JSES International 8 (2024) 740–745

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Relationship between the shoulder, trunk, and pelvis kinematics during the deceleration phase of throwing

Takuya Aso, PT, PhD[a,*], Yoshinori Kagaya, PT, JSPO-AT, PhD[b,a]

[a]Showa University Research Institute for Sport and Exercise Sciences, Kanagawa, Japan
[b]Department of Physical Therapy, Showa University School of Nursing and Rehabilitation Sciences, Kanagawa, Japan

ARTICLE INFO

Keywords:
Three-dimensional motion analysis
Shoulder motion
Trunk motion
Pelvis motion
Throwing
Deceleration phase

Level of evidence: Basic Science Study; Kinesiology

Background: The shoulder motion during pitching is influenced by the trunk and pelvis motions, but their relationship during the deceleration phase of throwing on flat ground has not yet been clarified. This study aimed to investigate the relationship between shoulder, trunk, and pelvis kinematics at the maximum internal rotation (MIR) of the shoulder during the deceleration phase of throwing on flat ground.

Methods: The study participants included 17 male baseball players over 20 years old and at the recreational playing level. The recreational level was illustrated by players who did not practice at high intensity and had played only 1-2 competitions per week. Reflective markers were applied to the subject, and throwing motion was assessed using a three-dimensional motion capture system. Data were captured at 1000 Hz. We assessed the angle of the shoulder, spine, and pelvis at the MIR on flat ground. Internal shoulder rotation velocity and spinal and pelvic angular velocities were also assessed. The relationship between the shoulder, spine, and pelvis kinematics at the MIR was examined using simple linear regression analysis.

Results: The internal shoulder rotation angle at the MIR was negatively associated with only the spinal flexion and rotation angle at the MIR ($P = .006$ and $P = .010$, respectively). No other significant associations between shoulder, spine, and pelvis kinematics were detected at the MIR.

Conclusion: For throwing on flat ground, the internal shoulder rotation motion may be suppressed by producing trunk flexion and rotation motion at the MIR.

© 2024 The Author(s). Published by Elsevier Inc. on behalf of American Shoulder and Elbow Surgeons. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Throwing injuries of the shoulder are common in overhead sports such as baseball.[15] The excessive stress that is placed on the shoulder, especially during the late cocking phase of pitching and ball release, has been associated with the development of superior labrum anterior-posterior lesions and other throwing injuries of the shoulder.[9,10] However, recent studies have focused on throwing injuries of the shoulder that occur during the deceleration phase of pitching, which represent the anterosuperior impingement (ASI) injuries.[3] ASI was first defined by Gerber and Sebesta[12] as the impingement of the reflection pulley and subscapularis tendon undersurface in the horizontal adduction and internal rotation positions of the shoulder against the anterosuperior glenoid rim. In addition, Valadie *et al*[25] verified the contact between the articular surface of the rotator cuff tendons and the anterosuperior glenoid with the arm when placed in the Hawkins position. Thus, it is important to suppress excessive shoulder horizontal adduction and internal rotation during the deceleration phase of pitching to prevent ASI.

The throwing motion is a movement that includes the whole body, where the energy generated from the lower extremity is transferred to the upper extremity.[4] In addition, the motor control of the trunk, including the pelvis that is located between the upper and lower extremities, is important to prevent throwing injuries of the shoulder.[1,7] Furthermore, many studies have reported that the relationship between the motions of the trunk and shoulder are dependent on the interval between the early cocking phase and ball release at the maximum external rotation (MER) of the shoulder during the late cocking phase.[1,7,16,19] Miyashita *et al*[19] reported that the MER angle was not only affected by the glenohumeral external rotation motion but also by the thoracic extension motion. In addition, Suzuki *et al*[23] reported that both the excessive glenohumeral external rotation and horizontal abduction motions can be suppressed through thoracic extension during the shoulder external rotation at 90° of the shoulder abductions. Manzi *et al*[16]

The study protocol was approved by the Research Ethics Committee of Showa University (study number: 543).

*Corresponding author: Takuya Aso, PT, PhD, Showa University Research Institute for Sport and Exercise Sciences, 2-1-1 Fujigaoka Aoba-ku, Yokohama, Kanagawa 227-8518, Japan.

