# COMPARISON OF THROWING ARM MECHANICS DURING LONG-TOSS THROWING AND PITCHING IN PROFESSIONAL BASEBALL PLAYERS

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The purpose of this study was to quantify long-toss throwing mechanics of professional baseball pitchers and compare biomechanics of mound pitching to long-toss throwing. Kinematic and kinetic data from 19 professional baseball pitchers throwing from 18-m to 91-m, along with fastball pitches were analyzed using marker-based motion analysis and linear mixed models. Throwing approach and arc were not restricted for long-toss throws. Linear associations were found between the long-toss throwing distances and biomechanical metrics. While elbow and shoulder kinetics increased with distance, they were lower than pitching kinetics at shorter distances and did not significantly exceed the average pitching kinetics at the maximum distance. This is the first study to quantify long-toss throwing mechanics without restriction of throwing style.

**KEYWORDS:** baseball, long-toss, pitching, kinematics, kinetics.

**INTRODUCTION:** Individualized interval throwing programs were initially developed as a safe method for baseball players to rehabilitate after injury, with the recommendation of a slight arc be used when long-toss throwing to regulate the effort of each throw (Wilk, Williams, Dugas, Cain, & Andrews, 2016). Long-toss is part of an interval throwing program commonly used by baseball pitchers to warm up and strengthen their arms. Players start throwing at a close distance, progressively moving back until they reach their maximum throwing distance, then gradually come back together to a close distance. While interval throwing programs often suggest long-toss distances between 37 to 55 m (Axe, Hurd, & Lynn Snyder-Mackler, 2009; Wilk et al., 2016), healthy pitchers often exceed these distances using crow-hop footwork and throwing with an arc to achieve distances more than 91 m (Stone, Mannava, Patel, Marquez-Lara, & Freehill, 2017). Maximum distance varies based on skill level, strength and endurance. Previous studies quantifying long-toss throwing mechanics have instructed players to throw hard, on a horizontal line (Dowling, McNally, Laughlin, & Onate, 2018; Fleisig, Bolt, Fortenbaugh, Wilk, & Andrews, 2011; Slenker, Limpisvasti, Mohr, Aguinaldo, & ElAttrache, 2014). Despite the widespread use of long-toss throwing in baseball outside of rehabilitation, the distances and throwing mechanics remain controversial (Stone et al., 2017). The purpose of this study was to quantify long-toss throwing mechanics of healthy professional baseball pitchers and compare the biomechanics of mound pitching and long-toss throwing. It was hypothesized that biomechanical changes occur as throwing distance increases and there are biomechanical differences between mound pitching and long-toss throwing. Due to differences in strength, endurance, and technique; it was hypothesized that players stress their arms differently while increasing throwing distance of long-toss.

**METHODS:** Nineteen healthy professional baseball pitchers (15 right handed, 4 left handed, 23.3 ± 1.5 years, 186.9 ± 6.2 cm, and 95 ± 6.9 kg) participated in this study. Each player completed informed consent, provided medical history, and physical information before two testing sessions were conducted. This study was approved by the Medical College of Wisconsin Institutional Review Board. For each session, 47 reflective markers (12.5 mm diameter) were attached to specific landmarks on the body. A system of 8 Raptor-E cameras (Motion Analysis Corporation, Santa Rosa, CA) was used to capture the motion of pitchers at 300 frames per second. All data were exported and processed with Visual 3D software (C-Motion, Germantown, MD) using a previously developed biomechanical pitching model (Adhithia, Cross, Harris, & Raasch, 2015; Badura, Raasch, Barber, & Harris, 2003). The long-toss session was performed in the outfield of a baseball field. The motion system was set up around a throwing release line. Distances were marked from 18-m to 91-m, in 4.6-m increments, for a total of 17 throwing distances. After the player warmed up, three throws at each distance were recorded until their maximum distance was reached, as indicated by the player. A catcher was standing at the marked distance line; the players were instructed to throw to the catcher, with their approach and throw trajectory not restricted. If the ball did not reach or over shot the catcher, it was considered a failed throw. Two successful throws at each distance were analysed. For the pitching test session, the motion system was set up in a bullpen surrounding the pitching mound, where each participant threw 10 fastballs to a catcher. Velocity was recorded using a Stalker Sport 2 radar gun behind the catcher (Stalker Sports Radar, Richardson, TX), along with the location of each pitch. The three best pitches thrown for a strike were analysed. Biomechanical variables were calculated throughout the throwing motion. Linear mixed models with a random subject effect to account for within-subject correlation were applied to the data to compare long-toss and pitching metrics, with a significance level set at $p < 0.0001$ to control for the false discovery rate due to the large number of statistical tests run. The effects of age, height, weight, and left/right hand were controlled.

