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Functional differences in softball pitchers with and without upper extremity pain☆

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ABSTRACT

Objectives: Though pitchers often throw during multiple games in a day, there are currently no pitch count restrictions in softball. The accumulation of high pitch counts over time may contribute to the development of upper extremity pain. The purpose of our study was to examine functional characteristics of shoulder and hip range of motion (ROM), isometric strength (ISO), and ball speed in softball pitchers with and without upper extremity (UE) pain.
Design: Controlled laboratory design.
Methods: Fifty-three NCAA Division I softball pitchers (20.0 ± 1.4 years; 173.3 ± 8.3 cm; 80.9 ± 12.3 kg) participated and were divided into two groups: pain-free (n = 30) and pain in the UE (n = 23). Bilateral shoulder and hip external rotation (ER) and internal rotation (IR) ROM and ISO were measured prior to pitching to a catcher located 13.1 m (43 ft) away.
Results: Independent samples t-tests revealed significantly greater throwing side (TS) hip ER ROM ($p = 0.012$), TS hip IR ISO ($p = 0.038$), glove side (GS) hip ER ISO ($p = 0.025$), TS shoulder ER ISO ($p = 0.002$), GS shoulder IR ($p = 0.006$) and ER ($p = 0.004$) ISO in the pain free group versus the UE pain group.
Conclusions: Differences in shoulder and hip ROM and ISO exist between those who have upper extremity pain and those who do not. Therefore, findings suggest that both the upper and lower extremities should be considered when treating softball pitchers with UE pain.

Practical implications

- The body works as a kinetic chain, thus in dynamic overhead throwing activities, training protocols should develop both the upper and lower extremities, specifically the shoulders and hips.
- Since there are differences in the functional measurements of ROM and ISO between pain and pain-free pitchers, these measurements could be used as screening tests to try to identify deficits prior to the development of pain.
- With differences found in glove shoulder ISO measurements between pain and pain free pitchers, training protocols should prioritize glove arm alongside throwing arm protocols.

1. Introduction

The sport of fastpitch softball is continuing to gain popularity. From the 2014–15 to the 2016–17 school year, high school participation increased from 365,528 to 368,734 athletes, respectively.[1] As the number of high school softball athletes has approached that of baseball athletes,[1] the amount of reported injuries has displayed an analogous trend.[2] Contrary to the high participation and injury rates, there are a rarity of data available regarding injury predisposition for fastpitch softball. Most of the literature regarding throwing and injury is focused on baseball.[3–5]

Similar to baseball, dynamic movement of the upper extremity, such as during the windmill softball pitch, requires the kinetic chain to efficiently work in a proximal to distal manner. The proximal aspect of the kinetic chain includes the lower extremity and lumbopelvic-hip complex, both of which must exhibit stability for the distal mobility of the shoulder.[6] Additionally, sufficient energy transfer from the lower extremity is crucial in decreasing the physical demands placed on the distal segments of the upper extremity, thereby minimizing the risk of injury in these throwing athletes.

☆ Auburn University Institutional Review Board approved the study protocol. The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the manuscript.

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Prior studies have eluded that strength and range of motion of the shoulder and hip, as well as ball speed could be associated with increased injury risks;[7] however, there are yet to be data available to establish a relationship between functional measures and pain history. Identifying these characteristics for softball pitchers with pain will allow for a greater understanding of potential injury propensity. Therefore, the purpose of this study was to examine functional measures of bilateral shoulder and hip range of motion (ROM), isometric strength (ISO), and ball speed between collegiate softball pitchers classified as either having upper extremity pain or being pain free. It was hypothesized that pitchers classified with upper extremity pain would display significantly lower ball speeds as well as decreased throwing side shoulder and bilateral hip rotational ROM and ISO than those pitchers classified as pain free.

