Journal of Athletic Training 2012;47(5):507–515
doi: 10.4085/1062-6050-47.3.11

www.nata.org/journal-of-athletic-training

original research

Trunk-Rotation Flexibility in Collegiate Softball Players With or Without a History of Shoulder or Elbow Injury

Veronica J. Aragon, MA, ATC*; Sakiko Oyama, MS, ATC†; Scott M. Oliaro, MA, ATC‡; Darin A. Padua, PhD, ATC†; Joseph B. Myers, PhD, ATC†

*Athletics Department, Duke University, Durham, NC; †Department of Exercise and Sport Science; ‡Campus Health Service, University of North Carolina at Chapel Hill

Context: Throwing is a whole-body motion that requires the transfer of momentum from the lower extremity to the upper extremity via the trunk. No research to date examines the association between a history of shoulder or elbow injury and trunk flexibility in overhead athletes.

Objective: To determine if injury history and trunk-rotation flexibility are associated and to compare trunk-rotation flexibility measured using 3 clinical tests: half-kneeling rotation test with the bar in the back, half-kneeling rotation test with the bar in the front, and seated rotation test in softball position players with or without a history of shoulder or elbow injury.

Design: Cross-sectional design.

Setting: University softball facilities.

Patients or Other Participants: Sixty-five female National Collegiate Athletic Association Division I softball position players.

Intervention(s): Trunk-rotation flexibility was measured with 3 clinical tests. Recent injury history was obtained using a questionnaire and verified by the certified athletic trainer.

Main Outcome Measure(s): Binomial regression models were used to determine if injury history was associated with flexibility categories (high, normal, or limited tertiles) for each of the 6 (3 tests $\times$ 2 directions) trunk-rotation flexibility measures. Trunk-rotation flexibility measures from 3 clinical tests were compared between participants with and without a history of shoulder or elbow injury using analysis-of-variance models.

Results: When measured using the half-kneeling rotation test with the bar in the back and the seated rotation test, injury history and forward trunk-rotation flexibility were associated. However, no mean group differences were seen in trunk-rotation flexibility between participants with and without a history of shoulder or elbow injury.

Conclusions: Limited forward trunk-rotation flexibility may be a risk factor for shoulder or elbow injuries. However, further study is needed to confirm the study finding.

Key Words: overhead athletes, throwing, range of motion

Key Points

- In these collegiate softball position players, a history of shoulder or elbow injury was associated with less trunk-rotation flexibility as measured using the half-kneeling rotation test with the bar in the back and the seated rotation test.
- A history of shoulder or elbow injury was more likely in players with low and high trunk-rotation flexibility than in players with normal flexibility.
- Means comparisons showed no difference among those players with or without a history of shoulder or elbow injury in trunk-rotation flexibility as measured by the half-kneeling rotation test with the bar in the back or the front and the seated rotation test.

Approximately 16 079 softball players participate at the collegiate level in the United States.[1] In a recent epidemiologic study[2] of high school athletes, girls were more likely to sustain upper extremity injuries as a result of overuse or chronic mechanisms than boys, who were more likely to sustain shoulder injuries from either contact with the playing surface or noncontact mechanisms. In another study of high school softball players,[2] 50.2% of all shoulder injuries resulted from nonpitching throws. Bonza et al[2] reported that sprains and strains were the most common shoulder injuries in softball players, accounting for 52.9%. Despite the increasing number of participants and the high prevalence of shoulder and elbow injuries, very little research has focused on softball players.

In baseball pitching, pelvic and trunk kinematics influence the magnitude of loads placed on the shoulder and elbow joints and thus injury.[3–7] During pitching or throwing, sequential rotation of the pelvis, upper torso, and arm creates a rotational lag between the segments, which contributes to momentum transfer across the trunk segment[8] and effective muscle force production through storage of elastic energy within the parallel elastic component of the musculotendinous unit and the stretch-shortening cycle.[9] Ineffective use of the trunk segment to transfer momentum and generate rotational momentum is thought to increase reliance on the upper extremity, thereby increasing the loads placed on the shoulder and elbow joints.[3,4] Limited trunk-rotation flexibility in the backward direction (ie, upper torso lags behind the pelvis) may be associated with upper extremity injuries in throwing athletes by interfering with the sequential rotation of the segments. After ball release, the torso rotates in a forward direction, helping to decelerate the throwing arm and minimizing the distraction forces experienced at the upper extremity joints.[10,11] Therefore, restricted trunk-rotation flexibility in the forward direction may limit the ability of the trunk segment to contribute to arm deceleration and thereby lead to greater upper extremity joint load and risk of injury.

The half-kneeling rotation test with the bar in the back (HKRTB) or the bar in the front (HKRTF) and seated rotation test (SRT) are clinical tests used to assess trunk-rotation flexibility.[12,13] The HKRTB and the HKRTF assess trunk flexibility in the half-kneeling position.[13] A half-kneeling position facilitates engagement of the muscles around the hip and pelvis (ie, hamstrings, hip flexors and adductors, gluteal and abdominal muscles) to stabilize the pelvis and may, therefore, allow functional assessment of trunk-rotation flexibility. The SRT is a traditional method of measuring trunk-rotation flexibility that simply assesses flexibility while the participant is seated.[12] To date, which of the 3 clinical tests of trunk-rotation flexibility may be most appropriate for use in throwing athletes is unknown. Furthermore, no authors have investigated the association of trunk-rotation flexibility and a history of shoulder or elbow injury.

