



Assessment of throwing arm biomechanics with a motusBASEBALL[™] pitching sleeve during long-toss throws and pitching in college baseball pitchers

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Jeff T. Wight ^{a,*}, Brittany Dowling ^b, Jaclyn O'Loughlin ^a

^a Brooks Rehabilitation College of Healthcare Sciences, Jacksonville University, 2800 University Blvd North, Jacksonville, FL 32211 USA.
 ^b Motus Global, 200 Sunrise Hwy, Rockville Centre, NY, 11570 USA.

*Corresponding Author Email: jwight@ju.edu

Abstract: In baseball, long-toss throws are commonly used in return-to-throw programs and for general conditioning; however, the majority of these programs are based on conventional wisdom. Few studies have examined the biomechanics of long-toss throwing and the impact of throw distance. The purpose of this study was to determine if significant differences exist among commonly-used sub-maximal distance long-toss throws and mound pitching. Nineteen college baseball pitchers (19 ± 1.3 years; 88.3 ± 8.4 kg; and 73.9 ± 18.6 cm) wore a motusBASEBALL[™] sleeve and sensor which measured peak elbow varus torque (VT), peak forearm angular velocity (Vmax), and peak arm-cocking angle (ACA). Each player completed five long-toss throws at distances of 27 m, 37 m, 46 m, 55 m and five pitches from a mound at regulation (18.4 m). There were no significant differences among throwing conditions for both VT and Vmax (p<0.05). For ACA, there was a significant increase (approximately 12°) as the long-toss distance increased. Coaches and trainers should be aware that sub-maximal distance long-toss throws (27 - 55 m+) generate high-magnitude throwing arm biomechanics (kinetics, velocities, range of motion) that approach or even exceed those generated during pitching; precaution needs to be used when implementing long-tosses into throwing and rehabilitation programs.

Key Words: Throwing shoulder, Elbow varus torque, Overhand athlete, Throwing kinematics



Jeff Wight is an Assistant Professor of Kinesiology at Iacksonville University (Jacksonville, Florida, USA) and the Director of the Running Laboratory. Dr. Wight is а sport biomechanist with а coaching background and degrees from the University of Wisconsin (BS in Biology),

University of Delaware (MS in Biomechanics), and University of Florida (PhD in Biomechanics). His primary research interests are baseball pitching biomechanics, throwing shoulder internal and external rotation flexibility (passive torque-angle plot analysis), and distance running biomechanics.



Brittany Dowling is the Director of Research at Motus Global (Rockville Centre, NY, USA). Her education is in biomechanics and exercise physiology from University of Colorado (B.A.) and Texas Tech University (MS). Dowling's research interests are in baseball pitching and throwing mechanics,

throwing arm workloads, and batting.

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Jaclyn O'Loughlin is a recent graduate of the Jacksonville University Kinesiology program (MS in Kinesiology) where she was a Graduate Assistant in the Jacksonville University Running Laboratory. She completed her BS in Exercise Science at the University of North Florida. Her primary

research interests are in sports biomechanics.

1. Introduction

Baseball pitching biomechanics are extreme, well-studied, and known to cause a plethora of serious throwing arm injuries [1-3]. Because of this, much attention has been focused on monitoring throwing volumes and developing comprehensive 'return-to-throw' programs [4, 5]. Long-toss throws (flat-ground, distance throws) are a key component of return-to-throw programs and general throwing programs [6-8]. The throw distances used during these programs are quite variable, ranging from 18m to as far as 80m+ [6, 9, 10]. The potential benefits of long-toss throws include effective warmup, injury prevention, injury rehabilitation, and performance enhancements [11-13]; however, these topics are not well-studied. In fact, the majority of these throwing programs are based on conventional wisdom or expert opinion [7, 11] with only a few studies having investigated long-toss throwing arm biomechanics [14-17]. Presumably, the number of studies is limited because long-toss throw distances are too far to analyze in traditional laboratory settings. Consequently, the two long-toss studies using motion capture had unique set-ups. First, Fleisig et al [15] used eight motion-analysis cameras in an outfield at night (under artificial stadium lighting). In the second, Slenker et al [17] were able to assess pitchers on a field during broad daylight but this required 10 specialized motion-analysis cameras. These preliminary studies revealed that long-toss biomechanics are extreme; the magnitudes of kinematics and kinetics were similar to, or even greater than, those generated during pitching.

It is clear that long-toss prescription should be taken very seriously and that thorough research is warranted.

