Fast-Pitch Softball Pitchers Experience a Significant Increase in Pain and Fatigue During a Single High School Season

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Abstract *Background:* Fast-pitch softball is one of the fastest growing sports, but there is little research regarding pitcher fatigue. Currently, there are no pitch limits or game counts. *Questions/Purposes:* To study the effect of fatigue on youth fast-pitch softball pitchers during a high school season, we hypothesized increased games pitched during the season would correlate with increased player-reported pain and fatigue and decreased with upper extremity strength and range of motion (ROM). *Methods:* This prospective cross-sectional study evaluated pre- and postgame shoulder and elbow strength, ROM, pain, and fatigue in 17 high school fast-pitch softball pitchers. These measures were recorded at two games, one at the beginning and one at the end of the season. Pitch count and number of games pitched during the season were recorded. We compared pre- and postgame

measurements and measurements made at the beginning and end of the season. *Results:* Supraspinatus, forward flexion strength, and external rotation strength in abduction decreased significantly postgame compared to pregame. Pregame pain and fatigue increased with a greater number of games pitched during the season. Forward flexion, supraspinatus, and external rotation strength decreased with increasing number of games pitched during the season. *Conclusions:* Fast-pitch softball pitchers experience increased pain and fatigue during a single game and over the entire season. The increase in fatigue may predispose the player to injury. Further studies are needed to understand the relationship of pain and fatigue with predisposition to injury.

Keywords fatigue · softball · pitchers · pitch counts

Level of Evidence Level IV: Prognostic Study

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Introduction

Fast-pitch softball is one of the fastest growing and most popular female sports in the USA with more than two million players between the ages of 12 and 18 competing per year [5, 7, 9, 18]. There has been no research documenting fatigue patterns related to participation in this sport. There are no pitch count or game limits which can increase the demand on these athletes.

Recent biomechanical studies have shown that the windmill pitch generates similar forces across the shoulder to those seen with the overhand baseball pitch [20, 22]. Therefore, fast-pitch softball pitchers may have a similar risk for fatigue and injury as baseball pitchers but are not subjected to same protective measures (pitch counts and game limits) as young baseball players [1, 20, 25]. In the baseball literature, fatigue has been measured using subjective fatigue questionnaires and objective strength and kinematic motion [15, 17, 18, 26]. No publications exist addressing the effects of subjective fatigue and objective fatigue in windmill softball pitchers.

The purpose of this project was (1) to examine the change in ROM, pain, and fatigue within a single game at the beginning and end of the season and (2) to examine the change in ROM, pain, and fatigue throughout the season. The hypothesis was that increased number of pitches during a single game and increased games pitched during the season will positively correlate with player-reported postgame pain and fatigue, and a decrease in objective upper extremity strength and range of motion. We further hypothesize that there's a critical limit in games pitched after which players show increased fatigue.

Patients and Methods

Institutional review board approval was obtained prior to conducting this study. Participants were recruited at local high school softball tournaments and league games during the first week of the 6-week fall season. Twenty-one female high school fast-pitch softball pitchers were prospectively evaluated. All participants were juniors or seniors, except for two participants who were sophomores. Participants were excluded from the study if they had any shoulder or elbow pain in the last year that lasted more than 2 weeks or resulted in a missed game, or any history of upper extremity surgery.

Consent/assent was obtained from each pitcher and/or their legal guardian before the start of the study. The average age of all pitchers was 17 years (range 15–18). The players pitched on average 2.2 seasons previously at the high school level. Of the 21 players, two players were injured mid-season related to pitching and could not complete follow-up. Two additional players were lost to follow-up as they were not in the pitching rotation during the final week of the season.

After agreeing to participate, each pitcher was assessed with objective pregame and postgame shoulder active range of motion (ROM) and strength testing. They also completed a subjective pain, Borg, and fatigue questionnaire. Pregame data were collected after warm-up, before the first pitch. Postgame data were collected immediately after the end of the game. Each pitcher was evaluated at a game during the first week of the season and re-evaluated at a game during the eighth (final) week of the season. Pitch count was recorded using "Tally Counter", a Pixel Research Labs phone application. At the end of the season, total game pitched was collected from the team records and confirmed with the parents.

