Changing Body Movement Patterns in 9-Year-Old Baseball Pitchers

A Pilot Study

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Background: Arm injuries in throwing athletes continue to increase. Injuries may be due to multiple variables, including inefficient body movement patterns, especially in young baseball throwers. It is unclear whether these patterns can be efficiently altered in this population.

Purpose/Hypothesis: To investigate the effect of a novel 21-day throwing program on body movement patterns in youth baseball players using common practical tools. Our hypothesis was that this program would change body movement patterns over a relatively short period.

Study Design: Descriptive laboratory study.

Methods: Ten 9-year-old baseball athletes were asked to participate in a 21–consecutive day throwing program focused on decreasing inefficiencies. All participants underwent video evaluation from 2 vantage points as well as radar evaluation before and after the programs. Throwing arm humerothoracic and antecubital angles as well as pelvic angles in the frontal view were measured at the time of front (directional) leg heel/toe down (late cocking) for each of 3 pitches. Glove-side humerothoracic angles and back leg minimum popliteal angles were measured from behind for each of 3 additional pitches. Velocity was measured using a radar gun. All angular measurements were performed by a physical therapist blinded to the purposes of the program and study as well as to video chronology.

Results: Throwing arm antecubital angle ($P = .01$) and humerothoracic angle ($P = .03$) as well as back leg minimum popliteal angle ($P = .03$) all decreased, with mean decreases of 35°, 10°, and 8°, respectively. Velocity increased with decreased back leg popliteal angles ($P = .019$); mean velocity increased 2.6 mph ($P = .016$).

Conclusion: Young baseball throwers can quickly retrain their bodies to accomplish different movement patterns.

Clinical Relevance: This novel throwing program may have implications for injury prevention and treatment as we identify better baseball-throwing movement patterns.

Keywords: shoulder; youth; baseball; pain; elbow; throwing injuries

Most of the 11.5 million athletes playing baseball in the United States compete at the high school or club level.[17] In 2016, increasing numbers of youth and professional baseball players developed shoulder and elbow injuries.[3,7,9,18,19,22] The number of players undergoing surgical intervention for arm injuries, particularly at young ages, has risen at an alarming rate.[3,7]

Major League Baseball (MLB) has enacted Pitch Smart guidelines to stratify the maximum number of pitches to be thrown by players based on their respective ages,[1] and the American Orthopaedic Society for Sports Medicine has employed a similar STOP Sports Injuries campaign[14] that provides guidance on how to prevent youth baseball overuse injuries. However, injuries continue to increase.[7,19] At the MLB level, fewer and fewer 130-pitch outings are being seen, with increasing numbers of injuries continuing to occur. In fact, annually, 60% of MLB pitchers spend time on the disabled list.[2] Unfortunately, it is unclear whether pitch counts and reduction in number of pitches has decreased arm pain or injury.[2,16,23] In addition, compliance with these pitch count recommendations in youth athletes is often poor.[8]

Some authors propose that optimizing pitching mechanics, which we refer to as "body movement patterns," may be more effective in preventing shoulder and elbow injuries in pitchers.[4,11,28] However, there is limited evidence that body

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movement patterns can be changed effectively, particularly in young athletes. The purpose of this study was to investigate the effect of a novel 21-day throwing program (Durathro program; Texas Baseball Ranch [TBR]) on body movement patterns in youth baseball players using common practical tools. Our hypothesis was that this program would change body movement patterns over a relatively short period.

METHODS

As a pilot project, a 9-year-old youth club baseball team of 10 boys was studied. This team had undergone 2 prior full seasons of training and travel, playing 30 and 36 games in those 2 seasons, respectively. Fall, winter, and spring practices were held both years. Two players were held from pitching for shoulder pain at various points during the second year; however, no player was held from playing altogether at any time during the 2-year period due to arm injury or pain. Pitch counts were closely monitored for all pitchers, and nationally accepted limits for their respective age group were strictly utilized (http://m.mlb.com/pitchsmart/pitching-guidelines). Pitching instruction emphasized throwing arm elbow extension and elevation ("reaching back and keeping the elbow up") as well as "standing tall and falling" (toward home plate). The information that follows was gathered after the second summer season.