2. Methods

Fifty-three softball pitchers (20.0 ± 1.4 years; 173.3 ± 8.3 cm; 80.9 ± 12.3 kg) were recruited to participate. Participants were recruited from teams competing against Auburn University's softball team during the spring season. This group of participants was a portion of participants from a larger study. All participants were active pitchers on NCAA Division I softball teams, in good physical condition, and medically cleared for competition. Participants were excluded from the study if they were not pitchers, if they had been injured in the past 6 months, and/or if they were not actively participating in college softball. Injury was defined as being diagnosed by a physician or athletic trainer resulting in time loss from either practice or competition. The Institutional Review Board of Auburn University approved all testing protocols and informed written consent was obtained from each participant prior to testing.

Participants were divided into two groups: those who were pain free and those with upper extremity pain (isolated to the shoulder and elbow). The groups were determined based on a pain history questionnaire. The criterion for the pain free participants (20.0 ± 1.4 years; 173.7 ± 6.7 cm; 80.4 ± 12.3 kg; n = 30) was currently experiencing no pain. The criterion for upper extremity pain participants (20.0 ± 1.5 years; 172.8 ± 10.2 cm; 81.6 ± 12.3 kg; n = 23) was currently experiencing pain in the throwing shoulder and/or elbow. Current pain was defined as any pain experienced immediately before, during, and/or immediately following pitching. For the purpose of this study, the arm contralateral to the throwing arm was defined as the glove side, and the stride leg was defined as the leg contralateral to the throwing arm.

Softball participation and pain information were obtained through a questionnaire that all participants completed prior to data collection. Age, height, weight, arm dominance, years of pitching experience, the average number of pitches thrown during a typical practice, the average number of pitches thrown during a typical game, previous injuries, and current pain location were recorded. The presence of pain was rated as a 'yes' or 'no' from the statement, "Do you currently experience any pain/discomfort?" If 'yes' was the answer, the area of the upper extremity where they experienced pain was selected. Those who answered 'yes' and selected any area on the shoulder and elbow of the throwing arm were designated to the upper extremity pain group. Participants who selected 'no' were assigned to the pain free group. Bilateral shoulder and hip ROM and ISO were collected following a brief demonstration from the investigator on the testing procedures. Additionally, those participants who were in the pain group were instructed to notify the investigator if anything during the ROM or ISO testing created more pain or discomfort than what they were currently experiencing. No participant indicated experiencing additional pain. Following ROM and ISO testing, participants threw three change-up pitches to a catcher located at regulation distance (13.11 m; 43 ft). The change-up was chosen because it was the most commonly thrown pitch amongst the athletes in this study.[8]

A digital inclinometer (Fabrication Enterprises, Inc., White Plains, NY) was used to measure ROM. Standard passive ROM techniques and the visual inspection technique were used to determine glenohumeral ROM, isolate glenohumeral movement, and control for scapulothoracic movement.[7,9,10] Participants were supine on a table with the shoulder in 90° of abduction and elbow in 90° of flexion. A rolled towel was placed under the distal humerus to maintain humeral position. The investigator placed the inclinometer on the soft tissue contour of the forearm between the olecranon process and the styloid process of the ulna. Measurements were recorded at scapulothoracic movement during IR and firm capsular end-feel during ER.[7,9,10] Glenohumeral internal rotation deficit (GIRD) between the throwing and glove arm was also calculated.

To measure hip ROM, participants were in a seated position with the knees flexed to 90° and a rolled towel placed under the distal femur.[7,9,11] The inclinometer was placed on the shaft of the fibula just proximal to the lateral malleolus to measure IR and on the shaft of the tibia just proximal to the medial malleolus to measure ER. Once a firm capsular end-feel was established, the measurement was recorded.[5,9,11,12] For all shoulder and hip ROM measurements a single trial was recorded. A study of 7 collegiate softball players was used to determine intra-rater reliability. Using the technique described above for shoulder and hip ROM, excellent intra-rater reliability was reported of an $ICC_{(3,k)}$ of 0.92–0.95 for all shoulder and hip ROM measurements.