**RESULTS:** The average maximum distance of long-toss throws was 80.6 ± 12 m, with 9 of the 19 pitchers throwing to the last distance marked. The average fastball pitch speed was 38.4 ± 1.3 m/s. Long-toss throwing speed was not recorded due to uncontrolled ball trajectory. Linear associations were found between long-toss throw distance and all metrics, except for shoulder horizontal abduction at foot contact. The adjusted distance effects, in parentheses for each metric, were significant with a $p < 0.0001$: foot contact – stride length (0.069), shoulder abduction (0.011), shoulder external rotation (0.062), elbow flexion (0.090); arm cocking – maximum shoulder external rotation (0.062), maximum elbow flexion (0.010), elbow varus torque (0.206), shoulder internal rotation torque (0.173); ball release – shoulder adduction (0.015), elbow flexion (-0.026), elbow flexion torque (0.096), shoulder proximal force (1.874). With the adjusted linear mixed model, 57.5 to 87.5% of the variance was attributed to the random subject effect, meaning a linear mixed model was well justified. Table 1 displays means and standard deviation of the fastball pitch data and a reduction of the throwing data.

**Table 1: Comparison of biomechanics among pitching and long-toss throws.**

| Kinematics | Pitch (18.4 m) | 18-m Throw | 37-m Throw | 55-m Throw | 73-m Throw | 91-m Throw |
|---|---|---|---|---|---|---|
| ***Foot Contact*** | | | | | | |
| Stride Length (% of Height) | 81.5 ± 4.5 | 58.4 ± 9.7 | 66.3 ± 9.3 | 69.5 ± 9.7 | 72.0 ± 8.7 | 75.7 ± 7.6 |
| Shoulder Horiz. Abduction (°) | 40.4 ± 9.1 | 38.5 ± 9.1 | 39.2 ± 9.5 | 38.2 ± 8.3 | 37.2 ± 8.8 | 43.2 ± 9.2 |
| Shoulder Abduction (°) | 79.0 ± 8.8 | 77.3 ± 7.2 | 79.4 ± 8.2 | 80.0 ± 7.8 | 80.4 ± 9.8 | 79.3 ± 7.4 |
| Shoulder Ext. Rot. (°) | 42.9 ± 26.7 | 18.0 ± 28.0 | 26.3 ± 30.3 | 29.9 ± 33.6 | 27.5 ± 29.2 | 24.7 ± 26.2 |
| Elbow Flexion (°) | 96.6 ± 17.0 | 78.2 ± 20.9 | 87.4 ± 18.7 | 91.3 ± 20.1 | 91.5 ± 19.6 | 97.9 ± 13.3 |
| ***Arm Cocking*** | | | | | | |
| Max Shoulder Ext. Rot. (°) | 159.5 ± 12.3 | 148.4 ± 7.7 | 155.6 ± 8.1 | 158.5 ± 8.2 | 160.5 ± 6.2 | 163.0 ± 6.7 |
| Max Elbow Flexion (°) | 89.3 ± 5.2 | 91.8 ± 8.0 | 92.8 ± 6.7 | 93.2 ± 5.6 | 92.9 ± 6.3 | 91.3 ± 5.6 |