The senior author (E.V.F.) attended a 3-day baseball pitching camp in the summer of 2015 in Omaha, Nebraska, that was put on by the TBR. The camp consisted of 9 hours over 3 days. Initial instruction focused on body movement patterns in baseball throwing. Practical, inexpensive, and reproducible tools and drills were introduced. After the camp, the senior author spent 50 hours studying DVDs from the TBR. These instructional videos focused on slow-motion video of body movement patterns with baseball throwing as well as specific drills and tools introduced at the camp. After this, the entire team was invited to participate in the program (Durathro program). Over the course of the next 8 weeks, the senior author held 90-minute teaching/training sessions every Wednesday evening for players and fathers; thus, there were a total of eight 90-minute sessions. Attendance was 100% for players and fathers. After the 8 sessions, 8 of the 10 players and their fathers completed the 21–consecutive day program. Two were unable as their fathers travel for work and were unable to work with their sons.

While young throwers often exhibit several inefficient body movement patterns due to many variables, we focused on the worst movement pattern for each player's throwing arm as well as their glove-sided arm and lower halves. Teaching prior to the program and instruction was "reach back, elbow up, be tall and fall." The significance of these positions and their relevance to arm injury prevention or performance enhancement is unknown. The premise of the program is that keeping throwing arms closer to the axial skeleton may limit soft tissue stresses. The TBR Durathro program is performed with the aid of "connection balls" (Oates Specialties, LLC). Connection balls are 12-inch-diameter inflatable lightweight balls placed in 1 or 2 of 3 locations: the proximal forearm of the throwing arm (position 1, Figure 1A), the posterior axilla of the throwing arm (position 2, Figure 1B), and the distal forearm of the glove side (position 3, Figure 1B). After initial video analysis, 6 players were diagnosed as having their worst throwing arm inefficiency being a throwing arm elbow higher than the shoulder in the late cocking phase,[12] and 2 were diagnosed as having their worst throwing arm inefficiency being premature throwing arm elbow extension (elbow flexed greater than 90° at late cocking phase). All 8 had inefficient glove-side arms and lower halves (legs, core, etc). As for the glove side, the glove was off line (toward the nondominant side) for all. As an example, for a right-handed thrower, his glove was noted to be left of his lead leg (left) at the time of ball release as opposed to being in line at the time of ball release. As part of their teaching had also been to "stand tall and fall," there was little lower half involvement as the dominant leg (back knee) was often extended at the time of late cocking.

All 8 players were taken through the same 21–consecutive day program. This program is designed in a "blended" fashion and focuses on retraining the entire body. As part of the "blending" prescribed by the program, there are 3 main modes of performing the throwing drills. In the first mode, drills are performed using a weighted club (2.2 pounds; Oates Specialties, LLC) (Figure 1) and the connection balls. The club is held during repetitions. The connection balls are allowed to move freely as part of each repetition. In the second mode, the same drills performed in the first mode are performed with baseballs (rather than weighted clubs) and the connection balls. In the third mode, the same drills are performed using baseballs alone. The premise of the program is to re-create new body movement patterns rather than unlearning old ones. The connection balls and club passively "retrain" the body. All

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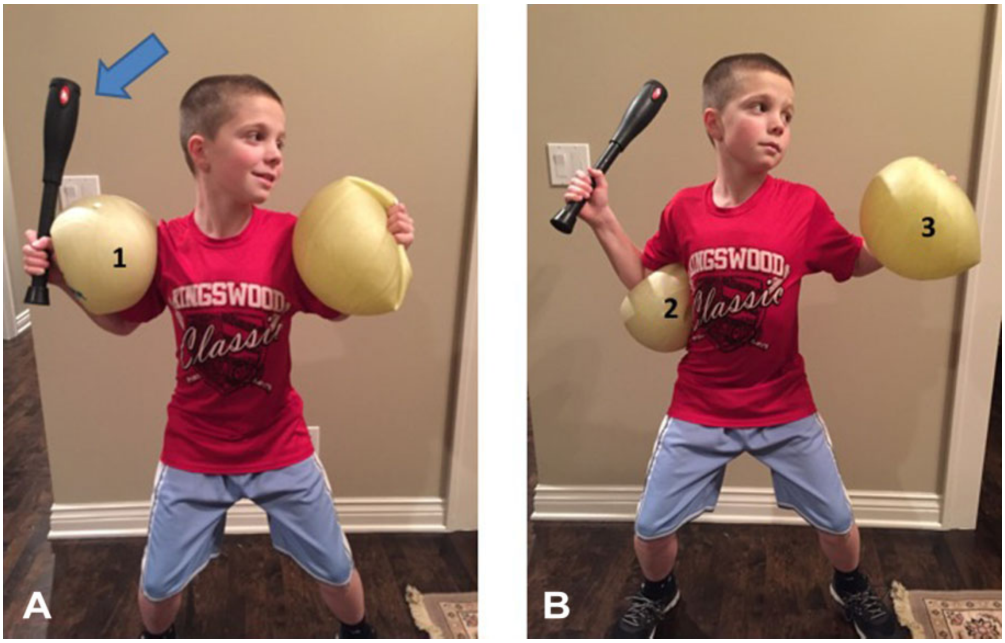