As the number of softball participants increases, the number of individuals affected by shoulder and elbow injuries is also expected to increase. Hence, it is important to study injury causes in these athletes to develop prevention strategies. Because trunk flexibility may influence trunk-rotation mechanics during throwing, its contribution to shoulder and elbow injures warrants investigation. Therefore, the purposes of this study were to identify associations between trunk-rotation flexibility and a history of shoulder or elbow injury and to compare trunk-rotation flexibility measured using 3 clinical tests (HKRTB, HKRTF, and SRT) in collegiate softball position players with or without a history of shoulder or elbow injury.

METHODS

Participants

Eighty female National Collegiate Athletic Association Division I softball position players from 5 schools were recruited for this study. Volunteers would have been excluded if they (1) reported currently having shoulder, elbow, neck, or back pain that would prevent them from throwing in a game situation; (2) had experienced numbness or tingling in the throwing arm within the past 3 days or had been diagnosed with a neurologic disorder; (3) reported having surgery on the throwing arm within the past 6 months; or (4) had been diagnosed by a physician or athletic trainer as having a strain of any trunk muscle within the past week. However, because none of the exclusion criteria were applicable, all softball players who attended the testing session participated in the study. To avoid the potential confounding factor of shoulder and elbow injuries caused by the underhand pitch, 15 softball players were excluded from the study because they pitched for more than 50% of their total playing time. Therefore, data from 65 position players were used in the analysis.

Study Design

We used a cross-sectional study design with retrospective group assignment. After data collection, we divided participants into groups with or without a history of shoulder or elbow injury based on an injury history questionnaire.

Procedures

Data were collected on the softball fields of 5 Division I schools in the off-season: 3 schools in the fall semester and 2 before the start of the spring season. Before the study, each participant signed an informed consent form approved by the Biomedical Institutional Review Board of the University of North Carolina at Chapel Hill. Participants were then screened for inclusion and exclusion criteria and provided demographic information and past medical history through completion of a questionnaire. Past medical history was used to determine the appropriate group assignment (ie, history of shoulder or elbow injury or no history of shoulder or elbow injury) for each person. A participant was placed in the former group if she reported a shoulder or elbow injury from throwing within the past 2 years after which she (1) was unable to throw for 3 or more days, (2) was allowed to participate only in a limited number of throws for more than 1 week, or (3) was asked to receive treatment for more than 1 week. All injuries were verified with the team's certified athletic trainer. Review of the questionnaires occurred after data collection, so the investigator was blinded to group assignment.

After the questionnaire was completed, trunk-rotation flexibility was measured with a standard goniometer using the HKRTB, HKRTF, and SRT (in this order). Moderate to high reliability and precision of the measurements were established before the study with 15 healthy volunteers (Table 1). The same investigator performed each test 3 times in both the right and left directions on all participants. To account for limb dominance, trunk rotation was expressed by the direction in which the throwing shoulder was moving (forward or backward). For example, in a right-handed thrower, rotation when the throwing shoulder is moving forward (forward rotation) is to the left, but in a left-handed thrower, rotation is to the right. Similarly, in a right-handed thrower, rotation when the throwing shoulder is moving backward (backward

Table 1. Clinical Assessment of Trunk Rotation (n = 15)

Clinical Test	Intraclass Correlation Coefficient	Standard Error of Measurement, °
Half-kneeling rotation with bar in back		
Throwing shoulder rotating backward	0.672	5.8
Throwing shoulder rotating forward	0.868	3.7
Half-knee rotation with bar in front		
Throwing shoulder rotating backward	0.811	5.0
Throwing shoulder rotating forward	0.856	4.0
Seated rotation		
Throwing shoulder rotating backward	0.798	4.1
Throwing shoulder rotating forward	0.727	5.0

