RELATIONSHIP OF THROWING ARM MECHANICS AND INTERVAL THORWING DISTANCE IN HIGH SCHOOL BASEBALL PLAYERS

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Ninety-five high school baseball players (16 ± 1 years; 75 ± 13 kg; and 178 ± 20 cm) threw from flat-ground at distances of 9 m, 18 m, 27 m, 37 m, and 46 m while wearing a motusBASEBALL™ sensor (Motus Global, Massapequa, NY USA). Linear mixed-effects models and likelihood ratio tests were utilized to estimate the within-subject relationship between throwing distance and arm slot, arm speed, shoulder rotation, and elbow varus torque. Increases in throwing distance were accompanied by significant increases in varus torque (χ^2 = 3509, p<0.01), arm speed (χ^2 = 5144, p<0.01), and shoulder external rotation (χ^2 = 3277, p<0.01) and significant decreases in arm slot (χ^2 = 952, p<0.01). The use of longer distances for training and conditioning are shown to be beneficial in increasing shoulder rotation and arm speed; however, precaution needs to be taken when reaching maximum distances as there is a subsequent increase in elbow varus torque.

KEYWORDS: long-toss, ulnar collateral ligament, elbow, rehabilitation, kinematics

INTRODUCTION: Shoulder and elbow injuries in baseball players have been on the rise for some time and the most pronounced increase has been noted for adolescent players (Erickson et al., 2015; Hodgins, Vitale, Arons, & Ahmad, 2016). In an attempt to prevent injuries and maximize return-to-play potential following injury, increased attention is being paid to return-to-throwing programs where athletes gradually increase throwing distances and speeds. These comprehensive rehabilitation programs generally include range of motion and flexibility exercises, open- and closed-chain strengthening exercises, plyometrics, proprioceptive neuromuscular feedback, stabilization techniques, and concentric and eccentric exercises. However, these exercises cannot completely reproduce the speed and stress of throwing a baseball; therefore, an interval throwing program is typically incorporated as the final step in the rehabilitation process (Slenker, Limpisvasti, Mohr, Aguinaldo, & Elattrache 2014). Although significant variation exists across published interval throwing programs, most begin with light throwing from short distances (around 14 m) and gradually increase distance (up to 55 m), effort, and velocity. Theoretically, increased throwing distance requires the throwing arm to generate greater force and torque, higher arm speed, and move through increased range of motion compared to throwing at shorter distances (Fleisig, Bolt, Fortenbaugh, Wilk, & Andrews 2011). However, as part of a general arm strengthening or return-to-throw protocol, increased distances might be ineffective or even harmful due to the increased load experienced by the throwing arm. Additionally, it has been demonstrated that significant variability in kinematics, workload, and elbow torque exists across collegiate and professional athletes throwing from a given distance, but this variability has not been quantified in adolescent throwers. In order to better inform these return to throw programs, a better understanding of the relationship between long-toss distance and arm slot, arm speed, shoulder external rotation, and elbow varus torque in high school baseball players is needed to better inform these return to throw programs.

METHODS: High school baseball players (n=95; age 16 ± 1 years; 75 ± 13 kg; and 178 ± 20 cm) were instrumented with a motusBASEBALL™ sensor and sleeve (Motus Global, Massapequa, NY) and underwent an standardized interval throwing program. After warming up,. each participant was tested for five throws at each distance: 9 m, 18 m, 27 m, 37 m, and 46 m.

For each throw, the sensor recorded arm slot (°), arm speed (°/s), maximum shoulder external rotation (°), and peak elbow varus torque (Nm). Arm slot was measured as the angle between the forearm and the ground at ball release, where 0° and 90° represented positions parallel and perpendicular to the ground, respectively. Arm speed represented the maximal rotational velocity of the forearm during the throwing motion. Shoulder external rotation was measured with reference to the ground so that if the arm were abducted 90° and the elbow flexed 90°, this would represent 0° of shoulder rotation. Elbow varus torque was the peak torque measured in Nm.

Data were summarized by computing composite means and standard deviations for all variables at each long-toss distance. Linear mixed-effects models and likelihood ratio tests were used to estimate the within-subject relationship between throw distance and arm slot, arm speed, torque, and shoulder external rotation. Tukey post-hoc tests were then used to analyze the significance of the within-subject effects. The level of significance for all tests was set at $p < 0.01$

RESULTS: Composite means and standard deviations for each throwing distance are shown in Table 1. Torque ($\chi^2 = 3509$, $p<0.01$), arm slot ($\chi^2 = 952$, $p<0.01$), arm speed ($\chi^2 = 5144$, $p<0.01$), and shoulder external rotation ($\chi^2 = 3277$, $p<0.01$) were significantly associated with throwing distance. Increases in throwing distance were accompanied with increases in arm speed, shoulder external rotation, and elbow varus torque and a decrease in arm slot.