Figure 1. The throwing program. In the initial phase of the throwing program, 12-inch-diameter inflatable lightweight "connection balls" are placed in 1 or 2 of 3 locations: the proximal forearm of the throwing arm (ball position 1, Figure 1A), the posterior axilla of the throwing arm (ball position 2, Figure 1B), and the distal forearm of the glove side (ball position 3, Figure 1B). The drills are first performed with the connection balls and a weighted club (arrow), progressed to a baseball with the connection ball, and then performed with a baseball alone.

players did the same drills on flat ground and threw into a net. The program calls for a slow weaning from weighted club and connection ball utilization over the 21-day period. In the first 5 days of the program, 111 repetitions were performed. By day 21, 33 repetitions were performed. The number of repetitions was determined by the TBR based on their experience and is part of their 21-day program. During the program, the 6 players with elevated elbows performed all drills that required connection balls in positions 2 and 3. For the 2 players with premature elbow extension, all drills that required connection balls were performed with the balls in positions 1 and 3. All 8 participants performed the same 11 drills in each of the 3 modes for 21 consecutive days.

Before instruction and after the 21-day program, each player was asked to pitch into a net 25 feet from a pitching rubber for 9 consecutive pitches after a 10-minute warm-up. The following protocol was used both before and after the programs. For the first 3 pitches, each player was recorded from the front to allow visualization of the anterior and throwing arm sides of their bodies. For the next 3 pitches, each player was recorded from behind. All videos were obtained with an iPad (Apple Inc) using 720 p definition at 60 frames/s from the same locations for each of the video angles (anterior, posterior). All 24 (3 videos × 8 players) videos recorded from the front (third-base vantage) were obtained consecutively with the camera in the same position. Then all 24 videos recorded from behind (second-base vantage point) were obtained consecutively with the camera in the same position. All players were right-handed throwers. Hudl Technique software (Hudl) was used to analyze the videos. For the last 3 pitches, velocity was measured and recorded from behind the net using a radar gun (STALKER Sport 2). This device measures velocity in miles per hour (mph). All pitches were thrown utilizing a windup and from an age-appropriate mound with a pitching rubber. All instruction of players and fathers and respective 21–consecutive day programs occurred over a 90-day period.

A physical therapist was asked to obtain measurements from the videos within the Hudl Technique application, which allows one to measure the angle to the nearest degree. He was blinded as to the purpose of the study, the throwing program, and the chronology of pitching dates of the videos. From the frontal or anterior view (facing the player), at the point of front leg (directional leg) heel or toe down (late cocking), he measured the antecubital angle of the throwing arm, the humerothoracic angle of the throwing arm, and the angle formed by the inner thighs for each of 3 pitches for each player (Figure 2A). From the posterior view, at the point of ball launch, he measured the humerothoracic angle of the glove-side arm (Figure 2B). Also from posterior, he measured the minimum popliteal angle achieved by the player over the course of his windup for the back leg (Figure 2C). Measurement for each of these 2 posterior angles was also obtained for 3 pitches for each player. Thus, in total, each player had 15 measurements obtained (5 angles × 3 pitches) before the program and 15 measurements obtained (5 angles × 3 pitches) after the program.