E-mail address: aso4201@yahoo.co.jp (T. Aso).

https://doi.org/10.1016/j.jseint.2024.03.008
2666-6383/© 2024 The Author(s). Published by Elsevier Inc. on behalf of American Shoulder and Elbow Surgeons. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

reported that the lateral trunk tilt at ball release increases the shoulder horizontal abduction motion. These reports suggest that by controlling the trunk motion, the shoulder motion can be controlled. On the other hand, there have been few reports that have examined the relationship between the trunk and shoulder movements during the deceleration phase. Oliver and Keeley[21] examined the relationship between the thoracic and shoulder motions during the deceleration phase in high school baseball players, and no relationship was reported between the two segments. However, because the shoulder motion at MER and ball release are influenced by the trunk motion, it is assumed that a similar relationship occurs during the deceleration phase and should be considered.

The control of the pelvis motion is necessary to reduce the pressure on the shoulder.[13,14] Laudner *et al*[14] reported that instability in the direction of the anterior-posterior pelvis tilt during the single-leg standing position was associated with increased shoulder horizontal abduction torque during pitching. In addition, an increase in the pelvis lateral tilt angle at the MER and pelvis rotation angular velocity at ball release resulted in an increased glenohumeral compressive force.[13] Thus, the effects of the pelvis motion at the MER and ball release on the shoulder have been previously reported; however, no study has reported on these effects through the deceleration phase or on the trunk. In addition, most studies have analyzed pitching on the mound but not throwing on a flat ground. However, throwing injury may occur during the deceleration phase even among fielders who throw on a flat ground, an effect that requires further investigation. Moreover, demonstrating the relationship between shoulder, trunk, and pelvis motions would help prevent throwing injuries of the shoulder that occur during the deceleration phase.

This study aimed to investigate the relationship between shoulder, trunk, and pelvis kinematics at the maximum internal rotation (MIR) of the shoulder during the deceleration phase of throwing on flat ground. We hypothesized that a correlation exists at the MIR as well as at the MER and ball release.

Materials and methods

Participants

Recreational-level baseball players over the age of 20 were recruited in this study. The recreational level was defined by players who did not practice at high intensity and had played only 1-2 competitions per week. Players with shoulder, trunk, and lower extremity pain at the time of testing were excluded from the study. The study protocol was approved by the Research Ethics Committee (study number: 543). All participants provide written informed consent before data collection.

Throwing analysis

Prior to the start of the throwing test, the participants were allowed an unlimited warm-up and stretching time. The participants were set positioned and threw three fastballs using the official baseball (ZETT Corp., Osaka, Japan) that weighed 145.0-147.0 g, with their maximum effort toward a 1.1 × 1.1 m target at a distance of 3 m.

The throwing motions were measured via a three-dimensional motion analysis system (Vicon MX; Vicon Motion Systems Ltd., London, UK), which houses nine infrared strobe cameras. We secured 39 reflective markers to the anatomic landmarks in accordance with the Plug-In Gait model (Vicon Motion Systems Ltd.) (spinous process of the 7th cervical vertebra, spinous process of the 10th thoracic vertebra, sternal notch, xiphoid process, right scapula, bilateral anterior/posterior head, acromioclavicular joint, lateral upper arm, lateral humeral epicondyle, lateral forearm, radial/ulnar styloid, second metacarpal head, anterior/posterior superior iliac spine, lateral thigh, lateral femoral condyle, lateral shank, lateral malleoli, second metatarsal head, and calcaneus) and captured the data at 1000 Hz. Based on the Vicon Plug-In Gait model, we computed the angles at the MIR of the following: shoulders (horizontal adduction/abduction, abduction/adduction, and internal/external rotation), spine (flexion/extension, nonthrowing/throwing side lateral flexion, and nonthrowing/throwing side rotation), and pelvis (anterior/posterior tilt, nonthrowing/throwing side lateral tilt, and nonthrowing/throwing side rotation).[2,20] In addition, we computed the internal shoulder rotation velocity at the MIR as well as the spinal (flexion/extension, nonthrowing/throwing side lateral flexion, and nonthrowing/throwing side rotation) and pelvic (anterior/posterior tilt, nonthrowing/throwing side lateral tilt, and nonthrowing/throwing side rotation) angular velocities at the MIR. We computed the MIR using the obtained joint angle data (Fig. 1). The marker trajectory data were low-pass filtered using a fourth-order Butterworth filter with a 13.4 Hz cutoff frequency.[8] We defined the axes as follows: The Y-axis extended toward the pitch; the X-axis, orthogonal to the Y-axis, extended from first toward third base; and the Z-axis was perpendicular to both the Y- and X-axes (Fig. 2). We defined the shoulder angle between the thoracic and upper arm segments, the spine angle between the thoracic and pelvis segments, and the pelvis angle as the absolute angle of the pelvis segment to the laboratory axis. Among the three-throwing tasks of each participant, we based our analysis on the throw in which the angle of the internal shoulder rotation at the MIR was the greatest.

