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The title: Range of motion patterning in trunk and upper and lower extremities of high school baseball pitchers

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Abstract（250words）

Introduction: Evaluating different range of motion using several joints is essential for rehabilitating throwing injuries. We used multivariate analysis to elucidate the range of motion patterns in baseball pitchers.

Methods: This cross-sectional study measured the 18 variable ranges of motions in the upper extremities, the trunk, and the lower extremities. High school baseball pitchers participated (N = 121). Factor analysis of ROM was performed using the maximum likelihood method. We analyzed the characteristics of pitchers with positive findings by classifying all players using cluster analysis (Ward method).

Results: Factor analysis showed a seven-factor solution was shown to be appropriate. Cluster analysis indicated that we could divide the players into three clusters that we named according to their characteristics and range of motion: Cluster A; “Low flexibility type, Cluster B; “High rotation type,” and Cluster C; “Poor rotation type. The results indicated that most positive players were in Cluster A (46.4%). Players in Cluster A had lower range of motion in the trunk, hip rotation, and SLR (Straight Leg Raising) than the other groups.

Conclusions: This is the first study to identify the patterns of range of motion in high school baseball pitchers with positive findings. These results are useful for conditioning baseball players.

Keywords（3-6）： range of motion, baseball, patterning, factor analysis, cluster analysis

高校生野球投手における関節可動域と肩肘障害との関係

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要旨

投球障害に対するリハビリテーションでは，個々の関節の可動域だけでなく，複数の関節を含む可動域を評価することが重要である．本研究の目的は，投球障害を有する高校生野球投手の可動域特性を多変量解析により明らかにすることである．高校野球部に所属する選手 121 名を対象に横断的に調査した．上肢，体幹，下肢の 18 項目の関節可動域を測定した．プロマックス回転法による因子分析を行い，クラスター分析（Ward 法）によって全選手を分類し，理学所見陽性の選手の特徴を評価した．クラスター分析の結果，121 名の選手はクラスターA（柔軟性低値群），クラスターB（回旋高値群），クラスターC（回旋低値群）の 3 つのクラスターに分類された．クラスターA に理学所見陽性の選手が最も多かった(46.4%)．クラスターA では，体幹回旋，股関節回旋，SLR の可動域が低値を示した．本報告は，理学所見陽性の高校野球投手の可動域パターンを初めて明らかにしたものである．これらの結果は，野球選手のコンディショニングを行う上で有用であると考えた．

Ⅰ Introduction

Baseball is a popular sport in Japan. Previous studies have investigated the characteristic of range of motion in the extremities of Baseball players. These studies have reported that the range of motion of external rotation in the throwing side's shoulder joint increases and internal rotation decreases compared to the non-throwing side.1, 2, 3, 4) Studies have also reported that the range of motion of internal and external rotation on the lead leg increases5). Shoulder internal impingement syndrome is a common throwing injuries among baseball players. Moreover, medial, posterior, and lateral injuries to the elbow joint also occur. The hyper external rotation Test (HERT), 6, 7) the valgus stress test, 8) and the overextension test9) are stress tests for identifying these conditions.

The limited range of motion in the joints of the lower extremities and trunk causes poor throwing form and could result in throwing injuries.10) Myers et al 11) in a cross-sectional study and Shanley et al 12) in a longitudinal study showed a relationship between internal rotation of the shoulder joint and throwing disorders. On the other hand, Sweitzer et al 13) in a cross-sectional study and Wilk et al 14) in a longitudinal study concluded that there is no relationship between shoulder internal rotation and throwing disorders. Both studies involved competitive-level athletes of high school age and above. However, the conflicting results suggest that examining the shoulder joint alone may not be sufficient. Thus, the relationship between range of motion and throwing injuries is unclear. It has been reported that a decrease in shoulder rotation angle, which is the sum of internal rotation and external rotation, is associated with elbow injuries. It has also been reported that players with a correlation between hip extension and shoulder external rotation experience shoulder injuries. 15) It might be possible to combine the range of motion in each joint and clarify its relationship with throwing injuries. The throwing motion is performed by the kinetic chain of the upper and lower extremities and the trunk. The trunk is critical for transferring the energy produced by the lower extremities to the ball. Therefore, it is necessary to consider the shoulder and the hip joints, and the trunk. 5, 16) Factor analysis and cluster analysis can classify and evaluate different factors. 17, 18) Medical studies using multivariate analysis have been conducted. Anderson et al. 17) used factor analysis to validate the new 10-item SPADI, a patient-reported outcome measure used in clinical and research settings in Spanish patients with musculoskeletal shoulder pain. Another study identified the characteristics of high school and university student softball batters' stepping motions, including the start time, the stepping time, and foot-stepping movement by cluster analysis18) and identified their characteristics. These studies demonstrate that multivariate analysis can identify features of athletes with throwing injuries. We hypothesized multivariate analysis could clarify the relationship between throwing injuries and range of motion. We examined the relationship between throwing injuries and range of motion in high school baseball players and conducted a multivariate analysis to test the hypothesis of this study.