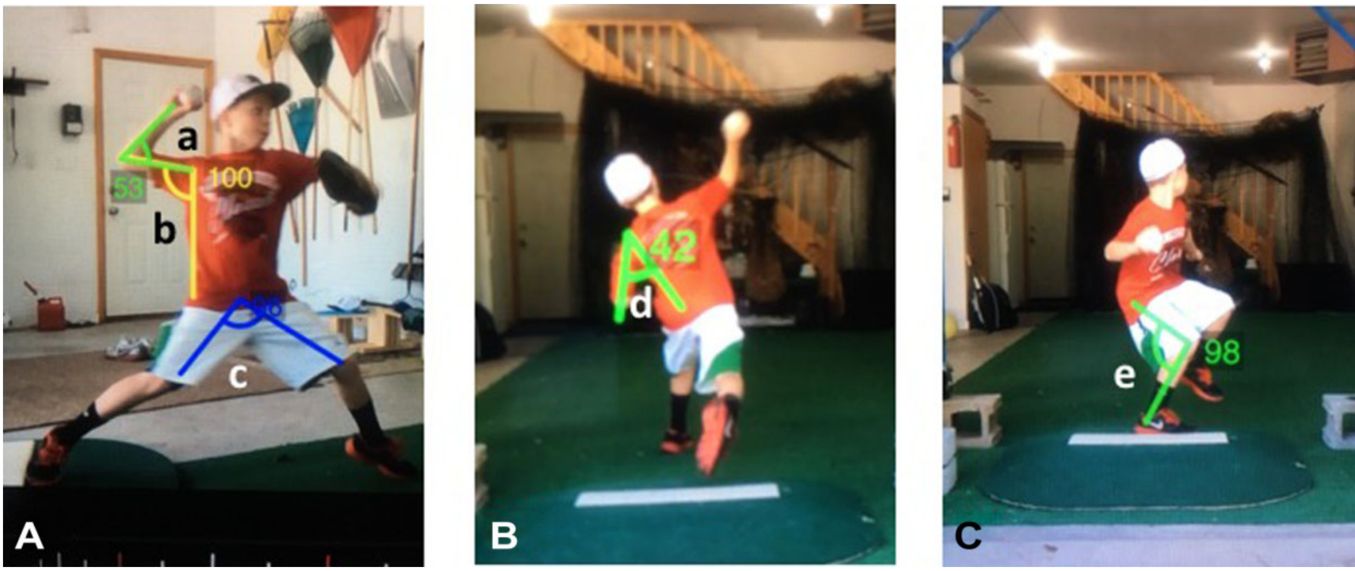

Figure 2. Body position measurements. Multiple angular measurements were captured from each player for analysis before and after the 21-day throwing program. From the frontal view at the point of toe/heel down (late cocking), the antecubital angle (*a*, Figure 2A) and the humerothoracic angle (*b*, Figure 2A) of the throwing arm were measured. The angle formed by the inner thighs was also measured (*c*, Figure 2A). From the posterior view, the humerothoracic angle (*d*, Figure 2B) of the glove-side arm at ball launch and minimum popliteal angle (*e*, Figure 2C) achieved by the player in the course of his windup were measured.

TABLE 1
Changes in Body Position and Pitch Velocity Before and After Throwing Program

	Day 0	Day 90	SD	Range	Difference	Effect Size	*P* Value[a]
Frontal antecubital angle, deg	98	63	29	9 to 60	35	1.19	**.01**
Frontal humerothoracic angle, deg	94	84	23	2 to 19	10	0.46	**.03**
Frontal inner thigh angle, deg	85	90	10	−14 to 4	−5	0.53	.23
Posterior popliteal angle, deg	103	95	8	1 to 15	8	0.99	**.03**
Posterior humerothoracic angle, deg	32	36	12	−13 to 5	−4	0.33	.32
Velocity, miles per hour	44.2	46.8	3.6	−5 to 0	2.6	0.84	**.016**

[a]Boldface *P* values indicate statistical significance ($P < .05$).