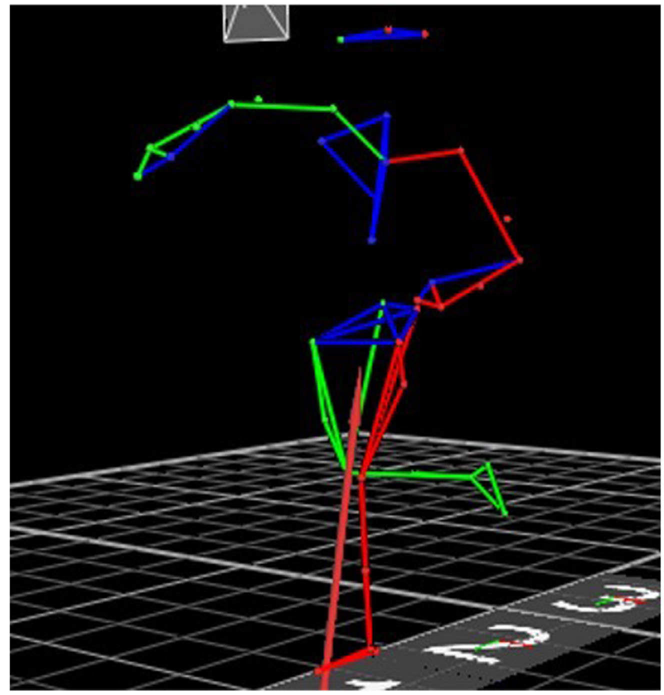

Figure 1 Analytic phase of a pitch. The maximum internal rotation (MIR) angle of the shoulder during the deceleration phase of a pitch was analyzed.

Statistical analysis

For statistical analysis, we utilized JMP Pro software, version 16 (SAS Institute Inc., Cary, NC, USA). The associations between the