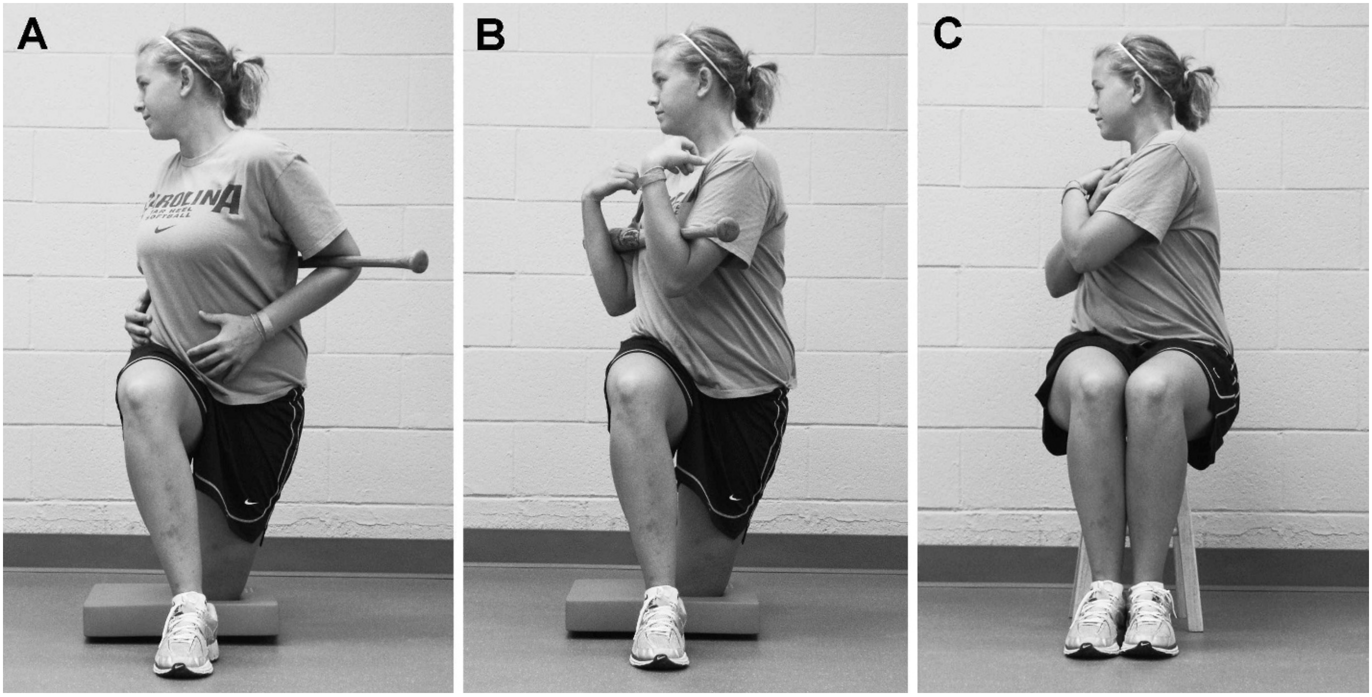

Figure 1. A, The half-kneeling rotation test with bar in the back. B, The half-kneeling rotation test with bar in the front. C, The seated rotation test.

rotation) is to the right, but in a left-handed thrower, rotation is to the left.

For the HKRTB, the participant was asked to place the left knee down on the ground and the right foot directly in front of the left knee (Figure 1A).[13] A softball bat was positioned behind the back and held in place by asking the participant to lock her arms around the bat while keeping her hands on her stomach. This position keeps the scapula in a retracted position, removing any range of motion that may occur from scapular movement. The examiner stood to the right of the participant and positioned the stationary arm of the goniometer parallel to her upper back. She was then asked to rotate as far to the right as possible without discomfort. As she rotated, the movable arm was aligned parallel to the upper back, and the angle between the stationary and moving arms was recorded (Figure 2). The test was repeated with the position of the legs switched in order to measure rotation to the left.

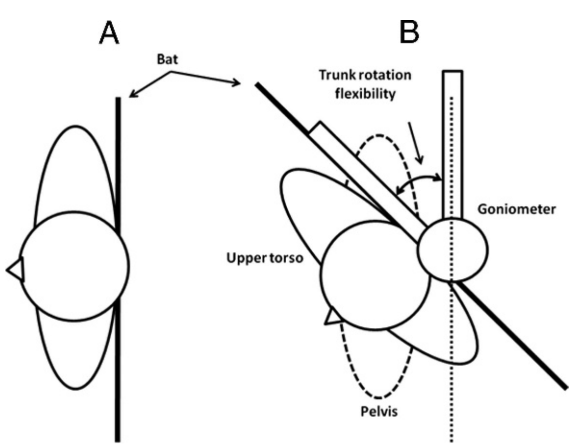

Figure 2. Alignment of the goniometer during trunk-rotation tests. A, Starting position. B, Ending position.

The HKRTF (Figure 1B) was performed in the same manner as the HKRTB, except that the bat was placed across the chest instead of behind the back.[13] This test allows movement of the scapula over the rib cage and measurement of the rotation flexibility achieved by scapular and spine movement. The test was repeated with the position of the legs switched in order to measure rotation to the left.

For the SRT, the participant was asked to sit in a chair with her feet together and touching the ground, the body in an erect upright posture, and arms across the chest (Figure 1C).[12] She was then instructed to rotate to the right as far as possible without discomfort. A goniometer was used to measure the amount of rotation with the same alignment as the HKRTB and HKRTF. The test was repeated with rotation to the left. For all flexibility measures, the average of 3 trials was used for analysis.

Data Analysis

Based on the trunk-rotation flexibility measures, participants were categorized into high, normal, and limited flexibility groups based on tertiles for each measure (3 tests $\times$ 2 directions). Six separate binomial regression models were used to determine if a history of shoulder or elbow injury and the flexibility category for each of the clinical flexibility measures were associated and to estimate prevalence ratios for injury history in each flexibility group when the model was significant. Comparisons of trunk-rotation flexibility measured using 3 clinical tests in participants with or without a history of shoulder or elbow injury were conducted using 1 within-subjects (test) and 1 between-subjects (injury group) factor analysis of variance. Separate analyses were calculated for rotation in the

Table 2. History of Shoulder or Elbow Injury by Position in Collegiate Softball Players

Position	History of Injury, No. (%)		Total (N = 65)
	Yes (n = 19)	No (n = 46)	
Catcher	7 (63.6)	4 (36.4)	11
First base	2 (22.2)	7 (77.8)	9
Second base	2 (28.6)	5 (71.4)	7
Third base	3 (37.5)	5 (62.5)	8
Shortstop	2 (33.3)	4 (66.7)	6
Left field	1 (11.)	8 (88.9)	9
Center field	1 (10.0)	9 (90.0)	10
Right field	1 (20.0)	4 (80.0)	5

forward and backward directions. All statistical analyses were performed with SAS (version 9.1; SAS Inc, Cary, NC). The level of significance was set a priori at .05.

RESULTS

Among the 65 participants, 19 reported a history of shoulder or elbow injury (age = 19.4 ± 1.2 years, height = 162.8 ± 4.8 cm, mass = 71.1 ± 8.8 kg, softball experience = 12.6 ± 2.2 years) and 46 reported no history of shoulder or elbow injury (age = 19.5 ± 1.2 years, height = 167.1 ± 8.1 cm, mass = 69.4 ± 9.4 kg, softball experience = 12.0 ± 2.8 years). In the former group, 14 participants had shoulder injuries, 3 had elbow injuries, and 2 had both shoulder and elbow injuries. Sixty participants were right handed, and 5 were left handed. A total of 28 injuries were reported by 19 athletes: labral lesion (n = 5), biceps or rotator cuff tendinosis (n = 12), subacromial impingement (n = 6), medial epicondylitis (n = 3), and biceps insertional tendinosis (n = 2). History of shoulder or elbow injury by player position is shown in Table 2.