A handheld dynamometer (Lafayette Instruments, Lafayette, IN) was used for all ISO assessments. Measurements were performed for bilateral hip and shoulder IR and ER. Isometric strength of glenohumeral joint rotation was performed with the participant supine, shoulder positioned at 90° of abduction and elbow flexed to 90°. A rolled towel was placed under the distal humerus to prevent horizontal extension and to assist in maintaining neutral position of the humerus.[5,9,10] The investigator positioned the dynamometer 3 in. proximal to the wrist, on the volar side of the forearm for IR and on the dorsal side for ER.[13,14] Participants performed one trial of maximal IR, followed by maximal ER. Participants were instructed to push with maximal effort against resistance from the investigator for 3 s.[13,14] The ratio between IR and ER strength (IR:ER) of the throwing arm was also calculated.

Hip IR and ER ISO were conducted with the participants seated, knees flexed to 90° and a rolled towel placed under the distal femur.[13,14] The dynamometer was positioned 3 in. proximal to the medial malleolus for ER and 3 in. proximal to the lateral malleolus for IR.[13,14] Participants were to execute maximal IR followed by maximal ER. Participants were instructed to push with maximal effort against resistance from the investigator for 3 s. Isometric strength intraclass correlation coefficients were reported as high for all shoulder and hip ISO measurements ($ICC_{(3,k)}$ of 0.86–0.99).

Prior to throwing, participants were allotted an unlimited amount of time to warm-up (average warm up time: 10 min). Ball speed was recorded with a Stalker Pro II Baseball Radar Speed Gun (Stalker Radar©, Applied Concepts Inc., Richardson, TX, USA). Ball speeds were recorded if the ball was in the strike zone. Of the three strikes thrown, the fastest of the three trials was used for statistical analysis.[8]

Statistical analyses were performed using IBM SPSS Statistics 21 software (IBM Corp., Armonk, NY) for normally distributed data with an alpha level set *a priori* at $\alpha = 0.05$. Prior to analysis, Shapiro–Wilks tests of normality were run, and results revealed approximate normal distributions for all non-demographic variables. Independent samples t-tests were employed to examine the differences between the upper extremity pain and pain free groups' ball speed, ROM and ISO. Homogeneity of variance was assessed using Levene's test for equality of variances. If homogeneity was not

Table 1
Variable means and standard deviations for the no pain (n = 30) and pain (n = 23) groups range of motion (ROM). All ROM are reported in degrees.

Variable	No pain	Pain	CI	Mean difference	p-Value
Throwing side hip IR ROM	38 ± 9	36 ± 11	−4, 8	2	0.518
Throwing side hip ER ROM	**44 ± 8***	**39 ± 5**	**1, 9**	**5**	**0.012**
Glove side hip IR ROM	35 ± 8	35 ± 9	−5, 5	0	0.997
Glove side hip ER ROM	44 ± 11	41 ± 6	−1, 7	3	0.348
Throwing shoulder IR ROM	47 ± 6	48 ± 11	−7, 4	−1	0.602
Throwing shoulder ER ROM	94 ± 13	93 ± 20	−9, 11	1	0.838
Glove side shoulder IR ROM	49 ± 9	52 ± 11	−9, 3	−3	0.298
Glove side shoulder ER ROM	97 ± 15	95 ± 17	−7, 11	2	0.591

* denotes significance with p < 0.05. CI stands for 95% confidence interval.

Table 2
Variable means and standard deviations for the no pain (n = 30) and pain (n = 23) groups for isometric strength (ISO). All ISO are reported as a percentage of body weight.