Strength and active ROM measurements were conducted by one of the two clinicians, a 4th year orthopedic resident and a 4th year medical student, who were previously trained in the techniques described. During training, the intra-observer Kappa for strength was 0.90, and the range of motion was 0.86. The inter-observer Kappa between the two clinicians was 0.8 for strength and range of motion. The same clinician followed the same athlete throughout the season. Active shoulder abduction (relative to the thoracic spine), forward flexion (relative to the thoracic spine), external rotation at 0°, and external rotation with shoulder abducted to 90° were measured to the nearest degree using a standard goniometer using previously described techniques [12]. Internal rotation was measured by noting how

far each pitcher's middle finger could reach up their back (pocket, tailbone, lower back, mid back, upper back).

Shoulder strength was measured using a handheld dynamometer (microFET 3, Hoggan Health Industries, West Jordan UT). The choice of various strength variables was based on the works of Werner and Maffett who showed that the biceps, the anterior deltoid, and the anterior rotator cuff (subscapularis, supraspinatus) seem to be more selectively activated [16, 23]. We thus chose to focus on those activated muscle groups for testing. External rotation strength was measured in three planes with the elbow flexed at 90°: (1) arm by the side in neutral rotation, (2) with the shoulder abducted 90° in 0° of external rotation, and (3) with the shoulder abducted 90° in 90° of external rotation [12]. The dynamometer was placed on the dorsal wrist to resist with an internal rotational force while the clinician stabilizes the subject's elbow to prevent shoulder abduction or adduction. Internal rotation strength was similarly measured with the shoulder abducted 90° in 0° of external rotation except with the dynamometer placed volarly at the wrist with an externally directed force. Internal rotation was also measured using hand behind back liftoff adjacent to the level of the sacrum with the dynamometer resisting liftoff. [12] Supraspinatus, shoulder forward flexion, and elbow flexion/extension strengths were also assessed. Supraspinatus strength was tested with the arm in 90° of abduction and 30° in front of the coronal plane. The thumb of the hand pointing was pointing down. The subject was asked to hold this position as the clinician applied a downward resistance at the wrist with the dynamometer [8, 11]. Shoulder forward flexion strength was measured with the shoulder at 90° flexion, elbow fully extended, and forearm in complete supination as the rater applied a downward resistance at the wrist with the dynamometer. Elbow flexion and extension was done with the elbow flexed at 90° with the dynamometer placed at the volar or dorsal wrist to resist the respective motion. All evaluations were done with the subject standing. Each measurement was completed on the high sensitivity setting [8]. Peak force measurements were recorded three times at each position in pounds of force. The average of the three peak measurements was used in data analysis.

Objective pain and fatigue were assessed using three different questionnaires [26]. Pitchers were asked to rate their exertion before and after each game using the Borg questionnaire, a validated scale rating on a scale from 6 to 20 (6 being no exertion and 20 being maximal exertion) [2, 3]. The pitchers then rated their pain and fatigue using two previously validated VAS questionnaires (0 = no pain/fatigue and 10 = worst possible pain/fatigue) [6].

Statistical Analysis

An a priori power analysis was based on an effect size of 0.7 at 80% power with an alpha set at 0.05 for supraspinatus strength and forward flexion strength. This analysis revealed 16 pitchers were needed for the study.

We used paired *t* tests and Wilcoxon signed rank tests for non-parametric data to determine if a significant difference existed between all pregame and postgame variables: VAS