| ***Ball Release*** | | | | | | |
| Shoulder Adduction (°) | 91.7 ± 6.9 | 91.0 ± 7.3 | 92.3 ± 7.3 | 93.1 ± 6.5 | 95.5 ± 7.1 | 94.9 ± 5.9 |
| Elbow Flexion (°) | 35.9 ± 4.7 | 40.8 ± 7.3 | 37.7 ± 6.1 | 36.5 ± 5.6 | 33.3 ± 5.1 | 31.5 ± 5.2 |
| **Kinetics** | **Pitch (18.4 m)** | **18-m Throw** | **37-m Throw** | **55-m Throw** | **73-m Throw** | **91-m Throw** |
| ***Arm Cocking*** | | | | | | |
| Elbow Varus Torque (Nm) | 131.3 ± 22.3 | 85.8 ± 15.3 | 106.1 ± 21.3 | 110.7 ± 19.3 | 128.7 ± 24.5 | 133.1 ± 19.9 |
| Shoulder Int. Rot. Torque (Nm) | 123.5 ± 18.8 | 84.1 ± 15.4 | 100.3 ± 18.1 | 105.2 ± 17.8 | 120.1 ± 18.4 | 123.0 ± 16.5 |
| ***Ball Release*** | | | | | | |
| Elbow Flexion Torque (Nm) | 53.7 ± 28.0 | 27.3 ± 16.1 | 32.0 ± 21.4 | 32.8 ± 21.3 | 38.8 ± 30.5 | 53.3 ± 27.1 |
| Shoulder Prox. Force (N) | 1115.5 ± 164.9 | 643.5 ± 154.5 | 838.4 ± 227.8 | 903.9 ± 231.1 | 933.1 ± 206.5 | 1076.5 ± 260.8 |
| **Peak Velocity** | **Pitch (18.4 m)** | **18-m Throw** | **37-m Throw** | **55-m Throw** | **73-m Throw** | **91-m Throw** |
| Pelvis Rotation Vel. (°/s) | 614.7 ± 79.1 | 481.2 ± 85.5 | 561.2 ± 86.0 | 594.5 ± 81.7 | 631.8 ± 86.2 | 698.2 ± 85.5 |
| Torso Rotation Vel. (°/s) | 1024.8 ± 65.7 | 775.9 ± 99.7 | 882.3 ± 111.9 | 924.6 ± 104.5 | 963.1 ± 91.6 | 1048.9 ± 67.4 |
| Elbow Extension Vel. (°/s) | 2043.2 ± 218.6 | 1500.8 ± 210.8 | 1711.4 ± 230.5 | 1816.0 ± 244.9 | 1906.6 ± 271.7 | 2068.9 ± 375.4 |
| Shoulder Int. Rot. Vel. (°/s) | 4461.9 ± 439.4 | 3419.7 ± 415.7 | 3853.5 ± 459.6 | 4088.9 ± 483.1 | 4197.3 ± 469.4 | 4565.2 ± 893.9 |

Figure 1 shows the adjusted linear model prediction for elbow varus torque differences between long-toss throwing and pitching during arm cocking across all subjects. The zero line is the pitching average. Confidence intervals below the zero line indicate that the long-toss throwing average was less than the pitching average, while confidence intervals above the zero line indicate that the long-toss throwing average was greater than the pitching average. Figure 2 displays the adjusted linear model prediction for shoulder internal rotation torque differences between long-toss throwing and pitching during arm cocking across all subjects.

