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Original Article

Effects of repetitive baseball throwing on hip muscle strength and trunk and pelvic motions at the shoulder's maximum external rotation position during the late cocking phase and ball release

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Abstract. [Purpose] This study aimed to investigate the changes in the trunk and pelvic lateral tilt angles at the shoulder's maximum external rotation during the late cocking phase (MER) and ball release (BR) and hip muscle strength during repetitive throwing. [Participants and Methods] In this study, 12 male baseball players participated. During the throwing, which was filmed using a high-speed video camera, the trunk and pelvic lateral tilt angles toward the nonthrowing side were measured at the MER and BR. Hip muscle strength during abduction, adduction, and external internal rotations were measured on the throwing and nonthrowing sides. Repetitive throwing was performed for nine innings, with 15 pitches per inning. Throwing motion was compared during innings 1, 7, 8, and 9. Hip muscle strength was measured before and after repetitive throwing. [Results] Compared with the trunk lateral tilt angle toward the nonthrowing side at BR in inning 1, the angle in innings 8 and 9 increased. The strength of hip abduction, adduction, and external and internal rotations on the throwing and nonthrowing sides decreased after repetitive throwing. [Conclusion] Hip muscle strength decreases after 135 pitches, and throwing >120 pitches changes the trunk lateral tilt angle at BR.
Key words: Hip muscle strength, Repetitive throwing injury, Trunk motion

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INTRODUCTION

Throwing injuries of the shoulder and elbow are common in overhead sports such as baseball, which affect the performance of athletes[1, 2)]. Risk factors for throwing injuries include repetitive throwing and a faulty throwing motion[3, 4)]. Among these, repetitive throwing is an area that has received much attention in recent years[3, 5)]. Lyman et al.[3)] reported that the incidence of shoulder pain increased with an increase in the number of pitches thrown per game. Okoroha et al.[6)] also looked at changes in the elbow varus torque over time during 90 repetitive throws and showed that the elbow varus torque increased after 45 pitches. These reports indicate that repetitive throwing can contribute to an increased load on the shoulder and elbow.

Throwing motion is a full-body movement, and an appropriate kinetic chain of the lower extremities and trunk is necessary to reduce the load on the shoulder and elbow[7)]. Previous studies have reported the importance of controlling trunk and pelvic motion[4, 8–11)]. Oyama et al.[9)] reported that the peak shoulder proximal force increases when trunk rotation is not controlled

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from stride-foot contact to ball release (BR). Douoguih et al.[4] reported that pitchers with early trunk rotation in stride-foot contact were at increased risk for shoulder and elbow injuries. These reports indicate that the control of trunk horizontal plane motion is necessary to reduce the load on the shoulder and elbow. However, in many cases of throwing injuries, not only the horizontal plane motion of the trunk and pelvis but also the coronal plane motion is abnormal. Oyama et al.[8] reported that the peak shoulder internal rotational moment and peak elbow varus moment increase as the trunk lateral flexion angle toward the nonthrowing side increases at the shoulder maximum external rotation position during the late cocking phase (MER). Additionally, Solomito et al.[10] reported that the shoulder internal rotation moment and elbow varus moment increase as the trunk lateral flexion angle to the nonthrowing side increases at BR. In the context of the pelvic tilt in the coronal plane, Tocci et al.[11] reported increased elbow varus torque in young baseball players with less pelvic tilt toward the nonthrowing side at BR. Furthermore, professional baseball players with shoulder or elbow injuries have greater pelvic tilt than healthy players with a single leg standing in a stride leg[12]. In other words, controlling the trunk lateral tilt and pelvic tilt motions during maximum effort throwing is necessary to reduce the load on the shoulder and elbow and prevent throwing injuries.

Regarding the effect of repetitive throwing on trunk motion during throwing, Escamilla et al.[13] reported no change in the trunk lateral flexion angle during pitching among Division I collegiate baseball players after approximately 120 pitches. In addition, Pei-His et al.[14] reported no change in the trunk lateral flexion angle during pitching after 100 pitches in national championship-level high school baseball players. Based on these reports, trunk lateral tilt motion during pitching is believed to be unaffected by the repetitive throwing task; however, drawing a conclusion is difficult because all athletes in the studies by Escamilla et al.[13] and Pei-His et al.[14] were at a high competition level. Conversely, only a few studies have examined changes in the trunk lateral tilt motion during pitching among athletes who are not at a strenuous training level[15], necessitating further investigation. Moreover, shoulder internal rotation and elbow varus moments, which are related to throwing injuries, are maximal just before MER and occur at high values over BR[16, 17]. Previous reports on changes in trunk lateral flexion motion with repetitive throwing have been analyzed at BR[13, 14]. However, given the phase in which these moments occur, we believe that not only BR but also MER should be analyzed for changes in trunk lateral tilt motion during repetitive throwing.

