The Effect of Straight-Line Long-Toss Versus Ultra-Long-Toss Throwing on Passive Glenohumeral Range of Motion Recovery After Pitching

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Background: Repetitive throwing in baseball pitchers can lead to pathologic changes in shoulder anatomy, range of motion (notably glenohumeral internal rotation deficit), and subsequent injury; however, the ideal strengthening, recovery, and maintenance protocol of the throwing shoulder in baseball remains unclear. Two strategies for throwing shoulder recovery from pitching are straight-line long-toss (SLT) throwing and ultra-long-toss (ULT) throwing, although neither is preferentially supported by empirical data.

Hypothesis: ULT will be more effective in returning baseline internal rotation as compared with SLT in collegiate pitchers after a pitching session.

Study Design: Cohort study.

Level of Evidence: Level 3.

Methods: A total of 24 National Collegiate Athletic Association Division I baseball pitchers with mean age 20.0 ± 1.1 years were randomized to either the ULT group (n = 13; 9 right-hand dominant, 4 left-hand dominant) or SLT group (n = 11; 10 right-hand dominant, 1 left-hand dominant). Measurements (dominant and nondominant, 90° abducted external rotation [ER], internal rotation [IR], and total range of motion [TROM]) were taken at 5 time points across 3 days: before and immediately after a standardized bullpen session on day 1; before and immediately after a randomized standardized ULT or SLT session on day 2; and before practice on Day 3.

Results: ULT demonstrated significantly greater final ER compared with baseline (+10°; $P = 0.05$), but did not demonstrate significant IR changes. Similarly, SLT demonstrated significantly greater post-SLT ER (+12°; $P = 0.02$) and TROM (+12°; $P = 0.01$) compared with baseline, but no significant IR changes. Final ER measurements were similar between ULT (135° ± 14°) and SLT (138° ± 10°) ($P = 0.59$). There was also no statistically significant difference in final IR between ULT (51° ± 14°) and SLT (56° ± 8°) ($P = 0.27$).

Conclusion: The routine use of postperformance, ULT throwing to recover from range of motion alterations, specifically IR loss, after a pitching session is not superior to standard, SLT throwing. Based on these findings, the choice of postpitching recovery throwing could be player specific based on experience and comfort.

Clinical Relevance: The most effective throwing regimens for enhancing performance and reducing residual impairment are unclear, and ideal recovery and maintenance protocols are frequently debated with little supporting data. Two strategies for throwing shoulder recovery from pitching are SLT and ULT throwing. These are employed to help maintain range of motion and limit IR loss in pitchers. The routine use of ULT throwing for recovery and to limit range of motion alterations after a pitching session is not superior to SLT throwing.

Keywords: shoulder; baseball; injury prevention; glenohumeral internal rotation deficit (GIRD); long toss

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The throwing shoulder of overhead athletes undergoes adaptive changes resulting in unique glenohumeral range of motion (ROM) characteristics, specifically greater external rotation (ER), and reduced internal rotation (IR) in comparison with their nonthrowing shoulder with retention of overall degree of motion.[3,4,6-8,13,15,19,24,26,27] These motion changes in adolescent throwers are attributed to a combination of osseous and soft tissue changes during skeletal development.[23] Osseous adaptations, such as greater humeral head retroversion in the throwing shoulder, are frequently seen in pitchers at the high school, collegiate, and professional levels.[13,15,24-27,31] Acute soft tissue adaptations associated with throwing on the resultant motion pattern have also been postulated. Alterations in glenohumeral range of motion have been documented as early as after 1 starting appearance in both collegiate[19] and minor league[12] pitchers. Freehill et al also demonstrated these changes over the course of a season in both collegiate[19] and Major League Baseball pitchers.[20] This time frame likely favors the soft tissues as the etiology of acute motion loss. The arc of motion changes are theorized to provide an advantageous adaptation for pitchers, allowing a greater degree of ER during the late arm cocking phase of a pitch, increasing the arc of rotation, maximizing IR angular velocity, and resulting in increased pitch velocity.[9,17]