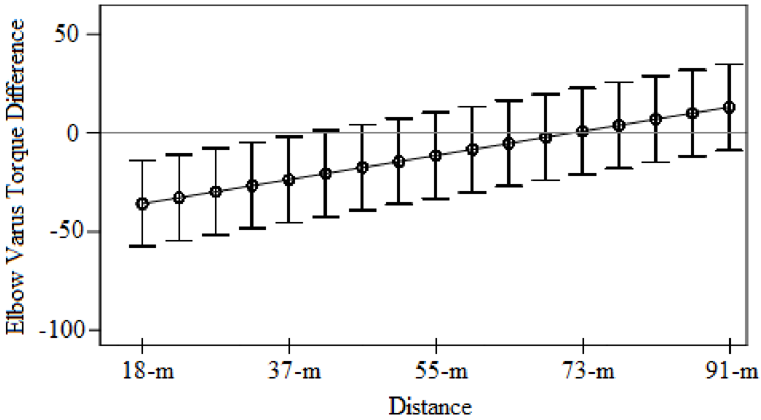


**Figure 1. Adjusted linear model prediction for elbow varus torque difference.**

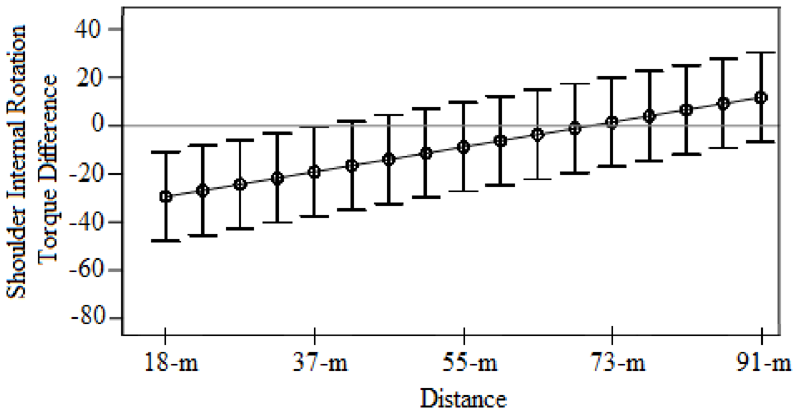


**Figure 2. Adjusted linear model prediction for shoulder internal rotation torque difference.**

**DISCUSSION:** Long-toss throwing is commonly used for rehabilitation and training in baseball to strengthen the arm, increase endurance, and progressively prepare players for loads associated with throwing (Stone et al., 2017). While baseball pitching mechanics have been extensively studied (Fleisig, Andrews, Dillman, & Escamilla, 1995; Fleisig et al., 2016), long-toss throwing mechanics studies have been limited to throwing hard on a horizontal line. It has been suggested that those methods may lead to the false conclusions that upper extremity loads are similar in long-toss throwing and mound pitching at all distances (Wong & Meister, 2014). The current study looked to avoid these limitations by not restricting the trajectory of the ball. Players were instructed to throw long-toss as they normally do and stop when they reached their maximum distance.

The results from this study supported the hypotheses that biomechanical changes occur as long-toss throwing distance increases, and that there are biomechanical differences between mound pitching and long-toss throwing. As long-toss throwing distance increased, pitchers increased their stride length and maximum shoulder external rotation angle. Also, as distance increased, the loads on the elbow and shoulder increased, along with the peak velocities (Table 1). Elbow varus torque and shoulder internal rotation torque during the arm cocking phase of throwing are commonly reported pitching metrics due to their associated risk of injury (Fleisig et al., 1995). While both elbow varus torque and shoulder internal rotation torque increased with distance (figures 1 and 2), they were lower than pitching kinetics at shorter distances and did not significantly exceed the average pitching kinetics at the maximum distance. These results differed from previous studies, likely due to the differences in methodology and study population (Fleisig et al., 2011; Slenker et al., 2014). This study used professional pitchers, while the two previous studies analysed college pitchers. Both previous studies found flat ground throwing kinetics to be at or close to pitching kinetics, even at short distances. Both Fleisig et al. and Slenker et al. found kinetics varied only 10 Nm or less across all throwing distances, while the current study showed kinetics varied 26 Nm or more across throwing distances. Overall, the previous studies had less variance across both kinetics and kinematics compared to the current study, highlighting the difference of throwing on a hard, horizontal line verses throwing with an arc. This study demonstrates the benefit of throwing with an arc to reduce throwing arm kinetics when returning to throwing from the offseason or injury. While the results show the group means, on an individual basis, the players maximum distance long-toss throwing stresses were generally at or slightly above their fastball mound pitching stresses. This study emphasises the importance of individualising long-toss programs, even in healthy pitchers.