No studies have examined changes in the pelvic lateral tilt angle during repetitive throwing. Neumann[18] reported that the contraction of the gluteus medius contributes to the control of pelvic motion in the coronal plane. Yanagisawa et al.[19] reported that hip abductor and adductor strength among college baseball players decreased after 117 repetitive throws. Thus, changes in pelvic motion in the coronal plane may occur with repetitive throwing. However, Yanagisawa et al.[19] reported only changes in hip muscle strength during repetitive throwing. No study has reported changes in the hip rotator muscles that contribute to pelvic stability. Therefore, it is important to examine not only changes in the pelvic lateral tilt angle but also changes in hip muscle strength during repetitive throwing to examine risk factors for throwing injuries.

This study aimed to investigate changes in the hip muscle strength and the trunk and pelvic lateral tilt angles at MER and BR during repetitive throwing. We hypothesized that the hip muscle strength would decrease, whereas the trunk lateral tilt angle toward the nonthrowing side and the pelvic tilt angle during pitching would increase after repetitive throwing.

PARTICIPANTS AND METHODS

The study included 12 male baseball players at a nonstrenuous training level who were aged >20 years (mean age: 22.8 ± 2.9 [range, 20–28] years; mean body mass: 67.5 ± 8.7 [range, 57–85] kg; mean height: 170.4 ± 5.4 [range, 165.0–180.0] cm; mean experience: 13.6 ± 1.9 [range, 11–16] years). Nonstrenuous-training level players in this study were defined as those who did not engage in physical training and played baseball once or twice a week.

Players with shoulder, trunk, and lower extremity pain at the time of testing were excluded from the study. The Research Ethics Committee of Showa University approved the study protocol (study number: 543). Informed consent forms were signed by all participants.

The repetitive throwing task and measurement protocol of the study are shown in Fig. 1. Participants were allowed to warm-up and stretch for 5 minutes before the repetitive throwing task. The participants threw 135 fastballs (9 innings of 15 per inning at ball intervals of 15 s) with their maximum effort from the set position toward the target[15]. The distance between the participants and the target was 3 m, and the size of the target was 1.1 × 1.1 m. The official baseball (ZETT Corp., Osaka, Japan), weighing 145.0–147.0 g, was used during the repetitive throwing task. The rest time between the innings was 5 minutes. The hip muscle strength was measured before and after the repetitive throwing task. The throwing motion was measured on the 1st, 2nd, and 3rd pitches of the 1st inning; 103rd, 104th, and 105th pitches of the 7th inning; 118th,119th, and 120th pitches of the 8th inning; and 133rd, 134th, and 135th pitches of the 9th inning[15]. In a typical Japanese baseball game, more than 100 pitches are often thrown. In addition, studies have shown that no change in trunk movement occurs before the sixth inning, that is, before 90 pitches or less[20] therefore, only the seventh inning and after (i.e., ≥100 pitches) were included in the analysis.

Hip muscle strength was measured for abduction, adduction, external rotation, and internal rotation on the throwing and nonthrowing sides. Hip muscle strength was measured using a hand-held dynamometer (μ-Tas MF-01, ANIMA Corp., Tokyo, Japan) (Fig. 2) as previously done by Thorborg et al[21]. The hip abduction and adduction strengths were measured in the supine position. The nontested leg was placed in a slight hip and knee flexion position. The test hip was placed in a neutral