Glenohumeral internal rotation deficit (GIRD) is defined as an IR deficit roughly ≥20° compared with the nonthrowing shoulder at 90° of abduction.[1,9,34] The GIRD phenomenon has been reported to pose a significant risk for overuse injuries of the shoulder and elbow in throwing athletes.[7,9-11,32,35,36] Despite substantial evidence that repetitive throwing in baseball pitchers can lead to pathologic changes in shoulder anatomy and subsequent injuries, the ideal method for strengthening, recovery, and maintenance of the throwing arm remains elusive. The most effective throwing regimens to enhance performance while reducing impairments (ie, GIRD) are unclear and frequently debated with little supporting data. Although the distance pitchers throw during games is approximately 60 feet, 6 inches (18.4 m), it has been suggested that training regimens include throwing at distances beyond that threshold to bolster neuromuscular adaptations and assist in postthrowing recovery.[37] Two strategies for throwing shoulder recovery after pitching are straight-line long-toss (SLT; limited distance, ≤120 feet) and ultra-long-toss (ULT; maximum distance).[2]

Limited-distance SLT throwing is thought to mimic more normal pitching mechanics, whereas ULT throwing alters shoulder kinematics but offers the theoretical advantage of stretching the posterior capsule, increasing flexibility, and building arm strength and endurance without recapitulating normal pitching mechanics.[16,18] Longer throwing distances require greater upward trunk extension and greater rotational velocity in the transverse plane (increased pelvic and trunk angular velocity) and leads to greater shoulder ROM and arm torque.[18] The increase in shoulder and elbow torque has led some authors to caution its use in early rehabilitation after injury or surgical procedures involving anterior capsular or capsulolabral repair.[18] Neither strategy is well-supported by objective data on the effects of ROM recovery. The broader purpose of this study was to determine if ULT or SLT was more efficacious at arm recovery by specifically evaluating restoration of passive glenohumeral ROM after baseball pitching. We hypothesized that ULT would preserve glenohumeral ROM after a standardized pitching session more effectively than SLT throwing.

METHODS

All aspects of the study were approved by the Wake Forest University Health Sciences Institutional Review Board (IRB number: IRB00047069). All participants were counseled on the purpose and methodology of the study and provided informed consent.

Study Population

A total of 24 National Collegiate Athletic Association Division I baseball pitchers were recruited to participate in this randomized, controlled study during the 2016 (n = 16) and 2019 (n = 8) preseasons. We were unable to conduct the experiment during the 2017 and 2018 preseasons due to logistical reasons. Players were excluded if they had a history of throwing shoulder surgery or current shoulder or elbow pain. Players who participated in 2016 were excluded as a repeat participant in 2019. Prior to a standardized pitching session, the pitchers were randomized to ULT or SLT throwing groups. Measurements were taken at 5 time points across 3 days (Figure 1): before and immediately after a standardized bullpen pitching session on day 1; before and immediately after a standardized ULT or SLT session on day 2; and before practice on day 3. Prior to each throwing session, the pitchers underwent routine 15-minute stretching and warm-up exercises directed by the head athletic trainer. The throwing prior to the bullpen was the individual's pre–mound throwing protocol or routine. For the bullpen session, the pitchers were asked to throw fastballs at maximum effort for a total of 30 pitches; however, velocity and throwing effort was not measured.

ULT Regimen

For the ULT, pitchers were instructed to throw the ball out to a maximum distance to a teammate randomized to the same group (Video Supplement 1, available in the online version of this article). For the SLT, pitchers reached a maximum of 37 m (120 ft) and were instructed to throw on a horizontal line to each other (Video Supplement 2, available online). For both throwing strategies, pitchers were allowed, but not mandated, to use crow-hop footwork. The pitchers in both groups were asked to throw at maximum effort at the intended distance for 10 minutes once they reached their terminal predetermined distance without a gradual increase from softer throws and without a limit in the total number of throws. We employed the standard time-based routine for throwing in baseball since sets are not usually determined by the numbers of throws in a nonrehabilitation setting.