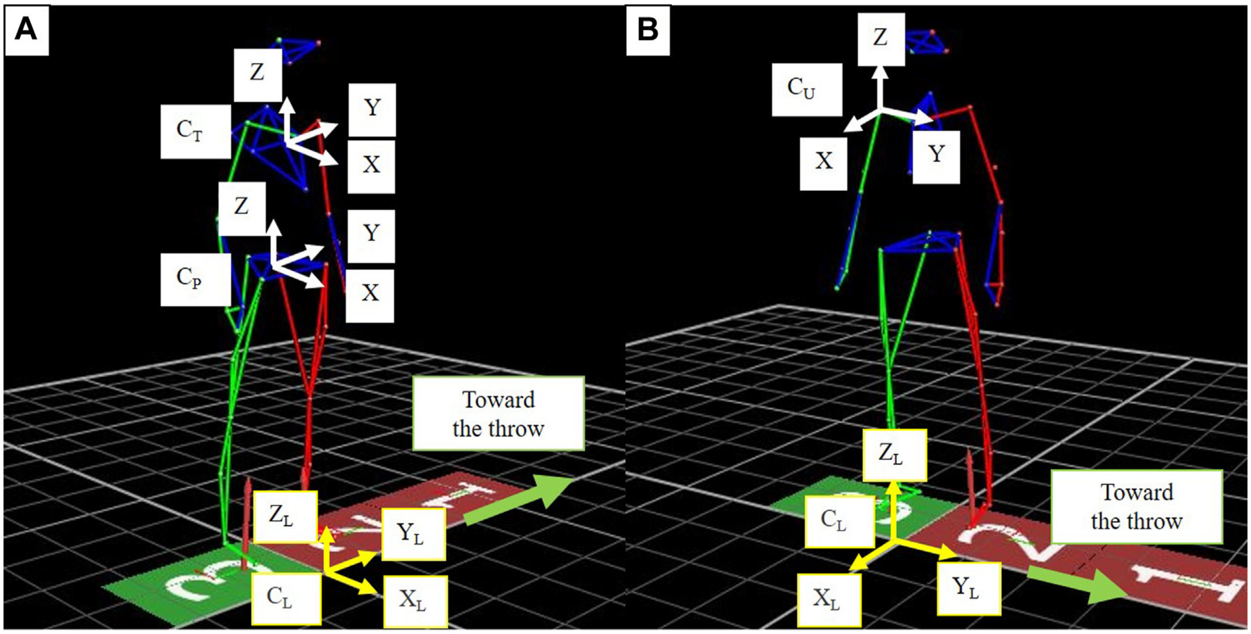

Figure 2 Coordinate system. (**A**) Coordinate system for the laboratory, thoracic, and pelvis segments. (**B**) Upper arm segment coordinate system. C_L, laboratory coordinate system; C_U, upper arm coordinate system; C_T, thoracic coordinate system; C_P, pelvis coordinate system; X_L, X-axis of C_L; Y_L, Y-axis of C_L; Z_L, Z-axis of C_L.

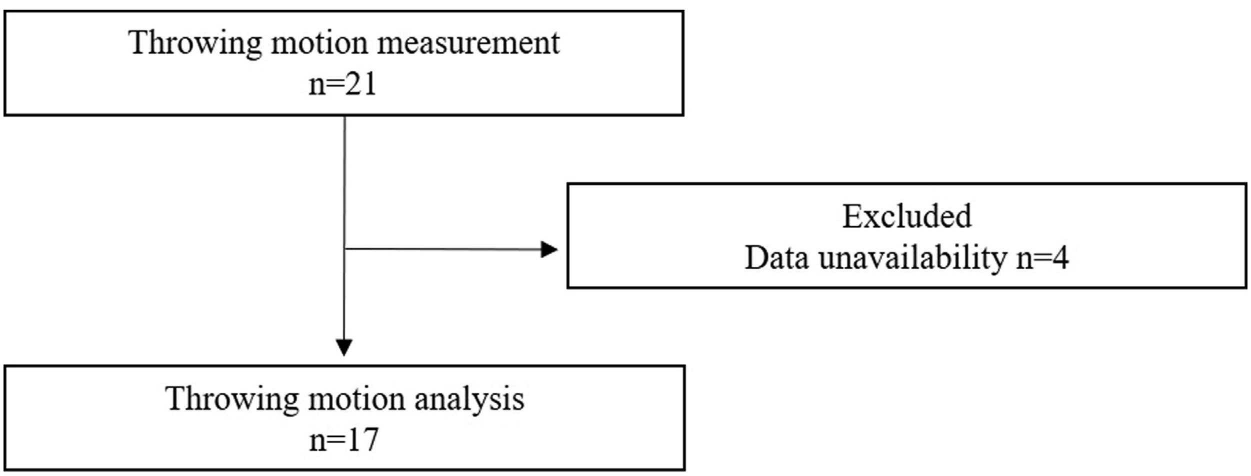

Figure 3 Flowchart of the study.

shoulder kinematics data and the spine and pelvic kinematics data were analyzed using simple linear regression analysis. Shoulder kinematics data were considered as objective variable, and spine and pelvic kinematics data were considered as explanatory variables. Statistical significance was set at $P < .05$. In a simple linear regression analysis, for an effect size of 0.15, a significance level of 0.05, and a power of analysis of 0.8, the required sample size was determined to be 55 participants.

Results

In this study, the throwing motion of 21 baseball players was measured. Of these, four players were excluded because their shoulder angle or pelvic angle at the MIR could not be calculated. Thus, only 17 players were included in the analysis (age, 22.4 ± 2.5 years; body mass, 67.2 ± 8.0 kg; height, 170.5 ± 4.4 cm; and experience, 11.7 ± 2.8 years) (Fig. 3).

Data regarding shoulder, spine, and pelvis kinematics at the MIR are presented in Table I and their associations are presented in Tables II and III. Using simple linear regression analysis, we determined that the internal shoulder rotation angle at the MIR was negatively associated with spine flexion and rotation angle at the MIR. No other significant associations between the shoulder, spine, and pelvis kinematics were detected at the MIR.