Recent developments in wearable technology have made it easier to analyze throwing arm biomechanics in field settings, rather than in a laboratory. Specifically, motusBASEBALL[™] was developed as a throwing arm compression sleeve that houses а small, lightweight inertial measurement unit (IMU) on the medial forearm. Consequently, the IMU analysis is limited to variables that are derived from forearm motion. However, those variables include peak arm-cocking angle (ACA), peak elbow varus torque (VT), and peak forearm angular velocity (Vmax) which are known to be some of the most relevant to performance and injury [18]. Elbow VT is particularly valuable as it was identified as a critical load to monitor and research 20+ years ago by preliminary pitching biomechanics laboratory studies [2, 19]. Since then, elbow VT has been one of the most studied kinetic variables in baseball research [20-22]. Elbow VT occurs near the end of the arm-cocking phase as shoulder external rotation ceases and shoulder internal rotation begins. This arm action causes strain at the medial elbow (that loads the ulnar collateral ligament near its limit) and compression at the lateral elbow [21, 23]. Severe injuries to the ulnar collateral ligament are prevalent and welldocumented for baseball pitchers of all levels of competition [24-26].

There is a need for thorough IMU normative data for the long toss. From a clinical perspective, athletes, coaches, and trainers have minimal scientific IMU data to compare their long-toss data to. From a research perspective, IMU long-toss data could help to better understand how throw distance impacts elbow VT. There are notable discrepancies in findings for the few studies that have been completed. Fleisig et al [15] found VT increased slightly (4-11%) as throw distance increased, while Slenker and colleagues [17] found no significant differences. Further, Dowling et al [14] reported a 19% increase in elbow VT (from the shortest to the longest distance). In that study, the IMU was used to study long-toss in high school players (including pitchers and position players) at 9 m, 18 m, 27 m, 37 m, and 46 m.

Also, IMU data can help to further address important basic questions about long-toss throwing arm kinematics. Kinematics are particularly important to study as they may influence (or help explain) the VT generated at the elbow and/or other injury mechanisms [18]. Fleisig et al [15] reported preliminary results (in the motion-analysis study) but only for two standardized distances (37m and 55m). Shoulder range of motion and angular velocities were found to increase slightly (with throw distance). Our understanding of this topic could be further enhanced using the IMU to assess additional long-toss distances.

Therefore, the purpose of this study was to use the motusBASEBALLTM system in a field setting to compare elbow VT and throwing shoulder kinematics among four standard distance long-toss throws and mound pitching. We hypothesized that 1) long-toss magnitudes would be similar to (or exceed) pitching magnitudes and 2) magnitudes would significantly increase as throw distance increased.

2. Materials and Methods

Nineteen collegiate baseball pitchers (19 \pm 1.3 years; 88.3 \pm 8.4 kg; and 73.9 \pm 18.6 cm) participated in this study. All pitchers were actively playing college baseball (NCAA Division I, II and III). To be included, pitchers had to be injury-free the

previous 12 months. The study was approved by the Institutional Review Board at XX (XX, XX, USA). Participants were assigned random player identifications to maintain anonymity and data deidentification. Prior to data collection, pitchers were fitted with the motusBASEBALL[™] system. The sensor was placed on the lateral aspect of the ulna, 5 cm distal to the medial epicondyle of the humerus (Figure 1). The participants were grouped into pairs and given unlimited time to complete their preferred warm-up routine with throws limited to 16 m. After pitchers finished their warm-up, data were collected for five long-tosses at four distances: 27 m, 37 m, 46 m, and 55 m (Figure 2).



Figure 1. motusBASEBALL^m sensor and sleeve. Players were instructed how to properly wear the system with the bull's eye printed on the sleeve sitting on the medial epicondyle of the humerus and the sensor 5 cm distal.



Figure 2. Players performing long-toss throw protocol in pairs while wearing motusBASEBALL[™] system.

Participants were instructed to 'throw hard and on a line' but no additional instruction or constraints were given since no standards exist in the literature and pitchers vary in their preferences, especially in 'crow-hop' footwork technique [12, 15]. Last, five fastballs were thrown from a regulation mound to a catcher (18.3 m). All pitchers in this study threw overhead (i.e. no side-arm pitchers participated). Throughout testing, the investigators continually monitored the sleeve and sensor location to ensure it was in the correct place.

The inertial measurement unit has a 3-axis accelerometer (\pm 24 gs) and 3-axis gyroscope (\pm 4000 °/s) with a sampling rate of 1000 Hz. Data were collected via Bluetooth LE transmission to a custom-built application with proprietary algorithms on an iPad. For each throw, the sensor calculated and recorded elbow VT in N·m, Vmax in °/s, and ACA in ° (Figure 3). The IMU has been shown to be a precise and reliable tool in measuring these metrics [18, 27, 28].



Figure 3. Sample data the motusTHROW[™] smartphone application provided with each throw.

For each variable (VT, Vmax, ACA), data were summarized by computing pooled means and standard deviations for the five throwing conditions (four long-toss distances and the pitch). Then, for each variable a 1-way ANOVA was completed with an alpha of 0.05. Post-hoc Tukey analyses were used to determine where significant differences existed among the five throwing conditions. Statistical analyses were completed using SPSS Version 22.

