

Youth Baseball Pitching Mechanics: A Systematic Review

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Context: Pitching injuries in youth baseball are increasing in incidence. Poor pitching mechanics in young throwers have not been sufficiently evaluated due to the lack of a basic biomechanical understanding of the “normal” youth pitching motion.

Objective: To provide a greater understanding of the kinetics and kinematics of the youth baseball pitching motion.

Data Sources: PubMed, MEDLINE, and SPORTDiscus databases were searched from database inception through February 2017.

Study Selection: A total of 10 biomechanical studies describing youth pitching mechanics were included.

Study Design: Systematic review.

Level of Evidence: Level 3.

Data Extraction: Manual extraction and compilation of demographic, methodology, kinetic, and kinematic variables from the included studies were completed.

Results: In studies of healthy youth baseball pitchers, progressive external rotation of the shoulder occurs throughout the start of the pitching motion, reaching a maximum of 166° to 178.2°, before internally rotating throughout the remainder of the cycle, reaching a minimum of 13.2° to 17°. Elbow valgus torque reaches the highest level (18 ± 4 N·m) just prior to maximum shoulder external rotation and decreases throughout the remainder of the pitch cycle. Stride length is 66% to 85% of pitcher height. In comparison with a fastball, a curveball demonstrates less elbow varus torque (31.6 ± 15.3 vs 34.8 ± 15.4 N·m).

Conclusion: Multiple studies show that maximum elbow valgus torque occurs just prior to maximum shoulder external rotation. Forces on the elbow and shoulder are greater for the fastball than the curveball.

Keywords: youth baseball; pitching; biomechanics; curveball; fastball

Baseball is a common childhood sport in the United States, with 4.34 million children aged 6 to 12 years participating on a team in 2014. Interestingly, participation actually declined by 1 million children from 2007 to 2014.⁴ Shoulder and elbow pain are common complaints of youth pitchers, with 26% to 51% of athletes reporting some type

of arm pain during the season.^{1,22,23} Although participation is decreasing, youth baseball pitching injuries appear to be on the rise.^{10,22} Improper mechanics, overuse due to pitching year-round, playing on multiple teams, and the susceptibility of the developing skeleton are the most commonly cited causes for this increase.^{19,28,31}

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The throwing motion for youth pitchers is developed at a young age as they learn to use their kinetic chain to develop pitching velocity.^{20,34,35} Poor pitching mechanics in youth throwers that could lead to injury have not been sufficiently evaluated because of the lack of a basic biomechanical understanding of the “normal” youth pitching motion. Lyman et al²² attempted to link youth pitcher arm pain to poor pitching mechanics, but no significant findings were discovered. Biomechanical studies of collegiate and professional pitchers, however, have shown how poor mechanics can lead to faulty kinematics and increased kinetic forces, which can increase risk for injury.¹⁵ Most biomechanical studies of the pitching motion have been conducted on collegiate and professional athletes; as such, there are noticeable limitations in applying the knowledge gained in these studies to youth pitchers.^{11,13,37} The normal youth pitching motion of healthy pitchers needs to be established before abnormal pitching motions can be determined.

The purpose of this study was to perform a systematic review of the biomechanics of youth baseball pitchers. The objective was to provide a summary of previous studies for the normal ranges of kinetic and kinematic values for the upper and lower body during the youth baseball pitching motion. This will provide a framework for further investigation of “abnormal” or “dangerous” pitching mechanics and their relationship to injury.

METHODS

Literature Search

A systematic review of the literature describing youth pitching mechanics was conducted according to the PRIMSA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines and the guidelines of Harris et al¹⁸ (Figure 1). Identification of relevant studies began with a search of PubMed, MEDLINE, and SPORTDiscus databases. Citations were limited to studies published from database inception through February 2017 and to those published in English. The keywords used were *baseball pitching*, *adolescent or youth*, *pitching biomechanics*, and *baseball pitch type*. Inclusion criteria were all original studies that either described biomechanical parameters of the normal youth baseball pitching motion or compared the mechanics of pitch types. Included studies were limited to those where the participants' mean ages were 13 years or less. Nonhuman studies, studies without biomechanical data, studies describing throwing mechanics of a position other than pitcher, review articles, case reports, non-English language articles, and articles with no full-text version available were excluded.