Ⅱ Methods

1. Participants

We enrolled male baseball pitchers as study participants from Baseball skills camps held annually during the off-season in the Kyoto Prefecture of Japan. (N = 121; Age range 15-17-years). Table 1 shows the demographic characteristics of the participants. The main pitchers at each high school who were pain-free and capable of pitching at full strength were included in the study. The study was approved by the Ethics Committee at the Rakwakai Research Ethics Review Committee (Raku-gaku-Rin-01-000100). All the participants gave their informed consent before participating in the study. This study was conducted according to the 1964 declaration of Helsinki on studies using human participants.

2. Measurements

(1) Definition of throwing injuries

Orthopedic surgeons performed the HERT (Hyper External Rotation Test) 6, 7) for detecting the shoulder intra-articular impingement syndrome, the elbow valgus stress test8) for detecting the medial elbow injuries, and the elbow hyperextension test9) for detecting the posterior elbow injuries19). We categorized the player in positive group if any of the tests were positive. We categorized them in negative group if all tests were negative.

The orthopedic surgeon performed an ultrasonography and found no findings of ligamentous injury that would have prompted a hospital visit. As for the posterior elbow injuries, which showed a positive hyperextension test, it was difficult to determine by ultrasonography and was discussed in the physical examination findings.

（2）range of motion

The measurement of the shoulder external and internal rotation (shoulder abducted to 90º), the shoulder 3rd internal rotation (shoulder flexed to 90º), the hip external and internal rotation (hip, knee flexed to 90º), the neck and trunk rotation, the straight leg raising (SLR), and the heel-buttock distance (HBD) were conducted by physical therapists based on the Japanese Orthopaedic Association and the Japanese Association of Rehabilitation Medicine20), and Kibler et al. 21)

The items selected were the range of rotational motion of the upper extremity, trunk, and lower extremity, based on previous research indicating the importance of the range of rotational motion. SLR and HBD were selected because they have been reported to be related to pitching disorders and to throwing motion.

The following measures were conducted. (a) The shoulder external and internal rotation angles in the supine position with the scapula fixed, the shoulder abducted to 90º, and the elbow flexed to 90º; (b)

The angle formed by the ulna and a line perpendicular to the frontal plane passing through the elbow; (c) The shoulder 3rd internal rotation angle in the supine position with the scapula fixed, the shoulder flexed to 90º, and the elbow flexed to 90º; (d) The angle formed by the ulna and a line connecting both acromions; 22）; (e) The hip external and internal rotation angles in the supine position with the pelvis fixed and the hip and knee flexed to 90º; (f) The angle formed by a line descending from the patella and the centerline of the lower leg (the line connecting the center of the patella with the point between the medial malleolus and lateral malleolus); (g) The trunk rotation angle in the sitting position with the pelvis fixed; (h) The angle formed by the line connecting both posterior superior iliac spines and the line connecting both acromions. ; (i) We defined the left rotation as the throwing direction, and the right rotation as the opposite direction for assessing the trunk rotation of right-handed pitchers. ; (j) The SLR angle in the supine position with the opposite leg and pelvis fixed and the lower extremity in a neutral position between internal and external rotation; (k) The angle formed by the thigh and the trunk axis; (l) The HBD in the prone position with the hip in a neutral position between internal rotation, external rotation, adduction, and abduction was measured; (m) We defined the right lower extremity as the pivot leg, and the left lower extremity as the lead leg for the ROM of the lower extremities in right-handed pitchers and measured the angles in 1º increments using a standard goniometer. We measured distances in 1-mm increments using a tape measure.

The extremities were moved or fixed based on Wilk et al. 23) to prevent compensatory movements during measurements. A 4-member team measured and recorded the angles. All four members confirmed the movable arm, stationary arm, and measured values. The techniques were thoroughly practiced before making evaluations. The interclass correlation coefficient was 0.817 (95%confidence interval [CI], 0.774–0.904) for the evaluation of ROM, indicating good inter-rater reliability. The intraclass correlation coefficient was 0.88 for the evaluation of ROM, indicating good intra-rater reliability24).

3. Statistical analysis.

We used unpaired Student t-tests to compare the injured and non-injured groups' demographic characteristics and ROMs between the throwing and the non-throwing sides. We used Pearson's rank correlation coefficient to assess the correlation between 18 ROMs evaluated in this study and demographic characteristics. All data are reported as the mean ± SD. We defined a P value < 0.05 as a significant difference. A factor analysis of the ROM was conducted using the maximum likelihood method. We estimated factor score coefficients from factor loadings obtained for each variable and calculated factor scores using these values. We used unpaired t-tests to compare the factor scores' means of the injured and non-injured groups. These factor scores were used to conduct cluster analysis using Ward's method and classify the players statistically. A one-way analysis of variance (ANOVA) was conducted to determine statistically significant differences in ROMs among the clusters (the Tukey correction was used for post-hoc analyses). We tested the association between the injured athletes and clusters using the chi-square test. The statistical software IBM SPSS 21(IBM, Corp., Armonk, New York) was used to conduct the statistical analyses.

Ⅲ Results

1. Throwing injuries and ROM

Of the players, 17 in the HERT, 22 in the elbow valgus test, and 19 in the elbow hyperextension test were positive 42 players were positive in one of these three tests.