3. Results

Pooled means and standard deviations for all variables are presented in Table 1. Results from the ANOVA revealed no significant differences in VT and Vmax for all five throwing conditions. For ACA, there was a significant difference between the shortest and longest throwing distance (p < 0.001) with the 55 m throw generating a greater arm angle. There were also significant differences between pitching and long-tosses (p < 0.001); the farthest long-tosses (46 m and 55 m) generated greater arm angles than pitching.

4. Discussion

In this study, college pitchers were equipped with the motusBASEBALL[™] pitching sleeve in a field setting to collect and analyze throwing arm biomechanics for standard long-toss throws and pitching. The literature has yet to clearly establish long-toss throw distances and protocols; however, throw distance appears to most commonly range from 37 m to 55 m for high school to professional baseball players [5, 8, 9, 11, 12, 15]. We analyzed throws across this entire range (27 m, 37 m, 46 m, 55 m) and revealed all distances generated throwing arm biomechanics comparable to those generated during pitching. For the long-toss throws, we hypothesized that magnitudes would significantly increase with throw distance. This was supported by the AMA results as there was a slight increase in arm angle as the throwing distance increased. However, there were no significant increases for VT and Vmax with increased throw distance. These results suggests that all four long-toss distances generated extreme throwing arm biomechanics that were comparable to those generated during pitching.

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Table 1. Throwing arm variables across throw conditions.

	Fastball pitch (18 m)	27 m Throw	37 m Throw	46 m Throw	55m Throw	Significance
Elbow varus torque (N·m)) 53.7 ± 7.7	54.6 ± 7.9	55.0 ± 7.4	55.1 ± 7.9	55.3 ± 8.1	
Arm cocking angle (°)	156.5 ± 10.5	158.9 ± 9.5	163.8 ± 8.6	166.5 ± 8.1	170.3 ± 7.6	a,b,c
Forearm angular velocity	5588.7 ± 557.2	5460.8 ± 713.4	5483.1 ± 657.5	5489.7 ± 506.3	5525.6 ± 468.6	

Note: Significant differences (p < 0.001) between a) 55m throw and fastball pitch, b) 46m throw and fastball pitch, and

c) 55m throw and 27m throw.

4.1 Elbow Varus Torque

Our IMU findings suggest that elbow VT appears to be consistent across standard long-toss throw distances. This corroborates previous laboratory findings in that standard long-toss throw distances generate high magnitude elbow VT, similar to pitching [15]. However, this contradicts results by Dowling et al [14] who reported elbow VT to increase with throwing distance in high school baseball players. These discrepancies could be related to the cohorts analyzed. The current study (and previous motionanalysis studies) analyzed college pitchers while Dowling et al [14] analyzed high school players of all positions. Future studies should compare players of varying age, ability, and position to better understand these topics.

It is critical for athletes, coaches, and trainers to understand that 'shorter throws' do not appear to be 'easier on the elbow'. Reducing the distance of a throw is not a good strategy for reducing elbow VT.

Particular caution should also be used with maximum distance longtoss throws. Fleisig et al [15] had pitchers complete maximum distance throws, 80 m \pm 9 m, which is far beyond the standard distances used in normal long-toss throwing programs (\leq 55 m). Elbow VT increased significantly at the maximum distance and was approximately 11% greater than the 37 m throw. This increase in magnitude is not proportional to the dramatic increase in throw distance; however, it is likely clinically relevant.

Throwing 'effort' appears to be more important to consider than throwing distance since all throw distances generated high magnitude VT. Slenker et al [17] studied throwing effort for the baseball pitch. Interestingly, when pitchers were instructed to throw at 60% effort, the ball velocity was 84% (of the maximum ball velocity) and the elbow VT was 75% (of maximum effort throw torque). Further, when instructed to throw at 80% effort, the ball velocity was 90% and the elbow VT was 90%. From these results, it is clear that elbow VT decreased when the pitchers were instructed to throw with reduced effort; however, throw effort is challenging for coaches and trainers to manage since pitchers tend to throw harder than instructed. Future studies should similarly explore this topic for the long-toss as it is important to better understand how throwing instruction and effort impacts elbow VT.

4.2 Arm Cocking Angle

In the current study, arm cocking angle is defined as the maximum 'global' forearm angle achieved (during the arm cocking phase). This forearm angle, acquired from the gyroscope that is mounted in the pitching sleeve, is measured in reference to the ground. In contrast, motion-analysis systems typically report the forearm angle in reference to the 'upper torso', in order to directly assess shoulder external rotation. Both measures can be used to better understand how far back the forearm is rotated during the arm-cocking phase of various throws. The advantage of the external rotation measurement is that it more clearly reveals how 'stretched' the shoulder becomes, indicating true range of motion. However, at this point, it is unclear if the shoulder external rotation measure has more clinical utility the than the global forearm measure.