Discussion

During pitching, the shoulder is overloaded from the MER to ball release; thus, a throwing injury of the shoulder is likely to occur during these phases.[9,10] However, throwing injury of the shoulder can also occur during the deceleration phase after ball release, such as ASI.[3] Because ASI results from the excessive shoulder horizontal adduction and internal rotation movement during the deceleration phase, controlling these movements is important to prevent

Table I
Kinematics data of the shoulder, spine, and pelvis at MIR during throwing.

Variables	Mean ± SD
Shoulder angle (°)	
Horizontal adduction (+)/horizontal abduction (−)	32.6 ± 10.8
Abduction (+)/adduction (−)	101.6 ± 10.9
Internal rotation (+)/external rotation (−)	2.8 ± 19.4
Spine angle (°)	
Flexion (+)/extension (−)	16.0 ± 15.7
Nonthrowing side lateral flexion (+)/throwing side lateral flexion (−)	21.5 ± 24.7
Nonthrowing side rotation (+)/throwing side rotation (−)	24.4 ± 13.6
Pelvic angle (°)	
Anterior tilt (+)/posterior tilt (−)	16.4 ± 12.3
Nonthrowing side lateral tilt (+)/throwing side lateral tilt (−)	8.1 ± 23.0
Nonthrowing side rotation (+)/throwing side rotation (−)	101.7 ± 9.1
Shoulder angular velocity (°/s)	
Internal rotation (+)/external rotation (−)	32.5 ± 23.9
Spine angular velocity (°/s)	
Flexion (+)/extension (−)	146.2 ± 92.4
Nonthrowing side lateral flexion (+)/throwing side lateral flexion (−)	66.9 ± 49.5
Nonthrowing side rotation (+)/throwing side rotation (−)	67.9 ± 66.0
Pelvic angular velocity (°/s)	
Anterior tilt (+)/posterior tilt (−)	−40.7 ± 77.7
Nonthrowing side lateral tilt (+)/throwing side lateral tilt (−)	49.8 ± 33.7
Nonthrowing side rotation (+)/throwing side rotation (−)	84.2 ± 58.0

Data are presented as the mean ± standard deviation (SD).
MIR, maximum internal rotation during the deceleration phase.

ASI.[12,25] In addition, the shoulder motion during pitching is influenced by the trunk and pelvis motions.[5,13,14,16,19,24] Previous studies have demonstrated the relationship between shoulder, trunk, and pelvis motions during the MER and ball release, but their relationship during the deceleration phase remains unknown.[13,16,19] This study utilized a three-dimensional motion analysis system to examine the relationship between shoulder, trunk, and pelvis kinematics at the MIR.

Based on the obtained results, none of the variables were associated with the shoulder horizontal adduction angle at the MIR. However, the internal shoulder rotation angle at the MIR was negatively associated with the spinal flexion and rotation angle at the MIR. These results suggest that the internal shoulder rotation motion may be suppressed by producing trunk flexion and rotation motion at the MIR.

Regarding the motion of the shoulder horizontal plane, Suzuki *et al*[23] compared the horizontal abduction angle of the glenohumeral joint during the shoulder external rotation at 90° of the shoulder abductions from the sitting position between the thoracic extension and thoracic flexion positions, and they reported that the horizontal abduction angle of the glenohumeral joint was significantly decreased in the thoracic extension position. Manzi *et al*[16] analyzed the pitching motion of professional baseball players, and they reported that players with a large trunk nonthrowing lateral flexion angle at ball release had a large shoulder horizontal abduction angle. Because the shoulder horizontal plane motion up to ball release was influenced by the trunk motion, the shoulder horizontal plane motion could also be influenced by the trunk motion at the MIR. However, the findings in this study differed. Therefore, the relationship between the shoulder horizontal plane motion and trunk motion varies depending on the throwing phase. However, the electromyographic analysis during the throwing motion showed that the muscle activity in the posterior deltoid and teres minor muscles was greater during the deceleration phase.[6] Since not only the posterior deltoid but also the teres minor were involved in the shoulder horizontal plane motion,[24] these muscles were thought to contract eccentrically during the deceleration phase. Thus, the shoulder horizontal adduction motion at the MIR could be controlled by the muscles around the shoulder.