The binomial regression model demonstrated an association between injury history and forward trunk-rotation flexibility measured using the HKRTB ($\chi^2 = 4.5$, $P = .03$; Table 3). The model estimated that injury prevalence was 2.75 times greater in the low (≤42.5°) flexibility group relative to the high (≥47.7°) flexibility group ($\chi^2 = 4.09$, $P = .043$, 95% confidence interval [CI] = 1.02, 7.32). In addition, the model demonstrated an association between injury history and forward trunk-rotation flexibility measured using the SRT ($\chi^2 = 10.3$, $P = .006$; Table 4). According to the model, compared with the normal (41.5°–47.3°) flexibility group, injury prevalence was estimated to be 7.3 times ($\chi^2 = 3.82$, $P = .05$, 95% CI = 1.00, 53.1) and 8.7 times ($\chi^2 = 4.65$, $P = .03$, 95% CI = 1.22, 62.1) greater in the high (≥47.3°) and low (≤41.5°) flexibility groups, respectively. Associations between a history of shoulder or elbow injury and the other flexibility measures were not statistically significant ($\chi^2 = .25$–3.8, $P = .15$–$.88$).

Table 3. Associations Between a History of Shoulder or Elbow Injury and Forward Trunk-Rotation Flexibility on the Half-Kneeling Rotation Test with Bar in Back[a]

History of Shoulder or Elbow Injury	Forward Trunk-Rotation Flexibility			Total, No.
	High	Normal	Limited	
Yes	4	4	11	19
No	18	17	11	46
Total (%)	22 (18.2)	21 (19.0)	22 (50.0)	65

[a] χ^2 Value = 4.5, P = 03.

Table 4. Associations Between a History of Shoulder or Elbow Injury and Forward Trunk-Rotation Flexibility on the Seated Rotation Test[a]

History of Shoulder or Elbow Injury	Forward Trunk-Rotation Flexibility			Total, No.
	High	Normal	Limited	
Yes	8	1	10	19
No	14	19	13	46
Total (%)	22 (36.4)	20 (50.0)	23 (43.5)	65

[a] χ^2 Value = 10.3, P = .006.

We did not find significant interactions among trunk-rotation flexibility measured using the 3 clinical tests in participants with or without a history of shoulder or elbow injury in the forward ($F_{2,154} = 1.9$, $P = .162$) or backward direction ($F_{2,154} = 2.8$, $P = .071$; Table 5). Main effects for tests were not significant for rotation in the forward ($P = .108$) or backward direction ($P = .257$). Main effects for groups were also not significant for rotation in the forward ($P = .228$) or backward direction ($P = .161$).

DISCUSSION

Trunk-rotation mechanics influence the stresses placed on the shoulder and elbow joints and, thus, ultimately the injuries incurred during baseball pitching.[3,4,6,7] Because trunk flexibility may influence trunk rotation during throwing, its association with shoulder or elbow injury needs to be examined. We found associations between a history of shoulder or elbow injury and trunk-rotation flexibility in the forward direction in 2 of 3 clinical tests. Based on the HKRTB results, the prevalence of injury history was almost 3 times higher among the individuals in the low-flexibility category than those in the high-flexibility category, which may indicate that people with limited forward trunk-rotation flexibility are at higher risk for injury. However, because cause and effect cannot be determined from our study, further investigation is needed. The greater prevalence of shoulder or elbow injury in the high and low trunk-rotation flexibility groups compared with those in the normal group based on SRT may indicate an optimal range of flexibility that helps to minimize shoulder and elbow loads during throwing. Yet the wide CI suggests low precision of the estimate, so this finding needs to be interpreted with caution.

The association between the greater prevalence of injury history and decreased trunk-rotation flexibility measured using the HKRTB may be explained by the influence of forward trunk-rotation flexibility on trunk motion during the deceleration and follow-through phases of throwing. Although the relationship between trunk-rotation flexibility and trunk kinematics during throwing has not been described, participants with limited forward trunk-rotation flexibility may not be able to achieve adequate trunk rotation to decelerate the throwing arm, thereby increasing stress on the upper extremity joints.

Limited trunk flexibility in the backward direction was hypothesized to be associated with a history of shoulder or elbow injury because limited backward trunk rotation may restrict use of the trunk segment to generate and transfer momentum, which could result in greater reliance on upper extremity joints to produce torque during the acceleration phase.[3,4] However, we did not find a difference in injury

Table 5. Comparison of Clinical Measures of Trunk Flexibility Between Participants With and Without a History of Shoulder or Elbow Injury

History of Shoulder or Elbow Injury	Test (°)					
	Half-Kneeling Rotation With Bar in Back		Half-Kneeling Rotation With Bar in Front		Seated Rotation	
	Forward	Backward	Forward	Backward	Forward	Backward
Yes	43.5 ± 3.9	44.8 ± 6.2	45.3 ± 5.3	46.2 ± 6.6	44.1 ± 7.9	46.2 ± 6.5
No	46.6 ± 5.5	48.3 ± 6.9	46.4 ± 5.7	48.6 ± 5.5	44.6 ± 5.1	46.8 ± 5.5

prevalence among the flexibility groups or in backward trunk-rotation flexibility among participants with or without history of shoulder or elbow injury. This finding may be explained by the fact that for the backward trunk-rotation test, the lower extremity was not positioned as it would be during the throwing motion. During the throwing motion, backward trunk rotation occurs during a cocking phase as the thrower steps forward with the stride leg (ie, side opposite the throwing shoulder). Instead, we assessed backward rotation flexibility while the participant knelt on the stride leg and stepped forward with the opposite (ie, stance) leg. We adopted the assessment procedures from the trunk-rotation flexibility screening tests designed for golfers.[13] Perhaps modifying the screening procedure to better mimic the throwing movement is necessary when throwing athletes are being tested.