Variable	No pain	Pain	CI	Mean difference	p-Value
Throwing side hip IR ISO	**18 ± 4***	**16 ± 3**	**0, 4**	**2**	**0.038**
Throwing side hip ER ISO	18 ± 3	16 ± 3	0, 4	2	0.058
Glove side hip IR ISO	18 ± 5	18 ± 3	−2, 2	3	0.808
Glove side hip ER ISO	**16 ± 4***	**13 ± 4**	**0, 5**	**2**	**0.025**
Throwing shoulder IR ISO	21 ± 5	18 ± 6	0, 5	3	0.068
Throwing shoulder ER ISO	**21 ± 5***	**17 ± 6**	**2, 7**	**5**	**0.002**
Glove side shoulder IR ISO	**19 ± 5***	**15 ± 4**	**1, 6**	**3**	**0.006**
Glove side shoulder ER ISO	**21 ± 5***	**18 ± 4**	**1, 5**	**4**	**0.004**

* denotes significance with p < 0.05. CI stands for 95% confidence interval.

Table 3
Median values for demographic variables. No significant differences were observed. Range for the values is shown in parenthesis.

Variable	No pain	Pain
Age (years)	20 (18–28)	20 (18–24)
Weight (kg)	81.2 (58.2–113.9)	79.7 (56.7–115.0)
Height (cm)	175.2 (144.5–196.9)	173.2 (148.9–196.5)
Years of experience	10 (6–19)	10 (7–16)
Warm-up pitches practice	35 (24–67)	35 (25–60)
Warm-up pitches game	45 (30–70)	35 (25–70)

observed, statistical values were determined using non-assumed values. Mann–Whitney U tests were employed to examine the differences in demographic variables, including age, weight, height, warm-up pitches before practice and game, and years of experience.

3. Results

Descriptive means, standard deviations, and statistics for ROM (in degrees) are reported in Table 1 and ISO (as a percent of body weight) values are reported in Table 2. Total ROM in the throwing side shoulder for both pain free and in pain athletes was 141°. Ball speeds for pain and pain free groups were 42 ± 6 mph and 43 ± 4 mph, respectively. GIRD for pain and pain free groups were −4° ± 9° and −2° ± 8°, respectively. No significant differences were observed between ball speed or GIRD. Participant demographic medians and ranges are presented in Table 3. Independent samples t-tests revealed significant differences in throwing side hip ER ROM, throwing side hip IR ISO, glove side hip ER ISO, throwing side shoulder ER ISO, and glove side shoulder IR and ER ISO. Specifically, the pain free group displayed more ER ROM in their throwing side hip than the pain group. The pain free group displayed greater IR ISO in their throwing side hip, as well as greater ER ISO in their glove side hip than the pain group. Shoulder ISO results revealed that the pain free group had greater bilateral ER ISO, as well as greater glove side IR ISO than the pain group. Additionally, there was a significant difference in throwing shoulder IR:ER strength ratio between the groups ($p = 0.017$, 95% CI [−0.26, −0.03]). The pain group had a higher strength ratio (1.15) than the pain free group (1.00). Mann Whitney U-tests revealed no significant differences in demographic variables.

4. Discussion

There is increasing evidence that flaws in the kinetic chain result in an increase in pain and injury susceptibility in subsequent segments.[4,6,15,16] Pain in a softball pitcher's throwing arm can limit performance and result in time-loss from participation. Therefore, the purpose of this study was to examine functional characteristics of shoulder and hip ROM, ISO, and ball speed in collegiate softball pitchers with and without upper extremity pain. It was hypothesized that pitchers in the pain group would display significantly lower ball speed as well as decreased throwing side shoulder and bilateral hip rotational ROM and ISO. Though there were no significant differences in ball speed between the two groups, there were differences in ROM and ISO. The pain group displayed decreased ROM and ISO of the throwing side hip as well as glove side hip ER ISO. Specifically, the pain group had less ER ROM and IR ISO on the throwing side hip and decreased ER ISO on glove side hip. Previous studies have reported the negative effects of decreased hip and shoulder ROM.[3,11,16] Hip ER is required to drive the body forward towards the target during the acceleration phase of the throw for ball release.[7,11,12] Additionally, to achieve the most advantageous hip and pelvis position for postural control at foot contact, the glove side hip needs adequate ER ROM and strength.[7,13] An explosive stride off the pitching rubber is a major component of efficient pitching performance in softball and maintenance of hip ER ROM is needed.[7,13,17,18] For optimal throwing, hip ROM and strength are necessary for efficient energy transfer from the lower extremity to the upper extremity.[7,9,11,12,19]

