashita et al., 2010)

While MER is vital for ball speed, it is also a position of potential injury. In this position the rotator cuff muscles on the back of the shoulder (especially the infraspinatus muscle) may become pinched in the shoulder joint. When this muscle is impinged, it may tear during the forceful shoulder rotation. At the same time, the front of the shoulder capsule is under tension and may tear. The torques at the shoulder and elbow both peak near the time of MER, as the joints must stop the arm cocking and initiate the forward rotation of the arm. Peak elbow varus torque is 99±17 Nm. (This is about equivalent to holding a 25 kg mass in the thrower's hand at this instant.) Repetition of this varus torque can lead to tension and tearing in the elbow's ulnar collateral ligament, and as well as bone spurs in the lateral and posteromedial elbow (Dun et al., 2008b).

From this cocked position, the athlete initiates arm acceleration. Elbow extension velocity reaches 2450±250°/s and shoulder internal rotation velocity reaches an incredible 7500±900°/s. This is the fastest joint rotation documented in any sport. The biceps muscle of the upper arm contracts to decelerate the elbow extension. This contraction in the arm cocking and arm acceleration phases may lead to a tear of the shoulder labrum.

The arm acceleration phase ends with ball release. At the time of ball release, the front knee is flexed 35±12°. The front knee is extending through ball release, which allows the athlete to stop the forward motion of his pelvis and transfer energy up his body to the ball. The trunk is tilted 36±7° forward and 23±10° to the side. The throwing shoulder is abducted 94±8° (that is, the throwing elbow is approximately on the imaginary line passing through both shoulders). If the shoulder is abducted significantly more or less than 90°, there can be misalignment in the shoulder leading to damage to the shoulder capsule and surrounding tissue. Different pitchers in various throwing situations may alter the sideways tilt of their trunk; however, the shoulder abduction at ball release should always be approximately 90° (Matsuo et al., 2002; 2006).

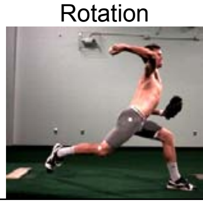
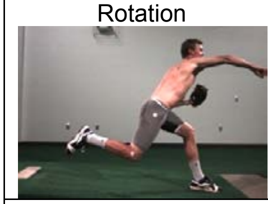
The rapid rotations of the upper trunk and throwing arm create a large force at both the shoulder and elbow. At the time of ball release, more than 1100 N are produced at both the shoulder and elbow to resist distraction. In other words, the body rotation creates forces greater than body weight that are trying to pull the arm out at the shoulder and elbow joint. Tension on the ligaments and muscles – especially the rotator cuff – may lead to tensile tears from repetitive throwing.

After ball release, the throwing arm continues to internally rotate, leaving the forearm in a pronated position. Pronation after release happens in all overhead throws – straight throws, curveballs, etc. The arm horizontally adducts in front of the chest. The trunk continues to tilt forward and the back leg steps forward. A pitcher with an abbreviated deceleration and follow-through may not be using his body to dissipate the energy produced in throwing; this may lead to excessive force in the shoulder and elbow.

A summary of proper pitching mechanics is shown in the table below. Variations from proper kinematics have been correlated with decreased ball velocity (Stodden et al., 2005) and increased shoulder and elbow kinetics (Aguinaldo et al., 2007; Matsuo et al., 2002; 2006; Wight et al., 2004) The consequences of these correlations are summarized in the table as well.

Other issues that have been shown to relate to pitching biomechanics are level (youth to professional) (Fleisig et al., 2006; 2009; Sabick et al., 2005, Ishida et al., 2006) fatigue (Escamilla et al., 2007), pitch type (fastball, curveball, etc.) (Nissen et al., 2009; Dun et al., 2008b, Fleisig et al., 2006) and technique (windup vs. stretch) (Dun et al., 2008a).

Table 1. Summary of proper and improper pitching mechanics

Phase / Event	Proper Mechanics	Pathomechanics → Consequences
Windup	Lift front leg.	
Maximum Knee Height 	Pitcher is balanced.	
Stride	Front leg goes down and forward. Arms separate, swing down, and up.	↓ push off rubber → ↓ball velocity
Foot Contact 	Front foot is planted slightly to 3B side (for a right-handed pitcher). Front foot is pointed slightly inward. Shoulder is abducted approx. 90°, with approx. 60° of external rotation.	↓stride length → ↓ball velocity Front foot open (position or angle) → ↑ shoulder and elbow force Improper shoulder external rotation and shoulder abduction → ↑ shoulder and elbow kinetics Excessive shoulder external rotation → ↓ ball velocity ↓ shoulder horizontal abduction → ↓ ball velocity
Arm Cocking	Pelvis rotation, followed by upper trunk rotation. Shoulder externally rotates, and trunk arches.	Early pelvis rotation → ↓ ball velocity Late pelvis rotation → ↑ shoulder and elbow kinetics ↓ pelvis rotation velocity → ↓ ball velocity Poor timing between pelvis rotation and upper trunk rotation → ↓ ball velocity Poor timing between pelvis rotation and upper trunk rotation → ↑ shoulder internal rotation torque
Maximum External Rotation 	Shoulder external rotation is approx. 180°. Elbow flexion is approx. 90°	↓ shoulder external rotation → ↓ ball velocity Excessive shoulder horizontal adduction & elbow flexion → ↑ shoulder kinetics
Arm Acceleration	Elbow extends, followed by shoulder internal rotation. Front knee extends.	
Ball Release 	The throwing shoulder is abducted approx. 90°	↑knee extension velocity →↑ ball velocity Improper shoulder abduction → ↓ball velocity Improper shoulder abduction → ↑elbow varus torque ↓forward trunk tilt →↓ball velocity
Arm Deceleration	Shoulder internally rotates and front knee extension continues. Trunk tilts forward.	
Maximum Internal Rotation 	Shoulder external rotation is approx 0°.	
Follow Through	Arm crosses in front of body. Trunk flexes forward.	

Definition of symbols in chart: ↓ Decreased ↑ Increased → Correlates with

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