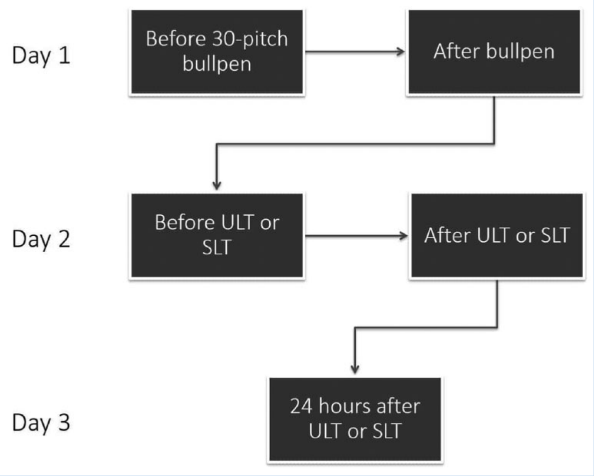

Figure 1. Measurements were taken at 5 time points across 3 days: before (baseline) and immediately after a standardized bullpen pitching session on day 1; before and immediately after a standardized ultra-long-toss (ULT) or straight-line long-toss (SLT) session on day 2; and before practice on day 3.

Figure 2. The pitchers were positioned supine on a standard treatment table. The shoulder was positioned at 90° of abduction with 30° of horizontal adduction in line with the scapular plane by the athletic trainer. Measurements were obtained with a bubble inclinometer using the olecranon as a reference point for the axis of the goniometer.

Range of Motion Measurement

The head athletic trainer was involved in positioning and stabilization of the shoulder, while 2 orthopaedic surgery residents performed all measurements under the supervision of an attending fellowship-trained orthopaedic sports medicine faculty. Measurements were obtained with the player lying supine on a standard treatment table as previously described and published (Figure 2).[38] The prebullpen measurement obtained on day 1 was designated as the baseline. The shoulder was positioned at 90° of abduction with 30° of horizontal adduction in line with the scapular plane. The elbow was flexed at 90°. A small foam roll was placed under the arm to help the examiner stabilize the scapular body and align the arm in the plane of the scapula.[38] The athletic trainer passively moved the shoulder to the endpoint of ER or IR without applying overpressure. This position was achieved using a combination of endpoint feel and visualization of compensatory movement of the shoulder girdle by the examiner and examination team. With the arm held in position, a standard long-arm goniometer with attached customized bubble inclinometer (Medco Supply Company, Inc) was used to measure maximal passive limits of ER and IR (Figure 2). The olecranon was used as a reference point for the axis of the goniometer, with the moving arm of the goniometer along the ulnar shaft and the stable arm perpendicular to the floor, as indicated by the bubble inclinometer. Both the dominant and nondominant sides were measured in the same manner based on previously established methods.[12,19,20] Each examiner performed the measurements twice and was blinded to the other examiner's results. Examiners were not blinded to hand-dominance of the pitchers for practical purposes. All study participants performed standardized shoulder and arm warm-ups and cool-downs per team protocol, which were performed after measurements were obtained before throwing and after throwing at all time points. Additionally, the players were responsible for performing self-directed daily sleeper stretches taught by a certified athletic trainer.

Statistical Analysis

The collected glenohumeral measurements were expressed as means and standard deviations. Total ROM (TROM) was calculated as a sum of ER and IR. GIRD was calculated as the difference between nondominant IR and dominant IR at 90° of abduction. The distribution of data for each variable was determined to be normal as assessed by the Shapiro-Wilk test. Repeated-measures analyses of variance were used to analyze within- and between-group measurement differences across the 5 time points. The change in ROM was calculated and compared between time points and throwing groups. Raw change for each parameter was calculated across the 5 time points and directly compared between the 2 groups of pitchers. Percentage change was only calculated for the TROM calculated across the 4 time points because the total range was independent of the arbitrary choice of the zero-position. Mauchly test was utilized to assess sphericity. In the event sphericity had been violated, a Greenhouse-Geisser correction was employed. The Bonferroni method was used for post hoc analysis as appropriate. Statistical significance was set at $P \leq 0.05$. The reporting of 95% CIs was made only when statistical significance was achieved. All analyses were performed on SPSS (Version 26; IBM Corp).