Currently, there is only one report that has examined the relationship between the internal shoulder rotation motion and trunk motion at the MIR.[21] Oliver and Keeley[21] performed a three-dimensional pitching motion analysis on high school baseball players and reported that there was no relationship between the shoulder rotation angle at the MIR and the thoracic flexion angle and angular velocity of rotation. However, the present study identified a relationship between the angle of the internal shoulder rotation at the MIR and the angle of spinal flexion and rotation. The definition of the thoracic angle during measurement was the absolute angle of the thorax relative to the laboratory coordinate system.[21] Due to the differences between the two studies regarding the participants and the definition of the trunk angle, it is challenging to form a comparison between previous[21] and present studies. However, the identification of a relationship between the internal shoulder rotation angle and the spinal flexion and rotation angle at the MIR is important when considering the mechanism of throwing injury of the shoulder at the MIR. In addition, this study showed no significant association between the internal shoulder rotation velocity and spinal angular velocity at the MIR; we have not found any reports examining the association between shoulder angular velocity and spinal angular velocity at the MIR, and many points remain unclear. In the future, it would be interesting to examine the factors that might influence internal shoulder rotation motion at the MIR in terms of spinal angular velocity at the MIR as well as maximum angular velocity of the spine during the entire throwing phase.

The thorax at the MER of a pitching motion is in an extension position; then, in the later phases, it undergoes flexion and nonthrowing side rotation.[19,21] It has also been shown that the angle of the scapular anterior tilt in the shoulder MER at 90° of abduction is greater in the thoracic flexion position compared to the thoracic extension position.[23] Miyakoshi *et al*[17] utilized three-dimensional motion analysis to examine the effects of trunk rotation on scapular motion. The results indicated that the scapular anterior tilt angle was greater during the contralateral trunk rotation compared to the trunk when in a neutral position. Consequently, the trunk movement affected the scapular movement, which exhibited an anterior tilt movement from the MER to MIR.[22] Miyashita *et al*[18] examined the relationship between the scapular anterior tilt motion and glenohumeral joint internal rotation motion at ball release and reported a negative correlation between these two variables. Thus, players with greater scapular anterior tilt motion at ball release exhibited less glenohumeral joint internal rotation motion. Based on these reports, it is possible that the participants in this study with greater spinal flexion and rotation motion to the nonthrowing side at the MIR had greater scapular anterior tilt motion, which resulted in a smaller internal rotation angle of the shoulder. However, because scapular motion was not measured in this study, further investigation is required to better explain the relationship between the spinal, scapular, and shoulder motions at the MIR.

This study has several limitations. First, the sample size was small. The required number of participants was 55; this criterion was not met in the current study. A small sample size is a concern for type I and type II errors. Therefore, a larger sample size is recommended for future studies. Second, the throwing distance was set at 3 m, owing to the limited space of the laboratory where this study was conducted. However, during real play, the throw distance is > 3 m. Moreover, longer throw distances have been reported to affect trunk and shoulder motions.[11] Therefore, if throws were made at similar distances, the results might differ. Third, only recreational-level baseball players were included in this study. Considering the differences in pitching kinematics observed at different levels of competition, [10] the results of this study may not be applicable to all college and professional baseball players. Fourth, the number of throws evaluated for each player was

Table II
Simple linear regression analysis between shoulder angle, spine, and pelvic angle at MIR during the deceleration phase.

	Shoulder angle											
	Horizontal adduction				Abduction				Internal rotation			
	Slope	R^2	*P* value	95% CI	Slope	R^2	*P* value	95% CI	Slope	R^2	*P* value	95% CI
Spine angle												
Flexion	−0.080	0.013	.650	−0.426 to 0.266	0.351	0.253	.024	0.046 to 0.656	−0.720	0.338	.006	−1.230 to −0.211
Nonthrowing side lateral flexion	−0.042	0.009	.709	−0.262 to 0.178	0.100	0.051	.370	−0.118 to 0.318	0.005	0.000	.981	−0.393 to 0.403
Nonthrowing side rotation	−0.037	0.002	.858	−0.438 to 0.365	0.111	0.019	.589	−0.292 to 0.515	−0.793	0.307	.010	−1.400 to −0.190
Pelvic angle												
Anterior tilt	−0.073	0.007	.746	0.515 to 0.369	−0.160	0.032	.479	−0.602 to 0.283	0.571	0.131	.133	−0.173 to 1.315
Nonthrowing side lateral tilt	0.005	0.000	.965	−0.232 to 0.242	−0.017	0.001	.888	−0.257 to 0.223	−0.152	0.033	.477	−0.572 to 0.267
Nonthrowing side rotation	−0.056	0.002	.853	−0.652 to 0.539	0.089	0.005	.773	−0.515 to 0.692	0.442	0.043	.409	−0.608 to 1.492

R^2, coefficient of determination; *CI*, confidence interval; *MIR*, maximum internal rotation.