All items measured were normally distributed. Table 1 shows the participants' characteristics, indicating no significant difference in positive and negative participants. Table 2 shows the ROMs, which indicates no significant difference between the injured and the non-injured groups. Table 3 shows the ROMs, which indicates left-right difference was observed only in the shoulder joint.

Age at start of competition showed a positive relationship with the trunk rotation in the opposite direction. Moreover, the height showed a negative association with the hip external rotation in the pivot and the lead leg and a positive relationship with the HBD in the pivot leg (Table 4).

2. Factor analysis

Factor analysis of the ROMs was conducted using the maximum likelihood method. The eigenvalues, slope of the screen plot, and interpretability of the factors indicated the appropriateness of a seven-factor solution. The eigenvalue of the first factor was 4.64, the second factor, 2.58, the third factor, 2.04, the fourth factor, 1.46, the fifth factor, 1.31, the sixth factor, 1.12, and the seventh factor was 0.98, which resulted in a cumulative contribution rate of 78.5%. The seven factors that we identified were obliquely rotated using the Promax method (Table 5).

The first factor was especially high for SLR, hip flexion, and shoulder internal rotation on the throwing side, and it was grouped by hip flexion. The HBD showed high values for the second factor, which was grouped by the HBD. The hip internal rotation was high values for the third factor, which, was grouped by hip internal rotation. The fourth factor showed high values for shoulder 3rd internal rotation and shoulder internal rotation on the non-throwing side, and it was grouped by shoulder internal rotation. The hip external rotation showed high values for the fifth factor, and it was grouped by hip external rotation. The trunk rotation showed high values for the sixth factor, and it was grouped by trunk rotation. The shoulder external rotation showed high values for the seventh factor, which was grouped by shoulder external rotation. Comparing the mean values of the factor scores in positive and negative participants indicated no significant differences in any items (Table 6).

3. Cluster analysis

The results of cluster analysis divided the 121 pitchers into 3 clusters, each with a specific ROM distribution characteristic. Cluster A (low flexibility type); Cluster B (good rotation type); Cluster C (poor rotation type). The F (F [4,537]) and P values of the ANOVA on each dimension indicated that each dimension discriminated well between clusters. The trunk rotation to throwing direction and hip external rotation in Cluster B was greater than in Clusters A or C. Furthermore, the trunk rotation in the opposite direction and hip external rotation in Cluster B was greater than in Clusters A or C. Internal hip rotation in Cluster A was greater than in Cluster C. Hip flex and SLR in Clusters B and C were larger than in Cluster A. The HBD in Cluster A was greater than in Clusters B or C. The groups were very similar in age, height, weight, and age at start of competition. The percentage of athletes classified as disabled was 46.4% (26 of 56) in group A, 20.9% (9 of 43) in group B, and 31.8% (7 of 22) in group C. A chi-square test showed a significant relationship between group and disability ($\chi2=7.08$, $p<.05$), and residuals were significantly higher in group A than in group B (Table 7).

Ⅳ Discussions

1. Shoulder/elbow injuries

We tested 121 high school baseball pitchers. Morihara et al.19) reported a HERT positivity rate of 12.4% for the shoulder joint, 16.1% for the elbow valgus stress test, and 8.8% for the elbow hyperextension test in 805 high school baseball players. The positive rate for the HERT and the elbow external stress test differed by 2% between the current study and Morihara et al., possibly because all the participants in the current study were pitchers. The positivity rate on the hyperextension test was higher than in the previous study. Unlike the previous study, all subjects in this study were pitchers. Pitchers have more opportunities to pitch and are more prone to shoulder and elbow injuries, which may explain the higher positivity rate.

2. ROM

We investigated the rotational angle of the shoulder joint, the trunk, and the hip joint and the relationship between throwing injuries and the ROMs. The lateral difference in ROMs indicated that shoulder external rotation was more significant on the throwing side and the non-throwing side for internal rotations and the 3rd internal rotation, which supported previous studies showing left and right differences in shoulder rotation. 1, 2, 3, 4)

The HBD of the pivot leg in the injured group was significantly greater. Stiffness of the iliopsoas muscle may have inhibited the center of gravity shift to the lead leg, leading to the disability. Shoulder rotation significantly differs from left to right. Consistent with previous studies, this is characteristic of athletes performing the throwing motion. Negative correlation between starting age and trunk rotation. Height was negatively correlated with hip external rotation and positively correlated with pivot leg HBD. The earlier the age at start, the greater the number of pitches they were expected to throw. The negative correlation between age at start and trunk rotation was attributed to changes in trunk rotation range of motion due to the throwing motion.

The limitation of hip external rotation is caused by the tightness of the gluteus maximus muscle. The relationship between the gluteus maximus muscle and height is unknown, and further research is needed to clarify the factors that led to the negative correlation between height and hip external rotation. The higher the height, the longer the thigh length may be. The positive correlation between height and HBD was attributed to the longer quadriceps muscle length, which tends to produce tightness. The correlation coefficient is about 0.20, which is statistically significant but of little clinical significance. In addition, the meaningfulness is poor just because it is statistically significant.