Statistical Analysis

For each of the 5 angles measured, the 8 players contributed 3 data points at 2 fixed time points (noted as before and after), which were 90 days apart. Data were first assessed graphically for outliers and missing data. One athlete was excluded for the 2 posterior angles because of missing data at the first time point due to a dysfunctional recording. With a continuous response variable, the relevant statistical analysis is a hierarchical linear model with the athlete as 1 source of variation (a random effect), and the 3 measurements at each time point also contribute to measurement variation. The within-player factor of time (before/after) is a fixed effect that was evaluated for statistical significance. Differences in the 2 means for time were evaluated with a paired *t* test using the appropriate elements of the variance/covariance matrix that account for correlations among the 6 measurements. The *P* value for equality and 95% confidence intervals for the differences in means were computed. All calculations were made using PROC MIXED with SAS/STAT software (version 9.4; SAS Institute).

RESULTS

When looking at the players from the frontal or anterior vantage point and measuring angles at the time of front (directional) leg heel/toe down (late cocking), throwing arm antecubital angle ($P = .01$) and throwing arm humerothoracic angle ($P = .03$) decreased (Table 1). When viewed from a posterior vantage point, the back leg minimum popliteal angle decreased ($P = .03$). The mean antecubital angle decreased from 98° to 63°, the mean humerothoracic angle decreased from 94° to 84°, and the mean minimum popliteal angle decreased from 103° to 95° (Figure 3).

Velocity increased with decreased back leg popliteal angle ($P = .019$), and the group's mean velocity increased

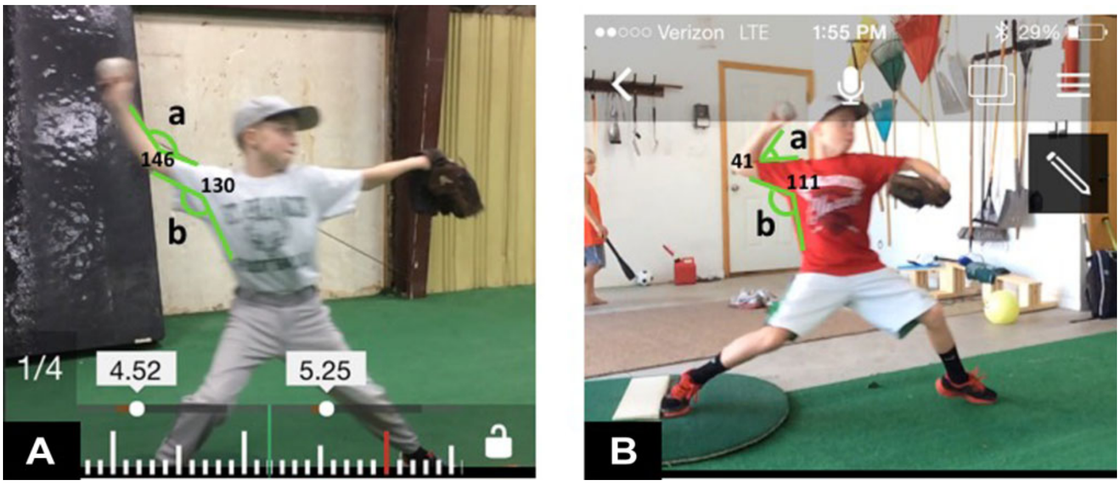

Figure 3. Body position before and after the throwing program. Frontal view of a 9-year-old thrower at the same toe/heel down (late cocking) phase of pitching (A) before and (B) after the 21-day throwing program. A clear decrease in the antecubital angle (*a*) and humerothoracic angle (*b*) are observed, accompanying the mean increase in velocity for the study group.

TABLE 2
Body Position and Pitch Velocity Before and After Throwing Program, Raw Data

		Range		
	Median	Minimum	Maximum	Total
Frontal antecubital angle, deg				
Day 0	94	47	161	114
Day 90	59	39	110	71
Frontal humerothoracic angle, deg				
Day 0	98	64	134	70
Day 90	87	51	111	60
Frontal inner thigh angle, deg				
Day 0	86	67	98	31
Day 90	89	71	111	40
Posterior popliteal angle, deg				
Day 0	103	86	115	29
Day 90	98	78	109	31
Posterior humerothoracic angle, deg				
Day 0	30	14	53	39
Day 90	33	18	55	37
Velocity, miles per hour				
Day 0	44	39	52	13
Day 90	48	42	50	8

2.6 mph ($P = .016$) (Table 1). All players but 1 improved their mean velocity, and variability improved; in other words, consistency was greater. Throwing arm antecubital angle ($P = .69$) and throwing arm humerothoracic angle ($P = .13$) were not associated with velocity changes.