Table 1 Changes in pregame vs. postgame pain, fatigue, and strength

	Beginning of season				End of season			
	Pregame	Postgame	Pre-post Avg.	<i>p</i> value	Pregame	Postgame	Pre-post Avg.	<i>p</i> value
Subjective pain and fatigue								
VAS pain	0.57	1.19	−0.62	0.009	1.4	2.8	−1.35	<i>0.004</i>
VAS fatigue	1.47	4.31	−2.83	<0.001	2.0	3.2	−1.17	<i>0.01</i>
Borg exertion	9.33	10	−0.67	0.29	9.0	10.8	−1.82	<i>0.01</i>
Strength								
Shoulder forward flexion strength (lb-f)	13.6	11.7	1.91	0.009	12.8	10.9	1.93	<i>0.004</i>
Supraspinatus strength (lb-f)	13.8	11.9	1.82	<0.001	12.8	10.8	1.98	<i>0.001</i>
External rotation (0° ER/0° Abd) strength (lb-f)	16.1	15.6	0.52	0.38	15.9	14.9	1.00	0.08
External rotation (0° ER/90° Abd) strength (lb-f)	16.5	15.0	1.51	0.02	16.5	14.6	1.84	<i>0.014</i>
External rotation (90° ER/90° Abd) strength (lb-f)	10.4	10.1	0.36	0.548	10.5	9.3	1.28	<i>0.028</i>
Subscapularis (lift-off) strength (lb-f)	12.6	12.0	0.66	0.363	12.5	12.7	−0.07	0.88
Elbow flexion strength (lb-f)	27.6	26.1	1.52	0.12	29.0	28.0	0.92	0.39
Elbow extension strength (lb-f)	24.3	22.4	1.83	0.13	24.9	23.6	1.35	0.332
Range of motion								
Forward flexion	150	147	3.38	0.175	152	148	4.59	0.15
Abduction	155	156	−0.24	0.85	153	153	2.82	<i>0.021</i>
External rotation at 90° abduction	111	111	−0.05	0.99	101	106	3.65	0.16
External rotation at 0° abduction	72	75	−2.29	0.64	72	73	−1.29	0.76

Italicized values indicate a significant *p* value less than 0.05

Fig. 1. Change in subjective scores and shoulder strength during a single game, both at the beginning and end of the season.

scores, shoulder strength measurements, and shoulder ROM measurements. Chi-square test was used to determine significant differences between categorical variables.

We used a repeated-measures general linear model (GLM) as well as simple linear correlation to examine the relationship between games pitched with subjective fatigue, strength, and ROM. A repeated-measures GLM was created for each pregame measurement collected at two time points, the beginning and the end of the season. The number of games pitched was the independent variable in each model. We also used Spearman's rho to determine if a linear correlation existed between change in any pregame measurement (pregame end of season measure–pregame beginning of season measure) and number of games pitched in the season.

Similar techniques were used to determine the relationship between pitch count and subjective fatigue, strength, and ROM. As above, a repeated-measures GLM was created for each measurement (VAS and all shoulder strength and ROM measurements). In this case, the two time points in the measurements were pregame and postgame. In these models, the pitch count was the independent variable. We then used Spearman's rho to determine if a linear correlation existed between pregame and postgame measurements and the number of pitches pitched. All pregame and postgame analysis was done using both beginning and end of season data separately.

During the analysis, there was a critical threshold point of ten games pitched for changes in VAS pain, VAS fatigue,

and strength. Thus, a subanalysis was performed examining players who pitched more than ten games (eight players) and less than ten games (nine players). We first calculated the difference between pregame VAS scores and shoulder strength measurements at the beginning and end of the season. An independent *t* test was then used to determine if those players who pitched more than ten games had significantly different changes in their VAS or shoulder strength scores than those who pitched less than ten games.

All analysis was done using IBM SPSS Statistics statistical software package version 19 (IBM, Armonk NY).

Results

The 17 pitchers made an average of 12 ± 5.7 (range 5–24) pitching appearances during a single 6-week season. Average pitches thrown per game studied were 89 ± 25 (range 30–161). Average innings pitched per player per game was 5.8 ± 1.3 (range 3–7). Average pitches thrown per inning were 15 ± 6.1 (range 4–38). Average time between data collection at the beginning and at the end of the season was 35 ± 8.3 days (range 18–45). The two injured players which were excluded from analysis both suffered shoulder injuries. Both players had bicep tendonitis diagnosed clinically, and one player suffered a partial articular sided rotator

Fig. 2. Change in pregame subjective scores and shoulder strength, at the end compared to the beginning of the season.

Fig. 3. Scatter plots with best-fit lines correlating games pitched vs. the difference in pregame VAS pain (a) and fatigue (b) scores from the beginning and end of the season.

cuff tear as described on an outside MRI report. None of the players in our cohort had shoulder pain prior to the season.

At the beginning of the season, postgame VAS pain and VAS fatigue scores were significantly higher than pregame scores ($p < 0.01$) [Table 1, Fig. 1]. Pregame and postgame Borg exertion scores were not significantly different. Single-game pitch count did not significantly correlate with pain, VAS fatigue, or Borg exertion.

At the end of the season, postgame VAS pain, VAS fatigue, and Borg exertion scores were significantly higher than pregame scores ($p < 0.01$, $p < 0.01$, $p = 0.01$, respectively). Higher single-game pitch count correlated with increased postgame Borg exertion score ($r = 0.50$, $p = 0.04$). Significantly more pitchers (7/17 pitchers, 41%) reported postgame pain scores higher than five than at the beginning of the season (1/17) ($p = 0.039$). Three additional pitchers reported mild pain (18%).