3. Multivariate analysis of throwing injuries and range of motion

This study conducted a factor analysis of the whole body’s ROM and identified seven factors. The lower extremity separates in the direction of movement to form three hip flexion and SLR factors, external rotation and internal rotation. Moreover, HBD, which evaluates the flexibility of the quadriceps muscle, was an independent factor. The upper extremities formed two elements, the shoulder external and internal rotation and the trunk rotation. This result suggested that the upper limbs, the trunk, and the lower limbs are whole-body movements involved in the throwing motion.

The three groups obtained by cluster analysis did not show significant differences based on age, age at start of competition, height, or weight. Comparing the three groups indicated significantly more positive players in Cluster A with lower hip flexion and SLR and larger HBD. This study's results support several previous studies reporting on ROM limitations associated with injuries. 11, 12)

The throwing motion can be divided into six phases: windup phase, stride phase, cocking phase, acceleration phase, deceleration phase, and follow-through phase 26, 27). The windup phase is the first movement when starting to throw after the stride leg lifts until it reaches the ground; the collapse of this period might lead to throwing injuries28). Hip flexion angle and quadriceps muscle flexibility (HBD) are required during the windup phase. The injury rate was high in Cluster A because this group was unable to take one leg standing, which affected the throwing motion afterward (Figure 1). The foot contact after the windup period consists of hip abduction, trunk rotation, and hip extrapolation. Because of the wide range of motion in cluster B, the kinetic chain of the upper extremity, trunk, and lower extremity may be smooth. The low injury rate may have been due to efficient throwing motion (Figure 2).

This study, because it is a cross-sectional study, has limited validity in specifying the risk factors for throwing injuries. The study only describes the characteristics of players with throwing injuries. Future study should be conducted longitudinally to clarify the risk of injuries.

Regarding the characteristics of the cluster C group, compared to the other groups, the range of rotational motion of the upper and lower limbs and trunk was low, and hip flexion and SLR were high. Previous studies have reported that the group with limited joint range of motion is more prone to disability. In the present study, despite the low values of joint range of motion, the positive rate of findings did not differ. Internal rotation in the 3rd shoulder position was lower than in the other groups, but was not statistically significant. We hypothesized that pitchers classified in this group had stiffness in the muscle group behind the shoulder as a result of pitching motion using flexion-extension movements. In this study, medical checkups were conducted during the off-season when the number of pitches was low. It is possible that the stiffness behind the shoulder did not reach statistical significance and did not result in a positive finding. We considered that this group required careful conditioning in preparation for the season.

In this study, high school pitchers were selected as subjects to examine range of motion characteristics. Baseball is played by various age groups, from elementary school students to adults. The results of this study may be applicable to throwing disorders in adults. However, the pathophysiology of high school students differs from that of elementary and junior high school students, who are in the growth phase of increasing height and weight. A new study is needed.

One limitation of this study is that the shoulder and elbow joints were evaluated together. Due to the small number of subjects in this study, the shoulder and elbow joints were evaluated together for statistical reasons. Another limitation is that only 18 items are measured: shoulder joint, trunk, and hip joint. Previous studies29) have reported that scapular motion is different in baseball players with and without throwing injuries. Scapular assessment, such as Scapular Retraction Test, should be considered. 30)

V Conclusion

1. We measured the ROM of high school baseball pitchers and classified them using factor analysis

and cluster analysis.

2. We extracted seven factors from eighteen ROM classified into three groups.
3. The group with Low hip flexion, SLR, and large HBD showed a high prevalence of positive.
4. Complex evaluations of ROM are necessary to show ROM characteristics of athletes with injuries.

Contributions： Conceived and designed the study: HM. Performed the study: AY, MT, SK. Analyzed the data: WY and KN. Interpreted the data: HM and MT. Wrote the paper: HM. Analyzing and writing advisory: KN and MT. All authors approved the final version of the manuscript.

Conflicts of Interest: None of the authors have any conflicts of interest with the findings of this study.

Reference

1. Brown LP, Niehues SL, Harrah A, Yavorsky P and Hirshman HP. 1988. Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players. Am J Sports Med 16(6): 2487-2493. doi: 10.1177/036354658801600604.

2. Bigliani LU, Codd TP, Connor PM, Levine WN, Littlefield MA and Hershon SJ. 1997. Shoulder Motion and Laxity in the Professional Baseball Player. Am J Sports Med 25 (5): 609-613． doi: 10.1177/036354659702500504.

3. EllenbeckerTS, Roetert EP, Bailie DS, Davies GJ and Brown SW. 2002.Glenohumeral joint total rotation range of motion in elite tennis players and baseball pitchers. Med Sci Sports Exerc 34(12):2052-2056． doi: 10.1097/00005768-200212000-00028.

4. Meister K, Day T, Horodyski M, Kaminski TW, Wasik MP and Tillman S. 2005. Rotational Motion Changes in the Glenohumeral Joint of the Adolescent/Little League Baseball Player. Am J Sports Med 33(5): 693-698． doi: 10.1177/0363546504269936.

5. Robb AJ, Fleisig G, Wilk K, Macrina L, Bolt B and Pajaczkowski, J. 2010. Passive ranges of motion of the hips and their relationship with pitching biomechanics and ball velocity in professional baseball pitchers. Am J Sports Med 38(12): 2487-2493.doi:10.1177/0363546510375535.