Interobserver reliability was determined using repeated measurements of ER and IR on both the dominant and the nondominant shoulders of 10 healthy volunteers. The intraclass correlation coefficient (ICC) was calculated within a 2-way random effects model (2,1) and absolute agreement. This

Table 1. Range of motion across time points for the ultra-long-toss (ULT) throwing group (n = 13) reported as mean (SD)

	Baseline, Prebullpen	Postbullpen	Pre-ULT	Post-ULT	Final
External rotation, deg	125 (11)	131 (17)	127 (18)	137 (14)	135 (14)[a]
Internal rotation, deg	55 (10)	57 (13)	52 (10)	56 (15)	51 (14)
Total range of motion, deg	180 (18)	187 (17)	179 (13)	193 (14)	186 (15)
GIRD, deg	12.6 (8)	8 (10)	15 (8)	14 (10)	15 (10)

GIRD, glenohumeral internal rotation deficit.
[a]Final significantly greater than baseline ($P = 0.05$).

yielded an ICC of 0.92 for ER and 0.73 for IR, demonstrating acceptable reliability. An ICC greater than 0.75 was interpreted as excellent while values between 0.40 and 0.75 were considered fair to good and values <0.40 were considered poor.[14] For ER, the standard error of measurement and minimal detectable change at the 90% confidence level was determined to be 3.8° and 8.9°, respectively. For IR, the standard error of measurement was 4.7° and minimal detectable change at the 90% confidence level was 11.0°.

Power Analysis

A sample size of 10 participants per group would have 80% power to detect a difference in means of −9° in IR (the difference between a baseline mean of 54° and a final measure of 45°). Statistical assumptions included a common SD of 7, a 2-group *t* test, and a 2-sided significance level of $\alpha \le 0.05$.[21,30]

RESULTS

Twenty-four pitchers with mean age 20.0 ± 1.1 years were randomized to either the ULT group (n = 13; 9 right-hand dominant, 4 left-hand dominant) or the SLT group (n = 11; 10 right-hand dominant, 1 left-hand dominant).

Comparison of ROM Within Each Throwing Group

ROM data for both groups demonstrated normal distribution. For the ULT group (Table 1), the majority of range of motion measurements did not differ between time points. Although ER increased by 2.3° to 10.4° across the various time points compared with the baseline, only the final ER measurement demonstrated a significant increase (+10.4°; $P = 0.05$; 95% CI = 0.07-20.7). When compared with the baseline, the post-ULT and final ER measurements exceeded the calculated minimal detectable change of 8.9°. None of the IR measurements exceeded the minimal detectable change of 11.0°.

For the SLT group (Table 2), ER increased by 7.7° to 11.6° across the various time points compared with the baseline measurement; however, only the post-SLT measurement was significantly greater compared with the baseline measurement (+11.6°; $P = 0.02$; 95% CI = 1.5-21.7). This was also the only time ER exceeded the minimal detectable change of 8.9°. The TROM measurement at the post-SLT time point was also significantly greater compared with the baseline measurement (+12.3°; $P = 0.01$; 95% CI = 1.8-22.9). None of the IR measurements exceeded the minimal detectable change of 11.0°.

Comparison of ROM Changes Between Throwing Groups

The SLT group (196° ± 12.2°) had significantly greater TROM at the prethrow time point compared with the ULT group (179° ± 12.8°) ($P = 0.003$). No other significant differences occurred between the groups for baseline to final measurements (Table 3). The ULT group gained 11.7° of ER after ULT throwing compared with baseline. Similarly, the SLT group gained 11.6° of ER after SLT throwing compared with baseline. The ULT group gained 0.7° of IR after ULT throwing compared with baseline. Similarly, the SLT group gained 0.8° of IR after SLT throwing compared with baseline. There was no statistically significant difference in final IR between ULT (51.2° ± 13.9°) and SLT (56.2° ± 8.3°). TROM increased by 12.3° (+7%) in both groups in the postthrow setting compared with baseline.

DISCUSSION

The principal finding of this study was that ULT throwing does not maintain or improve IR or TROM after a pitching session compared with SLT throwing. Thus, these findings do not support the theory that ULT is better at preserving throwing shoulder ROM compared with SLT. ROM recovery was expected to improve more readily with ULT, because it typically employs the use of a crow-hop and different posterior chain activation to gain the characteristic parabolic arc of the thrown ball. Although the different mechanics may negatively affect ROM over time, the data from this study revealed increases in ER, but no immediate influence on IR after either throwing regimen.