In a seeming contradiction to the regression analysis findings, our analyses using means comparisons failed to demonstrate differences in trunk-rotation flexibility measured with the HKRTB, HKRTF, and SRT between participants with and without a history of shoulder and elbow injury. This result suggests that there were no differences in trunk-rotation flexibility measured using the 3 clinical tests and that a history of shoulder or elbow injury is not linked with trunk-rotation flexibility. Yet the lack of a mean difference between the participants with and without a history of shoulder and elbow injury may be attributed to the multifactorial mechanisms of shoulder and elbow injuries in throwing athletes. In addition to the trunk-rotation flexibility we examined, shoulder flexibility,[14–16] strength characteristics,[17] and throwing and pitching mechanics[4,5,7,18–21] have been linked with the development of shoulder and elbow injuries in throwing athletes. A mean difference may have been obscured by the flexibility values from the individuals who were injured as a result of factors other than limited trunk-rotation flexibility.

A regression analysis that directly models the prevalence of injury based on flexibility category (high, normal, limited) may be more robust in demonstrating an association between injury history and trunk flexibility. Perhaps this is why the regression analysis demonstrated an association despite the lack of mean differences. The binomial regression analysis used in this study also allows estimation of the prevalence ratio (eg, injury prevalence was 2.7 times greater in the limited-flexibility versus the high-flexibility groups), which is easily interpreted by clinicians.

The SRT is the traditional method of measuring trunk flexibility and assesses flexibility in a seated position.[12] Assessing trunk-rotation flexibility in the half-kneeling position is a technique more commonly used by golf instructors, based on the idea that the half-kneeling position facilitates engagement of the hip and pelvic muscles to stabilize the pelvis and, therefore, may allow assessment of trunk-rotation flexibility in a functional manner.[13] Based on our observations, holding the bar in front of the chest in the HKRTF seems to permit additional range of motion via shoulder protraction and retraction. As a result, the measurement may reflect combined trunk rotation and movement of the scapula along the rib cage, which results in range-of-motion values that may not truly represent isolated trunk flexibility. Holding a bat behind the back in the HKRTB seems to require the participant to keep the scapula in a retracted position and thus prevents shoulder movement during rotation. Given these factors and the analysis demonstrating an association between injury history and forward trunk flexibility, the HKRTB or SRT may provide a better assessment of trunk-rotation flexibility than does the HKRTF. However, differences in trunk-rotation flexibility as assessed by the 3 clinical measures were not reflected in the analysis of means comparisons.

Interestingly, we found that a history of injury occurred more often in catchers than in other position players. A history of injury was present in 63% of catchers (7 of 11), whereas only 22% (12 of 54) of other position players reported injuries. This may reflect the nature of the position, with catchers having to throw as much as pitchers do, sometimes from a kneeling position. The kneeling position may limit the amount of trunk rotation and eliminate any momentum that could be created using the legs. Although biomechanical and sport injury research on baseball and softball players focuses on pitchers,[18,19,22–29] catchers may also be susceptible to chronic throwing-related upper extremity injuries and, therefore, may warrant focused attention.

Limitations

Limitations of this study warrant acknowledgment. Because of the retrospective nature of the investigation, we cannot determine if the trunk-rotation limitation resulted in or developed after the upper extremity injury. Additionally, we relied on participants' self-reports to collect injury histories from the past 2 years. However, the injuries reported were validated against the medical records maintained by the certified athletic trainer for each team. The types of upper extremity injuries reported in the study varied, as did injury mechanisms, so future authors may consider focusing on specific types of injuries. Because of the tapered nature of the softball bat, the shoulder complex may have been unevenly oriented relative to the trunk, which may have influenced the range-of-motion measurements. Use of an untapered bar, such as a broomstick, should be considered in future studies. In addition, the order of the clinical tests was not counterbalanced: tests were performed in the order of HKRTB, HKRTF, and SRT for all participants. This may have caused a stretching effect on the measures taken later (HKRTF and SRT). Lastly, trunk-rotation flexibility was measured actively; as such, we did not take into account any passive motion that occurred due to momentum. However, our aim was to examine the link between a history of shoulder and elbow injury and clinical measures of trunk-rotation flexibility.

Future Studies

We are the first to investigate the relationship between a history of shoulder or elbow injury and trunk-rotation flexibility. More studies need to be conducted in this area to confirm our findings. Ultimately, prospective studies are required to examine whether trunk-rotation flexibility predicts injury risk. Given that trunk-rotation flexibility as measured in the study reflects combined movements at the pelvis, trunk, and scapula, it may be helpful to use instrumented methods (eg, an electromagnetic tracking device) to assess the components of trunk motion and help us to understand where trunk-rotation restrictions are found in individuals with limited flexibility. In addition, we focused on trunk motion in the transverse plane. Trunk movements in the sagittal and frontal planes should be examined because they may also be linked to injuries. Finally, the relationship among trunk flexibility, performance (ball speed), and injury needs to be investigated in order to provide meaningful clinical recommendations.