**CONCLUSION:** The findings presented in this study demonstrate gradual increases in elbow and shoulder stress as throwing distance increases, which may aid in increasing arm strength and flexibility. This study may be limited by only studying throwing mechanics as the long-toss throwing distance increased. The second half of long-toss throwing of decreasing distances, after maximum throw distance was reached, may have a different impact on the biomechanics than observed here. While throwing longer distances for conditioning may be beneficial in increasing throwing arm strength and endurance, precautions should be taken with rehabilitation, as throwing longer distances is accompanied by an increase in load. If the goal of long-toss throwing is to increase arm strength and endurance in a less stressful manner than pitching, then long-toss throwing needs to be individualised to determine the maximum distance to throw. This can be accomplished using motion analysis methods presented in this study to compare pitching mechanics to long-toss throwing mechanics.

## REFERENCES

Adhithia, D, Cross, J, Harris, G, & Raasch, W. (2015). Elbow and shoulder kinetic model for baseball pitching: Implications on injury risk. *Proc of GCMAS,* Portland, OR. 84-85.

Axe, M, Hurd, W, & Snyder-Mackler, L. (2009). Data-based interval throwing programs for baseball players. *Sports Health, 1*(2), 145-153.

Badura, JM, Raasch, WG, Barber, MP, & Harris, GF. (2003). A kinematic and kinetic biomechanical model for baseball pitching and its use in the examination of flat-ground and mound pitching: A preliminary report. *Proc of IEEE/EMBS, 2*, 1803-1806.

Dowling, B, McNally, MP, Laughlin, WA, & Onate, JA. (2018). Changes in throwing arm mechanics at increased throwing distances during structured long-toss. *Am J Sports Med, 46*(12), 3002-3006.

Fleisig, GS, Andrews, JR, Dillman, CJ, & Escamilla, RF. (1995). Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med, 23*(2), 233-239.

Fleisig, GS, Bolt, B, Fortenbaugh, D, Wilk, KE, & Andrews, JR. (2011). Biomechanical comparison of baseball pitching and long-toss: Implications for training and rehabilitation. *J Orthop Sport Phys, 41*(5), 296-303.

Fleisig, GS, Laughlin, WA, Aune, KT, Cain, EL, Dugas, JR, & Andrews, JR. (2016). Differences among fastball, curveball, and change-up pitching biomechanics across various levels of baseball. *Sports Biomech, 15*(2), 128-138.

Slenker, NR, Limpisvasti, O, Mohr, K, Aguinaldo, A, & ElAttrache, NS. (2014). Biomechanical comparison of the interval throwing program and baseball pitching: Upper extremity loads in training and rehabilitation. *Am J Sports Med, 42*(5), 1226-1232.

Stone, AV, Mannava, S, Patel, A, Marquez-Lara, A, & Freehill, MT. (2017). Defining the long-toss: A professional baseball epidemiological study. *Orthop J Sport Med, 5*(2), 2325967116686773.

Wilk, KE, Williams, RA, Dugas, JR, Cain, EL, & Andrews, JR. (2016). Current concepts in the assessment and rehabilitation of the thrower's shoulder. *Oper Tech Sports Med, 24*(3), 170-180.

Wong, R, & Meister, K. (2014). Interval throwing program and baseball pitching: Letter to the editor. *Am J Sports Med, 42*(6), NP37-NP38.