The study selection process began by reviewing the abstracts of all citations identified using the inclusion and exclusion criteria. The full-text versions of this shorter list were then reviewed based on the eligibility criteria. The citation lists of the identified publications were also hand-searched for any relevant studies that had not yet been included. From the potential studies identified by our electronic database search and manual searching of reference lists, 10 citations remained for study inclusion.^{7,12,21,24,26,28,32,33}

Data Abstraction

Two reviewers independently extracted relevant data. The demographics and data collection methods were compared between studies. Comparisons of biomechanics were organized by positional parameters at various time points in the pitching cycle and throughout pitch cycle phases, joint torques at various time points in the pitching cycle and throughout pitch cycle phases, and maximum angular velocities reached when throwing the fastball (see Figure A1 in the Appendix, available in the online version of this article). Keeley et al²¹ reported inverse values for elbow flexion angles in comparison with the other studies. For convention purposes, these data were standardized to allow for more appropriate comparisons. For example, an elbow flexion angle of 101.5° was converted to 78.5° ($180^\circ - 101.5^\circ = 78.5^\circ$). Complete elbow extension was defined as 0° of elbow flexion. A positive value indicates a greater degree of elbow flexion, and a negative value indicates hyperextension. For shoulder horizontal motion, a positive value indicates the elbow is in front of the shoulder in the coronal plane, and a negative value indicates the elbow is behind the shoulder in the coronal plane. Individual data points were extracted from each study to compare all measured parameters, and the data were then aggregated to present an overall range from the included studies.