Pregame VAS pain and fatigue scores were significantly higher at the end of the season ($p = 0.001$ and $p = 0.02$, respectively) [Fig. 2]. Increasing number of games pitched over the course of the season correlated with higher pregame

Fig. 4. Scatter plots with best-fit lines correlating games pitched vs. the difference in pregame supraspinatus (a), shoulder forward flexion (b), and external rotation (c) strengths from the beginning and end of the season.

VAS fatigue at the end of the season ($r = 0.66$, $p = 0.006$ and $r = 0.73$, $p = 0.001$, respectively) [Fig. 3].

Table 2 Association between games pitched and changes in pregame pain, fatigue, and strength

	Spearman's rho (correlation coefficient)	<i>p</i> value
VAS pain	0.727	0.001
VAS fatigue	0.659	0.006
Borg exertion	0.437	0.091
Shoulder forward flexion strength	−0.656	0.006
Supraspinatus strength	−0.669	0.005
External rotation (90 ER/90 Abd) strength	−0.881	<0.001
Subscapularis (lift-off) strength	−0.285	0.285

Supraspinatus, forward flexion, and external rotation strength decreased significantly postgame regardless of the time of the season. Single-game pitch count did not correlate with strength differences after a single game.

Pregame shoulder forward flexion and suprascapular strength were significantly lower at the end of the season ($p < 0.001$ and $p = 0.002$, respectively). Furthermore, a greater number of games pitched over the course of the season correlated with lower pregame forward flexion, supraspinatus, and external rotation strength ($r = -0.66$ – 0.88 , $p < 0.006$) [Fig. 4] [Table 2].

ROM did not change significantly pregame to postgame at the beginning of the season. At the end of the season, only shoulder abduction decreased from pre- to postgame. Greater number of games pitched over the course of the season was correlated with lower pregame external rotation at the side ($r = -0.62$, $p = 0.011$) [Fig. 5].

The scatter plot showed a critical threshold point of ten games pitched for changes in VAS pain, VAS fatigue, and strength. Thus, a subanalysis was performed examining players who pitched more than ten games (8/17) and less than ten games (9/17). At the end of season compared to the beginning of season, there was a significant difference in pregame pain, fatigue, forward flexion, supraspinatus, and

external rotation strength in players pitching more than ten games ($p < 0.033$) [Table 3].

Discussion

This study measured the effect of single-season pitching on player-reported fatigue, player-reported pain, objective strength, and range of motion in high school fast-pitch softball pitchers before and after games both at the beginning and at the end of a single high school season. We found that shoulder strength decreased significantly through the course of a game throughout the season. Also, more games pitched during the season significantly increased pregame pain and fatigue while decreasing pregame shoulder strength. The cumulative effects of pitching through the course of the season, particularly more than ten games, appear to predispose pitchers to increased pain and fatigue.

This study is the first to document the influence of windmill pitching and games played on fatigue and pain patterns in adolescent fast-pitch softball pitchers. Our study does have some limitations. Since we only recorded games at the beginning and at the end of the season, there is no data on fluctuations of pain, fatigue, and strength during the season. Although a majority of our participants pitched throughout the year, we did not account for games pitched prior to the fall season during summer tournaments; a more detailed pitching history may have helped to overcome this. In addition, we did not examine the effect of the pitcher's practice and strengthening regimen during the season. External validity is limited due to the fact that high school adolescent pitchers may have variations in technique which could dramatically impact our findings. We also focused our objective measures of strength in the shoulder rather than the entire kinetic chain to limit measurement burden on players during competition. We decided to measure player pain instead of injury as the definition of what qualifies as an injury varies from player to player and clinician to clinician. Furthermore, the development of pain may be considered a precursor to injury. Our cross-sectional assessment of the single-game effect pitch counts on fatigue and pain does not account for the cumulative effect of pitch counts throughout the season.