CONCLUSIONS

We had 2 main findings in these collegiate softball position players. A history of shoulder or elbow injury was associated with forward trunk-rotation flexibility as measured using the HKRTB and SRT. However, mean trunk-rotation flexibility was not different between tests or between players with and without history of shoulder or elbow pain (HKRTB, HKRTF, or SRT). These trunk-rotation flexibility tests are simple and quick clinical assessments that can be used by sports medicine clinicians in preseason screenings to identify individuals with limited flexibility. Improving trunk-rotation flexibility may prevent shoulder or elbow injuries.

REFERENCES

1. Marshall SW, Hamstra-Wright KL, Dick R, Grove KA, Agel J. Descriptive epidemiology of collegiate women's softball injuries: National Collegiate Athletic Association Injury Surveillance System, 1988–1989 through 2003–2004. *J Athl Train*. 2007;42(2):286–294.
2. Bonza JE, Fields SK, Yard EE, Comstock RD. Shoulder injuries among United States high school athletes during the 2005–2006 and 2006–2007 school years. *J Athl Train*. 2009;44(1):76–83.
3. Aguinaldo AL, Buttermore J, Chambers H. Effects of upper trunk rotation on shoulder joint torque among baseball pitchers of various levels. *J Appl Biomech*. 2007;23(1):42–51.
4. Aguinaldo AL, Chambers H. Correlation of throwing mechanics with elbow valgus load in adult baseball pitchers. *Am J Sports Med*. 2009;37(10):2043–2048.
5. Anz AW, Bushnell BD, Griffin LP, Noonan TJ, Torry MR, Hawkins RJ. Correlation of torque and elbow injury in professional baseball pitchers. *Am J Sports Med*. 2010;38(7):1368–1374.
6. 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(8):1484–1491.
7. Wight J, Richards J, Hall S. Influence of pelvis rotation styles on baseball pitching mechanics. *Sports Biomech*. 2004;3(1):67–84.
8. Putnam CA. A segment interaction analysis of proximal-to-distal sequential segment motion patterns. *Med Sci Sports Exerc*. 1991;23(1):130–144.
9. Hill AV. The efficiency of mechanical power development during muscular shortening and its relation to load. *Proc R Soc Lond B Biol Sci*. 1964;159:319–324.
10. Dillman CJ, Fleisig GS, Andrews JR. Biomechanics of pitching with emphasis upon shoulder kinematics. *J Orthop Sports Phys Ther*. 1993;18(2):402–408.
11. Pappas AM, Zawacki RM, Sullivan TJ. Biomechanics of baseball pitching: a preliminary report. *Am J Sports Med*. 1985;13(4): 216–222.
12. Norkin CC, White DJ. Rotation. *Measurement of Joint Motion: A Guide to Goniometry*. 2nd ed. Philadelphia, PA: FA Davis, 1995: 213.
13. Rose G, Phillips D, Gill L. *TPI Certified Golf Fitness Instructor 1*. Oceanside, CA: Titleist Performance Institute, 2008.
14. Laudner KG, Myers JB, Pasquale MR, Bradley JP, Lephart SM. Scapular dysfunction in throwers with pathologic internal impingement. *J Orthop Sports Phys Ther*. 2006;36(7):485–494.
15. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am J Sports Med*. 2006;34(3):385–391.
16. Ruotolo C, Price E, Panchal A. Loss of total arc of motion in collegiate baseball players. *J Shoulder Elbow Surg*. 2006;15(1): 67–71.
17. Byram IR, Bushnell BD, Dugger K, Charron K, Harrell FE Jr, Noonan TJ. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. *Am J Sports Med*. 2010;38(7):1375–1382.
18. Albright JA, Jokl P, Shaw R, Albright JP. Clinical study of baseball pitchers: correlation of injury to the throwing arm with method of delivery. *Am J Sports Med*. 1978;6(1):15–21.
19. Werner SL, Gill TJ, Murray TA, Cook TD, Hawkins RJ. Relationships between throwing mechanics and shoulder distraction in professional baseball pitchers. *Am J Sports Med*. 2001;29(3):354–358.
20. 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(1):37–42.
21. Werner SL, Murray TA, Hawkins RJ, Gill TJ. Relationship between throwing mechanics and elbow valgus in professional baseball pitchers. *J Shoulder Elbow Surg*. 2002;11(2):151–155.
22. Barrentine SW, Fleisig GS, Whiteside JA, Escamilla RF, Andrews JR. Biomechanics of windmill softball pitching with implications about injury mechanisms at the shoulder and elbow. *J Orthop Sports Phys Ther*. 1998;28(6):405–415.
23. Downar JM, Sauers EL. Clinical measures of shoulder mobility in the professional baseball player. *J Athl Train*. 2005;40(1):23–29.
24. Dun S, Fleisig GS, Loftice J, Kingsley D, Andrews JR. The relationship between age and baseball pitching kinematics in professional baseball pitchers. *J Biomech*. 2007;40(2):265–270.
25. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med*. 1995;23(2):233–239.
26. 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(12):1371–1375.
27. Fleisig GS, Escamilla RF, Andrews JR, Matsuo T, Satterwhite Y, Barrentine SW. Kinematic and kinetic comparison of between baseball pitching and football passing. *J Appl Biomech*. 1996;12(2): 207–224.

28. Werner SL, Fleisig GS, Dillman CJ, Andrews JR. Biomechanics of the elbow during baseball pitching. *J Orthop Sports Phys Ther*. 1993;17(6):274–278.

29. Werner SL, Jones DG, Guido JA Jr, Brunet ME. Kinematics and kinetics of elite windmill softball pitching. *Am J Sports Med*. 2006;34(4):597–603.