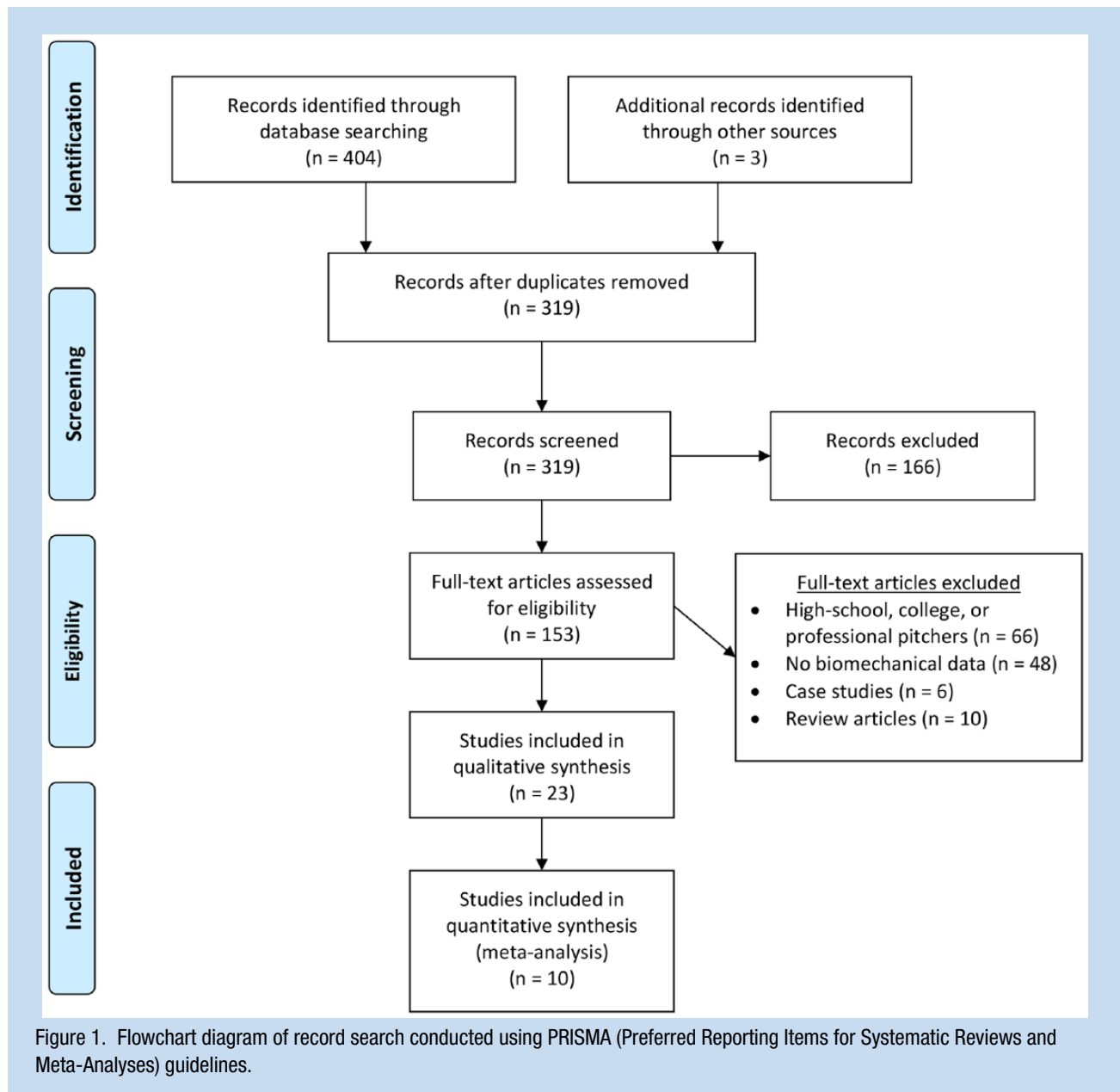
RESULTS

A total of 10 biomechanical studies met the inclusion criteria (Table 1). These studies included athletes aged 10 to 15 years (mean age, 12.1 years). Pitchers threw from an artificial pitching mound in 7 studies,^{7,12,21,32,33} no pitching mound was used in 2 studies,^{24,28} the pitchers threw from both flat ground and a pitching mound in 1 study.²⁶ Two biomechanical laboratory studies included upper extremity kinematic and kinetic data for the fastball,^{32,33} 4 studies included upper and lower extremity kinematic and kinetic data for the fastball,^{12,21,26,28} 2 studies evaluated only lower extremity biomechanics for the fastball,²⁵ and 2 studies compared the upper and lower extremity biomechanics between the fastball, curveball, and change-up.⁷ The dates of publication ranged from 1999¹² to 2017.¹⁶ Table 2 provides overall ranges of biomechanical values reported in the reviewed studies. More complete biomechanical comparisons between studies can be found in the tables in the Appendix.

DISCUSSION

The neuromuscular memory of throwing mechanics is developed at a young age. When proper techniques are learned at this age, they will likely continue through adolescence and beyond.^{20,34,35} Instructing youth pitchers on proper mechanics when they are developing their throwing motion is key. Poor mechanics lead to increased forces on joints, bones, and ligaments without increased velocity.¹⁰

Understanding the different phases and key moments in the pitching motion is important to understand the results of this



study. The windup and the stretch are the 2 traditional starting positions used during the pitching delivery of a baseball (see Figure A1 in the Appendix). The mechanics of both positions converge when the lead hip and knee are flexed; they should be in similar positioning during the rest of the throwing motion. From this point, the lead leg extends toward home plate, and the pitcher's upper trunk rotates to face the target.

Elbow valgus torque occurs during the arm-cocking phase (Figure 2) and is a factor in many elbow pathologies seen in youth pitchers. A pitcher's weight is the biomechanical factor most closely correlated with the magnitude of valgus torque and has also been correlated with elbow injuries.^{23,33}

The arm deceleration phase begins when the ball is released and ends with maximum shoulder internal rotation. After ball

release, youth pitchers may have difficulty controlling throwing-arm deceleration as a result of underdeveloped rotator cuff musculature; this can result in increased horizontal flexion across the torso in an attempt to decelerate the throwing arm.²¹ Increased horizontal flexion during deceleration can potentially produce overuse tendinopathy.²¹

The association between the curveball and pitching injuries in youth baseball pitchers has long been controversial. Experts in the field of sports medicine have cautioned for decades that youth may increase the risk of throwing injuries by using the curveball at a young age.² A rise in the number of high school and collegiate pitchers requiring elbow surgeries over the past 2 decades has raised growing concern.^{13,29} Little League Baseball, in fact, currently recommends that breaking pitches (curveball,