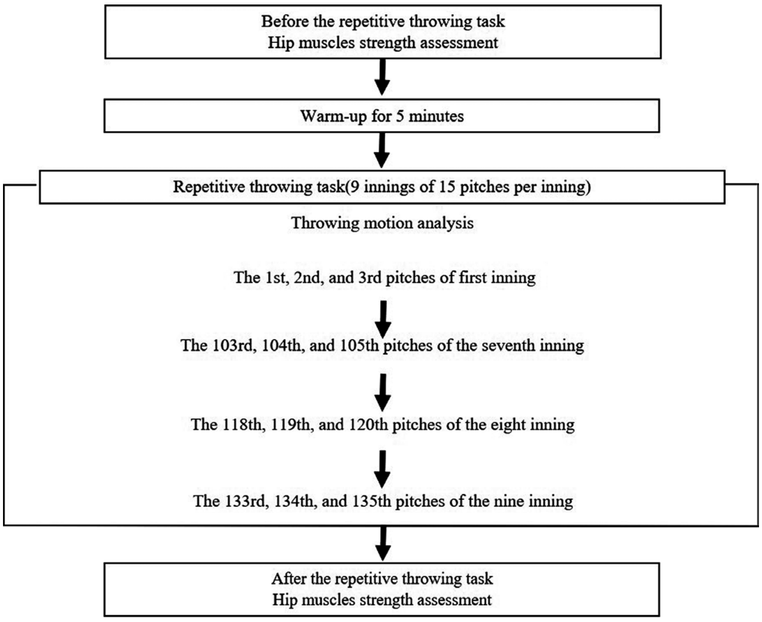

Fig. 1. Repetitive throwing task and the experimental protocol.
The repetitive throwing task was conducted for a total 9 innings with 15 pitches per inning. Hip muscle strength was measured before and after the repetitive throwing task. The throwing motion was measured in the 1st, 7th, 8th, and 9th innings.

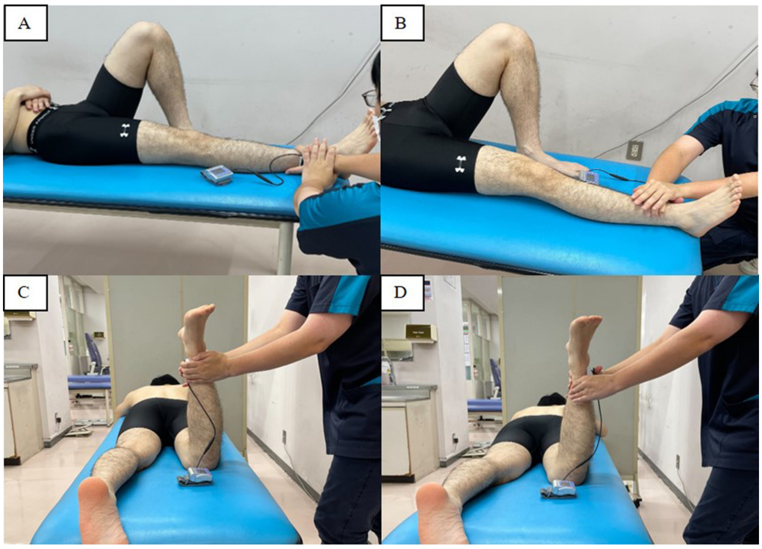

Fig. 2. Hip muscle strength assessment.
A: abduction; B: adduction; C: external rotation; D: internal rotation.
Isometric muscle strength on the throwing and nonthrowing sides of the body was measured three times each.

position. The hand-held dynamometer was positioned in the distal portion of the shank, just proximal to the ankle. When measuring hip abduction or adduction strength, the examiner applies resistance in the direction of adduction or abduction. The hip external and internal rotation strengths were measured in the prone position. The test hip was placed in the neutral position with 90° of flexion in the knee. The hand-held dynamometer was positioned in the distal portion of the shank, just proximal to the ankle. The examiner applied resistance in the direction of internal or external rotation when measuring hip external or internal rotation strength. The participants maximally contracted against this force for 5 s. Muscle strength was measured three times, and the maximum muscle strength was adopted. The intrarater reliability for hip muscle strength was measured as substantial or almost perfect (intraclass correlation coefficient [ICC]=0.74–0.99).