Previous reports in overhead throwing suggest that limited IR strength and ROM of the throwing side hip could lead to a player throwing across their body, limiting energy transfer from the lower extremity and ultimately predisposing them to injury.[11] Additionally, hip rotational weakness has been associated with throwing pathomechanics, specifically a decrease in kinetic chain efficiency.[16,20,21] This finding reiterates the importance of hip ROM and strength in not only overhead throwing but also underhand throwing.[7,16,20] Burkhart et al.[16] reported that hip weakness results in less force generation from the lower extremity and ultimately decreased energy transfer to the upper extremity. If the lower extremity is unable to adequately transfer energy to the upper extremity, pitchers may have to generate greater force in the upper extremity. These compensations have the potential to place the body, specifically the upper extremity, in a vulnerable position at risk for injury.

Examination of the upper extremity revealed significant differences in throwing shoulder ER ISO. The pain group displayed decreased ISO strength in throwing shoulder ER of 3% body weight when compared to the pain free group. Considering the pain classification used in this study, the decreased ISO in the throwing shoulder of the pain group is not surprising. Pain may have limited the participants' ability to exert maximal force during testing, however no participant reported that the exertion of maximum effort during the ISO testing elicited greater pain than what they were currently experiencing. The pain group had a higher IR:ER strength ratio (1.15) indicating this group had greater IR strength in the throwing arm compared to ER strength. The IR:ER strength ratio in the pain free group was 1.00 indicating IR and ER strengths were equal, and there were no deficits in either of the values. It is unclear if the imbalance of the IR:ER strength ratio in the pain group was due to the current pain the pitchers were experiencing or if the imbalance was present prior to pain development and therefore contributed to the pitcher experiencing pain. In any case, the relationship here is worth further investigation.

Significant differences were also observed in glove side shoulder IR and ER ISO between the pain and pain free groups. Ishida and Hirano noted that an unused glove arm restricts trunk control and the ability for the athlete to rotate toward their target in overhead throwing.[22] Additionally, Barfield et al. found a more extended glove arm elbow and more horizontally abducted glove shoulder results in a more efficient throwing motion within the baseball pitching motion.[23] Therefore, studying ROM and ISO in the glove arm is important for understanding throwing arm upper extremity pain. In the current study, those athletes with upper extremity pain displayed significantly less strength in their glove shoulder, suggesting their glove arm creates a break in the kinetic chain, thus causing an increased load and increased injury susceptibility for the throwing arm.

Despite differences in throwing shoulder ER strength, and glove shoulder IR and ER ISO, there were no significant differences in total shoulder ROM between the groups. ROM as a contributor to upper extremity injury in baseball has been thoroughly examined in the literature, and deficits in IR are thought to be a risk factor.[11,16] The combination of the lack of differences in throwing side shoulder ROM and presence of pain in the throwing side arm implies more proximal links, such as hip mobility, is important to understand in the context of upper extremity pain and injury prevention. Although not significantly different, the pain and pain free groups did have slight deficits in GIRD between shoulders. These results may indicate the physiological adaptation of glenohumeral internal rotation deficit that occurs from repetitive overhead motion is not present to the same extent in softball pitchers as is seen in baseball pitchers.