Table 1. Comparison of demographics and data collection methods between studies

Study	N	Age, Mean \pm SD, y	Height, Mean \pm SD, cm	Weight, Mean \pm SD, kg	Data Collection Method	Pitching Distance/Mound
Sabick et al ³²	14	12.1 \pm 0.4	154 \pm 0.08	44.3 \pm 8.7	2-camera, 120-Hz videographic analysis, locations of 21 bony landmarks hand-digitized	14-m pitching distance, with mound
Nissen et al ²⁸	24	12.25 ^a	154 \pm 12	48 \pm 14	12-camera, 250-Hz (Vicon 512 Motion System), 38 reflective markers	13.7-m pitching distance, without mound
Fleisig et al ¹²	23	10-15 ^a	167 \pm 9	55 \pm 10	4-camera, 200-Hz automatic digitizing system (Motion Analysis Corporation), 14 bony landmarks	16-m pitching distance, with mound
Fleisig et al ¹⁴	26	12.2 \pm 1.6	158.9 \pm 12.3	48.2 \pm 11.3	8-camera, 240-Hz automatic digitizing system (Motion Analysis Corporation), 23 reflective markers	13.7-m pitching distance, with mound
Keeley et al ²¹	16	12 ^a	153 \pm 7	43.44 \pm 8.45	High-speed videographic analysis, locations of 21 bony landmarks hand-digitized	14-m pitching distance, with mound
Dun et al ⁷	29	12.5 \pm 1.7	160.7 \pm 12.8	50.6 \pm 13.5	8-camera, 240-Hz automatic digitizing system (Motion Analysis Corporation), 16 reflective markers	18.4-m pitching distance, with mound
Milewski et al ²⁴	32	12.4 ^a	157 \pm 13	51 \pm 15	12-camera, 250-Hz (Vicon 512 Motion System), 38 reflective markers	13.7-m pitching distance, without mound
Sabick et al ³³	12	12.1 \pm 0.4	154 \pm 0.08	44.3 \pm 8.7	2-camera, 120-Hz videographic analysis, locations of 21 bony landmarks hand-digitized	14-m pitching distance, with mound
Nissen et al ²⁶	15	12.7 \pm 1.3	162 \pm 10	54 \pm 15.8	12-camera, 250-Hz (Vicon 512 Motion System), 38 reflective markers	13.7-m pitching distance, with and without mound
Fry et al ¹⁶	92	10.4 \pm 1.3	NA	41.5 \pm 10.2	1-camera videographic analysis of stride length (Dartfish System)	12- to 16-m pitching distance, with mound

NA, not available.

^aStandard deviation was not provided in the study.

Table 2. Biomechanics results from studies

Positional Parameter Measured at Various Time Points and Pitch Cycle Phases	Mean Value, Range
At foot contact	
Shoulder abduction, deg	78-95
Shoulder horizontal flexion, ^a deg	-18 to -30
Shoulder external rotation, deg	60-80.4
Elbow flexion, ^b deg	74-85
Knee flexion, deg	40-49
Stride length, % height	66-85
Foot angle, deg	14-21.6
Arm-cocking phase	
Maximum shoulder external rotation, deg	166-178.2
Maximum elbow flexion, ^b deg	95-100.8
At maximum shoulder external rotation	
Shoulder abduction, deg	66-92
Shoulder horizontal flexion, ^a deg	-4 to -20
Elbow flexion, ^b deg	57-95
At ball release	
Shoulder abduction, deg	70-94
Shoulder horizontal flexion, ^a deg	0-23
Shoulder external rotation, deg	109-143.4
Elbow flexion, ^b deg	24-39
Forward trunk tilt, deg	30-33.4
Lateral trunk tilt, deg	21-29.5
Knee flexion, deg	31.2-41
Arm deceleration phase	
Minimum elbow flexion, deg	-8
At maximum shoulder internal rotation	
Shoulder abduction, deg	99.6-101
Shoulder horizontal flexion, ^a deg	11-33.6
Shoulder external rotation, deg	13.2-17
Elbow flexion, ^b deg	18.5
Maximum Angular Velocities (Fastball)	Overall Range
Maximum shoulder internal rotation angular velocity, deg/s	3396-9000
Maximum elbow extension angular velocity, deg/s	1742-2272
Maximum pelvis velocity, deg/s	601.9-1202.2
Joint Torque Measured at Various Time Points and Pitch Cycle Phases	Overall Range
At foot contact	
Elbow valgus torque, N-m	1.7-2

(continued)

Table 2. (continued)

Joint Torque Measured at Various Time Points and Pitch Cycle Phases	Overall Range
Arm-cocking phase	
Maximum shoulder internal rotation torque, N·m	17.7-36.9
Maximum elbow varus torque, N·m	27-37
Maximum elbow valgus torque, N·m	18
Elbow flexion ^b (deg) at maximum valgus torque	87
At maximum external rotation	
Elbow valgus torque, N·m	12.8-13
Arm acceleration phase	
Elbow flexion torque, N·m	16.4-28
Shoulder horizontal adduction torque, N·m	39.1
At ball release	
Elbow valgus torque, N·m	3.5-4
Arm deceleration phase	
Maximum shoulder horizontal abduction torque, N·m	40
Maximum shoulder proximal force, N	214.7-480

^aFor shoulder horizontal motion, a positive value indicates that the elbow is in front of the shoulder in the coronal plane and a negative value indicates that the elbow is behind the shoulder in the coronal plane.

^b0° of elbow flexion = full elbow extension. A positive value indicates elbow flexion and a negative value indicates elbow hyperextension.