Address correspondence to Joseph B. Myers, PhD, ATC, Department of Exercise and Sport Science, University of North Carolina at Chapel Hill, 2201 Stallings-Evan, CB#8700, Chapel Hill, NC 27599-8700. Address e-mail to joemyers@email.unc.edu.

COMMENTARY

Timothy J. Brindle, PhD, PT, ATC

Editor's note: Institute for Disabilities Research and Training, Wheaton, MD

I congratulate the authors in addressing 2 very important issues with this study. First is the natural link between trunk and arm kinematics and how this may influence injury patterns in the upper extremity; second is the limited objectivity associated with measuring trunk, or thoracolumbar, motion using standard goniometry. Unfortunately, I do not believe that the objective measures the authors used in this study are sensitive enough to assist in identifying a link between trunk kinematics and upper extremity injury patterns. Regardless, the kinematic and kinetic link between trunk and upper extremity function surely is an area that warrants further investigation. Ultimately I believe that it is equally important to continue developing objective measurements of human motion, especially trunk motion, that will enhance athletic trainers' ability to provide improved care and treatment programs for athletes.

Clinically, thoracolumbar rotational range of motion can be measured between 30° and 45°, based on American Medical Association[1] or American Academy of Orthopaedic Surgeons[2] recommendations. Thoracolumbar rotation is assessed by visualizing a line connecting both acromion processes relative to a fixed horizontal reference. Combined thoracolumbar rotation should approximate 35° in both directions, with 30° coming from the thoracic spine and only 5° from the lumbar region.[3] These clinical measures of combined thoracolumbar motion are based on classic goniometry measures taught in basic athletic training courses.[4] However, reliability of goniometry testing can be suspect; this is especially true for movements of large segments such as the trunk. Imagining a line connecting both acromion processes and measuring this line against a fixed reference has proved problematic for clinicians. Attempts to improve reliability of trunk motion have included the use of inclinometers. Intraclass correlation coefficients (ICCs) for thoracolumbar rotation range of motion have been reported to range from 0.56 to 0.93 when healthy adults are measured while sitting.[5,6] The authors of the study introduce 2 new clinical measures: a seated rotation test and a half-kneeling rotation test in which they use a bar in the front or back of the thoracic segment to isolate trunk motion and provide better visualization of trunk rotation. The bar (or any other straight object across the thoracic segment) allows the examiner to directly visualize rotation, reducing the number of visual estimates and, ideally, improving the reliability associated with thoracolumbar motion measures.

The authors cite this method of quantifying thoracolumbar rotation from a golf publication, but that publication and another using similar methods do not report any reliability associated with these tests.[7] It is therefore difficult to determine the reliability and clinical usefulness of these new tests. The authors of this study address the gap by reporting ICCs for the new tests. The ICCs reported in this study compare favorably with those from studies that used inclinometers to measure thoracolumbar rotation. The half-kneeling rotation test with the bar in the back demonstrated a minimum ICC of 0.672 with the throwing shoulder rotating backward and 0.868 for the same test with the throwing shoulder rotated forward (see Table 1 of the study). As with any new test, a clinician must, as the authors suggest, be cautious in interpreting the results until these objective measures of thoracolumbar rotation are widely accepted.

Although ICCs measure reliability and describe the ability to differentiate measures associated with a sample, the SEM estimates the variability within a sample and is also known as absolute measurement error.[8] From the SEM, one can calculate the minimal detectable change (MDC), or the smallest within-subjects change that can be detected from a measurement beyond error when $P <$ .05.[8,9] The MDC is calculated by multiplying 1.96 $\sqrt{2 * \mathrm{SEM}}$. Thus, by calculating the MDC of the reported thoracolumbar measures described in this study, we find a range of 10.2° (half-kneeling rotation with bar in the back and the throwing shoulder rotating forward) to 13.8° (with the seated rotation test and the throwing shoulder rotating forward). The authors did not use goniometry to determine if there was an effective or detectable change in rotation, but they did use the goniometric measurements to stratify the athletes into 3 groups, or tertiles: limited, normal, or high flexibility. The normal–range-of-motion group was defined as 42.5° to 47.7° of rotation. The limited-flexibility group demonstrated rotation less than 42.5°, and the high-flexibility group demonstrated rotation greater than 47.7°. Therefore, a difference of only 5.2° separated the limited-flexibility and high-flexibility groups. For a meaningful difference between these groups, there should be at least 10.2° to 13.8° of difference in thoracolumbar rotation. As a result, the methods used in this study lack the sensitivity to differentiate between the limited- and high-flexibility groups. The authors recognized this because they cited the need to reduce variability by using an electromagnetic tracking device in the ''Discussion'' section of the study. This suggests that repeating the study using the same methods may generate another random assignment of individuals to the different groups. As the published record for these clinical measures advances, other methods may be put in place to improve the MDC associated with these measures of trunk rotation. Therefore, the authors were correct to caution us that these are only preliminary results. Most important is the need to continually improve the objectivity of our clinical tests, including those demonstrated with this publication.

The other important issue presented by the authors of this study is the link between trunk motion and upper extremity injuries. Unfortunately, based on the information above, the clinical tests introduced in this study may not be ideally suited to assess this phenomenon because of the lack of sensitivity associated with these testing methods. Using more sensitive equipment such as video-based motion-capture or electromagnetic motion-tracking systems may better enable them to answer their research question. Ultimately, the authors may have designed their research study based on either resources available or applicability of the results toward the athletic training community. Regardless, their resources, or the lack thereof, may be more representative of the athletic training community because most clinics have a goniometer but not high-tech motion-capture systems. The authors introduce a progressive approach toward a clinically observed problem: trunk kinematics affecting arm function and possibly upper extremity injury. In hindsight, the authors might have been better served by using a more sensitive method (video-based motion capture) for exploring the link between trunk flexibility and upper extremity injury and then follow-up with improved clinical testing methods that may translate better to the practicing clinician. Once the link between trunk and arm kinematics is more clearly substantiated, treatment programs can be developed that will influence practice patterns for our profession.