6. Walch G, Boileau P, Noel E and Donell ST. 1992. Impingement of the deep surface of the supraspinatus tendon on the posterosuperior glenoid rim: An arthroscopic study. J Shoulder Elbow Surg 1 (5): 238-245.doi: 10.1016/S1058-2746(09)80065-7.

7. Carson WG Jr and Gasser SI. 1998. Little leaguer's shoulder: a report of 23 cases. Am J Sports Med 26: 575-580. doi:10.1177/03635465980260041901.

8. O'Driscoll SW, Lawton RL and Smith AM. 2005. The "moving valgus stress test" for medial collateral ligament tears of the elbow. Am J Sports Med 33(2):231-239. doi: 10.1177/0363546504267804.

9. Wilson FD, Andrews JR, Blackburn TA and McCluskey G. 1983. Valgus extension overload in the pitching elbow. Am J Sports Med 11: 83-88.doi:10.1177/036354658301100206.

10. Scher S, Anderson K, Weber N, Bajorek J, Rand K and Bey MJ. 2010. Associations among hip and shoulder range of motion and shoulder injury in professional baseball players. J Athl Train 45 (2): 191-197.doi: 10.4085/1062-6050-45.2.191.

11. Myers JB, Laudner KG, Pasquale MR, Bradley JP and Lephart SM. 2006. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. Am J Sports Med 34(3): 385-91.doi: 10.1177/0363546505281804.

12. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS, Garrison JC and Thigpen CA. 2011. Shoulder range of motion measures as risk factors for shoulder and elbow injuries in high school softball and baseball players. Am J Sports Med 39(9): 1997-2006. doi: 10.1177/0363546511408876.

13. Sweitzer BA, Thigpen CA, Shanley E, Stranges G, Wienke JR, Storey T, Noonan TJ, Hawkins RJ and Wyland DJ. 2012. A comparison of glenoid morphology and glenohumeral range of motion

between professional baseball pitchers with and without a history of SLAP repair. Arthroscopy 28(9): 1206-1213.doi: 10.1016/j.arthro.2012.02.023.

14. Wilk KE, Macrina LC, Fleisig GS, Aune KT, Porterfield RA, Harker P, Evans TJ and Andrews JR. 2014. Deficits in glenohumeral passive range of motion increase risk of elbow injury in professional baseball pitchers: a prospective study. Am J Sports Med 42(9): 2075-2081.doi: 10.1177/0363546514538391.

15. Garrison JC, Cole MA, Conway JE, Macko MJ, Thigpen C and Shanley E. 2012. Shoulder range of motion deficits in baseball players with an ulnar collateral ligament tear. Am J Sports Med 40(11): 2597-603.doi: 10.1177/0363546512459175.

16. Oyama S, Yu B, Blackburn JT, Padua DA, Li L and Myers JB. 2014. Improper trunk rotation sequence is associated with increased maximal shoulder external rotation angle and shoulder joint force in high school baseball pitchers. Am J Sports Med 42(9):2089-94. doi: 10.1177/0363546514536871.

17. Anderson AB, Tenan MS and Dickens JF.2021.Latent Factor Analysis of the PROMIS and Single Assessment Numeric Evaluation in Patients Undergoing Shoulder Surgery. Mil Med. online. doi: 10.1093/milmed/usab327.

18. Takamido R, Yokoyama K and Yamamoto Y. 2019. Task constraints and stepping movement of fast-pitch softball hitting. PLoS One 14(2). doi: 10.1371/journal.pone.0212997.

19. Morihara, T, Kida Y, Iwata Y, Furukawa R, Sukenari T, Matsui T, Azuma Y, Seo K, Hiramoto M, Ito S, Soma H, Hojo T, Yamada Y, Horii M and Kubo T.2014.Medical examination for the prevention from the throwing shoulder and elbow disorders in the senior high school baseball players. J Jpn Society Cli Sports Med 22（2）：309-317 (in Japanese).

20. Yonemoto K, Ishigami J and Kondo T. 1995. Measurement Method for Range of Motion. Jpn J Reha Med32（4）：207-217 (in Japanese). doi: 10.2490/jjrm1963.32.207.

21. Kibler WB, Chandler TJ, Uhl T and Maddux RE. 1989. A musculoskeletal approach to the preparticipation physical examination Preventing injury and improving performance. Am J Sports Med , 17(4): 525-531. doi: 10.1177/036354658901700413.

22.Toyoda D, Kurosawa K, FUukuda D and MizunoI T.2021. Position-related Differences in the Passive Shoulder Rotation Range of Motion. Rigakuryoho Kagaku, 36(3): 403–408. doi:https://doi.org/10.1589/rika.36.403.

23.Wilk KE, Reinold MM, Macrina LC, Porterfield R, Devine KM, Suarez K and Andrews JR.2009 Shoulder internal rotation measurements differ depending on stabilization techniques. Sports Health, 1(2):131-136. doi: 10.1177/1941738108331201.

24. Hiramoto M, Morihara T, Kida Y, Matsui T, Azuma Y, Seo K, Miyazaki T, Watanabe Y, Kai Y, Yamada Y, Kida N and Morifusa Shuhei. 2019. Hip, Trunk, and Shoulder Rotational Range of Motion in Healthy Japanese Youth and High-school Baseball Pitchers. Prog Rehabil Med 4:online.doi:10.2490/prm.20190009.