When designing preventative or maintenance programs for softball pitchers, both shoulder and hip strength and ROM should be addressed. As the primary energy generator during any type of dynamic upper extremity movement, the lower extremity is required to transfer that energy via the kinetic chain through the pelvis and trunk and up to the shoulder and elbow for ball release.[4,6,15,24] During the softball pitch, adequate postural control of the lower extremity, lumbopelvic-hip complex, and upper extremity is required for efficient utilization of the kinetic chain.[7,8,13,21] A break in the kinetic chain due to restrictions in hip ROM and strength ultimately increases the loads on the upper extremity.[4,16,25,26] If less force is generated from the lower extremity, the upper extremity must create the missing energy necessary to maintain ball velocity during pitching.[6,11] The function of the lower extremity is critical in any dynamic throwing motion such as the windmill softball pitch, and a number of throwing studies have demonstrated increased injury risk associated specifically with restricted hip ROM.[16,25,26] These findings support the postulation that dysfunction or limitations due to pain at the proximal segments of the kinetic chain could contribute to the development of injury distally at the upper extremity.

Although differences were observed between ROM and ISO, no significant differences were observed in ball speeds. This suggests that although the athletes reporting upper extremity pain display loss of ISO and ROM, they are still able to generate an appropriate amount of energy and transfer it to the ball. Thus, it is postulated that these athletes may be compensating throughout the kinetic chain in attempt to generate the needed energy to sustain maximum ball speed. The authors recommend future studies examine throwing mechanics and muscle activations in softball pitchers with and without pain in attempt to determine if and where compensations are being made.

This study has limitations that should be acknowledged. Participants were classified to the upper extremity pain or pain free groups based on a self-reported questionnaire. We did not require pain to be associated with a medical diagnosis. No inferences can be made from the upper extremity pain group actually having a diagnosed injury, nor to what degree the pain was accurately related. However, this type of self-reporting of pain allowed us to classify two specific groups and give insight to differences in functional measures that may over time lead to injury. Additionally, although the study can identify functional differences between the two groups, there is not enough evidence to identify a causal relationship, therefore this study is acknowledged as being exploratory in nature. Specifically, differences seen between those with and without pain could be a result of the current pain experienced, could be an adaptation of lingering pain, or could be the underlying reason why the pitcher is currently experiencing pain. Furthermore, the testing procedures were not randomized, which can affect the effort of the later assessments. Future research should prospectively investigate shoulder and hip ROM and ISO and pitch counts as risk factors for injury during a competitive softball season.

5. Conclusion

Regular assessment of a softball pitchers' shoulder and hip ROM and strength throughout the competitive season could be beneficial in pain and injury prevention efforts. This study demonstrated softball pitchers with upper extremity pain tend to have decreased throwing side hip ER ROM, throwing side hip IR ISO, glove side hip ER ISO, bilateral shoulder ER ISO, and glove side shoulder IR ISO when compared to pain-free softball pitchers. Limited hip ROM results in decreased force production via the lower extremity and lumbopelvic-hip complex; however, with the lack of significant differences in ball speeds, these findings suggest energy is not being transferred as efficiently form the lower extremity and compensations in the upper extremity could be occurring and potentially a precursor to injury susceptibility. Previous studies have suggested limited hip IR strength will lead the athlete to transfer energy inefficiently across their body and therefore predispose the upper extremity to injury.[7,9,11,12,19,24] Since the pitching groups were determined based on pain in the throwing arm, the difference in throwing side ISO is not surprising; however, it is still unclear what is causing these athletes pain. The authors speculate the imbalance in shoulder IR:ER ISO may be contributing to the upper extremity pain. Interestingly, there were no significant differences in GIRD or ball speed, suggesting that there may be physiological and biomechanical adaptations and compensations throughout the kinetic chain to make up for this pain. Overall, these findings imply that when treating upper extremity pain, strength and range of motion of the hip and shoulder should be investigated and improved. Further research is needed to gain greater understanding of these functional characteristics, specifically the relationship with pain and injury in softball pitching.

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