The current literature is limited on the most effective program for recovery of baseline shoulder range of motion the day after mound pitching.[18,33] While rest has been proposed and may be a viable option in starting pitchers who do not compete on a daily

Table 2. Range of motion across time points for the straight-line long-toss (SLT) throwing group (n = 11) reported as mean (SD)

	Baseline, Prebullpen	Postbullpen	Pre-SLT	Post-SLT	Final
External rotation, deg	130 (15)	137 (16)	137 (9)	141 (12)[a]	138 (10)
Internal rotation, deg	59 (14)	57 (12)	59 (8)	60 (14)	56 (8)
Total range of motion, deg	189 (11)	193 (14)	196 (12)	201 (14)[a]	194 (9)
GIRD, deg	10 (18)	8 (11)	10 (6)	11 (10)	14 (7)

GIRD, glenohumeral internal rotation deficit.
[a]Post-SLT significantly greater than baseline ($P \le 0.02$).

basis, Reinold et al[30] demonstrated that the reduction in glenohumeral IR and total motion seen immediately after pitching is present even after 24 hours, while Kibler et al[21] demonstrated that these motion reductions can linger for up to 72 hours after pitching. The present study introduces a differential throwing program to compare the in vivo changes in glenohumeral ROM before and after the intervention. Various programs aimed at stretching the posterior capsule and musculature are employed to help pitchers recover. Lintner et al[22] demonstrated significantly greater dominant shoulder IR and TROM in male professional pitchers who participated in a dedicated stretching program for 3 or more years compared with pitchers who did not participate in a formal stretching program. Yamauchi et al[39] compared 2 stretching programs (modified cross-body stretch and modified sleeper stretch) over 4 weeks in college players with GIRD and found similar efficacy in improvements in glenohumeral IR and TROM. Finally, a weighted baseball throwing program has been shown to increase throwing velocity but also resulted in increased glenohumeral ER and injury rates.[28,29]

Fleisig et al[18] demonstrated significant kinematic differences between 4 types of throwing (traditional mound pitching at 18.4 m [60 ft], flat-ground throwing at 37 m [120 ft], flat-ground throwing at 55 m [180 ft], and flat-ground throwing at maximum distance). Based on 3-dimensional motion analysis, maximum distance throwing (80 ± 9 m; 262 ± 30 ft) demonstrated greater maximum shoulder ER, greater IR torque at the moment of maximum shoulder ER, and greater shoulder and elbow torque compared with the other throws. Similarly, a recent evaluation in high school players of varying positions demonstrated increasing maximum shoulder ER with increasing throwing distance during long-toss.[16] These findings suggest that the altered kinetic chain in the transverse plane and increased anterior shoulder tension during ULT would stretch the shoulder capsule to allow greater overall glenohumeral ROM, especially increased ER. Our results further demonstrate that this increase in ER is maintained the day after ULT.

Slenker et al[33] compared hard throwing on a horizontal line from 18 m (60 ft), 27 m (90 ft), 37 m (120 ft), and 55 m (180 ft) versus fastball pitching from the mound at 18 m (60 ft). The short distance flat-ground throwing did not utilize a running start or crow-hop footwork, and so straight-line throwing more closely resembled mound pitching mechanics. The authors did not find statistically significant differences in humeral IR torque or elbow valgus load between mound pitching and flat-ground throwing from any distance.

In this study, pitchers in the SLT group threw to a maximum distance of 37 m (120 ft). While this is twice the distance of traditional mound pitching, SLT still simulated normal pitching mechanics and did not exhibit a significant impact on ROM. Debate remains how much ER is too much and how much stretching of the anterior capsule is advantageous versus detrimental. Although the authors anticipated both ER and IR increase after ULT, only the final ER measurement was significantly greater compared with baseline. Furthermore, the authors expected that hard throwing on a line during SLT would exacerbate GIRD due to similar throwing mechanics and shoulder torque to mound pitching; however, IR was not significantly affected by either throwing intervention in this study. These findings could occur because (1) throwing for 10 minutes may not have been enough time for the posterior soft tissue adaptations to occur and/or (2) the initial postbullpen IR may not have been as affected in a nongame situation, a limit of 30 pitches, and a more limited number of throws an athlete may have performed in an actual game day situation. Despite these potential confounders, the goal of implementing a maintenance and recovery throwing program is to effect change and neither program significantly altered short-term IR.