25. Harada M, Takahara M, Mura N, Sasaki J, Ito T, and Ogino T. 2010. Risk factors for elbow injuries among young baseball players. J Shoulder Elbow Surg 19(4): 502-507. doi: 10.1016/j.jse.2009.10.022.

26.Thomas SJ, Swanik CB, Kaminski TW, Higginson JS, Swanik KA, Bartolozzi AR and Nazarian LN. 2012. Humeral retroversion and its association with posterior capsule thickness in collegiate baseball players. J Shoulder Elbow Surg 21(7):910-6, doi: 10.1016/j.jse.2011.05.028.

27. Fleisig GS, Andrews JR, Dillman CJ and Escamilla RF. 1995. Kinetics of baseball pitching with implications about injury mechanisms. Am J Sports Med 23(2): 233-239. doi: 10.1177/036354659502300218.

28. Fortenbaugh D, Fleisig GS and Andrews JR. 2009. Baseball pitching biomechanics in relation to injury risk and performance. Sports Health 1(4):314-20.doi: 10.1177/1941738109338546.

29. Laudner KG, Myers JB, Pasquale MR, Bradley JP and Lephart SM. 2006. Scapular

dysfunction in throwers with pathologic internal impingement. J Orthop Sports Phys Ther 36(7):485-94. doi: 10.2519/jospt.2006.2146.

30.Kawai K, Funasaki H, Hayashi H, Kato H and Numazawa H.2017. Differences of Shoulder Function between Pitching Side and Non-pitching Side of Patients with Throwing Shoulder Injuries. Rigakuryoho Kagaku 32(1): 39–43 (in Japanese).

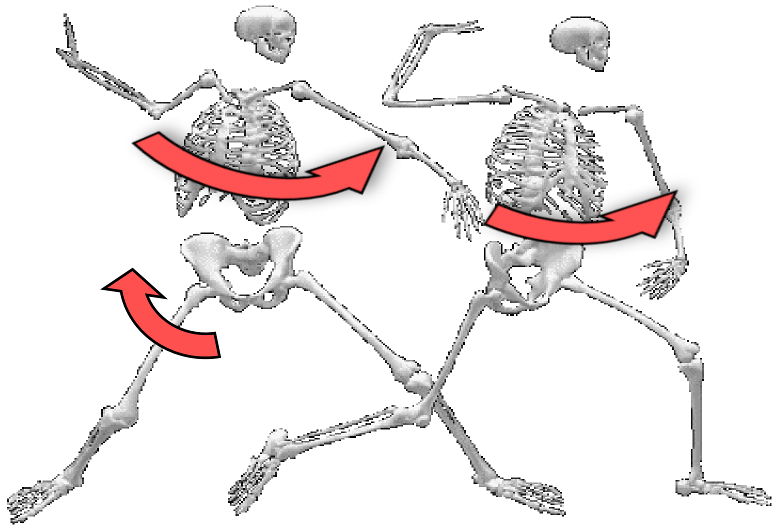

Figure 1. Relationship between Cluster A and throwing motion

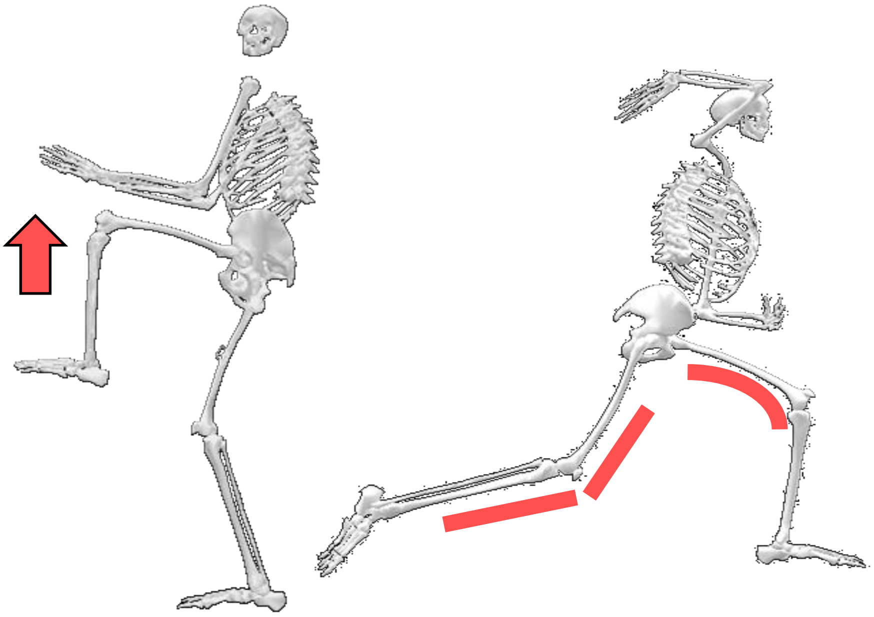

Figure 2. Relationship between Cluster B and throwing motion

Table 1. Participants' characteristics

	negative group *n* =79 *M* ±*SD*	positive group *n* =42 *M* ±*SD*	*t value*	*p value*
age（years old）	16.2±0.7	16.4±0.7	-1.49	.18
age at start（years old）	7.6±2.1	7.6±1.8	-1.06	.12
height（cm）	172.5±4.9	174.0±5.7	-0.25	.36
body weight（kg）	63.5±7.1	65.8±6.8	-0.08	.82