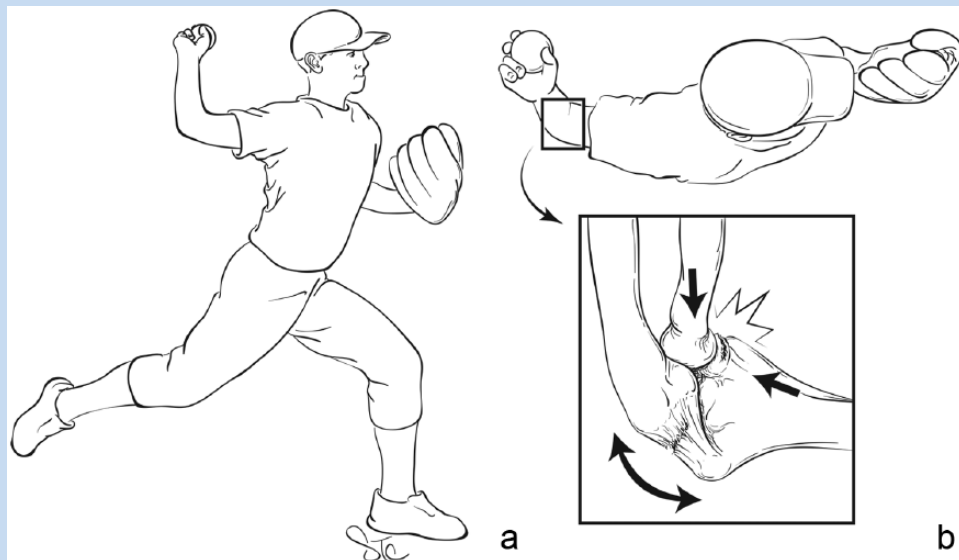


Figure 2. In the arm-cocking phase (a) a tensile force is placed on the medial elbow and (b) a compressive force on the lateral elbow.

slider) not be thrown until age 14 years, and an association has been reported between shoulder pain and curveball use.^{22,36} Additionally, a strong relationship was seen between the slider and elbow pain. This correlation was especially high in pitchers aged 13 to 14 years, which is a period of increased skeletal

growth. As others have noted, the risk of overuse injuries increases during the adolescent growth spurt, and extra caution should be used with pitchers of this age.^{3,5,6,8,25} Despite these associations, biomechanical studies have actually shown decreased torques and forces at the shoulder and elbow in

youth pitchers throwing a curveball compared with a fastball.^{7,27} In a thorough review of the curveball as a potential risk factor for injury in youth baseball pitchers, no additional strain on the throwing arm was found. Recommendations to limit curveballs in young pitchers are not supported by biomechanical studies.¹⁷

The majority of research on youth pitching mechanics has focused on the upper extremity and trunk. The lack of studies on the lower extremity is concerning because the biomechanics of the lower extremity are foundational components to the throwing motion, as the lower extremity initiates the kinetic chain, leading to the transmission of force into the baseball at the point of release. In an attempt to compensate, a young pitcher with poor lower body mechanics will subject the upper extremity to added stress and increased risk of injury. A study of 72 high school pitchers showed improper trunk rotation sequences when peak pelvic torso rotation velocity occurred later than peak upper torso rotation velocity in the pitch cycle by more than 3.7% of pitch time.³⁰ Pitchers with improper trunk rotation sequences exhibited greater maximal shoulder external rotation angles and peak shoulder proximal force compared with high school pitchers with proper trunk rotation sequences.³⁰ An open lead foot angle can cause the pelvis to rotate prematurely, producing increased anterior shoulder force and medial elbow force, subsequently increasing the risk for injury.⁹ A more complete understanding of lower extremity biomechanics in the pitching motion, and the relationship to the upper body, could potentially reduce the risk of injury in young throwers.

Commonalities in the throwing mechanics of healthy youth pitchers were elbow flexion at foot contact, maximum elbow flexion, maximum shoulder external rotation, and elbow valgus torque at all pitch cycle time points. Some discrepancies were found across the reviewed studies, including large differences in maximum angular velocities.

A significant limitation to the studies reviewed is that they were performed in a laboratory setting without a catcher or a batter in the box. Live-game situations may alter pitching mechanics and joint forces. Additionally, pitching from a dirt pitching mound with cleats could slightly alter throwing mechanics compared with pitching from an artificial indoor pitching mound. Furthermore, direct comparison of pitching parameters between laboratories was made difficult by the use of various methodologies of data collection.

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