Throwing motions were measured using two high-speed video cameras (GC-LJ25B, JVCKENWOOD Corp., Kanagawa, Japan). These cameras recorded the throwing motion at 240 fps, and the high-speed camera was placed 2 m to the back and side of the participant. In addition, parallel installation of the camera and floor was verified using an inclinometer. To synchronize the two cameras, we first measured the time from the maximum knee height during the wind-up phase to the MER and BR using a video taken from the side. Based on the measured time, the MER and BR were subsequently identified in the video from the back, after which still images were created. MER was identified as the frame in which the shoulder appeared to be maximally externally rotated (Fig. 3A). BR was identified as the first frame in which the ball became separated from the hand (Fig. 3B)[22]. Oyama et al.[22] compared the trunk contralateral flexion angles during pitching between two- and three-dimensional analyses and examined the reliability of the two-dimensional analysis. They reported that MER had high accuracy, whereas BR had moderate accuracy. To facilitate two-dimensional throwing motion analysis, markers were affixed to the spinous processes of the 7th cervical vertebra (C7), 10th thoracic vertebra (Th10), and bilateral posterior superior iliac spines (PSIS) of the participant. The bony landmarks were selected with reference to the Vicon plug in the gait model, and markers were affixed to the same sites to facilitate the identification of the bony landmarks during measurement. The trunk lateral tilt angle and pelvic tilt angle were calculated from the still images using ImageJ software (National Institutes of Health, Bethesda, MD, USA). The trunk lateral tilt angle was defined as the angle between the line connecting C7 and Th10 and the vertical line relative to the bottom of the image, and the lateral tilt to the nonthrowing side was defined as positive (Fig. 3C). The pelvic tilt angle was defined as the angle between the line connecting the bilateral PSIS and the parallel line relative to the bottom of the image, with a positive tilt toward the nonthrowing side (Fig. 3C). Additionally, the participants in this study threw without shoes. This was done after considering the possible differences in the shape of the shoes worn by each participant. To eliminate this effect, the participants threw barefoot. The participants did not slip during the throwing task, indicating that throwing barefoot did not have a significant effect on the results. Of the three pitches in each inning, the trial in which the player was most satisfied was included in the analysis[23]. The intrarater reliability for the throwing motion analysis was calculated as substantial or almost perfect (ICC=0.78–0.98).

For statistical analysis, we used IBM SPSS Statistics software, version 23 (IBM Corp., Armonk, NY, USA). Shapiro and Wilk's W-statistic was used to assess the normality of the distribution. A paired t-test or Wilcoxon signed-rank test was used to compare hip muscle strength before and after throwing, depending on whether the data were normally distributed or not. Repeated measures analysis of variance was performed to assess changes in throwing motion in innings 7, 8, and 9 versus inning 1. When this analysis indicated statistical significance, Bonferroni analysis was performed for multiple comparison depending on normality. Statistical significance was set at $p<0.05$. Moreover, effect sizes between each measure were calculated. Effect sizes measured (Cohen's *d*) using the paired t-test were rated as small ($0.20 \leq d < 0.50$), moderate ($0.50 \leq d < 0.80$), and large ($d \geq 0.80$)[24]. Effect sizes (*r*) measured using the Wilcoxon signed-rank test were rated as small ($0.10 \leq r < 0.30$), moderate ($0.30 \leq r < 0.50$), and large ($r \geq 0.50$)[24].

RESULTS

Changes in the hip muscle strength before and after repetitive throwing are shown in Table 1. The strength of hip abduction ($p<0.001$, $r=0.88$), adduction ($p=0.003$, $r=0.79$), and external ($p=0.035$, $d=0.39$) and internal rotation ($p=0.003$, $d=0.45$) on the throwing side as well as hip abduction ($p=0.001$, $d=0.50$), adduction ($p=0.001$, $r=0.88$), and external ($p=0.004$, $d=0.73$) and internal rotation ($p=0.001$, $d=0.91$) on the nonthrowing side significantly decreased after repetitive throwing.

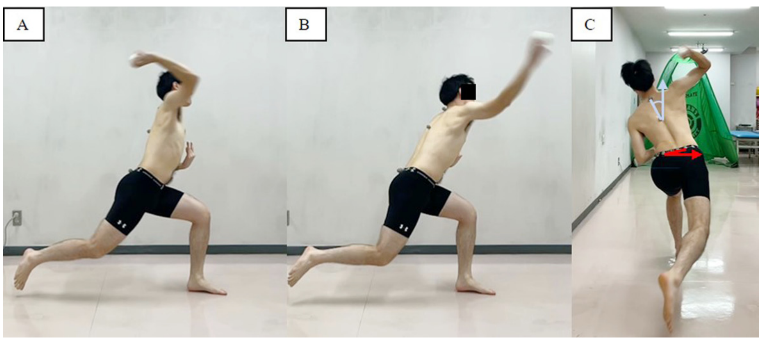

Fig. 3. Throwing motion analysis.
A: side view at MER; B: side view at ball release; C: angle measurement of trunk lateral tilt and pelvic lateral tilt.
Trunk and pelvic angles were measured from the posterior view. Blue arrows indicate lines perpendicular to the bottom of the image, whereas red arrows indicate lines parallel to the bottom of the image. The bottom edge of the image was assumed to be parallel to the floor.
MER: shoulder's maximum external rotation during the late cocking phase.