Table 2. Comparison of range of motion between negative group and positive group

	negative group *n* =79 *M* ±*SD*	positive group *n* =42 *M* ±*SD*	*t value*	*p value*	
shoulder external rotation throwing side	125.0±9.9	126.0±10.2	-0.51	.54	
shoulder external rotation non-throwing side	117.6±11.4	118.7±9.1	-0.53	.53	
shoulder internal rotation throwing side	38.7±11.4	40.3±11.7	-0.73	.49	
shoulder internal rotation non-throwing side	54.5±12.0	53.2±12.5	0.57	.39	
shoulder 3rd internal rotation throwing side	7.4±12.7	9.4±13.3	-0.82	.42	
shoulder 3rd internal rotation non-throwing side	19.2±12.2	18.4±11.5	0.36	.58	
trunk rotation throwing direction	49.8±8.7	49.0±8.7	0.54	.62	
trunk rotation opposite direction	50.6±6.5	49.9±9.6	0.43	.67	
hip external rotation pivot leg	57.7±8.0	56.6±9.5	0.68	.44	
hip external rotation lead leg	56.2±8.8	55.6±9.8	0.38	.07	
hip internal rotation pivot leg	33.3±13.7	35.2±13.8	-0.74	.49	
hip internal rotation lead leg	31.3±12.6	35.6±14.5	-1.70	.69	
hip flextion pivot leg	85.6±21.0	78.4±23.4	1.75	.08	
hip flextion lead leg	85.0±21.9	77.1±22.1	1.87	.06	
SLR pivot leg	51.4±14.3	46.1±16.6	1.81	.08	
SLR lead leg	52.0±15.7	47.5±17.0	1.44	.17	
HBD pivot leg	14.6±6.9	17.3±6.6	-2.07	.04	*
HBD lead leg	14.8±6.8	17.2±6.4	-1.83	.06	

*, p <.05

Table 3. Comparison of range of motion between throwing side and non-throwing side

	throwing side throwing direction pivot leg *M* ±*SD*	non-throwing side opposite direction lead leg *M* ±*SD*	*t value*	p value	
shoulder external rotation	125.3±10.0	118.0±10.6	6.85	.00	**
shoulder internal rotation	39.3±11.5	54.1±12.1	-11.78	.00	**
shoulder 3rd internal rotation	8.1±12.9	18.9±11.9	-11.15	.00	**
trunk rotation	49.5±8.7	50.4±8.9	-1.06	.29	
hip external rotation	57.3±8.5	56.0±9.1	1.65	.21	
hip internal rotation	33.9±13.7	32.8±13.4	1.25	.10	
hip flextion	83.1±22.1	82.2±22.2	1.01	.31	
SLR	49.6±15.3	50.4±16.2	-1.39	.17	
HBD	15.5±6.9	15.6±6.7	-0.33	.74	

**,$p<.01$

Table 4. Relationships between range of motion and participants' characteristics

	age		age at start		height		body weight	
	r value	*p value*	*r value*	*p value*	*r value*	*p value*	*r value*	*p value*
shoulder external rotation throwing side	-0.11	.22	-0.01	.71	0.04	.70	-0.13	.14
shoulder internal rotation throwing side	0.03	.73	-0.06	.46	0.01	.88	0.08	.38
shoulder 3rd internal rotation throwing side	-0.06	.53	-0.12	.24	0.03	.78	0.10	.29
trunk rotation throwing direction	0.03	.74	-0.03	.56	-0.07	.43	0.11	.22
trunk rotation opposite direction	-0.01	.91	-0.20	.02 *	-0.02	.86	0.05	.56
hip external rotation pivot leg	-0.15	.11	-0.10	.54	-0.22	.01 *	-0.10	.27
hip external rotation lead leg	0.01	.92	-0.06	.52	-0.18	.04 *	0.01	.90
hip internal rotation pivot leg	0.02	.81	-0.06	.42	-0.03	.76	0.01	.91
hip internal rotation lead leg	0.02	.84	-0.11	.18	-0.06	.50	-0.08	.37
hip flextion pivot leg	-0.07	.46	-0.11	.38	-0.05	.59	-0.09	.33
hip flextion lead leg	-0.04	.64	-0.05	.74	-0.07	.44	-0.12	.19
SLR pivot leg	-0.09	.34	-0.14	.24	-0.07	.43	-0.07	.48
SLR lead leg	-0.04	.69	-0.11	.34	-0.12	.19	-0.11	.24
HBD pivot leg	0.00	.96	0.05	.55	0.18	.04 *	0.16	.09
HBD lead leg	0.09	.35	0.10	.42	0.14	.12	0.11	.22