Also, viewed from the front, the angle formed by the thrower's legs at the time of toe/heel down was unchanged. From posterior, glove side humerothoracic angle was also unchanged (Table 2).

DISCUSSION

The principal findings of this study demonstrate a significant decrease in throwing arm antecubital angle, throwing arm humerothoracic angle, and back leg popliteal angle. Mean velocity increased 2.6 mph. While the distance from the front of the pitching rubber to the front of the directional leg was visually greater in all 8 players, this distance could not be accurately measured using the Hudl Technique. These data support our hypothesis that a throwing program can change body movement patterns in youth baseball throwers relatively quickly.

While the phases of throwing have been well described,[5,10,12,15,21,26] optimal body and arm positioning during pitch delivery have yet to be defined. This may be difficult because of the variability between players. Yet, maximum shoulder external rotation, peak elbow extension, lead knee flexion, maximum pelvis angular velocity, and forward trunk tilt have all been associated with an increase in pitching velocity independent of age and body habitus.[20,25,28] However, the association between these parameters and the risk of overuse injury risk to the shoulder and elbow over the course of a player's career is unknown. The task of youth, collegiate, and professional pitching coaches is to optimize a thrower's movement patterns by instructing a player to manipulate these variables while still respecting the athlete's unique throwing delivery that had already helped him or her achieve success to that point (M. Prior, conversation, June 2015). It is unclear with our study what the optimal patterns for injury prevention and/or performance enhancement are as they may be different among players. We can conclude that change in movement patterns can be achieved quickly in this group of young baseball pitchers.

Davis et al[4] demonstrated that "better" pitching mechanics demonstrated lower elbow valgus loads and lower humeral internal rotation torque in young pitchers. They defined 5 biomechanical parameters during the phases of throwing that are common errors in youth pitching, such as leading with the hips and stride foot toward home plate. The authors concluded that optimizing these body movement patterns may prevent shoulder and elbow injuries in youth athletes based on "pitching efficiency," which was ball velocity of the resultant torque applied to the shoulder or elbow.[4] Werner et al[27,28] defined similar components or phases of throwing that were independent variables that increased shoulder strain during delivery. All of these authors concluded that youth athletes should be taught to deliver the baseball in a way that minimizes shoulder and elbow strain while optimizing ball velocity to potentially prevent overuse injuries to the shoulder and elbow. The results of our study demonstrated that these changes in movement patterns can be taught, which supports the feasibility of these recommendations. However, we found the changes in the antecubital and humerothoracic angles were not directly associated with velocity changes. There were no other data available with which to correlate velocity, and multiple factors were not collected that could address the influence of confounding factors over time.

Baseball overuse injuries have clearly been identified as a problem by both MLB and professional orthopaedic societies,[1,14] especially in younger athletes. The universal approach to addressing the epidemic to this point has been pitch count restrictions, as decreased volume in immature athletes with inefficiencies is plausible. However, it is unclear whether the implementation of these initiatives has effectively decreased or even stabilized the number of shoulder and elbow injuries in baseball in the United States.[7,19] Some authors have suggested that pitch count policies are ineffective and alternative approaches to injury prevention should be investigated.[11,16] The popular upper-extremity injury prevention strategies are in stark contrast to the current lower-extremity injury strategies such as that for anterior cruciate ligament (ACL) injury prevention, where neuromuscular training is utilized to optimize knee kinematics to minimize at-risk body movement patterns and positioning for an ACL injury.[6,13,24,29] These programs have demonstrated a significant effect on ACL injury prevention in at-risk populations. In comparison, "at-risk" movements about the upper extremity during throwing likely involve increased shoulder and elbow stress. While optimal body movement patterns have not been defined, the program's drills attempt to utilize the entire kinetic chain and keep the arm close to the body, which may minimize the stress translated to the arm.