Table 1
Composite mean (± SD) for recorded metrics at each distance for all 95 players

Distance	9 m	18 m	27 m	37 m	46 m
Torque (Nm)[b]	39 (± 4)	50 (± 5)	55 (± 3)	58 (± 3)	58 (± 7)
Arm slot (°)[a]	55 (± 6)	50 (± 5)	48 (± 5)	46 (± 6)	44 (± 7)
Arm speed (°/s)[a]	2731 (± 563)	4066 (± 480)	4622 (± 328)	4909 (± 332)	5044 (± 416)
Shoulder rotation (°)[a]	147 (± 7)	155 (± 5)	161 (± 4)	165 (±4)	167 (± 5)

Note: Significant differences (p < 0.01) between: **a**) all groups and **b**) all groups except for 37 m and 46

DISCUSSION: Individualization of a throwing program is key to maintaining health of a player, as well as returning a player to pre-injury activities. However, previous long-toss research has only studied college players, forcing researchers and coaches to apply these data to high school players. In the current study we found, in contrast to previous reports on collegiate and professional baseball players, the progression of throwing distances for high school throwers consistently resulted in increased shoulder rotation and arm speed. Similarly, the increased distances exposed the elbow to higher stress during the throwing motion.

Fleisig and colleagues (2011) reported maximum distance throws (80 ± 9 m) produced greater elbow and shoulder torques compared to the shorter flat-ground and mound throws. Similarly, we found as the throwing distance increased there was an associated increase in elbow varus torque. However, throws from 37 m and 46 m distances had the same elbow varus torque (both 58 Nm). It is possible that players who are able to withstand the elbow stress while throwing at 37 m can safely increase to 46 m distance without worrying they are increasing the stress per throw on their elbow. Moreover, it is possible that there were no differences found between 37 m and 46 m because players were allowed to use crow-hop footwork during throws. Previous reports have indicated the use of the crow-hop facilitates the use of the whole body, or kinetic chain, and can be a protective mechanism for the upper body (Slenker et al., 2014). Slenker et al. (2014) reported no significant differences found across all long-toss distances (18 m, 27 m, 37 m, and 55 m) for both shoulder and elbow kinetics. The authors emphasized the use of a crow-hop footwork to reduce the stress on the upper extremity. While the current study did not restrict the use of crow-hop footwork, future studies should investigate the effects of crow-hop footwork compared to set position throws at different distances on elbow varus torque.

As players progressed to greater long-toss distances there was a decrease in arm slot positioning. It is possible that with the shorter distances (9 m and 18 m) the players were throwing with less effort, resulting in a more 'over the top' throw, and as they progressed to greater distances their arm slot decreased to a more natural position. Miyanishi, Fujii, Ae, Kunugi, and Okada (1995) reported no difference in elbow flexion at ball release between distance and speed throws; however, players had greater trunk lateral flexion during the distance throws (33°) compared to speed throws (24°). Traditionally arm slot is a combination of trunk lateral flexion, shoulder abduction, and elbow flexion; however, the motusBASEBALL™ sensor measured arm slot relative to the ground, and does not account for trunk and shoulder movement. It is possible that changes in arm slot with increased throwing distance are actually a result of trunk lateral flexion rather than changes in elbow flexion. Previously published research has not investigated the specific changes in elbow flexion during interval throwing and future research should be explored to confirm this idea.
Many proponents of interval throwing programs argue that with continued use and increased distance, increased arm speed will develop. While the long term effects of interval throwing were not investigated, the current study found that increased throwing distances were accompanied by within-subject increases in arm speed. Conversely, Fleisig et al. (2011) reported no significant differences in shoulder internal rotation velocity between throwing distances. It is possible that we detected these differences in arm speed due to of our computation method. While internal rotation velocity is defined as the angular velocity of the long axis of the upper arm only, the device calculates a composite angular velocity using all three axes. Future research should be conducted on the long-term effects of interval throwing programs and the translation to normal throwing mechanics.
Previous research has shown that maximum shoulder external rotation increases with throwing distance (Fleisig et al., 2011; Miyanishi et al., 1995). This was confirmed in the current study with a 21° increase in shoulder external rotation from 9 m to the longest distance (46 m) within-subject. In previous research comparing partial- to full-effort throws, Fleisig et al. (1996) reported shoulder external rotation increased as pitchers progressed from 50% effort throws to 100% effort. As previously mentioned regarding arm slot, it is possible that players were not throwing with full effort at shorter distances, but as the distance increased, players started to throw with greater effort, resulting in increased shoulder rotation. However, comparing shoulder external rotation values to other studies warrants caution as the sensor used in the current study measured shoulder external rotation relative to the ground, whereas other studies reported shoulder external rotation relative to the trunk. Increasing shoulder range of motion has shown to translate into increased performance in pitching, specifically ball speed (Hurd et al., 2012; Olsen, Fleisig, Dun, Loftice, & Andrews, 2006). Unfortunately, excessive shoulder external rotation during pitching has also been shown to result in higher elbow varus torque (Aguinaldo & Chambers 2009; Anz et al., 2010). In a previous study using the motusBASEBALL™ sensor on professional baseball players, every 8° increase in shoulder external rotation was associated with a 1-Nm increase in elbow varus torque (unpublished). Therefore, increased shoulder external rotation resulting from increased throwing distances may contribute to added varus torque at the elbow.

CONCLUSION: In the current study, as the throwing distance increased there was an associated increase in elbow varus torque, arm speed, and arm rotation. As players progressed to greater long-toss distances, arm slot decreased. Results from this study on high school baseball players differ from previous research on college players during a long-toss protocol. Utilizing longer distances for training and conditioning has been shown to be beneficial in increasing shoulder range of motion and arm speed; however, caution is warranted when increasing throwing distances as there is a subsequent increase in elbow varus torque.

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