Table III
Simple linear regression analysis between shoulder internal rotation angular velocity, spine, and pelvic angular velocity at MIR during the deceleration phase.

	Shoulder internal rotation: angular velocity			
	Slope	R^2	*P* value	95% CI
Spine angular velocity				
Flexion	0.092	0.126	.142	−0.031 to 0.214
Nonthrowing side lateral flexion	−0.066	0.018	.600	−0.308 to 0.176
Nonthrowing side rotation	−0.103	0.081	.251	−0.278 to 0.073
Pelvic angular velocity				
Anterior tilt	0.051	0.028	.512	−0.102 to 0.205
Nonthrowing side lateral tilt	0.041	0.003	.822	−0.317 to 0.400
Nonthrowing side rotation	0.024	0.003	.823	−0.184 to 0.232

R^2, coefficient of determination; *CI*, confidence interval; *MIR*, maximum internal rotation.

limited. Because players with a large internal shoulder rotation angle at the MIR often complain of shoulder pain in clinics, this study analyzed trials, and the maximum internal shoulder rotation angle was observed in three trials. However, to further generalize the data, it is necessary to increase the number of throws and consider the data variability. The strength of this study is that, while few reports have demonstrated the relationship between the shoulder, pelvis, and trunk motions at the MIR, this study clarified those relationships. Because the internal shoulder rotation motion at the MIR is influenced by other joints, the results of this study may assist in the rehabilitation of athletes with shoulder injury symptoms at the MIR.

Conclusion

This study utilized a three-dimensional motion analysis system to examine the associations between the shoulder kinematics at the MIR and the pelvis and trunk kinematics in healthy participants. Players with greater spinal flexion and nonthrowing side rotation angle at the MIR had smaller angles of internal shoulder rotation. This demonstrates the need to control the spinal flexion and nonthrowing side rotation to suppress the internal shoulder rotation at the MIR.

Acknowledgements

The authors thank the study participants and acknowledge Enago for their support in editing the final draft of this manuscript.

Disclaimers:

Funding: No funding was disclosed by the authors.

Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. 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;23:42-51. https://doi.org/10.1123/jab.23.1.42.
2. Aso T, Kagaya Y. Effects of repetitive pitching on trunk muscle endurance and thoracic and shoulder kinematics. Int J Sports Phys Ther 2023;18:388-96. https://doi.org/10.26603/001c.73038.
3. Boes MT, Thiel JA, Morgan CD. Arthroscopic treatment of the disabled throwing shoulder. In: Cole BJ, Sekiya JK, editors. Surgical techniques of the shoulder elbow and knee in sports medicine. 2nd edition. Amsterdam: Elsevier Health Sci; 2013. p. 109-31 (ISBN No. 9781455723584).
4. Braun S, Kokmeyer D, Millett PJ. Shoulder injuries in the throwing athlete. J Bone Joint Surg Am 2009;91:966-78. https://doi.org/10.2106/JBJS.H.01341.
5. DeFroda SF, Thigpen CA, Kriz PK. Two-dimensional video analysis of youth and adolescent pitching biomechanics: a tool for the common athlete. Curr Sports Med Rep 2016;15:350-8. https://doi.org/10.1249/JSR.0000000000000295.
6. Digiovine NM, Jobe FW, Pink M, Perry J. An electromyographic analysis of the upper extremity in pitching. J Shoulder Elbow Surg 1992;1:15-25.
7. Douoguih WA, Dolce DL, Lincoln AE. Early cocking phase mechanics and upper extremity surgery risk in starting professional baseball pitchers. Orthop J Sports Med 2015;3, 2325967115581594. https://doi.org/10.1177/2325967115581594.
8. Escamilla RF, Fleisig GS, Barrentine SW, Zheng N, Andrews JR. Kinematic comparisons of throwing different types of baseball pitches. J Appl Biomech 1998;14:1-23.
9. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. Am J Sports Med 1995;23:233-9.
10. 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;32:1371-5.
11. Fleisig GS, Bolt B, Fortenbaugh D, Wilk KE, Andrews JR. Biomechanical comparison of baseball pitching and long-toss: implications for training and rehabilitation. J Orthop Sports Phys Ther 2011;41:296-303. https://doi.org/10.2519/jospt.2011.3568.
12. Gerber C, Sebesta A. Impingement of the deep surface of the subscapularis tendon and the reflection pulley on the anterosuperior glenoid rim: a preliminary report. J Shoulder Elbow Surg 2000;9:483-90.
13. Keeley DW, Oliver GD, Dougherty CP, Torry MR. Lower body predictors of glenohumeral compressive force in high school baseball pitchers. J Appl Biomech 2015;31:181-8. https://doi.org/10.1123/jab.2011-0229.
14. Laudner KG, Wong R, Meister K. The influence of lumbopelvic control on shoulder and elbow kinetics in elite baseball pitchers. J Shoulder Elbow Surg 2019;28:330-4. https://doi.org/10.1016/j.jse.2018.07.015.
15. Lyman S, Fleisig GS, Waterbor JW, Funkhouser EM, Pulley L, Andrews JR, et al. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. Med Sci Sports Exerc 2001;33:1803-10.
16. Manzi JE, Estrada JA, Quan T, Ruzbarsky JJ, Ciccotti MC, Dines JS. The influence of excessive ipsilateral trunk tilt on upper-extremity throwing mechanics: a newly characterized parameter for biomechanical evaluation in high school and professional pitchers. J Shoulder Elbow Surg 2022;31:1909-21. https://doi.org/10.1016/j.jse.2022.01.153.
17. Miyakoshi K, Umehara J, Komamura T, Ueda Y, Tamezawa T, Kitamura G, et al. Effect of different trunk postures on scapular muscle activities and kinematics during shoulder external rotation. J Shoulder Elbow Surg 2019;28:2438-46. https://doi.org/10.1016/j.jse.2019.04.059.

18. Miyashita K, Kobayashi H, Koshida S. Kinetic chain upper extremity joints during acceleration phase in throwing motion. Jpn J orthop Sports Med 2015;35:114-9. No doi.
19. Miyashita K, Kobayashi H, Koshida S, Urabe Y. Glenohumeral, scapular, and thoracic angles at maximum shoulder external rotation in throwing. Am J Sports Med 2010;38:363-8. https://doi.org/10.1177/0363546509347542.
20. Miyazaki S, Yamako G, Totoribe K, Sekimoto T, Kadowaki Y, Tsuruta K, et al. Shadow pitching deviates ball release position: kinematic analysis in high school baseball pitchers. BMC Sports Sci Med Rehabil 2021;13:26. https://doi.org/10.1186/s13102-021-00255-7.
21. Oliver GD, Keeley DW. Pelvis and torso kinematics and their relationship to shoulder kinematics in high-school baseball pitchers. J Strength Cond Res 2010;24:3241-6. https://doi.org/10.1519/JSC.0b013e3181cc22de.
22. Oliver G, Weimar W. Scapula kinematics of youth baseball players. J Hum Kinet 2015;49:47-54. https://doi.org/10.1515/hukin-2015-0107.
23. Suzuki Y, Muraki T, Sekiguchi Y, Ishikawa H, Yaguchi H, Suzuki Y, et al. Influence of thoracic posture on scapulothoracic and glenohumeral motions during eccentric shoulder external rotation. Gait Posture 2019;67:207-12. https://doi.org/10.1016/j.gaitpost.2018.10.022.
24. Tsuruike M, Ellenbecker TS, Lauffenburger C. Electromyography activity of the teres minor muscle with varying positions of horizontal abduction in the quadruped position. JSES Int 2021;5:480-5. https://doi.org/10.1016/j.jseint.2020.12.014.
25. Valadie IIIAL, Jobe CM, Pink MM, Ekman EF, Jobe FW. Anatomy of provocative tests for impingement syndrome of the shoulder. J Shoulder Elbow Surg 2000;9:36-46.