The arm-cocking motion has received considerable attention in the baseball pitching literature since pitchers commonly generate an astonishing 180° of shoulder external rotation [2, 19]. This places stress on the throwing shoulder and serious overuse injuries are common [2, 8]. However, generating an excessive external rotation range of motion appears to be very important for performance: high velocity pitchers generate approximately 10° more shoulder rotation than low velocity pitchers [29, 30].

Fleisig and colleagues [15] used motionanalysis in their investigation of long- toss throws and reported shoulder external rotation (relative to the trunk). For a moderate long-toss throw distance (37 m), shoulder external rotation was 174°. When the long-toss distance increased to 55 m, shoulder external rotation increased significantly to 176° and for maximum distance throws (approximately 80 m) rotation increased further to 180°. In the current study, the IMU measure also increased significantly with throw distance. For the shortest throw (27 m), the ACA was 158.9° and it increased significantly by 11.4° to an angle of 170.3° for the longest throw (55 m). Comparable IMU results were reported by Dowling et al [14]; high school players had an increase of approximately 20° when the throw increased from 9 m to 46 m. From this data, it is clear that the pitchers rotated the forearm back farther when the distance increased. However, since the IMU is not yet capable of monitoring the upper torso, it is unclear if the amount of range of motion between the forearm and torso increased to the same degree.

When using the IMU to assess mound pitching, it is important to consider that the pitcher throws 'downhill' to a catcher. In theory, this should reduce the peak 'global' angle of the forearm by the slope of the mound, approximately 8°. The discrepancy may help explain why we found the ACA during the pitch to be significantly reduced compared to the long-toss throws; however, this reduction appears to be more than the slope of the mound $(10^{\circ}-14^{\circ}$ for the two longest throws). Therefore, in this study, the ACA generated during long-toss may be greater than pitching. This supports previous motion-analysis findings by Fleisig et al [15] who reported long-toss external rotation to exceed pitching by 2°-6°. Future studies should carefully control and alter the slope of the mound to better understand how mound pitching influences shoulder rotation. Athletes, coaches, and trainers should be aware that the slope will influence the IMU ACA measure and challenge the ability to compare the arm-cocking forearm angle for flat ground throwing to mound throwing.

4.3 Vmax

For the long-toss throws, there is limited reported data for the Vmax variable. Camp et al [18] studied professional pitchers and reported Vmax for all throwing conditions as 4011°/s. Our values were greater (5460°/s - 5589°/s) most likely because Camp et al. included all types of throws (i.e. lowereffort warm-up, long-toss, and game throws). For high-school players, Dowling et al [14] reported Vmax to range from $2731^{\circ}/s$ to $5044^{\circ}/s$, which is well below the average in the current study. Further, Makhni et al [28] reported high school pitchers to have a Vmax of $5054.4^{\circ}/s$ for the fastball pitch which slightly slower than our finding for college pitchers ($5588.7^{\circ}/s$). More research needs to be conducted to examine Vmax in relation to age and playing level.

To our knowledge, Fleisig et al [15] is the only previous study to report long-toss throwing arm velocities using motion capture. The authors reported shoulder internal rotational angular velocity relative to the trunk. This velocity has received considerable attention as it is one of the fastest human motions recorded, reaching levels of 7,000°/s to 7,500°/s [2, 29]. Similar to our IMU findings, there were no throwing arm velocity differences between pitching and long-toss throws. However, the arm speed values in this study $(5460^{\circ}/s - 5589^{\circ}/s)$ were substantially less than the internal rotation velocities reported by Fleisig and colleagues [15] (7600°/s - 8100°/s) for the same distances. Though the measures are different, both studies support the finding that long-tosses generate high throwing arm velocities that are comparable to pitching.

5. Conclusions

Long-toss throws should be used with caution. The four sub-maximal distances assessed in this study appeared to generate high-magnitude throwing arm biomechanics that are similar to (or beyond) those generated during baseball pitching. Therefore, athletes, coaches, trainers, and clinicians to be aware that standard long-toss throws should not be considered 'easy workouts' or 'low-stress recovery'. In addition, it is important to understand that throw distance appears to have minimal/no impact on elbow VT. Reducing the throw distance is not a good strategy for reducing elbow VT. Future studies should strive to better understand how throw effort and technique influence throwing arm biomechanics.

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Conflict of interest

None of the authors have any conflicts of interest to declare.

Informed consent

All participants gave written informed consent to participate in this study.

Ethical Approval

The study was approved by the Institutional Review Board at Jacksonville University (Jacksonville, FL, USA)

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