To facilitate throwing at longer distances, Slenker et al[33] found that pitchers often used the crow-hop technique, which theoretically places less stress on the upper extremity while generating a similar amount of torque during the throwing motion by increasing power output from the lower extremity.

In this study, pitchers were not given specific instructions on technique during long-toss. Our players were permitted to use the crow-hop footwork based on personal preference. Furthermore, we did not collect data on precise crow-hop

Table 3. Throwing arm range of motion comparison between ultra-long-toss (ULT; n = 13) and straight-line long-toss (SLT; n = 11) throwing groups reported as mean (SD)

	External Rotation[a]			Internal Rotation[a]			Total Range of Motion		
	ULT, deg	SLT, deg	*P*	ULT, deg	SLT, deg	*P*	ULT, deg	SLT, deg	*P*
Baseline, prebullpen	125 (11)	130 (15)	0.40	55 (10)	59 (14)	0.46	180 (12)	189 (11)	0.09
Postbullpen	131 (13)	137 (17)	0.38	57 (13)	57 (12)	0.99	187 (17)	193 (14)	0.35
% Change from baseline	—	—	—	—	—	—	4	3	0.79
Prethrow	127 (18)	137 (9)	0.08	52 (10)	59 (8)	0.07	179 (13)	196 (12)	0.003[b]
% Change from baseline	—	—	—	—	—	—	−1	4	0.09
Postthrow	137 (14)	141 (12)	0.40	56 (15)	60 (14)	0.52	193 (14)	201 (14)	0.16
% Change from baseline	—	—	—	—	—	—	7	7	0.93
Final	135 (14)	138 (10)	0.59	51 (14)	56 (8)	0.27	186 (15)	194 (9)	0.13
% Change from baseline	—	—	—	—	—	—	4	3	0.92

[a]Percentage change for external rotation and internal rotation were omitted, denoted by —, as the baseline values needed to calculate degree change depended on the zero-position (forearm in the horizontal plane vs the vertical plane).
[b]Pre–long toss total range of motion significantly greater in the SLT group ($P = 0.003$).

technique, which could potentially contribute to variability in the results. This demonstrates the need for future research to define the components of long-toss and ULT to standardize these throwing programs for pitchers.

While our study has the distinct advantage of being randomized and prospective in elite throwers from 1 program, it carries several limitations. The study design was limited by the small sample size, as the study was conducted at a single program; however, we performed an a priori power analysis, which ensured that we had a sufficient number of participants to find the minimal detectable changes in ROM outcomes. A subgroup analysis of starters versus relievers could not be performed due to a small number of participants and variability of their utilization during the season. It is possible that pitcher classification could affect the results. The bubble goniometer (inclinometer) is another source of potential error and limitation to the study, as measurement errors of ±5° have been reported when even more than 1 examiner performed the measurements[5]; however, we demonstrated acceptable interobserver measurement reliability. The ICC was greater for ER measurements (ICC = 0.92) compared with IR measurements (ICC = 0.73), which may be due to the difficulty in precisely controlling scapular motion during IR measurements.[38] However, an ICC of 0.73 for IR is deemed acceptable and lies just outside the threshold for an excellent rating.[14] We set a 10-minute session to ensure focus and compliance with the testing protocol, and while the number of throws varied slightly between pitchers, all easily met the 15-throw minimum necessary to produce statistically significant data based on previous kinematic studies.[18,33] Postbullpen stretching was self-directed, which may have contributed to the greater than expected difference in glenohumeral ROM between the 2 groups prior to the long-toss session. Last, given the short duration of the study, we cannot extrapolate whether either throwing regimen yields substantial change over the course of an entire season.

CONCLUSION

The routine use of postperformance, ULT throwing to recover from IR loss after a pitching session is not superior to standard, SLT throwing. Further investigation is needed into these different throwing routines to determine definitively if they can be considered equal or one superior to the other. Based on these findings, the choice of postpitching recovery throwing could be player specific based on experience and comfort.

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