*,p<.05

Table 5. Factor analysis

item	F1	F2	F3	F4	F5	F6	F7
the first factor (α = .88)							
・ SLR lead leg	.984	.013	.018	-.011	-.001	.028	-.302
・ hip flextion pivot leg	.928	.005	-.014	-.015	.049	-.049	.268
・ SLR pivot leg	.898	-.003	-.037	.033	-.041	.034	-.170
・ hip flextion lead leg	.865	-.115	.017	-.124	-.010	.011	.122
・ shoulder internal rotation throwing side	.126	-.008	.022	.120	.038	.116	.015
the second factor (α= .95)							
・ HBD pivot leg	-.040	.988	-.015	.039	-.008	.019	-.005
・ HBD lead leg	-.123	.803	.039	-.147	-.014	.013	-.050
the third factor (α= .85)							
・ hip internal rotation lead leg	-.024	-.040	.991	-.056	-.108	.021	.060
・ hip internal rotation pivot leg	.010	.067	.739	.103	.108	-.010	.083
the fourth factor (α= .66)							
・ shoulder 3rd internal rotation throwing side	.017	.004	.043	.789	-.082	-.060	.017
・ shoulder 3rd internal rotation non-throwing side	-.085	-.106	.034	.749	.074	.022	-.038
・ shoulder internal rotation non-throwing side	-.088	.016	-.076	.414	-.010	.138	.211
the fifth factor (α= .69)							
・ hip external rotation lead leg	.110	.099	.007	.080	1.010	-.070	.033
・ hip external rotation pivot leg	-.148	-.158	-.031	-.123	.534	.145	-.010
the sixth factor (α= .69)							
・ trunk rotation throwing direction	.006	-.034	.109	-.063	.129	.884	-.157
・ trunk rotation opposite direction	.195	.112	-.047	.187	-.151	.600	-.014
the seventh factor (α= .51)							
・ shoulder external rotation non-throwing side	.206	.028	.094	.055	-.040	-.379	.193
・ shoulder external rotation throwing side	-.034	-.039	.108	.012	.020	-.213	.250

inter-factor correlation	F1	-.509	.043	.067	-.041	.199	.090
	F2		-.070	-.234	-.111	-.153	-.050
	F3			.408	.021	.058	.029
	F4				.120	.113	-.085
	F5					.116	-.145
	F6						.244

Table 6. Comparison of factor scores between negative group and positive group

		negative group *n* =79 *M* ±*SD*	positive group *n* =42 *M* ±*SD*	*t value*
the first factor	Hip flexion	0.11±0.96	-0.13±0.25	1.68
the second factor	HBD	-0.13±1.00	0.25±0.96	-2.05
the third factor	Hip internal rotation	-0.11±0.93	0.21±1.06	-1.69
the fourth factor	Shoulder internal rotation	-0.02±0.91	0.03±0.89	-0.25
the fifth factor	Hip external rotation	0.03±0.96	-0.06±1.08	0.46
the sixth factor	Trunk rotation	0.05±0.88	-0.09±0.96	0.81
the seventh factor	Shoulder external rotation	-0.07±1.02	-0.16±0.84	0.59

Table 7. Cluster analysis

	cluster A n = 56 M ±SD	cluster B n =43 M ±SD	cluster C n = 22 M ±SD	F value	p value		multiple comparison
subjects characteristics							
age	16.3±0.6	16.3±0.7	16.2±0.8	0.22	.05		
age at start	8.6±1.7	8.9±2.0	8.5±2.1	0.35	.30		
height	173.6±5.0	171.5±5.1	174.5±5.5	2.97	.80		
body weight（kg）	65.3±7.1	63.6±6.7	63.0±7.4	1.22	.71		
range of motion							
shoulder external rotation throwing side	125.6±8.6	124.5±10.6	126.4±12.1	0.29	.75		
shoulder internal rotation throwing side	38.4±10.6	41.4±11.2	37.4±14.0	1.2	.31		
shoulder 3rd internal rotation throwing side	9.9±12.1	8.7±13.9	2.3±11.8	2.9	.06		
trunk rotation throwing direction	49.3±7.3	54.3±8.3	40.8±5.1	24.8	<.001	**	C<A<B
trunk rotation opposite direction	48.9±8.3	53.6±9.4	47.6±7.5	5.0	<.001	**	A,C<B
hip external rotation pivot leg	56.8±8.8	60.9±6.9	51.5±7.3	10.5	<.001	**	C<A<B
hip external rotation lead leg	56.0±8.3	60.8±7.0	46.8±7.8	23.4	<.001	**	C<A<B
hip internal rotation pivot leg	37.3±13.8	33.6±13.3	26.0±11.4	5.8	<.001	**	C<A
hip internal rotation lead leg	35.2±13.8	33.0±14.1	26.5±8.6	3.4	.04	*	C<A
hip flextion pivot leg	65.0±16.7	98.2±12.9	99.8±9.1	83.8	<.001	**	A<B,C
hip flextion lead leg	63.4±14.8	99.0±14.3	97.6±7.9	100.0	<.001	**	A<B,C
SLR pivot leg	37.7±12.2	59.9±9.6	59.5±7.8	65.4	<.001	**	A<B,C
SLR lead leg	37.6±12.3	62.3±11.2	59.9±6.3	70.5	<.001	**	A<B,C
HBD pivot leg	19.8±5.4	10.2±4.1	15.3±7.2	38.9	<.001	**	B<C<A
HBD lead leg	19.4±5.7	10.9±4.4	15.4±7.3	27.5	<.001	**	B<C<A

*,p<.01,**,p<.01