The principal teachings of this team's pitching instruction for their first 2 years were to "reach back and get the elbow up" as well as to "stand tall and fall" (toward home plate). The goals of the drills utilized in this study were to accomplish throwing patterns that were in stark contrast to those we had been teaching. Theoretically, but unproven, the drills work to keep the arm closer to the axial skeleton by keeping the throwing elbow below the level of the throwing shoulder and the throwing elbow flexed less than 90° at the point of the front toe/heel down (late cocking). In addition, in contrast to "standing tall and falling," the drills focus on lower half involvement. In an effort to improve hip rotation and strength, knee flexion must occur. At the late cocking phase, antecubital and humerothoracic angles from a third-base vantage point for a right-handed thrower and popliteal angle of the back leg from a second-base vantage point are relatively easy to measure. As such, we selected these 3 angles since their changes reflected the planes in which the drills were designed to effect change. While the entire body's movement patterns are likely changed, these were the simplest (and likely most reproducible) with our setup and player group.

There are several limitations of this study. Only eight 9-year-old athletes were included in this pilot study, which limits the applicability of the results to other populations. Only a single throwing program was analyzed, and different programs may have yielded different results, especially given player variables. We had no control group, and it is possible that these movement pattern changes may have occurred as a result of 3 months of maturation or through another program. An iPad was used to obtain all videos. It is possible that better equipment and video from additional angles may have yielded different results. Optimal body movement patterns have not been defined, so it cannot be determined whether the changes demonstrated with this throwing program can be associated with a decreased risk of shoulder and elbow injuries. Finally, it is unclear whether maintenance drills are necessary to retain changes found after a 21–consecutive day program, but this was beyond the scope of this study. None of these limitations, however, underscores this study's attempt to investigate whether body movement patterns can be efficiently changed in young baseball throwers as an initial step in studying this population. This study was accomplished with inexpensive tools and simple drills that can be taught to players and fathers. Moreover, the analyses were performed with technology that is freely available, which allows for great applicability. Continued research is needed to define optimal body movement patterns in all age groups and to investigate whether programs and changes in patterns can affect the epidemic of baseball throwing–related shoulder and elbow injuries.

Possibly, ideal body movement patterns are different for different throwers given interindividual variability. Clearly, a much larger cohort with longer-term follow-up would be needed to study players more comprehensively. Certainly, one would hope that the more efficient and painless the throwing motion, the better the performance, but this may not always be the case. We are unsure whether these "inefficiencies" are indicators for future injury as this is also beyond the scope of this study. However, if it is determined that certain motions are at risk, we feel that studies of programs such as that performed here will help us better understand whether we can actually change body movement patterns.

CONCLUSION

Young baseball throwers can retrain their arms and bodies to accomplish different movement patterns in a relatively short period of time. This may have implications for injury prevention and treatment as we identify better body movement patterns for individual baseball throwers.