Table 2 shows the angle of the trunk and pelvis at MER and BR during the 1st, 7th, 8th, and 9th innings. The trunk lateral tilt angles at BR during the 8th (p=0.005, *d*=0.62) and 9th (p=0.002, *d*=0.77) innings were significantly higher than those during the 1st inning. No changes were found in the trunk lateral tilt angle at MER or the pelvic lateral tilt angle at MER or BR.

DISCUSSION

Recently, repetitive throwing has been considered a risk factor for throwing injuries[3, 6)], and repetitive throwing has been suggested to increase the load on the shoulder and elbow. In addition, to reduce the load on the shoulder and elbow during pitching, the trunk and pelvis lateral tilt motions should be controlled[8, 10–12)]. However, only a few studies have examined changes in the trunk and pelvic lateral tilt motions associated with repetitive throwing among nonstrenuous training-level baseball players[15)]. In addition, only a few studies have examined the hip muscle strength that controls the pelvic coronal plane motion before and after repetitive throwing[19)]. This study investigated changes in the hip muscle strength on the throwing and nonthrowing sides of the body and the trunk and pelvic lateral tilt angles at MER and BR using repetitive throwing in a simulated game.

The results of the present study indicated that the hip abduction, adduction, external rotation, and internal rotation strengths of both throwing and nonthrowing sides decreased after repetitive throwing. Regarding throwing motion, the pelvic lateral tilt angle did not change after repetitive throwing. Moreover, the trunk lateral tilt angle did not change at MER, but the

Table 1. Data regarding hip muscle strength before and after repetitive throwing

Variables	Before	After
Abduction (N)		
Throwing side	103.8 ± 32.4	79.8 ± 35.0***
Nonthrowing side	97.8 ± 27.9	83.1 ± 30.2**
Adduction (N)		
Throwing side	86.1 ± 24.3	71.1 ± 18.2**
Nonthrowing side	87.3 ± 24.2	71.3 ± 17.9**
External Rotation (N)		
Throwing side	89.8 ± 16.3	83.7 ± 15.1*
Nonthrowing side	95.5 ± 19.0	82.3 ± 17.3**
Internal Rotation (N)		
Throwing side	98.7 ± 22.8	88.4 ± 23.5**
Nonthrowing side	105.4 ± 18.5	88.3 ± 19.3**

The Wilcoxon signed-rank test was used to compare hip abduction and adduction strength on the throwing and adduction strength on the nonthrowing sides before and after throwing. Other variables were compared using paired t-tests.
Data are presented as mean ± standard deviation.
*p<0.05, **p<0.01, ***p<0.001.
(N): Newton.

Table 2. Trunk and pelvic lateral tilt angles in each inning

	Innings			
	1st	7th	8th	9th
MER (degrees)				
Trunk lateral tilt angle	21.6 ± 9.6	20.7 ± 7.0	20.2 ± 9.1	19.6 ± 8.3
Pelvic lateral tilt angle	5.4 ± 8.6	5.6 ± 7.6	6.1 ± 6.1	5.1 ± 8.3
BR (degrees)				
Trunk lateral tilt angle	36.0 ± 8.9	38.8 ± 11.3	41.9 ± 10.2*	43.0 ± 9.3*
Pelvic lateral tilt angle	2.6 ± 8.3	0.1 ± 8.9	−0.6 ± 10.3	−0.1 ± 8.9

Positive values indicate a tilt toward the nonthrowing side.
Each variable was compared between the 1st and 7th innings, 1st and 8th innings, and 1st and 9th innings. The Wilcoxon signed-rank test was used to compare trunk lateral tilt angles at MER, followed by Bonferroni correction. Other variables were compared using paired t-tests, followed by Bonferroni correction.
Data are presented as mean ± standard deviation.
*p<0.01.
MER: shoulder's maximum external rotation during the late cocking phase; BR: ball release.

trunk lateral tilt angle at BR increased after eight or more innings of throwing. In other words, all the changes in hip muscle strength were consistent with our hypotheses. Among the changes in trunk movement, those at BR were consistent with our hypotheses. However, the changes in pelvic movement were not consistent with our hypotheses.