In summary, I thank the *Journal of Athletic Training* for allowing me to open the dialogue about the benefits and drawbacks associated with this research study. I also thank the authors for their willingness to embark on research that will advance our profession. As these and other authors continue to develop more sensitive testing methods, more complicated questions can be asked that will ultimately change clinical practice. I look forward to advances in our understanding of thoracolumbar influence on upper extremities and the maturation of these new tests to quantify thoracolumbar rotation.

REFERENCES

1. American Medical Association. *Guides to the Evaluation of Permanent Impairment.* 3rd ed. Milwaukee, WI: American Medical Association; 1990.
2. Green WB, Heckman JD, eds. *The Clinical Measurement of Joint Motion.* 2nd ed. Rosemont, IL: American Academy of Orthopaedic Surgeons; 1994.
3. Neumann DA. *Kinesiology of the Musculoskeletal System: Foundations for Physical Rehabilitation*. St Louis, MO: Mosby; 2002:287–303.
4. Norkin CC, White J. *Measurement of Joint Motion: A Guide to Goniometry.* 2nd ed. Philadelphia, PA: FA Davis Co; 1995:213.
5. Breum J, Wiberg J, Bolton JE. Reliability and concurrent validity of the BROM II for measuring lumbar mobility. *J Manipulative Physiol Ther*. 1995;18(8):497–502.
6. Madson TJ, Youdas JW, Suman VJ. Reproducibility of lumbar spine range of motion measurements using the back range of motion device. *J Orthop Sports Phys Ther*. 1999;29(8):470–477.
7. Johnson KD, Grindstaff TL. Thoracic rotation measurement techniques: clinical commentary. *N Am J Sports Phys Ther*. 2010;5(4):252–256.
8. Beckerman H, Roebroeck ME, Lankhorst GJ, Becher JG, Bezemer PD, Verbeek AL. Smallest real difference, a link between reproducibility and responsiveness. *Qual Life Res*. 2001;10(7):571–578.
9. Terwee CB, Bot SD, deBoer MR, et al. Quality criteria were proposed for measurement properties of health status questionnaires. *J Clin Epidemiol*. 2007;60(1):34–42.

AUTHORS' REPLY

We thank the *Journal of Athletic Training* for giving us the opportunity to present our research. We believe that understanding the link between trunk kinematics and upper extremity function can assist athletic trainers in preventing and rehabilitating upper extremity dysfunctions in overhead-sport athletes. We hope that our study opens the door for future research in this area, not just in the sport of softball but in all overhead sports.

We strongly agree with the comments regarding the need for caution in interpreting the results because of the error that is associated with the measurement technique. We believe that potential sources of error may include challenges in goniometer placement, limiting pelvic rotation, isolating transverse-plane thoracolumbar movement, and minimizing scapulothoracic movement during the tests.

Although the goniometer is a standard tool that can be found readily in athletic training settings, holding the stationary arm still while adjusting the moving arm is difficult to do and requires extensive practice. It is also difficult to accurately align the goniometer with the upper back unless the examiner is tall enough to be able to look straight down on the goniometer and the upper back. When using the half-kneeling rotation or seated rotation test to measure thoracolumbar rotation, the pelvis needs to remain in the original starting position, so that any rotation in the upper torso can be attributed to rotation of the upper torso relative to the pelvis. During the half-kneeling rotation tests, the participants were asked to bring the rotation-side leg forward (eg, right leg forward if rotating to the right) so that the forward leg could keep the pelvis from rotating with the upper torso. However, this testing position still allowed a small degree of pelvis rotation. Furthermore, we observed some participants initially attempting to achieve additional rotation range of motion by using hip flexion and lateral or forward trunk flexion, which was corrected by our instruction. Gross compensation patterns can be easily detected, but more subtle patterns may be difficult to observe. The scapulothoracic movement may be another source of error. We attempted to limit the scapulothoracic movement by asking participants to keep the scapulae retracted; whether that successfully limited the motion is unknown.

In the future, the measurement technique may be improved by addressing the challenges listed above through development of devices, methods, and instructions to minimize the error. Although we agree that the use of a motion-capture system may be needed to accurately measure the thoracolumbar rotation, we believe that the development of a reliable clinical test is needed for the study finding to be applicable to the athletic trainers. When used correctly by a trained professional, a goniometer can give consistent data for athletic trainers to track improvements and assess the results of therapeutic interventions. We understand that a goniometer is not reliable enough to be a gold standard, but it may be sensitive enough to assist in making clinical decisions. A motion-capture system may be used to validate the clinical test but does not serve any practical or clinical relevance in an athletic training room.

We truly hope that research continues to grow in this area of study. Further research is needed to understand the link between thoracolumbar rotation range of motion and various upper extremity injuries and the influence of rotation range of motion on trunk kinematics during sport-specific movements to improve the care of overhead athletes.

Veronica J. Aragon, MA, ATC
Athletics Department
Duke University
Durham, NC

Sakiko Oyama, MS, ATC
Department of Exercise and Sport Science
University of North Carolina at Chapel Hill

Scott M. Oliaro, MA, ATC
Campus Health Service
University of North Carolina at Chapel Hill

Darin A. Padua, PhD, ATC
Joseph B. Myers, PhD, ATC
Department of Exercise and Sport Science
University of North Carolina at Chapel Hill
e-mail: joemyers@email.unc.edu