REFERENCES

1. Andrews JR, Fleisig GS, Elattrache NS, et al. Guidelines for youth and adolescent pitchers. http://m.mlb.com/pitchsmart/pitching guidelines. 2016. Accessed January 23, 2016.
2. Conte S, Requa RK, Garrick JG. Disability days in Major League Baseball. *Am J Sports Med*. 2001;29:431-436.
3. Conte SA, Fleisig GS, Dines JS, et al. Prevalence of ulnar collateral ligament surgery in professional baseball players. *Am J Sports Med*. 2015;43:1764-1769.
4. Davis JT, Limpisvasti O, Fluhme D, et al. The effect of pitching biomechanics on the upper extremity in youth and adolescent baseball pitchers. *Am J Sports Med*. 2009;37:1484-1491.
5. Dillman CJ, Fleisig GS, Andrews JR. Biomechanics of pitching with emphasis upon shoulder kinematics. *J Orthop Sports Phys Ther*. 1993;18:402-408.
6. Donnell-Fink LA, Klara K, Collins JE, et al. Effectiveness of knee injury and anterior cruciate ligament tear prevention programs: a meta-analysis. *PLoS One*. 2015;10:e0144063.
7. Erickson BJ, Nwachukwu BU, Rosas S, et al. Trends in medial ulnar collateral ligament reconstruction in the United States: a retrospective review of a large private-payer database from 2007 to 2011. *Am J Sports Med*. 2015;43:1770-1774.
8. Fazarale JJ, Magnussen RA, Pedroza AD, Kaeding CC, Best TM, Classie J. Knowledge of and compliance with pitch count recommendations: a survey of youth baseball coaches. *Sports Health*. 2012;4:202-204.
9. Fleisig GS, Andrews JR. Prevention of elbow injuries in youth baseball pitchers. *Sports Health*. 2012;4:419-424.
10. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med*. 1995;23:233-239.
11. Fleisig GS, Barrentine SW, Zheng N, Escamilla RF, Andrews JR. Kinematic and kinetic comparison of baseball pitching among various levels of development. *J Biomech*. 1999;32:1371-1375.
12. Fleisig GS, Dillman CJ, Andrews JR. Biomechanics of the shoulder during throwing. In: Andrews JR, ed. *The Athlete's Shoulder*. New York, NY: Churchill Livingstone; 1994:360-365.
13. Hewett TE, Ford KR, Myer GD. Anterior cruciate ligament injuries in female athletes: part 2, a meta-analysis of neuromuscular interventions aimed at injury prevention. *Am J Sports Med*. 2006;34:490-498.
14. Ireland ML, Andrews JR, Fleisig GS. Preventing baseball injuries. http://www.stopsportsinjuries.org. 2010. Accessed January 23, 2016.
15. Jobe FW, Tibone JE, Perry J, Moynes D. An EMG analysis of the shoulder in throwing and pitching: a preliminary report. *Am J Sports Med*. 1983;11:3-5.
16. Karakolis T, Bhan S, Crotin RL. Injuries to young professional baseball pitchers cannot be prevented solely by restricting number of innings pitched. *J Sports Med Phys Fitness*. 2016;56:554-559.
17. Lawson BR, Comstock RD, Smith GA. Baseball-related injuries to children treated in hospital emergency departments in the United States, 1994-2006. *Pediatrics*. 2009;123:e1028-e1034.
18. Lyman S, Fleisig GS, Waterbor JW, et al. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Med Sci Sports Exerc*. 2001;33:1803-1810.
19. Makhni EC, Morrow ZS, Luchetti TJ, et al. Arm pain in youth baseball players: a survey of healthy players. *Am J Sports Med*. 2015;43:41-46.
20. Matsuo T, Escamilla R, Fleisig GS, Barrentine SW, Andrews JR. Comparison of kinematic and temporal parameters between different pitch velocity groups. *J Appl Biomech*. 2001;17:1-13.
21. Pappas AM, Zawacki RM, Sullivan TJ. Biomechanics of baseball pitching. A preliminary report. *Am J Sports Med*. 1985;13:216-222.
22. Petty DH, Andrews JR, Fleisig GS, Cain EL. Ulnar collateral ligament reconstruction in high school baseball players: clinical results and injury risk factors. *Am J Sports Med*. 2004;32:1158-1164.
23. Posner M, Cameron KL, Wolf JM, Belmont PJ Jr, Owens BD. Epidemiology of Major League Baseball injuries. *Am J Sports Med*. 2011;39:1676-1680.
24. Sadoghi P, von Keudell A, Vavken P. Effectiveness of anterior cruciate ligament injury prevention training programs. *J Bone Joint Surg Am*. 2012;94:769-776.
25. Stodden DF, Fleisig GS, McLean SP, Andrews JR. Relationship of biomechanical factors to baseball pitching velocity: within pitcher variation. *J Appl Biomech*. 2005;21:44-56.
26. Tullos HS, King JW. Throwing mechanism in sports. *Orthop Clin North Am*. 1973;4:709-720.
27. Werner SL, Guido JA Jr, Stewart GW, McNeice RP, VanDyke T, Jones DG. Relationships between throwing mechanics and shoulder distraction in collegiate baseball pitchers. *J Shoulder Elbow Surg*. 2007;16:37-42.
28. Werner SL, Suri M, Guido JA Jr, Meister K, Jones DG. Relationships between ball velocity and throwing mechanics in collegiate baseball pitchers. *J Shoulder Elbow Surg*. 2008;17:905-908.
29. Zebis MK, Andersen LL, Brandt M, et al. Effects of evidence-based prevention training on neuromuscular and biomechanical risk factors for ACL injury in adolescent female athletes: a randomised controlled trial. *Br J Sports Med*. 2016;50:552-557.