Table 3 Change in pregame pain, fatigue, and strength at the end vs. beginning of season

	Pitched <10 games	Pitched >10 games	<i>p</i> value
VAS pain	0.00	1.78	0.029
VAS fatigue	−0.63	1.67	0.027
Borg exertion	−0.88	0.78	0.211
Shoulder forward flexion strength (lb-f)	0.41	−1.64	0.004
Supraspinatus strength (lb-f)	0.35	−1.88	0.033
External rotation (90 ER/90 Abd) strength (lb-f)	1.47	−0.59	0.002
Subscapularis (lift-off) strength (lb-f)	1.00	−0.81	0.059

Fig. 5. Scatter plot with best-fit line correlating games pitched vs. the difference in pregame external rotation ROM with arm in 0° abduction from the beginning and end of the season.

Pain in our study was measured with the VAS pain scale which increased both during the game and during the season between 0.62 and 1.35. The minimal clinically important difference (MCID) for VAS pain has been reported ranging from 1.1 to 1.4 [9, 21]. The players experienced an increase in VAS fatigue 1.17 to 2.83 during the games. The published MCID for VAS fatigue is 0.82 to 1.13 [13]. Finally, the players experienced an increase in exertion with Borg scale of 1.82 during the game at the end of the season, and the MCID for Borg scale is 1 [19] showing our results were statistically and clinically significant.

The prevalence of shoulder pain in the softball pitcher has been estimated from 45 to 82% [10, 14]. Although our pain questionnaire did not specify the location of the pain, seven out of 17 pitchers (41%) reported moderate or severe pain postgame at the end of the season. This prevalence is consistent with previous reports [10, 14].

Previous biomechanical studies on windmill softball pitching [7, 16, 20, 23, 24] help explain our findings. Rojas and colleagues found that at the 9 o'clock position (right-handed thrower), shoulder forward flexor activation on electromyogram in windmill pitching was double that of overhead throw and higher throughout the entire pitching motion [20]. They theorized that the eccentric contraction of forward flexion contributes to anterior shoulder pain in this population. In our study, forward flexion strength decreased significantly in each game and throughout the season. Furthermore, both decrease in strength and increase in fatigue correlated strongly with games pitched.

Distraction stress and joint torques at the throwing-arm elbow and shoulder have been shown to be similar to those found in baseball pitchers [1, 7, 23]. Shoulder distraction forces during windmill pitching could reach up to 94% of body weight [1, 16, 23]. It is thought this distraction force is in part dissipated by compressive action of the supraspinatus and infraspinatus, during the upward acceleration phase from 6 o'clock to 12 o'clock (right-handed thrower) [4]. This was consistent with our findings of decreases in strength of the supraspinatus and external rotators.

Maffett et al. found that internal rotators (subscapularis and pectoralis major) exhibit high activity in the downward acceleration phase of windmill pitching from 12 o'clock to ball release [16]. However, in our study, internal rotation strength did change with the effects of fatigue. This may be related to the relative strength and bulk of internal rotators compared to other muscle groups, leading to a higher tolerance to fatigue.

We did not collect pitch counts for each player over an entire season due to a lack of a reliable method to obtain and validate the accuracy of this information. Therefore, we cannot directly correlate pitch counts to the development of pain or fatigue over the season. Therefore, we are reluctant to extrapolate pitch count limits or recommend game limitations from our data. Clearly, fatigue plays a role in the development of pain since higher VAS fatigue and pain scores were associated with more than ten games pitched. However, the Borg questionnaire did not reflect a change in

exertion during a single game or longitudinally through the season. Future studies evaluating the association between pitch counts and fatigue are needed to make rational recommendation for changes in pitch count limits or competition habits.

In conclusion, fast-pitch softball pitchers experience increased fatigue during the course of a single game and over the entire season. Increase in games pitched during a season with higher pain and fatigue and decreased strength. Forward flexion and rotator cuff strength decreased significantly throughout the course of a game. Future studies are needed to better understand the relationship of pitch count to injury and fatigue.

Compliance with Ethical Standards

Conflict of Interest: Justin S. Yang, MD, Jeffrey G. Stepan, MD, MSc, Lucas Dvoracek, BS, Robert H. Brophy, MD, and Matthew V. Smith, MD have declared that they have no conflict of interest. Rick W. Wright, MD reports institutional research grants support from Smith Nephew and National Institute Health, National Institute of Arthritis and Musculoskeletal and Skin Diseases, and book royalties from Wolters Kluwer Lippincott Williams & Wilkin, outside the work.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

Informed Consent: Informed consent was obtained from all patients for being included in the study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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