Japanese high school and college baseball players engage in high-intensity physical training and frequently play games and practice. However, junior high school baseball players and adult baseball enthusiasts do not necessarily engage in physical training nor do they frequently play games or practice. Given that the nonstrenuous training-level baseball players in this study had similar athletic backgrounds to junior high school baseball players and baseball enthusiasts, the results of this study may be useful for these players.

Hip muscle strength is important for force generation, transfer, absorption, and stabilization of the body as it moves over the lower extremity during the throwing motion[25, 26]. Regarding changes in hip strength, Yanagisawa et al.[19] reported that hip abductor and adductor strength among college baseball players decreased after 117 repetitive throws. In addition, after the cocking phase, both the throwing and nonthrowing sides require not only hip abduction/adduction movements but also hip rotation movements[27]. This suggests that repetitive throwing causes muscle fatigue in the hip muscles, resulting in a decrease in hip muscle strength after repetitive throwing. In the present study, there was no change in the pelvic lateral tilt angle that decreased the hip muscle strength, especially in hip abductor muscles. Although the gluteus medius is involved in controlling the pelvic coronal plane motion[28], the gluteus medius also has a hip internal rotation function that influences the velocity of the pelvic rotation during pitching[29]. In the present study, hip internal rotation muscle strength on the nonthrowing side decreased, which could have affected pelvic rotation movement after repetitive throwing. However, because rotational movement cannot be examined in a two-dimensional analysis, this is yet to be explored.

A three-dimensional throwing motion analysis showed that the trunk lateral flexion angle at MER does not change among baseball players who are not strenuously training[15], even after throwing repetitively. In this study, a throwing motion analysis was performed in two dimensions for convenience of measurement; however, the results were similar to previous reports of three-dimensional throwing motion analysis[15]. Although the trunk lateral flexion angle at BR did not change after repetitive throwing among strenuously training baseball players[13, 14], no studies have examined changes in the trunk lateral tilt angle at BR with repetitive throwing among nonstrenuous training-level baseball players. To the best of our knowledge, this study is the first to show that baseball players who are not undergoing strenuous training increase their trunk lateral tilt angle during the acceleration phase, including BR, when they throw more than 120 pitches. Based on previous reports[13, 14] and the present study, changes in trunk lateral tilt movement after repetitive throwing may differ depending on the level of competition.

Regarding the factor that causes changes in trunk lateral tilt during the acceleration phase, including at BR, the trunk lateral flexion strength on the throwing and nonthrowing sides decreased with repetitive throwing[15]. Excessive contralateral trunk tilt during pitching is associated with the imbalance between oblique muscles on the dominant and nondominant sides[30]. When these finding are taken into account, repetitive throwing may have decreased trunk muscle function in this study, which further increased the trunk lateral tilt at BR.

This study has various limitations. First, this study used projected angles to investigate the movement of the coronal plane of the trunk and pelvis. According to Oyama et al., two-dimensional analysis of trunk lateral flexion angles showed moderate to high accuracy[22]. However, there are still a few reports of two-dimensional analysis, and the trunk and pelvis move in three dimensions during pitching; hence, the projected angle measurement may lack accuracy. Second, we could not examine the shoulder motion during throwing because of issues related to measurement reliability[22]. If the shoulder motion was examined, the results of this study would have been more reliable for the examination of the relationship between changes in the trunk and shoulder motions with repetitive throwing. Third, the throwing distance was set at 3 m; and, the size of the laboratory is different from the actual competition situation. We believe that more reliable data can be returned to the field sites if we secure the throwing distance and conduct measurements under conditions similar to those in the actual field conditions.

In conclusion, the results of this study indicate that repetitive throwing for 135 times decreases the hip muscle strength but does not change the pelvic lateral tilt angle during pitching. Moreover, the trunk lateral tilt angle at MER did not change, but the trunk lateral tilt angle at BR increased with 120 or more pitches.

Conference presentation

Portions of this study were presented at a conference (Japanese Society of Clinical Sports Medicine, 2022; 30(4)).

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This study was not funded and no potential conflicts of interest were reported by the authors.

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